Handbook of mold, tool and die repair welding

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Preface

My fascination with welding tool steels began when, as a novice, I tried to weld two pieces of ground flat stock together with mild steel filler wire and no pre-heat. The weld was neat and tidy (which was always my trade mark), so I thought that I had done a good job. As I was welding the two pieces of tool steel, I had heard funny noises like somebody tapping two wrenches together several times! 'Never mind', I thought, but as I moved the welded pieces to one side, they just fell apart! I couldn't believe my eyes – what had happened? It defied all the laws of my logic that two pieces of metal should fall apart when they had just been welded!

When the trauma of this subsided, I went to my boss to confess my ignorance. He laughed and told me that you are supposed to pre-heat tool steels before you weld them. I then asked him how much pre-heat tool steel needed, but he said, 'I don't know, just heat it up'. I did as he said and it worked! But I *had* to find out more information just in case there was more than one type of tool steel and possibly a more accurate method of choosing a pre-heat. The more I searched, the more I realized how little anybody understood of this area. So the challenge was on – who would I ask and where would I find this type of information?

I joined The Welding Institute and began regular visits to my city's central library. All I needed was a book on how to weld molds, tools and dies but this did not exist. All I could find was general information on how to weld tool steels.

So, slowly but surely, I started to build up my own bank of information from trade literature, from welding and metallurgy books and from valuable advice from a close friend who is a metallurgist. This gradually evolved into specific working practices which best suited my customers' demands.

Eventually, it came to the point when I had so much general information and enough years of practical knowledge that I decided to combine them into the book that I could not find when I needed it. I had found my niche, my project!

I hope what I have put together answers most of the questions that you might have been asking yourself about the confusingly technical and practically demanding but overlooked corner of industry that deals with the repair of molds, tools and dies.

Steve Thompson

Introduction

This book is not a metallurgist's definitive tool steel chemical composition handbook or a welding engineer's definitive guide. It is a book designed for the shop floor, written from the shop floor, using the 25 years of my experience to convey the most practical ways that I have found for tackling the repair of molds, tools and dies.

Mold, tool and die repair welding is a very complicated process, shrouded in mysteries, myths and closely guarded secrets! This is because two very different trades have overlapped – welding and toolmaking. For many years, toolmakers and tool users have had to rely on the small number of specialist welders who do understand exactly what repair welding involves, and who have the hand skills to do it, especially when it comes to welding mold tools.

Understanding the technical side of tool steels is a big problem for welders and understanding the practical side of welding is a big problem for machinists. I have tried to write this book so that either will understand it and learn something from it.

Tool steels should be pre-heated or even annealed before welding and then cooled carefully or even post-heat treated. But in all my years of welding tool steels, I have never been allowed to anneal a tool before welding because the customer would never accept the increased down time and cost! This book, therefore, tells the repair welder how to compromise between what the customer wants and how best to give him that within the constraints of good welding practice.

Purchasing and safely setting up suitable equipment is an essential part of mold tool and die repair welding. If you do not have suitable equipment, it will be like trying to play classical guitar music on a banjo – inappropriate and not always possible. Unfortunately, welding suppliers are not always as expert as they should be in selling toolmakers the most appropriate welding equipment for the kind of work they have in hand.

It is not always necessary to spend a lot of money to get the equipment that lets you do your job properly. Learning how to choose your equipment well is something that comes with experience. If more of us shopped around and insisted on borrowing equipment on approval before purchasing, fewer expensive mistakes would be made. Purchasing and safely setting up suitable equipment is discussed in Chapter 7.

The chemical compositions in this book come from many different sources, old and new. Some may, therefore, be incomplete or slightly inaccurate but I have still used them because they contain sufficient information for welding purposes.

All the technical and practical information in this book is based on the way that I approach mold, tool and die repair welding, and should not be confused with official tool steel welding procedures.

Contents

1

How to use this book

This book covers most of the aspects of mold, tool and die repair TIG (tungsten inert gas) welding at shop floor level as well as the relative technical areas. In time, it will help you to understand the difference between tool steels and why they need to be repaired differently, and aspects such as what your tool is made of, whether you need to pre-heat and what type of welding rods you should use, or even how do you weld and what should you weld with! Hopefully this book will answer most, if not all, of these questions. So, whatever stage of welding competence you are at, this is your starting point.

Can you TIG weld?

No: if you cannot TIG weld, Chapter 7 discusses welding equipment, the types of accessory you will need and how to set them up. Chapter 7 also discusses safety, which is essential when dealing with welding. Chapter 8 goes on to tell you how to use your equipment and it also gives you welding exercises to help you develop your hand skills. **Go to** Chapter 7 then carry on to Chapter 8.

Yes: read through Chapters 7 and 8 to make sure that you have suitable equipment and that it is set up correctly, and that you fully understand the weld techniques you may need to master before you undertake tool repairs. **Go to** Chapters 7 and 8.

Weld procedure

Now you should be as comfortable and happy as possible with your equipment, so the next step is to understand what you are welding and how you are going to weld it.

I will assume that you have a tool that needs repair either in front of you or in mind. Your first step is to gather as much information as possible about the tool and what welding work is required. Write this all down in a format that you can understand. This will be called your 'weld procedure'; **Go to** Chapter 2.

Once you understand why all the information is put down in a format that is easy to understand, you will have learned that the basis for all quality welding is the 'weld procedure'.

Review

- What type of equipment you should use and how to set it up: **Go to** Chapter 7.
- How to TIG weld: **Go to** Chapter 8.
- Where to start when you are happy with your equipment and welding ability: **Go to** Chapter 2.
- What material your tool is made from: **Go to** Chapter 3.
- Whether you need to pre-heat, and if so, how much: **Go to** Chapter 5.
- What filler wires you should use: **Go to** Chapter 4.
- Where to go for practical advice on weld techniques: **Go to** Chapter 6.

Once you understand how to use the chapters to complete your weld procedure, and how to put into practice the weld techniques outlined in Chapter 6, the rest is a matter of practice. Reading this book alone will not make you a good tool welder, but it will put you in a position to become one.

2

Writing your weld procedure

A weld procedure is a set of instructions telling you how to perform a particular welding task. Like a recipe for baking a cake, it tells you the ingredients and their quantities followed by the cooking instructions. So you could equally call your weld procedure a welding recipe with welding instructions.

All of the weld procedures and welding information in this book are general purpose and intended for the maintenance, repair and modification welding of molds, tools and dies. Any tools in need of repair that could threaten life or limb if not repaired correctly, e.g. aviation parts or vehicle parts, should never be repaired without prior consultation with the owner's insurers.

Why you may need a weld procedure

1 To keep all of your repair information together on one sheet of paper.
2 As a detailed set of instructions for an operator.
3 As a detailed repair record for future reference.

What you need is a format for laying out your information in a logical progressive way, with a sketch if necessary. This is because the person who collects the information may not be available when the operator eventually undertakes the repair. You will need to have all the relevant information written into your weld procedure, even if you write it for your own use. Are you really likely to remember every detail that was available when you first discussed the repair? You may receive a tool with the damaged area highlighted in ink marker and then, without thinking, clean it off with a solvent as part of your preparation and not remember what needs to go where! What follows is a lot of head scratching, guessing and eventually going back to your source for the repair information again. A customer may come back to you and tell you that the repair you made the last time was perfect and can he have the same again? But that was six months ago and you cannot remember because it was an unusual choice of filler wire. This is why detailed weld procedures are so important.

On page 197, there is a blank weld procedure form for you to copy and use for recording your information. The following pages will help you to fill it in.

Collecting your information

Before filling out the weld procedure, collect all the information on a note pad. It is useful to use a black pen for writing and for drawing outlines, a red pen for drawing in the welds and a black ink marker to draw on the tool itself to highlight the areas to be worked on. Keep handy a piece of sharpened filler wire to point at the areas of the tool when discussing fine details. Once you have your note book at the ready, these are the questions to ask and why you have to ask them:

1 What is the tool's function, e.g. chuck jaws, aluminum die cast mold, sheet metal blanking die? This will go under 'Description'. It will be valuable information if you do not know what the tool is made of (see page 24, Table 3.2). Also, if you have contamination problems, it helps to know what environment the tool has been used in.
2 What material is the tool made of, e.g. D2, P20, H13? This will go under 'Material'. It will tell you the tool's chemical composition (see Chapter 3, Tables 3.3 and 3.4) and will give you a guide to the types of filler wire and pre-heat that you will need.

3 What weld hardness is required, e.g. very hard (60HRC), medium hard (45HRC), soft (30HRC)? This will go under 'HRC'. HRC stands for Hardness Rockwell 'C'. More information is available in Chapter 3 and in Appendix V. It will give you a guide to possible filler wires.
4 Will general heat discoloration be a problem? This will give you a guide on pre-heats (see Chapter 5, Table 5.1, page 50).
5 Is the area to be welded going to have a special finish, e.g. high polish, photo/acid etched, case hardened? This will give you a guide to filler wire selection (see Chapter 4, Table 4.2, page 44). This information should be put under 'Other requirements'.
6 After you have discussed all the owner's requirements, check the tool for any other problems and make sure that you mention any potential problems as soon as possible; see Chapter 6.

By this time you should have enough information to complete your weld procedure. Although many people may think that this amount of paper work is a waste of time, I can assure you that it is a most important routine, and avoids mistakes being made even before an arc is struck. As a learning aid, the weld procedure comprises a list of essential questions which have to be answered before any welding is started. I hope that the answers you need are in this book but, if not, get in touch with the company that makes your filler wires and talk to their technical department. Joining your national welding society will also give you a mine of readily accessed information.

The rest of this chapter is dedicated to four weld procedures used to repair the following tools:

1 H13 core: a core from an aluminum die cast mold.
2 D2 die: part of a punch and die set.
3 Aluminum cavity: part of a plastic blow mold.
4 Copper core: an inner/ejector core of a plastic injection mold.

Each weld procedure is followed by a weld procedure breakdown to help you to see where the information came from.

Weld procedure 1

The first weld procedure features an H13 core from an aluminum die cast mold which is worn through general use. The core's top shut off face and lower shut off edge are in need of repair.

Weld procedure 1 breakdown

As you can see from this weld procedure (Fig. 2.1), it could double as a progress sheet which may be used by some companies but I will only concentrate on the weld procedure side.

Description: core

This is a brief description of the tool to be repaired.

Material: H13

This is what the tool is made of. This information was supplied by the owner. If the owner did not know what the tool was made of, a full description of the tool (mold, aluminum die cast) should be taken and matched against Table 3.2, page 24, for a possible material. Table 3.2 would suggest a hot working tool steel, most likely H13 or possibly H21.

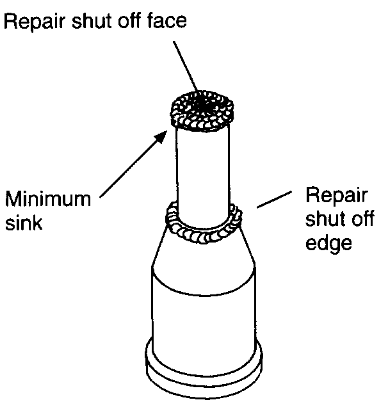
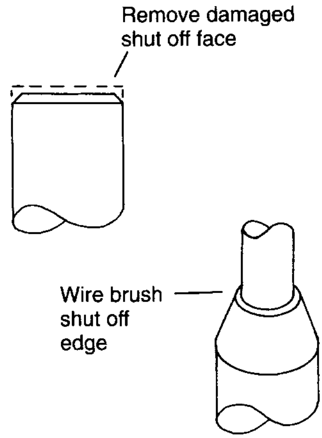
HRC: 52–55

This is the weld hardness requested by the owner of the tool.

Instruction sketch

This drawing shows the areas to be welded, i.e. the top shut off face which is worn and pitted due to general wear and tear. The uneven wear needs to be rebuilt with weld. The owner of the tool requested that care be taken to minimize sink where indicated to avoid molding problems. The lower shut off edge is also worn and needs to be rebuilt with weld; see Chapter 6, page 57, for welding instructions.

Job no.	Company	Description	Date
		Core	
Contact	**Material**	**HRC**	**Quantity**
	H13	52–55	

Instruction sketch	Preparation sketch.
	

Pre-inspection					
Visual	√		Dye pen		
Weld process		TIG	Pre-heat		150 °C
Consumable	1	H13			
	2				
	3				
Gas		Argon	Backing gas		
Other requirements		Minimum sink below top shut off face			

Operation:	Quantity	Sign	Date
Preparation			
Weld			
Weld			

Cooling:	Heat insulating material		Air	√

Final inspection					
Dye pen			Visual	√	

Fig. 2.1

Preparation sketch

This sketch tells you to grind off the damaged shut off edge and that only a wire brush is needed to prepare the lower shut off edge.

Visual

This is a 'pre-inspection' request. This particular tool only needs a visual inspection before any welding takes place just to make sure that there are no other problems other than what has been stated. Although H13 die cast mold tools can suffer from severe surface cracking because of their working environment, this is unlikely to cause any major problems other than contamination during welding. If you see any potential problems with your tool, discuss this with the tool's owner as soon as possible.

Weld process: TIG (direct current, DC)

Of the many different types of welding processes, e.g. TIG, MIG (metal inert gas), stick, that can be used on mold, tool and die repair welding, TIG is the most suitable on this occasion.

Pre-heat: 150 °C

The pre-heat for H13 can be anywhere from 110 °C to avoid general discoloration on fine finished tools up to 375 °C when welding larger tools in crack-sensitive areas; see Chapter 5. This core is only 100 mm (4″) high, so it is a small tool that only needs the minimum pre-heat for H13, with general discoloration not being a problem.

Consumable: H13

With the base metal being H13 and the required hardness being 52–55 HRC the automatic choice would be H13 filler wire. If you do not have an H13 filler wire because you do not weld H13, very often a general-purpose medium hard tool steel filler wire for welding hot and cold tools would be suitable; see Chapter 4.

Gas: argon

Your welding gas will always be argon unless you are welding pure or larger sections of aluminum or copper, when welding may become a problem, or if you are using the MIG welding process. See your gas supplier if you need more details.

Other requirements: Minimum sink below top shut off face

This is basically a request from the owner of the core. Beneath the weld on the top shut off face where indicated in the instruction sketch, the owner requests minimum sink because this may hinder the separation of the core and the molded component after cooling; see Chapter 6, 'Sink', page 71.

Cooling: air

H13 has a carbon content of 0.3–0.4% which makes it unlikely to crack during cooling so it can be put to one side away from drafts, preferably at room temperature, and allowed to cool naturally.

Final inspection: visual

Because H13 is unlikely to crack (unless the repair is in a 'crack-sensitive area', see Chapter 6, 'Cracking', page 63), a simple visual inspection is all that is needed to check for welding errors, e.g. insufficient weld metal, excessive sink, contaminated weld metal (porosity/scale inclusions) or missing welds.

This is weld procedure 1 complete. Weld techniques and practical advice on this weld procedure are found in Chapter 6, page 57.

Weld procedure 2

This second weld procedure (Fig. 2.2) shows a broken D2 spoon blanking die from a punch and die set. The die is broken into two pieces. The owner of the die wants the die to be welded back together, retaining its hard 60 HRC cutting edge. The owner also wants no post-heat treatment and minimum distortion.

Weld procedure 2 breakdown

Description: Spoon die

This is a brief description of the tool to be welded.

Material: D2

This tool is made out of D2.

HRC: 60 HRC

This is the finished hardness, requested by the owner.

Instruction sketch

The instruction sketch shows the broken die: 'Prep. & fully weld on outside faces only'. It was requested by the owner that there must be a minimum amount of weld on the inside faces of the die because the inside faces will need to be finished by hand. The other faces will be surface ground: 'Keep cutting edges 60 HRC'. The inside top edge is the tool's cutting edge and needs to be of a similar hardness to the rest of the cutting edge, which is about 60 HRC.

Preparation sketch

In most cases preparation is obvious, e.g. 'remove the damaged area and rebuild'. This time the preparation is specific. The preparation for this tool is 'one-third preparation on outside faces only'; as you can see by the sketch provided, two-thirds of the thickness of the tool is removed as a weld prep. and one-third remains for location purposes. See Chapter 6, page 59 for full details.

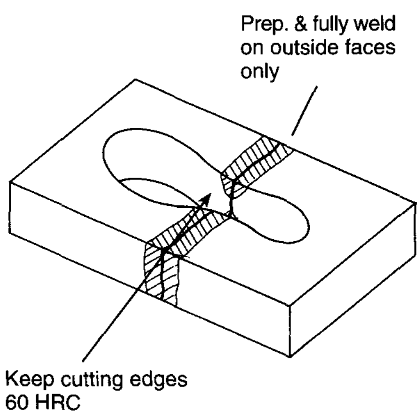
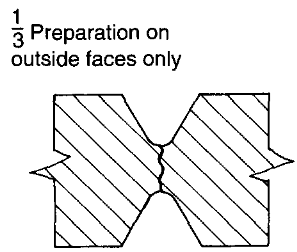
Job no.	Company	Description	Date
		Spoon die	
Contact	**Material**	**HRC**	**Quantity**
	D2	60	
Instruction sketch		**Preparation sketch**	
			
Pre-inspection			
Visual √		Dye pen √	
Weld process	TIG	Pre-heat	300–400 °C
Consumable 1	312 stainless steel		
2	60 HRC tool steel filler wire		
3			
Gas	Argon	Backing gas	
Other requirements	Restrain during welding		
Operation:	**Quantity**	**Sign**	**Date**
Preparation			
Weld			
Weld			
Cooling:	Heat insulating material √	Air	
Final inspection			
Dye pen √		Visual √	

Fig. 2.2

Pre-inspection: visual and dye pen

A visual pre-inspection is standard on all tools. All tools should be inspected before any work takes place. This section is also a record of who performed the dye penetrant examination (dye pen) which is an essential pre-inspection process when dealing with high carbon, brittle tools such as D2. Dye pen is a crack detection process which is discussed in detail in Chapter 6, page 66, under 'Excavating cracked material'.

Weld process: TIG (DC)

TIG welding is most suitable for this repair. TIG is also known as GTAW (gas tungsten arc welding), GTA (gas tungsten arc) or just argon welding.

Pre-heat: 300–400 °C

The pre-heats for high carbon/high chrome tool steels such as D2 can be anywhere between 140 and 450 °C depending on the tool itself; see Chapter 5. In this case a minimum of 300 °C pre-heat was chosen because it is a severe repair and a maximum of 400 °C because 312 stainless steel will be used as the main filler wire and this starts to lose its excellent properties over 450 °C.

Consumable: 312 stainless steel and a 60 HRC tool steel filler wire

This repair needs two different types of filler wire, 312 stainless steel filler wire to join the two broken pieces together and a 60 HRC tool steel filler wire to replace the 60 HRC cutting edge; see Chapter 6, Fig. 6.6, page 60.

Gas: argon

This is the most suitable torch gas for this type of repair.

Other requirements: restrain during welding

The owner of the tool requested minimum distortion to help reduce the amount of surface grinding required to get the spoon die level again after welding. Restraining the die and using an alternated run sequence is very successful for repairs like this; see Chapter 6, Fig. 6.4, 6.5 and 6.6.

Cooling: heat insulating material

D2 is a brittle material because of its high carbon and high chrome content so it is given a high pre-heat to minimize the risk of cracking during welding. Once the tool is welded it needs to be slow cooled in vermiculite or dry sand; see Table 5.1, and 'Cooling' in Chapter 5, page 50.

Final inspection: dye pen and visual

Once the die reaches room temperature, in this case about 12 hours, it can be taken out of the heat insulating material and the restraint can be removed. A dye penetrant examination is performed to check for any cracking that may have occurred during welding or cooling. If this is clear, the tool repair is complete.

Weld procedure 3

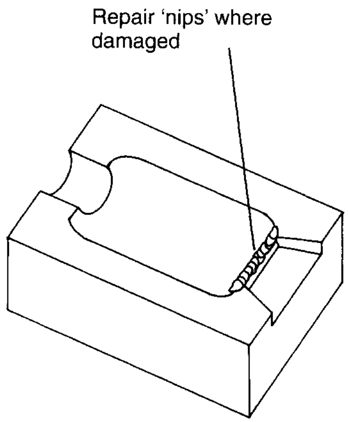
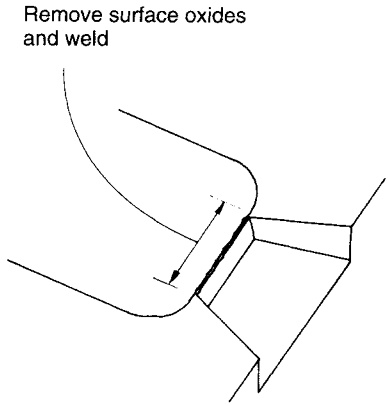
This next weld procedure discusses the repair of a blow mold. The blow mold's cut-off or pinch-off edges (nips) are worn and in need of repair.

Weld procedure 3 breakdown

Description: blow mold

This is a brief description of the tool to be repaired (Fig. 2.3).

Job no.	Company	Description	Date
		Blow mold	
Contact	Material	HRC	Quantity
	Aluminum		

Instruction sketch	Preparation sketch
	

Pre-inspection					
Visual	√		Dye pen		
Weld process		TIG (AC)	Pre-heat		100–150*
Consumable	1	5356 (NG6)			
	2				
	3				
Gas		Argon	Backing gas		
Other requirements		*Important maximum temp. during welding 180°C			

Operation:	Quantity	Sign	Date
Preparation			
Weld			
Weld			

Cooling:	Heat insulating material		Air	√

Final inspection					
Dye pen			Visual	√	

Fig. 2.3

Material: aluminum

Most blow molds are made from aluminum, although there are some very long production run blow molds made from high chrome steels, e.g. 420 stainless steels or D2, but these are easily distinguished from aluminum. Obviously there are many different types of aluminum so it is very important to find out as much information as possible; see Chapter 3, page 36.

Instruction sketch

This sketch shows the damaged area to be welded: 'Repair nips where damaged'. Blow molding is a continuous process which relies on clean cutting nips. After a while these nips will become worn and will need to be welded.

Preparation sketch

This preparation sketch tells you to remove the surface oxides and any contaminated material before you can start welding. Full welding details in Chapter 6, page 61.

Pre-inspection: visual

A visual inspection is all that is generally needed for this type of repair. Give your tool a dye penetrant inspection if you feel it needs one.

Weld process: TIG (alternating current, AC)

The most suitable weld process for this type of repair is TIG, switched into AC (alternating current) mode; see Chapter 7, page 111, for more details.

Pre-heat: 100–150 °C

Aluminum is an excellent heat conductor which makes it difficult to weld cold because the heat will dissipate from the weld area very quickly. A pre-heat is needed just to make welding easier; see Chapter 5, 'Pre-heating aluminum and copper', page 55, for more details.

Consumable: 5356 (NG6)

Unfortunately the owner of this tool did not know what type of aluminum his tool was made of. Most aluminum tools tend to be 6 series magnesium/silicon or 7 series zinc alloyed which are readily weldable with 5356; see page 43, 'No. 11, 5356 standard filler wire' and Table 4.1.

Without knowing what type of aluminum was being dealt with, it was decided to perform a tab test (see Chapter 4, 'Tab testing', page 47) just to make sure the weld metal held firm. It did, so the choice was made.

Gas: argon

Because this repair was on an open edge and the tool had been given a 100 °C pre-heat, argon was all that was needed for the torch gas; see Chapter 5, 'Minimizing pre-heats on aluminum and copper', page 56.

Other requirements: 180 °C strict maximum base metal temperature

It is very important not to allow the temperature of your aluminum tool metal to rise above 180 °C during welding because it can start to lose its properties and begin to soften. See 'Minimizing pre-heats on aluminum and copper, page 56.

Cooling: air

Aluminum does not usually suffer from cracking on cooling, so the tool can be cooled naturally in air, preferably away from drafts and at room temperature.

Final inspection: visual

A visual inspection is all that is needed to make sure that there is enough weld metal to cover the repair and that there is no under cut (notches) at the ends of the welds, etc.; see Chapter 6, page 61, for welding details.

Weld procedure 4

This final weld procedure looks at the repair of a hard copper mold tool from a plastic injection mold (Fig. 2.4). The inner/ejector core has a damaged shut off edge which is in need of repair.

Weld procedure 4 breakdown

Description: ejector core

This tool is an inner/ejector tool copper core out of a plastic injection mold.

Material: tool copper

This has an unknown chemical composition so it is just classed as tool copper.

HRC: 40HRC

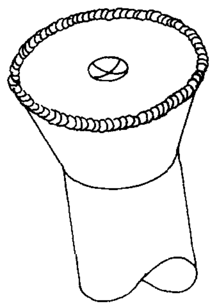
This tool was about 40HRC after a file hardness test; see Chapter 3, Table 3.1.

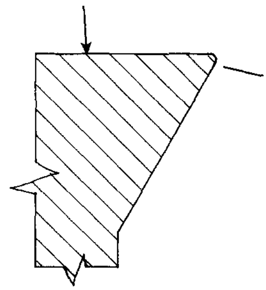
Instruction sketch

The sketch shows the ejector core. The core's shut off edge has been damaged during assembly after routine maintenance and is in need of repair; see Chapter 6, page 62, for full welding details.

Job no.	Company	Description	Date
		Ejector core	
Contact	Material	HRC	Quantity
	Tool copper	*40*	

Instruction sketch	Preparation sketch





Pre-inspection					
Visual	√		Dye pen		
Weld process		*TIG*	Pre-heat		*100–150 °C*
Consumable	1	*410 stainless steel*			
	2				
	3				
Gas		*Argon*	Backing gas		
Other requirements		*Wear protective breathing mask against welding fumes*			

Operation:	Quantity	Sign	Date
Preparation			
Weld			
Weld			

Cooling:	Heat insulating material		Air	√

Final inspection					
Dye pen			Visual	√	

Fig. 2.4

Preparation sketch

This sketch shows the damaged edge and suggests that it only needs a wire brushing and a clean down with a solvent, keeping the wire brush away from the mold face.

Pre-inspection: visual

This tool only needed a visual pre-inspection because it was unlikely to be cracked.

Weld process: TIG (DC)

TIG is the most suitable weld process for this type of repair.

Pre-heat: 100–150 °C

Because we do not know what type of alloy copper is in this tool, we should assume the worst – beryllium copper, which is about 98% copper, making it an excellent conductor of heat, and 2% beryllium, giving the copper its 40 HRC hardness.

Pre-heating copper is only to assist welding by counteracting its excellent conductivity; see Chapter 5, 'Pre-heating aluminum and copper', page 55.

Consumable: 410 stainless steel

When I first started welding tool coppers, hard copper filler wires were unobtainable so I improvised with anything I could find, and discovered that stainless steels worked best. Since this tool required a 40 HRC weld finish, 410 stainless steel was chosen; see Chapter 4, 'Filler wires for tool coppers', page 47, for alternatives.

Gas: argon

This is the most suitable torch gas for this type of repair. If you intend to weld heavier section copper, see Chapter 7, page 113, 'TIG welding gases', and Chapter 5, page 56, 'Minimizing pre-heats on aluminum and copper'.

Other requirements: wear protective breathing mask

Even with the very low fume emissions given off by the TIG welding process, it is essential to protect yourself against possible beryllium welding fumes so a fume mask must be worn. For more information on welding fumes see Chapter 7, 'Welding fumes', page 106.

Cooling: air

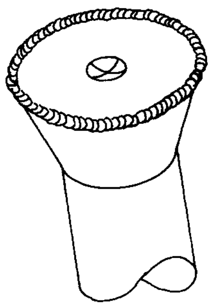
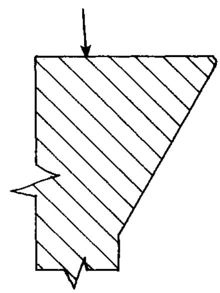
Copper tools are unlikely to suffer from cracking during cooling so always cool this type of tool naturally away from drafts.

Final inspection: visual

This tool only needs a visual inspection to make sure there is no damage to the mold face, that there is sufficient weld metal to cover the repair and that there is no under cut on the mold face.

For the reader who wishes to use this weld procedure as a progress sheet, Fig. 2.5 shows how it would look if I had completed all the work and inspection from start to finish.

Job no.	Company	Description	Date
0004	Debut Tools	Ejector core	9:7:99
Contact	**Material**	**HRC**	**Quantity**
J. K. Rob	Tool copper	40	2

Instruction sketch	Preparation sketch
Fully weld shut off edge 	Avoid mold face  Wire brush and clean edge only

Pre-inspection					
Visual	√	S. Thompson	Dye pen		
Weld process		TIG	Pre-heat		100–150 °C
Consumable	1	410 stainless steel			
	2				
	3				
Gas		Argon	Backing gas		
Other requirements		Wear protective breathing mask against welding fumes			

Operation:	Quantity	Sign	Date
Preparation	2	S. Thompson	9:7:99
Weld	2	S. Thompson	9:7:99
Weld			

Cooling:	Heat insulating material		Air	√

Final inspection					
Dye pen			Visual	√	S. Thompson

Fig. 2.5

3

Identification of material

Tool steels

One of the most important steps in mold, tool and die repair welding is to identify the chemical composition of your work piece (what is your tool made of, e.g. carbon content, chromium content?). You must have this information in order to decide on the type of pre-heat needed; see Chapter 5. If it is not practical to pre-heat your tool, what type of weld technique would be suitable? (See Chapter 6, 'Welding without full pre-heat', page 96.) Choosing the right type of filler wire can also depend upon your tool's chemical composition especially if you need to color match or if you intend to weld repair photo-etched tools; see Chapter 4, Table 4.2, page 44.

If you intend to weld a tool and you do not know what it is made of, you can either send it away for analysis to your local inspecting and testing engineers or you can guess. In my experience, most people are prepared to settle for a good guess rather than incur the time and expense of an analysis.

This chapter has four tables to help you to decide the tool's hardness (HRC) and its chemical composition, e.g. carbon (C), chrome (Cr), molybdenum (Mo) content.

Table 3.1 gives you a guide to tool HRC (Hardness Rockwell 'C'). Table 3.2 will give you some help if you know the tool's name (e.g. aluminum die cast mold) but you do not know what it is made of, i.e. its material name, e.g. P20, H21.

Tables 3.3 and 3.4 give you the two most commonly used standards, the American Iron and Steel Institute (AISI) and the German Werkstoff material numbers and their mean (average) chemical compositions. Chemical compositions will always differ from book to book and from one manufacturer's tool steel stock list to another, so it will be unlikely that your piece of P20 tool steel will exactly match the chemical composition in these tables, but they will be close enough for this type of work.

Appendix I lists other steels and tool steel names and numbers, old and new, with a close AISI or Werkstoff number comparison or a close chemical composition. These 'comparisons' only serve as a close guide to a tool's chemical composition, not necessarily an exact match. This book is not a metallurgist's handbook.

HRC file check

This can only be a rough guide because there are many tool metals, such as D2, that are occasionally used in their natural state (soft) when their carbon content is 1.40–1.60%, and tool metals such as P20 which are generally used in a pre-toughened state (not fully hardened). Run a file across a discreet corner of your tool and compare your finding with Table 3.1 below.

Table 3.1 HRC file check

Findings	HRC	Possible carbon content
Easy to file (soft)	25–30	0.2–0.3%
Hard but possible to file (medium)	40–55	0.3–0.7%
Unable to file (hard)	60–70	0.6–2.5%

Table 3.2 Types of tool and their possible material type

Types of tool	Possible types of material
Anvils	W1
Axes	1045
Blades	
flying shear	D2
granulator	D2
hot shearing	H13
rotary shear	O1
shear	A2, S1, L6
shear, for hard thin materials	D3
shear, heavy duty, cold	D3
shear, thick materials	1.2767
Blocks, die, cold, high pressing stress	6F5
Broaches	O1
Bushings	O1
Cams	O1
Centers, lathe	O1, L3
Chasers	1.2419
Chisels	
hand	S1
pneumatic	S1
Chucks	
collet	W1
split	S4
Collets	O1
Cores	
hammer	W2
hot working	1.2567
Cutters	
circular, for cold rolled strip	D2
milling	O1
strip splitting	O1
Dies	
wire drawing	D2
blanking	D2, D3, S1
coining	A2, O1, S1
cold working	W2
cupping	D2
cutting	W110
cutting, hot	S1
deep drawing, for sheet metal	D2
die casting	H13
die forging, small to medium work	L6, S4

Table 3.2 *Continued*

Types of tool	Possible types of material
die-casting, to be hobbed	P4
embossing	6F5, 1.2762
embossing, hollow	W110
embossing, large	W110
extrusion, cold working	D2
extrusion, for aluminum and copper	H13, H21
extrusion, for rubber bonded synthetics	H13, H21
extrusion, hot working	H19
forging, cold working	A2, H13
forging, hot working (non-excessive temps.)	S1
forging, hot working	H13, H21
forging, hot working, heavy duty	1.2744
forming, for sheet metal	D2
gravity, for aluminum die casting	H13, H21
gripper	H13
hammer, drop forge	L6
heading	D2 A, L6
heading, cold working	A2, L6, H13
hobbing	D2, L6
hot extrusion	H21
hot working for non-ferrous metals	1.2567, H21
leather	W1
lower, hot working	H21
medium run	O1
molding part	L6
molding, for abrasive powder (ceramic)	D3
molding, synthetic plastic	P4, 1.2738
nail making, cold working	S1
plastic, corrosive	420
pressing, chemically agressive compounds	1.2316
pressing, component	1.2744, 1.2766, H12
pressure, for aluminum and zinc die cast	H13, H21
punching	W108, W110, A2, D2
resin (artificial), highly stressed	P6
resin, corrosive	420
snap	W108, S1
split hot heading	H13
swaging, hot working (non-excessive temps.)	S1
thread rolling	A2, D2, D3
threading	L3
trimming	A2, D2
Files	1.2008

Table 3.2 *Continued*

Types of tool	Possible types of material
Gages	
master	D3
plug	D2, O1
ring	D2, O1
Hammers	W1,1045
Hobs	
cutting	O1
master, for cold hobbing	D2, D3, L6, M2, T1
Jaws, chuck	O1
Knives	
cloth cutting	O1
paper cutting	O1
resin bonded material cutting	A2
wood cutting	A2
Liners, mold, for bricks and tiles	D3
Mandrels	
for aluminum tube drawing	H13
for copper tube drawing	H13
for steel tube drawing	S1
Molds	
aluminum or zinc die cast	H13, H21
chemically aggressive material	420, 420mod.
complicated/intricate	A2, D2, O1
compression	H13
compression, for lead, zinc and tin alloys	420, 420mod.
compressive, high	EN30B
cutt	EN30B, 410
cutt, high wear resisting	D2
die casting, heavy duty	420, 420mod.
glass	420
long production run	A2, D2, O1, 420mod.
plastic cut	D2
plastic injection, very high polish	420mod.
plastic injection, very large	P20
presser casting, for light metals	H11
pressure casting	1.2567
pressure casting, brass	H19
rubber seal	D2
transfer	H13
Pins	
core, for molds	D2
ejector	H13, L1

Table 3.2 *Continued*

Types of tool	Possible types of material
Plungers	H13
Presses, metal extruding, non-ferrous metals	H12
Punches	
blanking	D3
cold working	L2
cutting, complicated	1.2127
drawing	O1
engraving	S1
head	S1
high silicon and transformer material	D2, D3
hot working	H13, S1
stainless steel sheet and plate	D2
steel sheet and plate	D2, D3
tableting, for abrasive and corrosive powers	D3
Reamers	L3, D3, D2, O1
Rings, hammer roll	1.2766
Rollers	
sheet metal forming	D2
spinning	A2
Rolls	
cold, small	1.2057
tube expanding	O1
Saddles	
hammer	W1, S4
pressing	S4
Saws	
circular, woodworking	1.1830
frame, woodworking	1.1830
metal cutting	1.2442
Scythe	W110
Shears	1045
Sleeves	
abrasive and corrosive powder tabletting	D3
drill	1.2378
Stamps, minting	W2
Strainers	W108
Taps	
cold	O1, L2
special	D2, M2
Tools	
bending	1.2767
blanking, hot	S1

Table 3.2 *Continued*

Types of tool	Possible types of material
blanking, nut	S1
burnishing	1.2008
countersinking	L2
cutting, cold	W108
cutting, dynamo and transformer sheets	1.2378
cutting, heavy duty, cold	D3
cutting, medium duty, cold	A2, S1
cutting, medium temperature	S4
cutting, precision, cold	1.2008
cutting, thread machining	O1
drawing, cold	1.2057
embossing	W110, 1.2767
embossing, high stress	1.2762
heading, cold	W2
impact, cold	W108
knurling	A2,1.2057
medium temp. piercing	S1
metal extrusion press	H11
metal extrusion	L6
piercing, hot	H13
pneumatic	S1
pre-forming	S1
press, extrusion, heavy duty	H10A
press, for fine and medium work	D2, O1
press, heavy duty	D2, D3
pressing, hot, complexed engravings	1.2767
pressing, tube	L6
processing, synthetic plastics	P20
punching, heavy duty, cold	D3
punching, hot	S1
punching, medium duty, cold	A2
scraping	L2
sone working, hard	W110
stone working, medium hard	W1
trimming, cold	S4
trimming, hot	H13, M2, S1, S4
trimming, medium temp.	S1, M1, M2

Table 3.3 AISI and some BS numbers without their 'B' prefix (BH10A/H10A) with comparable Werkstoff numbers and their mean (average) chemical compositions

AISI	Werkstoff	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
A2	1.2363	1.00	0.60	–	5.00	1.15	–	–	–
A3	–	1.25	0.30	–	5.00	1.00	–	1.00	–
A4	–	1.00	2.00	–	1.00	1.00	–	–	–
A5	–	1.00	3.00	–	1.00	1.15	–	–	–
A6	–	0.70	2.00	–	1.00	1.25	–	–	–
A7	–	2.25	0.30	–	5.25	1.00	–	4.75	–
A8	–	0.55	0.30	–	5.00	1.25	–	–	1.25
A9	–	0.50	0.30	–	5.00	1.40	1.40	1.00	–
A10	–	1.35	1.80	–	–	1.50	1.80	–	–
A11	–	2.45	0.50	–	5.15	1.30	–	9.75	0.50
D1	–	1.00	0.40	–	12.0	1.00	–	–	–
D2	1.2379	1.50	0.40	–	12.0	0.95	–	–	–
D2A	1.2601	1.75	0.40	–	12.0	0.80	–	–	–
D3	1.2080	2.20	0.35	–	12.0	–	–	–	–
D4	–	2.25	0.30	–	12.0	1.00	–	–	–
D5	–	1.50	0.40	3.00	12.0	0.95	–	–	–
D6	–	2.25	0.40	–	12.0	–	–	–	1.00
D7	–	2.30	0.40	–	12.5	0.95	–	4.10	–
F1	–	1.10	0.50	–	–	–	–	–	1.50
F2	–	1.30	0.50	–	0.30	–	–	–	3.75
F3	–	1.25	0.50	–	0.75	–	–	–	3.75
H10	1.2365	0.40	0.30	–	3.25	2.50	–	0.40	–
H10A	1.2885	0.32	0.30	3.00	3.00	2.80	–	0.50	–
H11	1.2343	0.35	0.30	–	5.10	1.50	–	0.40	–
H12	1.2606	0.35	0.30	–	5.10	1.50	–	0.30	1.35
H13	1.2344	0.35	0.30	–	5.10	1.50	–	1.00	–
H14	–	0.40	0.30	–	5.00	–	–	–	5.00
H15	–	0.40	0.30	–	5.00	5.00	–	–	–
H16	–	0.55	0.30	–	7.00	–	–	–	7.00
H19	–	0.40	0.30	4.25	4.25	–	–	2.00	4.25
H20	–	0.35	0.30	–	2.00	–	–	–	9.00
H21	1.2581	0.35	0.30	–	3.40	–	–	0.40	9.40
H21A	–	0.30	0.30	–	2.75	0.60	2.25	0.50	9.25
H22	–	0.35	0.30	–	2.00	–	–	–	11.0
H23	–	0.30	0.30	–	12.0	–	–	–	12.0
H24	–	0.45	0.30	–	3.00	–	–	–	12.0
H25	–	0.25	0.30	–	4.00	–	–	–	15.0
H26	–	0.50	0.30	–	4.00	–	–	1.00	18.0
H41	1.3346	0.65	0.30	–	3.75	8.00	–	1.15	1.80
H42	–	0.60	0.30	–	4.00	5.00	–	2.00	6.00
H43	–	0.58	0.30	–	4.10	8.00	–	2.00	–

Table 3.3 *Continued*

AISI	Werkstoff	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
H224	1.2713	0.50	0.85	–	0.90	0.30	1.50	–	–
H225	1.2713	0.50	0.85	–	0.90	0.30	1.50	–	–
L1	–	1.00	0.30	–	1.25	–	–	–	–
L2	1.2210	0.80	0.30	–	1.00	–	–	0.20	–
L3	1.2067	1.00	0.40	–	1.50	–	–	0.20	–
L4	–	1.00	0.60	–	1.50	–	–	0.20	–
L5	–	1.00	1.00	–	1.00	0.25	–	–	–
L6	1.2713	0.70	0.70	–	0.75	–	1.50	–	–
L7	1.2303	1.00	0.35	–	1.50	0.40	–	–	–
M1	1.3346	0.80	0.30	–	4.10	8.00	–	1.10	1.50
M2	1.3343	0.95	0.30	–	4.10	5.00	–	1.90	6.10
M3	1.3342	1.10	0.30	–	4.10	5.50	–	2.75	6.10
M4	–	1.30	0.30	–	4.40	5.00	–	4.20	5.90
M6	–	0.80	0.30	12.0	4.00	5.00	–	1.50	4.00
M7	1.3348	1.00	0.30	–	4.00	8.75	–	2.00	1.75
M10	–	0.95	0.30	–	4.00	8.00	–	2.00	–
M15	–	1.50	0.30	5.00	4.00	3.50	–	5.00	6.50
M30	–	0.80	0.30	5.00	4.00	8.00	–	1.25	2.00
M33	1.3249	0.90	0.30	8.00	4.00	9.50	–	1.15	1.50
M34	1.3249	0.90	0.30	8.00	4.00	8.00	–	2.00	2.00
M35	–	0.80	0.30	5.00	4.00	5.00	–	2.00	6.00
M36	–	0.80	0.30	8.00	4.00	5.00	–	2.00	6.00
M41	1.3246	1.10	0.30	5.00	4.25	3.75	–	2.00	6.75
M42	1.3247	1.10	0.30	8.00	3.75	9.50	–	1.15	1.50
M43	–	1.20	0.30	8.25	3.75	8.00	–	1.60	2.75
M44	–	1.15	0.30	12.0	4.25	6.25	–	2.00	5.25
M46	–	1.25	0.30	8.25	4.00	8.25	–	3.20	2.00
M47	–	1.10	0.30	5.00	3.75	9.50	–	1.25	1.50
M48	–	1.50	0.30	9.00	3.90	5.10	–	3.00	10.0
M50	1.3551	0.81	0.30	0.25	4.00	4.25	0.10	1.00	0.25
M52	–	0.90	0.25	–	4.00	4.50	–	1.90	1.25
M61	–	1.80	0.35	–	3.90	6.40	–	4.90	12.5
M62	–	1.30	0.30	–	3.90	10.5	–	2.00	6.25
O1	1.2510	0.90	1.15	–	0.50	–	–	–	0.50
O2	1.2842	0.90	1.60	–	–	–	–	–	–
O6	–	1.45	0.65	–	–	0.25	–	–	–
O7	–	1.20	0.30	–	0.75	–	–	–	1.75
P1	–	0.10	0.30	–	–	–	–	–	–
P2	–	0.07	0.30	–	2.00	0.20	0.50	–	–
P3	–	0.10	0.30	–	0.60	–	1.25	–	–

Table 3.3 *Continued*

AISI	Werkstoff	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
P4	1.2341	0.07	0.30	–	5.00	0.75	–	–	–
P5	–	0.10	0.30	–	2.25	–	–	–	–
P6	1.2735	0.10	0.30	–	1.50	–	3.50	–	–
P20	1.2330	0.35	0.30	–	1.70	0.40	–	–	–
P21	–	0.20	0.30	–	–	–	4.00	–	–
P30	1.2766	0.30	0.55	–	1.20	0.30	4.10	–	–
S1	1.2542	0.50	0.30	–	1.50	–	–	0.20	2.00
S2	–	0.50	0.40	–	–	0.50	–	–	–
S3	–	0.50	0.40	–	0.75	–	–	–	1.00
S4	–	0.55	0.80	–	0.35	–	–	0.35	–
S5	–	0.55	0.75	–	–	0.40	–	–	–
S6	–	0.45	1.40	–	1.50	0.40	–	–	–
S7	–	0.50	0.30	–	3.25	1.40	–	–	–
T1	1.3355	0.70	0.30	–	4.10	–	–	1.10	18.0
T2	–	0.80	0.30	–	4.10	0.85	–	2.10	18.2
T3	–	1.05	0.30	–	4.10	–	–	3.00	18.0
T4	1.3255	0.90	0.30	5.00	4.10	0.85	–	1.00	18.0
T5	1.3265	0.80	0.30	8.00	4.10	0.85	–	2.10	18.2
T6	–	0.80	0.30	12.0	4.50	–	–	1.50	20.0
T7	–	0.75	0.30	–	4.10	–	–	2.10	14.0
T8	–	0.80	0.30	5.00	4.10	0.85	–	2.10	14.0
T9	–	1.20	0.30	–	4.00	–	–	4.00	12.0
T15	1.3202	1.50	0.30	5.00	4.00	–	–	5.00	12.0
T20	–	0.80	0.30	0.50	4.60	0.80	–	1.50	21.8
T21	–	0.65	0.30	1.00	3.80	0.70	0.40	0.50	14.0
T42	1.3207	1.30	0.30	9.50	4.10	3.10	0.40	3.00	9.00
W1	–	1.00	0.30	–	–	–	–	–	–
W2	–	1.00	0.30	–	–	–	–	0.25	–
W3	–	1.00	0.30	–	–	–	–	0.50	–
W4	–	1.00	0.30	–	0.25	–	–	–	–
W5	–	1.00	0.30	–	0.50	–	–	–	–
W6	–	1.00	0.30	–	0.25	–	–	0.25	–
W7	–	1.00	0.30	–	0.50	–	–	0.20	–
W108	1.1525	0.80	0.30	–	0.18*	–	–	–	–
W109	–	0.90	0.30	–	0.18*	–	–	–	–
W110	1.1545	1.05	0.30	–	0.18*	–	–	–	–
W112	1.1663	1.20	0.30	–	0.18*	–	–	–	–
W209	–	0.90	0.30	–	0.18*	–	–	0.25	–
W210	1.2833	1.05	0.30	–	0.18*	–	–	0.25	–
W310	–	1.05	0.30	–	0.18*	–	–	0.45	–

Table 3.3 *Continued*

AISI	Werkstoff	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
6G	–	0.55	0.80	–	1.00	0.45	–	0.10	–
6F2	–	0.55	0.75	–	1.00	0.35	1.00	0.10	–
6F3	–	0.55	0.60	–	1.00	0.75	1.80	0.10	–
6F4	–	0.20	0.70	–	–	3.35	3.00	–	–
6F5	–	0.55	1.00	–	0.50	0.50	2.70	0.10	–
6F6	–	0.50	–	–	1.50	0.20	–	–	–
6F7	–	0.40	0.35	–	1.50	0.75	4.25	–	–
6H1	–	0.55	–	–	4.00	0.45	–	0.85	–
6H2	–	0.55	0.45	–	5.00	1.50	–	1.00	–
410	1.4006	0.11	0.80	–	12.5	–	–	–	–
416	1.4005	0.15	1.20	–	13.0	0.50	–	–	–
420	1.4021	0.20	0.80	–	13.0	–	–	–	–
431	1.4057	0.19	0.80	–	16.0	–	1.60	–	–
440A	–	0.70	0.80	–	17.0	0.65	–	–	–
440B	–	0.85	0.80	–	17.0	0.65	–	–	–
440C	–	1.10	0.80	–	17.0	0.65	–	–	–

*Estimated chrome content.

Table 3.4 German Werkstoff numbers with comparable AISI numbers or a close matching chemical composition

Werkstoff	AISI/SAE	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
1.1525	W108								
1.1545	W110								
1.1625	W1								
1.1645	W1								
1.1663	W112								
1.1673	–	1.40	0.50	–	–	–	–	–	–
1.1730	1045	0.45	0.70	–	–	–	–	–	–
1.1740	–	0.60	–	–	–	–	–	–	–
1.1750	W1								
1.1820	–	0.55	0.70	–	–	–	–	–	–
1.1830	–	0.86	–	–	–	–	–	–	–
1.2002	–	1.20	0.40	–	0.40	–	–	–	–
1.2008	–	1.40	0.50	–	0.35	–	–	–	–
1.2057	–	1.00	0.50	–	1.10	–	0.20	–	–
1.2067	L3								
1.2080	D3								
1.2082	420								

Table 3.4 *Continued*

Werkstoff	AISI/SAE	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
1.2083	420	0.42	–	–	13.0	–	–	–	–
1.2162	–	0.21	1.25	–	1.20	–	–	–	–
1.2127	–	1.00	1.05	–	1.05	–	–	–	–
1.2210	L2								
1.2241	L2								
1.2303	L7								
1.2311	P20								
1.2312	P20								
1.2316	–	0.36	–	–	16.0	1.20	–	–	–
1.2330	P20								
1.2332	4142								
1.2341	P4								
1.2343	H11								
1.2344	H13								
1.2361	440B								
1.2363	A2								
1.2365	H10								
1.2367	–	0.37	–	–	5.00	3.00	–	0.60	–
1.2378	–	2.20	0.30	–	13.0	–	–	–	0.80
1.2379	D2								
1.2419	–	1.15	0.95	–	1.10	–	–	–	1.20
1.2436	–	2.20	0.30	–	12.0	–	–	–	–
1.2442	–	1.05	–	–	0.50	–	–	–	2.10
1.2510	O1								
1.2515	–	1.05	0.50	–	0.35	–	–	0.20	0.75
1.2542	S1								
1.2547	S1								
1.2550	S1								
1.2562	–	1.25	0.50	–	0.35	–	–	0.20	3.50
1.2567	–	0.32	–	–	2.40	–	–	0.60	4.30
1.2581	H21								
1.2601	D2A								
1.2606	H12								
1.2631	–	0.53	–	–	8.30	1.20	–	–	1.20
1.2663	A2								
1.2678	H19								
1.2711	6F2								
1.2713	L6								
1.2714	L6								
1.2718	6F5								
1.2721	L6								
1.2735	P6								
1.2738	–	0.40	1.45	–	1.95	0.20	1.05	–	–

Table 3.4 *Continued*

Werkstoff	AISI/SAE	C %	Mn %	Co %	Cr %	Mo %	Ni %	V %	W %
1.2744	–	0.57	–	–	1.10	0.80	1.70	0.10	–
1.2762	–	0.70	–	–	1.50	0.70	0.50	–	0.30
1.2764	–	0.19	0.40	–	1.25	0.20	4.00	–	–
1.2766	–	0.32	–	–	1.20	0.20	4.10	–	–
1.2767	–	0.45	0.40	–	1.35	0.25	4.00	–	–
1.2770	–	0.85	–	–	–	–	0.80	0.10	–
1.2787	431ss								
1.2826	S4								
1.2833	W2								
1.2842	O2								
1.2885	H10A								
1.3202	T15								
1.3207		1.30	0.30	9.50	4.10	3.10	–	3.10	9.00
1.3243	–	0.90	0.30	5.00	4.10	5.00	–	2.00	6.20
1.3246	M41								
1.3247	M42								
1.3249	M33/34								
1.3255	T4								
1.3265	T5								
1.3342	M3								
1.3343	M2								
1.3344	M3								
1.3346	H41/M1	0.82	0.40	–	3.80	8.60	–	1.15	1.75
1.3348	M7								
1.3355	T1								
1.3505	–	1.00	0.50	–	1.45	–	–	–	–
1.3551	M50								
1.3554LW	M2								
1.4005	–	0.12	–	–	12.5	–	–	–	–
1.4006	410								
1.4014LW	420								
1.4021	420								
1.4028	–	0.33	–	–	13.5	–	–	–	–
1.4034	–	0.46	–	–	13.0	–	–	–	–
1.4057	431								
1.4110	–	0.60	–	–	14.1	0.60	–	0.10	–
1.4112	440B								
1.4140	–	0.43	–	–	13.2	–	1.00	–	–
1.4528	–	1.07	–	1.50	17.0	1.10	–	0.10	–
1.5864	–	0.32	–	–	1.20	0.20	4.10	–	–
1.6582	4340								
1.6747	–	0.30	–	–	1.25	0.30	4.25	–	–

Tool coppers

There are many types of copper alloy used in the manufacture of tools across the whole spectrum of industry. This section concentrates on the types of tool copper used in the manufacture of mold tools.

Most tool coppers connected with mold tools tend to be two main types: mold face coppers and working coppers.

Mold face coppers (color: copper and light copper)

Copper color

Copper colored, copper mold tools will be of low alloy copper. If the tool is soft it may contain low levels of nickel (2%), chromium (0.5%) and/or beryllium (0.5%). If the tool is hard, it may contain high levels of beryllium (2–3%).

Light copper color

Light copper colored, copper mold tools will be of a higher alloy copper. These tools may contain high levels of nickel (10%), silicon (3%) with additions of chromium.

These coppers and light coppers tend to be used in the manufacture of mold cores, cavities, pinch offs (nips), sprue bushings, hot runner systems, core pins ejector pins and blow pins, etc.

Some mold face tool coppers (trade names)

- AMPCO; 83, 91, 95, 97, 940, 945
- UDDEHOLM; Moldmax and Protherm

Working coppers (color: yellow copper)

These yellow copper tools (slides, bushes, wear plates, etc.) used behind the scenes on mold tools will be a high alloy copper. They are likely to contain 8–15% aluminum, 3–5% ferrite and, if they are hard, up to 3% beryllium.

Other behind the scenes tools include gibs, mold locking devices, sleeve bearings, guide pin bushings, guide rails, lifter blades and leader pin bushings.

Some working coppers (trade names)

- AMPCO; 18, 21/21W, 22/22W, 25, M4

Tool aluminum

Today, aluminum is becoming more and more popular in the production of mold tools and other tools. Its uses include: injection blow molding, extrusion blow molding, injection molding, vacuum forming lay-up molds, rubber molds, shoe molds, load cells, foam molds, prototype tooling, carpet forming molds, robotics, general tools, jigs and fixtures.

Although you may feel that you can identify aluminum without any help, beware! Aluminum can look like anything; only its weight will give it away. Aluminum can be hard chromium plated which will give it an 80 HRC mirror finish, it can be bright red or green or it can look and feel like cast iron because it can have tool steel inserts fitted. Fortunately most forming and molding aluminum is easy to recognize. Here are some that you may come across:

- Wrought tool aluminum – 1050A, 6061 / HE20, 6063 / HE9, 6063A, 6082 / HE30, 7020 / HE17, ALUMEC 79 and 89.
- Cast aluminum – LM6, LM25, LM5.

4

Choosing your filler wire

Once you have decided that you intend to weld molds, tools or dies, you will need to make a list of all the different types of tool metals that you are likely to come across. You will have to decide, with the help of this chapter, exactly what you want because there are suppliers that will sell you what they have, not necessarily what you need. Write down as much information about each tool metal as possible: chemical composition, e.g. 0.35C, 5.0Cr, 1.0V, 1.5Mo; material name, e.g. H13; hardness, e.g. 52–55HRC, and whether the tool is to have a special finish, e.g. case hardened, high polish, photo/acid etch. This list will be the basis for your filler wire selection. If you need help to identify your material, *go to* Chapter 3.

Buying filler wires

Get in touch with your local welding equipment suppliers and tell them that you need filler wires to cover your list of tool metals. They will probably not stock tool metal filler wires, so they will contact their main supplier and pass you on to them. Their main supplier will probably send a representative round with his or her trusty product handbook that details their product range. To help you to understand filler wires and the metals they are designed to weld, try to persuade the main supplier's representative to leave you a product handbook so that you can match any future tools against their filler wires. Not every local welding supplier will carry tool metal filler wires, so you may have to shop around. Even if you do find a supplier for your filler wires, they might not be able to supply you with every kind you need, so try other suppliers and avoid buying a 'general-purpose filler wire' when you need a 'matching filler wire'.

'General-purpose filler wires' are filler wires that cover groups of tool steels, e.g. if you intend to weld cutting tools like punches and dies, the most important character of your filler wire should be its hardness and its edge retention (will it do the job and will it last?), not necessarily its chemical composition. 'Matching filler wires' are filler wires that have been specially made to chemically match one type of tool metal, e.g. if you intend to weld repair a photo etched P20 mold you should be using a chemically matching filler wire, *not* a general-purpose filler wire; see Table 4.2, page 44, also see Chapter 6, page 98, 'Welding photo/acid etched and polished tools'.

Choosing filler wires

There are thousands of different types of tool steel, and many types of tool copper and tool aluminum, but only a limited number of tool filler wires, so choosing a 'matching filler wire' for your tool metal can be a problem. Fortunately there are some specialist tool steel manufacturers who make filler wires to go with their tool metals, which can be very helpful, such as Modified 420, P20, H13, A2, M2, some copper and some aluminum, so if you use specialized tool metals you could contact your main tool metal supplier for guidance.

Basically when choosing tool filler wires you have to decide what you want the end result to be because you can put just about any steel filler wire on any tool steel. Aluminum, though, does not weld on steel or steel on aluminum although they can be joined with other processes. High alloy steels like stainless steels will weld on coppers and coppers on steels, so do not be afraid to experiment. It is generally understood, however, that if you cannot find a filler wire with a matching chemical composition to the tool you intend to weld, then you should 'over match' e.g. pick a filler wire that has more, not less, of the tool's main alloys: Cr, W, Mo, V, Ni, Mn, Co (steel's main alloys), Mg, Si, Mn, Zn, (aluminum's main alloys).

So to summarize, identify your material, contact your local welding suppliers and get them to send a representative to discuss suitable filler wires.

To help you to choose your filler wires, here is my day-to-day selection of TIG filler wires:

1 1% Cr Mo (A32) standard filler wire.
2 P20 tool steel filler wire.
3 H13 tool steel filler wire.
4 Medium hard (50 HRC) general-purpose tool steel filler wire.
5 Very hard (60 HRC) general-purpose tool steel filler wire.
6 410 stainless steel standard filler wire.
7 Modified 420 stainless tool steel filler wire.
8 312 stainless steel standard filler wire.
9 Inconel 625 'type' standard filler wire.
10 4043 standard aluminum filler wire.
11 5356 standard aluminum filler wire.

1 1% Cr Mo (A32, ER 80 S-B2, SG CrMo 1, 1.7339) standard filler wire

Chemical composition: 0.1 C, 0.9 Mn, 1.1 Cr, 0.5 Mo
Hardness: 25 HRC
1.6 mm and 2.4 mm diameter filler wires

This filler wire has a similar chemical composition to P20, so it can be used as a 'soft' P20 because of its lower carbon (C) content. I have also used it to repair photo-etched P20 mold tools when full hardness was not required. It is also very useful for bulking out large repairs instead of using all P20 filler wire because it is relatively inexpensive. This wire is also suitable for case hardening and nitriding.

2 P20 tool steel filler wire

Chemical composition: 0.33 C, 1.5 Cr, 1.0 Mn, 0.5 Mo
Hardness: 40 HRC
1.6 mm diameter TIG filler wire

This filler wire is made to closely match P20, so it is ideal for the repair of photo etched and high polished P20 type tools. Unfortunately, you are very unlikely to get a filler wire that matches a tool metal exactly, unless you buy your filler wire from the company that makes the tool metal.

3 H13 tool steel filler wire (SG 6-60)

Chemical composition: 0.35 C, 5.0 Cr, 1.3 Mo, 1.0 V
Hardness: 52 HRC
1.6 mm diameter filler wire

This filler wire is specially designed for the repair of H13 tools, although it could also be used on low alloy tool steels if a medium hard weld was needed. I have used two different types of H13 filler wire: a flux cored TIG wire which was found to be unsuitable for plastic mold tool repair and fine die cast molds and a solid TIG wire suitable for all repairs.

4 Medium hard general-purpose tool steel filler wire (SG 3-45, 1.2567)

Chemical composition: 0.32 C, 0.3 Mn, 2.5 Cr, 0.43 W, 0.5 V
Hardness: 50 HRC
1.6 mm diameter TIG filler wire

This is a tool steel filler wire that has been specially designed to weld hot working tools of a similar chemical composition, e.g. 2567, SKD 4 and S1, and lower alloy tools of a similar nature. I tend to use this filler wire on most materials that need a 45 to 50 HRC weld repair when there is a closer match and where the chemical composition is not important, e.g. 2767, EN30B, H13, H21. This filler wire acid etches to a similar depth as 2767 even though the chemical composition is completely different.

5 Very hard general-purpose tool steel filler wire (high speed steel)

Chemical composition: Cr, Mo, V, W, high speed steel, e.g. M3, M1 type alloys
Hardness: 60 HRC
1.6 mm diameter TIG filler wire

This type of filler wire is designed to weld cutting tools such as lathe tools, milling cutters of a similar chemical composition and low alloy tools of a similar nature. Small repairs can be performed using a pre-heat and a slow cool as described in Chapter 5; larger repairs should be annealed first followed by hardening and tempering. This type of filler wire can be used on any steel that needs a 60 HRC finish.

6 410 stainless steel standard filler wire

Chemical composition: 0.1 C, 14.5 Cr
Hardness: 40 HRC
1.6 mm and 2.4 mm diameter TIG filler wire

I use this filler wire to repair 13 chrome type tools, e.g. D2, 420 stainless steel, where hardness is not important but chemical composition is. It can also be used to repair shut off edges on copper tools, e.g. inserts and cores, if that tool requires a 35 to 40 HRC weld. Unfortunately stainless steels are bad conductors of heat so this might reduce the effectiveness of copper heat soak inserts.

7 Modified 420 stainless steel, tool steel filler wire

Chemical composition: modified 13% chrome
Hardness: 52–56 HRC
1.6 mm diameter TIG filler wire

This filler wire is a high quality hybrid of 420 stainless, specially made to complement modified 420 stainless steel tool steel. This filler wire can be used to repair D2 and modified 420 stainless steel mold tools when chemical composition and hardness are important, e.g. highly polished and photo etched tools. It can also be used to re-edge hard copper tools.

8 312 stainless steel

Chemical composition: 0.10C, 1.60Mn, 30.0Cr, 9.0Ni
Hardness: 26HRC
1.6mm and 2.4mm diameter TIG filler wire
Elongation: 25%

This filler wire is an excellent all-rounder because of its tough but elastic nature. It is designed for joining and surfacing difficult to weld steels. It can be used to reassemble broken tools such as D2 stripper plates and dies (see Chapter 2, 'Weld procedure 2', page 9), as a buffer layer on hard tool steels requiring large repairs see 'Butter/crack repair', page 46, and repairing cracked tools where chemical composition is not a problem. Also, this filler wire is commonly sold to inexperienced 'would be' tool welders who wish to weld P20 tools. It will happily weld P20 but its chemical composition is completely different. Unfortunately this makes 312 stainless steel unsuitable for polished and photo etched tools because cosmetically it would look different. This filler wire is not suitable for use over 450 °C, so do not use it to repair very high carbon tools such as D3 because the pre-heat and maintained welding temperature will probably damage its properties. For this, use ER Ni Cr Mo-3.

9 ER Ni Cr Mo-3 (Inconel 625 type) standard filler wire

Chemical composition: 60.0Ni, 22Cr, 9Mo, 3.5Nb (Cb)/Ta
Hardness: 160HV (very soft)
1.6mm diameter TIG filler wire
Elongation: 30%

This is the ultimate in filler wires, my safety net! If all else fails, this will do the job, unless you are trying to weld your pocket calculator to your coffee cup. This filler wire was developed as a joining and surfacing wire of chemical related work for its high strength, high heat and corrosion resistance. I tend to use this wire on high carbon tools where high pre-heats are required, e.g. D3, and instead of 312 stainless steel if this starts cracking. I also find it suitable for repairing some copper tools when hardness is not a problem, and for joining coppers to steels even though it is not designed to do so.

10 4043 standard aluminum filler wire

Chemical composition: 5% Si
2.4 mm and 3.2 mm diameter TIG filler wire

This filler wire is designed for joining and surfacing aluminum alloys with up to 7% silicon content, with silicon being the principal alloying element. It is also suitable for welding aluminum alloys with less than 2% alloying elements; see Table 4.1, below. If an aluminum alloy's chemical composition cannot be identified, perform a 'tab test' (see 'Tab testing on aluminum and copper tools', page 47), with 4043 on cast aluminum. If it takes, weld it with 4043 (always perform your tab test on a discreet outside corner). If there are any problems, try 5356, and if there are problems with that, send the tool away for analysis. 4043 filler wire is not considered suitable for tools to be anodized.

11 5356 standard aluminum filler wire

Chemical composition: 5% Mg
1.6 mm, 2.4 mm and 3.2 mm diameter TIG filler wire

This filler wire is designed to weld aluminum alloys with more than 3% magnesium content and it is considered suitable for repairs on tools to be anodized. It is used mainly on wrought aluminum (not cast) especially on hardenable aluminum alloys, e.g. blow molds and other aluminum mold tools, see Table 4.1 below.

Table 4.1

Wrought Al	Filler wire	Cast Al	Filler wire
1050A/1B	4043	LM2	4043
6061/HE20	Either	LM5	5356
6063/HE9	Either	LM6	4043
6082/HE30	Either	LM18	4043
7004	5356	LM25	4043
7020/HE17	5356	356.0	4043
7075	5356	A356.0	4043
Alumec 79/89	5356		

Table 4.2 A choice of tool filler wires

	Base metals										
Important issues	A2	D2	D3	H13	L6	O1	P20	S1	2767	Modified 420 stainless steel	Copper tools
General color match	2, 1	7, 6	7, 6	3, 4	2, 1	2, 1	2, 1	2, 1	4, 3	7, 6	see page 47
Photo/acid etch	2*	7, 6	7, 6	3	2*	2*	2, 1	2*	4*	7, 6	see page 47
Cheapest filler	1, 2	6	6	3	1, 2	1, 2	1, 2	1, 2	4	6	see page 47
Hardness (HRC) match	5, 7	5	5	3, 4	4, 3	5, 4	2, 1	4, 5	4, 7	7, 6	7, 6, 8 or 9
Butter/crack repair	8, 9	8, 9	9	8, 9	8, 9	8, 9	8, 9	8, 9	8, 9	8, 9	9

*Close match only.
1, 1% Cr Mo; 2, P20; 3, H13; 4, general-purpose (50 HRC); 5, general-purpose (60 HRC); 6, 410 stainless steel; 7, modified 420 stainless steel; 8, 312 stainless steel; 9, Inconel 625 type.

The following sections give you an easy reference on how to use different filler wires on a particular tool metal to achieve different results; see Table 4.2. The 'important issues' from Table 4.2 are discussed in more detail: general color match, acid/photo etch, cheapest filler, hardness (HRC) and butter/crack repair.

General color match

A general color match in mold, tool and die repair welding is when the weld metal's actual color has to match the tool metal's actual color (e.g. if the toolmaker makes a mistake on a new tool and needs to make a weld repair and they do not want the customer to know about it). But this is only a general color match in some cases and should not be confused with an actual chemical composition match, e.g. modified 420 stainless steel can be repaired with 410 stainless steel to give an excellent color match but the 410 stainless steel carbon content is only 0.1% instead of 0.4%, making it much softer after hardening. If you need an exact match and there is no matching filler wire available, cut a piece of parent metal into matchsticks as described in Chapter 6, page 101.

Photo/acid etch

This is very important and probably the least understood field in mold repair. The practical welding technique is discussed in Chapter 6, page 98, 'Welding photo/acid etched and polished tools', but in this section only filler wires are discussed. Choosing the wrong filler wire for an acid etched repair will give dark or bald patches on your molded plastic component. If you have had this problem, you will understand what I mean. You must choose a wire that corrodes at the same rate as the parent metal.

In some cases you may need to repair a tool that does not have a matching filler wire, e.g. 2767 (EN30B, 6F7, Cly die, Rab 1, 4% Ni types). In this case you can use a piece of parent metal as discussed in Chapter 6, page 101, 'Using base metal as a filler wire', or you can try to match its corrosive potential by using a filler wire with a similar percentage of alloys. For example, I welded a 2767 (0.45 C, 0.40 Mn, 4.10 Ni, 1.40 Cr, 0.30 Mo) test piece with my medium hard general-purpose 50 HRC tool steel filler wire (0.4 C, 2.5 Cr, 4.5 W, 0.5 V) and found that they both etched to a similar depth, so, if in doubt, 'experiment'!

Cheapest filler

This is basically a money-saving tip because some tool steel filler wires can be very expensive, e.g. if I had to repair a large D2 punch tool which needed a large amount of weld, I would lay down a single layer of 312 stainless steel to act as a buffer layer, build up the bulk of the repair with 410 stainless steel then the last three or four layers of weld would be my general-purpose 60 HRC hard filler wire; see Chapter 6, page 103, 'Economical weld technique (bulking out)'. As you can see from Table 4.2, this technique can be used on most tool steels.

Hardness (HRC)

This entails finding out what hardness is required and matching that to the filler wires that are available. I am quite happy to use my two general-purpose filler wires on any tool steel to achieve a required hardness unless a 'matching filler' is required. Avoid using low alloy, high carbon tool steel filler wire as a general-purpose filler as this may cause problems with higher alloy tools.

Butter/crack repair

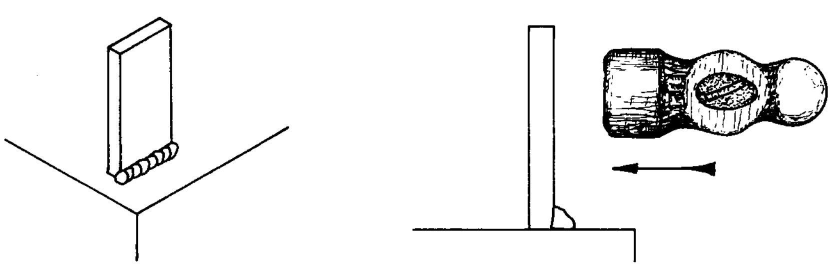
When repairing cracked and broken tools it is easier to use a filler wire that has more give (elongation properties) than the parent metal to reduce the risk of cracking during welding and to reduce the risk of further cracking during the tool's productive life. When repairing cracks I will use as much 312 stainless steel or Inconel 625 type weld metal as possible and then finish off with at least three layers of my final wire; see Chapter 6, Fig. 6.6(b), page 60, and 6.47(d), page 96. Where possible, I will always try to use a matching filler wire to retain the tool's original properties but there are many cases when this is not practical, especially on high carbon and high speed tools which would need to be annealed first. Generally the most important part of repairing cracked and broken mold tools, punches and dies is achieving minimum distortion so that only minimum re-machining and finishing are necessary after welding, thereby minimizing down time. Annealing these tools before welding is not an option.

Filler wires for tool coppers

Most copper filler wires are readily available from your local welding supplier, e.g. C7 for the repair of pure coppers, C11 for the repair of phosphor bronzes and brasses, C13 for the repair of aluminum bronze. Hardenable copper filler wires will not be kept in stock so they will need to be specially ordered in. These filler wires will generally have to come from the manufacturer of the hardenable tool copper parent metal. When I repair small areas such as shut off edges on mold tool inserts that are made out of hardened tool copper, I will generally use modified 420 stainless steel (53 HRC), 410 stainless steel (43 HRC), 312 stainless steel (26 HRC) or Inconel 625 type (160 HV, very soft) depending upon what is required. Obviously stainless steels are totally different from coppers so there will be a difference in texture on the molded component. If this causes a problem, get in touch with your tool copper supplier and ask them if they sell filler wires to go with their product.

Tab testing on aluminum and copper tools

There are going to be many occasions when you cannot identify a tool's chemical composition and it is not practical to send it away for analysis. Once you have exhausted all efforts trying to identify your



(a) Weld tab to work piece as close to edge as possible in a discreet area

(b) Hit off with hammer, against the weld

Fig. 4.1

tool metal, tab testing could at least give you a reasonable option. There are two types of tab test:

- **Tab test 1**. Run an inch of weld on a discreet part of your tool with the filler wire or wires you think could be suitable and try to chisel it off. Then you will have to make a decision whether you think it held firm or not.
- **Tab test 2**. Your tab test metal is not part of your tool – it will be a piece of scrap metal (bar or plate) which has been prepared from a known source. Decide on which filler wire or wires you think may be suitable. Cut a piece of metal to use as a tab, ideally 50 mm × 25 mm × 5 mm for each filler wire you intend to try. Make sure that your tab metal is made out of a material that is compatible with your test filler wire. Weld the tab onto a discreet, area on your tool as shown in Fig. 4.1. and try to hit it off with a hammer in the direction shown. Then you will have to decide whether you think it held firm or not.

5

Heat control

Pre-heats

In tool and die repair welding, pre-heats, cooling and discoloration are very controversial areas. Generally the customer insists on no discoloration, which is impossible if the tool is to be welded correctly (unless the tool is welded in an argon chamber). Also there are many 'past practice' people who believe that pre-heat is simply not necessary. Basically, welding without pre-heat is simply taking a risk and from time to time you have to take that risk. Because of customer demands I have welded hundreds of tools this way and I will continue to do so, but in this situation, it is important to use a very cautious weld technique as discussed in Chapter 6, page 96, 'Welding without full pre-heat'. For the sake of the tool and for customer satisfaction, a compromise has to be found between the customer's request for no discoloration and the higher the risk of cracking when no or low pre-heat is carried out.

The standard pre-heats and my compromised, no discoloration pre-heats are given here. It is important to note, however, that as soon as you start welding, the temperature of the tool will automatically increase.

Table 5.1 No discoloration pre-heats (°C)

Material	Standard	No discoloration	Cooling
A2	250–350	100–140* max	Slow
D2	250–350	140–180* max	Slow
D3	350–450	Not recommended*	Slow
H13	150–250	110–150 max	Air
L6	200–250	110–150 max	Air
O1	250–350	100–140* max	Slow
P20	150–200	100–140 max	Air
S1	200–250	110–150 max	Air
2767	150–250	110–150 max	Air
Modified 420 stainless steel Stavax type	200–250	140–180 max	Air

*A2, D2 and O1 are very crack sensitive and must be welded with extreme caution at lower than standard pre-heat temperatures; see Chapter 6, page 96, 'Welding without full pre-heat'. D3, however, is extremely crack sensitive even at its standard pre-heat temperature.

Cooling

In Table 5.1 there are two types of cooling 'air' and 'slow'. Air cooling your tool after welding allows it to cool naturally, away from drafts where possible. To slow cool your tool after welding, bury it in sand or vermiculite – both materials are readily available from your local builder.

Because of the number of tool steels available, each having many different names, it is impossible to list every one and its pre-heat temperature. Table 5.2 gives a general guide towards pre-heats based on the tool's carbon content. To help you determine the carbon content, turn to Chapter 3.

Tools that are 60 HRC and above should have a minimum pre-heat of 350 °C. Hardened and tempered high speed tool steels should have a minimum pre-heat of 400 °C and tempering after welding for one to two hours at 540–550 °C, then slow cool.

Table 5.2 Pre-heats

Carbon content (%)		Pre-heat (°C)	Cooling
Low	0.2–0.3	100–150	Air
	0.3–0.4	150–200	Air
Medium	0.4–0.5	150–250	Air
	0.5–0.6	200–300	Slow
High	0.6–0.7	250–350	Slow
	0.7–2.5	250–450	Slow

Even after you have decided on your pre-heat based upon your tool's carbon content, it is also very important to increase your pre-heat for larger tools, tools that need large amounts of weld and tools welded in 'crack-sensitive areas'; see Chapter 6, page 63, 'Cracking'. Table 5.2 would be relevant for up to pint-pot size tools. For television size tools, tools that need large amounts of weld and tools welded in crack-sensitive areas, an increase of up to 50% extra pre-heat is needed, but do not go above 450 °C.

Once you have decided upon your pre-heat temperature, it must be reached gradually and evenly and then maintained, not allowing the tool to go below or more than a hundred degrees above that temperature during welding, until your weld is complete. Avoid keeping the tool at temperatures in excess of 475 °C during welding.

Table 5.3 Low alloy tool steel discoloration

Very pale yellow to light yellow	225 °C
Straw to deep straw yellow	235 °C
Dark yellow to brown yellow	245 °C
Brown to reddish brown	258 °C
Purple brown to light purple	270 °C
Full purple to dark purple	280 °C
Blue	295 °C
Dark blue	315 °C

Heat sources

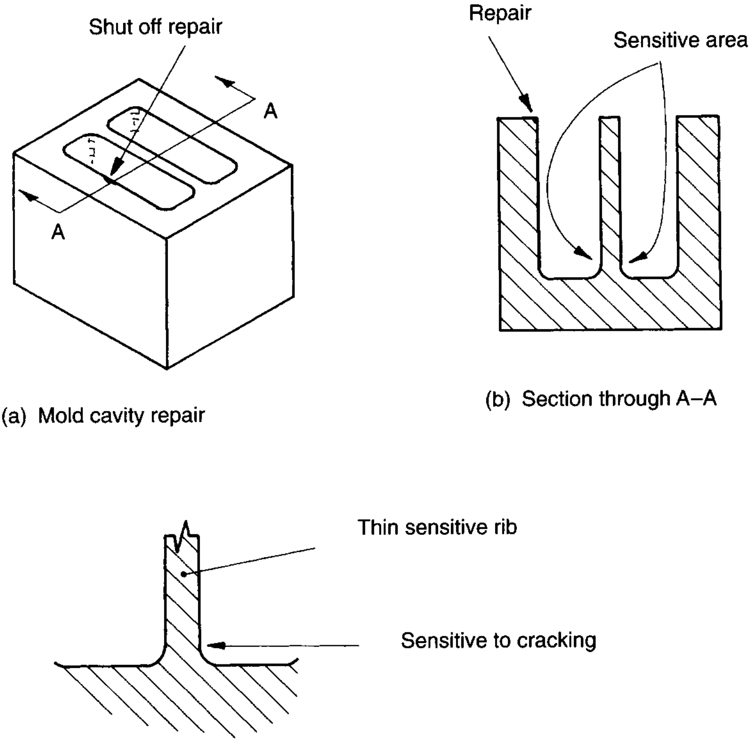
The heat sources that I use are a combination of electricity and gas. I have a 350 °C electric rod oven purchased from my local welding suppliers and a home made hot plate heated by a hand-held propane torch which is discussed in more detail in Chapter 7, page 123. For television sized tools and above, I have a home made, heavy duty hot bench which is heated in the same way as my hot plate, also discussed on page 124. Most of the larger tools that I have welded were generally made out of P20 type materials which can be safely welded cold if proper care is taken; see Chapter 6, page 96, 'Welding without full pre-heat'.

Pre-heating

Once you have decided on your final pre-heat temperature, it is now time to heat the tool itself. Ensure that all preparation has been completed, e.g. that you have identified the material and chosen an appropriate pre-heat temperature, that you can maintain your pre-heat temperature during welding and that you know how you are going to cool it after welding. Remember to remove from the tool any perishables such as seals, hoses or any non-metallic attachments that would be damaged at high temperatures. The tool must be thoroughly cleaned to remove any oils or cooling fluids.

Oven heating

Whatever type of oven you use, it is best to bring your tool up to working temperature gradually. Introducing a cold tool into an oven over 120 °C should be avoided, especially if the tool contains a variety of thicknesses which will heat up at different rates, increasing the chance of cracking and discoloration in sensitive areas, as shown in Fig. 5.1.



(a) Mold cavity repair

(b) Section through A–A

(c) Sensitive area

Fig. 5.1

There is, however, a way of speeding up your pre-heat process by leaving a piece of 25 mm thick bar in your oven, with your oven set at 120 °C. Place the tool on the bar, and it will conduct heat into the base of the tool as it heats up in the normal manner. Once the whole of your tool reaches 120 °C, it is then safe to turn your oven up to your final pre-heat temperature.

Heating larger tools

For larger tools that will not fit in your oven, or if you do not have an oven, tools can be heated on a hot plate and gradually brought up to temperature. This will not be practical if you have more than one tool to weld, so keep the hot plate at 180 °C and use two loose plates of 10 mm thick aluminum alternately as a heat buffer as shown in Fig. 5.2.

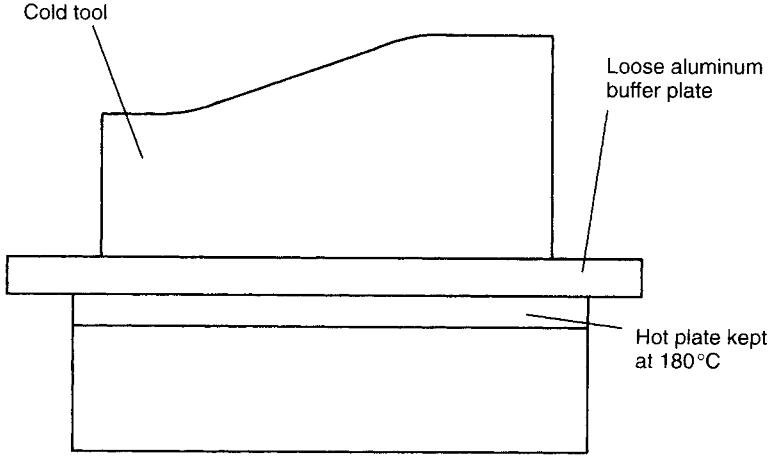


Fig. 5.2

The cold sheet of aluminum heats up gradually and evenly which in turn heats up the tool. In this situation, to stop discoloration, you need to monitor the temperature. You can use a digital thermometer or temple sticks which are available from your welding supplier.

If your only heating source is a propane heating torch and a bottle of gas, then extra care must be taken. When using a naked flame to heat tools, you *must* make your working area safe, e.g. move your gas bottle a safe distance away, along with any flammable materials or pressurized canisters, and make sure that you are working in a well-ventilated area. It is also very important to make sure that you will not be heating any concrete flooring because this has a tendency to explode. Support the tool in such a way that you can heat its base without damaging any flooring or yourself!

Once you feel happy with your set up, it is important to heat the tool gradually and evenly, keeping your torch moving all the time, not allowing the flame to settle in one place as this might cause surface cracking. It is very important not to allow your flame to touch any part of your molding face or any finished sensitive area because the flame contains water vapor which will condense and then evaporate, leaving a layer of rust which will require polishing. Once the tool's temperature rises above 50 °C, the water vapor in your flame will not condense and it is then safe to heat your finish-sensitive areas.

Important note: when heating with a naked flame you must be more aware than normal of any fine areas that might over-heat because you will not notice that they have over-heated until you have moved your flame away.

Post-heat treatment

The type of tools that I normally repair (mold tools, punches and dies and small to medium sized fine tolerance tools) will not have any post-heat treatment because of re-machining and finishing costs.

The tools I have sent away for post-heat treatment have been larger heavy duty machine tools that are likely to suffer from high stress and fatigue. If you have any doubts in this area, get in touch with your local heat treatment company.

Pre-heating aluminum and copper

Generally, pre-heats are designed to minimize cracking but this is not the reason why aluminum and copper are pre-heated, although even aluminum and copper would be less likely to crack when pre-heated. Pure aluminum and copper are both excellent conductors of heat, so the heat from your arc is very quickly absorbed, giving the welder the impression that not enough amps are being used. The natural reaction to this is to keep turning up your amps until you get a molten pool. This is when problems can start, e.g. tungsten disintegrating and an inability to feed the filler wire into the pool because your arc is too ferocious. To counteract this, you need to pre-heat the base material to reduce the amount of heat loss from the pool. When pre-heating aluminum, it is very important to stay below 180 °C because the aluminum will start to lose its original properties if held at elevated temperatures and tool aluminum would become soft. Also pre-heats on tool coppers should be limited to 400 °C on chromium coppers, 350 °C on nickel coppers and 215 °C on beryllium coppers.

Minimizing pre-heats on aluminum and copper

To help to keep your pre-heat to a minimum, change the argon gas to an argon/helium or helium/argon gas. This will raise the temperature of your weld pool without increasing your amps. Mixed gases are very important when welding heavier sections of aluminum and especially copper. See your local supplier for more details.

6

Weld techniques

As you fill in your weld procedure, think how you are going to approach the repair. You will probably know what the tool has to look like when it is complete, so you must decide how you are going to get there. Once you have decided upon your base material, possible filler wires and pre-heat (your technical information), you can move on to the practical side of things – what preparation is needed, does the tool need restraining to reduce distortion, where do I put my first weld? Sometimes you might need arc guards to stop stray arcs from damaging nearby sensitive areas, or maybe a heat soak. Once you know what sort of assistance you can call on in the form of welding aids and tricks of the trade, you can start planning your practical approach.

The first section in this chapter discusses the practical methods used in the four welding procedures described in Chapter 2. It includes the necessary technical information and how best to set it out.

Weld procedures

Weld procedure 1: worn H13 core

Shut off face repair

Problem 1a The top shut off face on this core is badly pitted through general use, causing flashing to occur.

Solution 1a The top face must be removed by grinding because it is pitted and contaminated. Then the face will be rebuilt by welding. See Fig. 6.1.

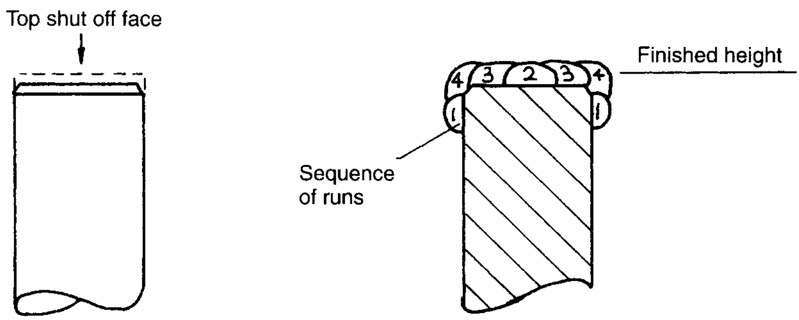


Fig. 6.1

Shut off edge repair

Problem 1b The shut off edge on this core is badly worn through general wear, causing flashing to occur.

Solution 1b The shut edge is wire brushed, cleaned with a solvent and rebuilt with weld; see Fig. 6.2.

A single run of weld is all that is needed to cover the damaged area.

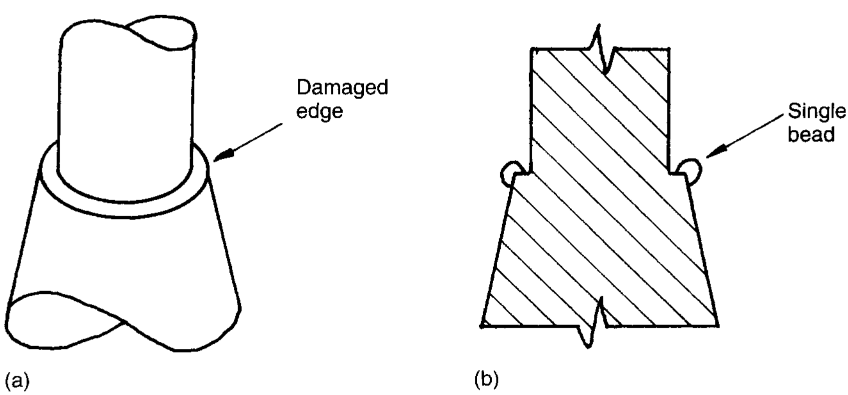


Fig. 6.2

Weld procedure 2: broken D2 spoon die

Problem 2 This spoon die has been broken into two pieces; see Fig. 6.3.

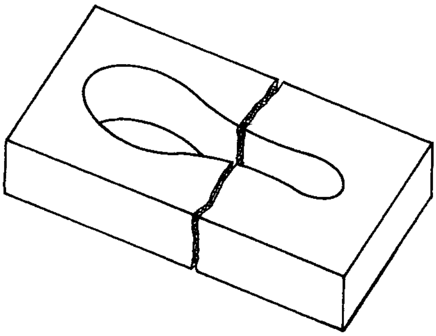
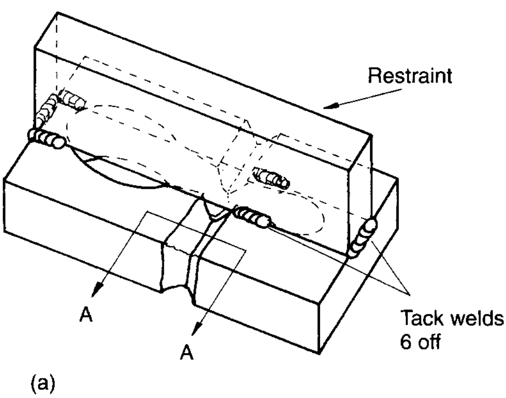
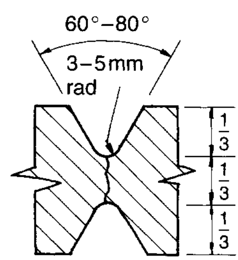


Fig. 6.3

Solution 2 The broken spoon die is to have a one-third preparation on the outside faces only because the customer insisted on minimum weld metal on the inside faces, minimum shrinkage and excellent relocation of the broken pieces; see Fig. 6.4. To minimize distortion the tool must be restrained during welding (see Fig. 6.5) and welded in alternate sequence; see Fig. 6.6.





(b) Section through A–A

Fig. 6.4

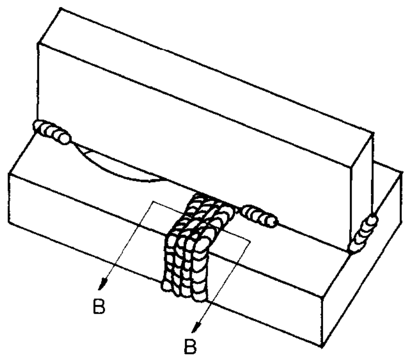
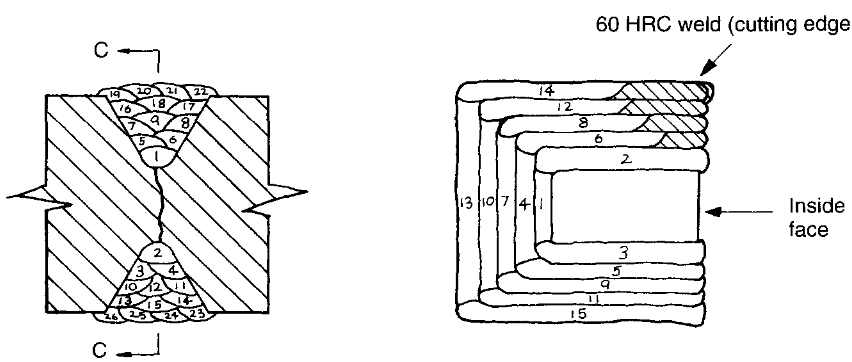


Fig. 6.5

The tool and its restraint must be heated to the same temperature before they are tacked together so they can be equally at the same heat-expanded size or they will fight against each other like a bi-metal strip and become distorted on cooling.

After welding, the restraint must be left on until the tool has cooled to at least 150 °C if the tool could not be fully welded because of the restraint. Once the restraint has been removed the tool must be heated back to its pre-heat temperature before any final welding can take place.

In Fig. 6.6(a), the weld sequence shows a cross section of each run. In Fig. 6.6(b), a section through the layers of weld shows the alternated sequence on all three sides including the 60 HRC filler metal layers.

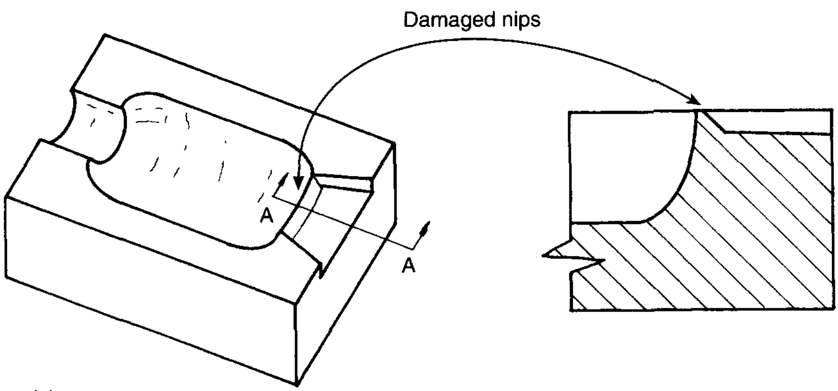


(a) Section through B–B
(b) Section through C–C

Fig. 6.6

Weld procedure 3: worn aluminum blow mold

Problem 3 The nips on this aluminum blow mold do not cut cleanly because of general wear and tear; see Fig. 6.7.

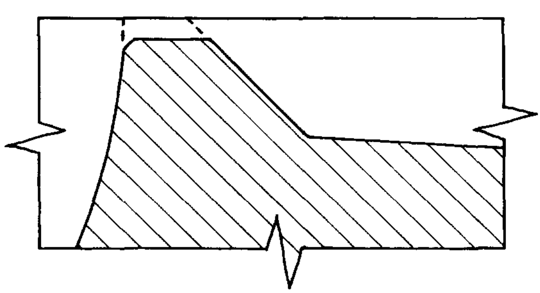


(a) (b) Section through A–A

Fig. 6.7

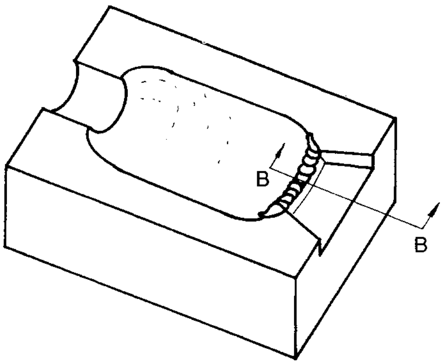
Solution 3 Remove worn contaminated surface layer on nips and clean thoroughly with a solvent (see Fig. 6.8(a)) and rebuild with weld (see Fig. 6.8(b)).

A single run of weld is all that is generally needed to complete this type of weld repair, the main problem being to minimize under cut (notches) at either side of the weld. See page 73, 'Under cut (notches)'.

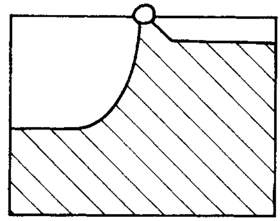


(a) Section through A–A (highlighted above) after preparation

Fig. 6.8



(b) Finished weld

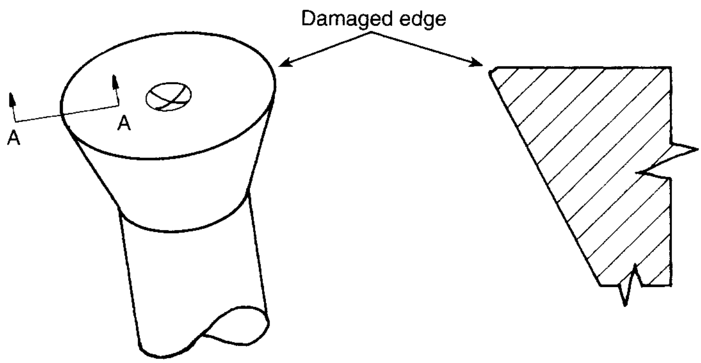


(c) Section through B–B

Fig. 6.8 cont'd

Weld procedure 4: damaged tool copper, inner ejector core

Problem 4 The shut off edge of this tool copper, inner/ejector core has sustained damage during insertion; see Fig. 6.9.



(a)

(b) Section through A–A

Fig. 6.9

Solution 4 The damaged edge will be cleaned with a solvent and possibly a fine wire brush, avoiding the mold face at all times, then welded; see Fig. 6.10.

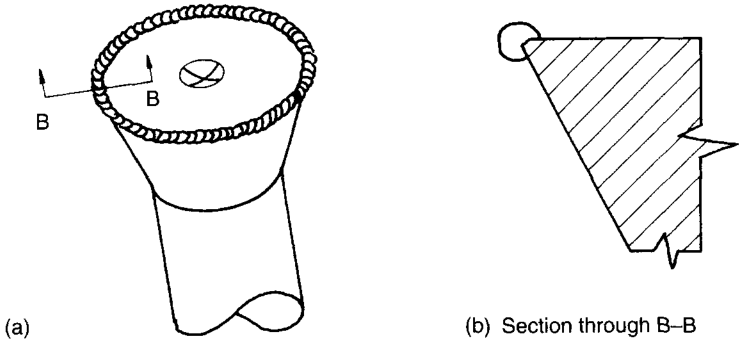


Fig. 6.10

Because the weld area is about 25% of the full diameter, incorporating two damaged areas, it is more sensible to weld the whole edge with a single run of weld, eliminating any chance of notches.

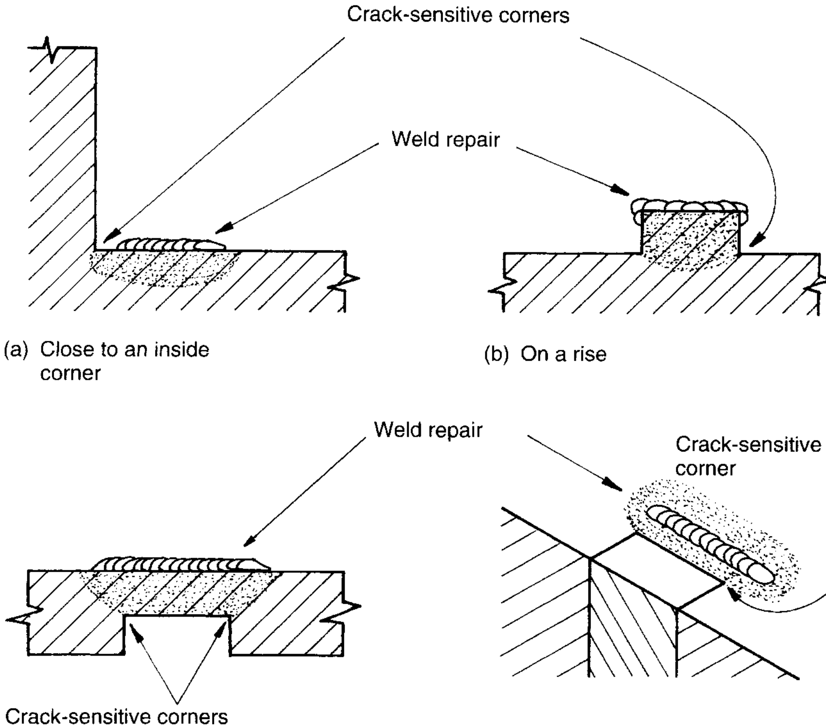
Cracking

There are two main issues concerning cracking. The first is preventing a tool from cracking during welding and the second is repairing tools that have already cracked. To prevent a tool from cracking during or just after welding, read Chapter 5. This chapter discusses pre-heat and heat control during welding and cooling after welding, and will help you to solve most cracking problems.

Crack-sensitive areas

Even with a recommended pre-heat, you can run into problems because certain areas on a tool can be more sensitive to cracking than others. The main problem areas tend to be close to inside corners; see Fig. 6.11.

Outside edges can be problematic, especially if you have decided not to use a full pre-heat. Figure 6.12 shows examples of cracks forming on the edge of the heat affected zone (HAZ) on inside corners and outside edges.



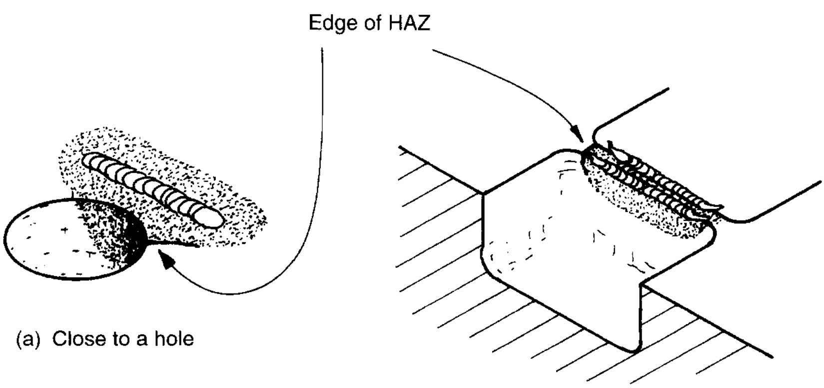
(a) Close to an inside corner

(b) On a rise

(c) Close to unseen corners

(d) Close to an insert

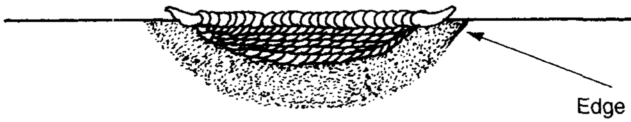
Fig. 6.11



(a) Close to a hole

(b) On a restrained gusset

Fig. 6.12



(c) Large repair on an open edge

Fig. 6.12 cont'd

If you decide to undertake any repairs, especially in sensitive areas, with a reduced pre-heat to avoid discoloration (see Chapter 5, 'Pre-heats', page 49), then I suggest using a cold welding technique (see page 96, 'Welding without full pre-heat') together with that reduced pre-heat. Generally when working in crack-sensitive areas, increase the standard pre-heat temperature by 25–50%, not exceeding 450 °C.

Repairing cracked and broken tools

The first thing you need to do is find out why the tool cracked in the first place. Was it because of:

- bad design,
- misuse,
- a previous bad weld,
- general wear and tear,
- an accident?

It is important to know why a tool has cracked or become broken because you will tend to see the same tools coming back again and again, and if a tool has been badly designed, it is important to complete the repair and make it known that the tool has a weak, crack-sensitive area (see problems 5–8 below).

Misuse of such things as hand tools can be pre-empted by strengthening certain areas to withstand any further abuse. Accidental damage should be treated in much the same way as misuse.

A previous bad weld repair can be a big problem, see page 70, 'Previous bad weld repairs'. This is why it is so important to get it right first time!

A tool's resilience to further cracking during general wear and tear can be improved by using a softer or harder filler wire to repair the cracked or broken area.

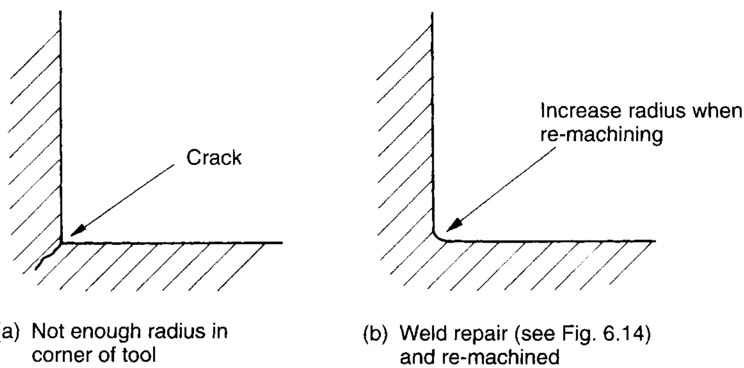
Bad design problems

Problem 5 Material is too brittle for the job it has to do.

Solution 5 Repair tool with matching filler material and heat treat tool to be less brittle or re-make tool out of more suitable material.

Problem 6 Tools that have inside corners with little or no radius, see Fig. 6.11 and 6.13.

Solution 6 Complete your weld repair and increase the size of radius when re-machining; see Fig. 6.13.



(a) Not enough radius in corner of tool

(b) Weld repair (see Fig. 6.14) and re-machined

Fig. 6.13

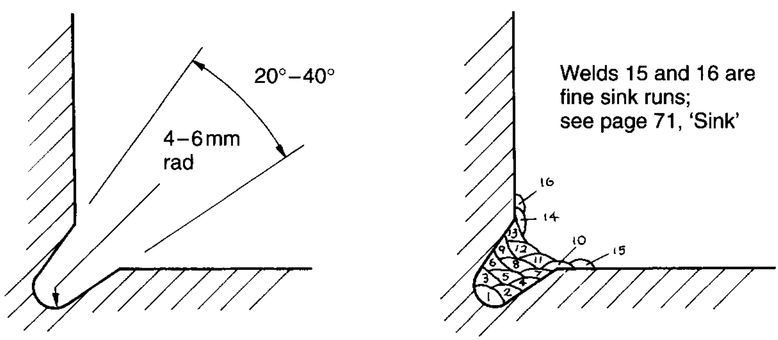
Excavating cracked material

Before you excavate a crack, it is important to find out the extent of the damage by performing a dye penetrant examination (dye pen).

You will need three aerosol cans for this. The first contains solvent cleaner for cleaning the area to be examined and the second contains dye which is sprayed over the damaged area and allowed to seep into the crack for 10–15 minutes (see can for details). After the dye has been allowed to seep into the crack, the excess dye is removed with absorbent paper towels. To finish off the cleaning, spray a clean paper towel with the solvent cleaner (do not spray the cracked area) and wipe until there are no traces of the dye. The third can contains a developer which is shaken vigorously for several minutes before spraying over the damaged area. The developer then acts like a poultice drawing out any dye to reveal the crack so that it can be excavated.

For most excavations, I would suggest using an angle grinder, die grinder or spark erosion, especially on mold tools and dies. Periodically you will need to dye pen your tool when excavating to see how much of the crack is left until the examination is clear. On other tools, if you intend to use arc air or stick rod gaging, pre-heat your tool to its welding temperature to avoid further cracking.

The important point in excavating cracks is to remove all of the crack and to create access; see Fig. 6.14. If your preparation is too narrow, you will deny yourself access and if your preparation is too wide you will increase your welding time, cost and distortion.



(a) Excavate corner crack and increase recommended pre-heat; see page 51

(b) Weld run sequence

Fig. 6.14

Problem 7 Cooling waterways on tools being too close to sensitive areas; see Fig. 6.15.

Solution 7 Fully plug waterway and repair as shown in Fig. 6.15(c).

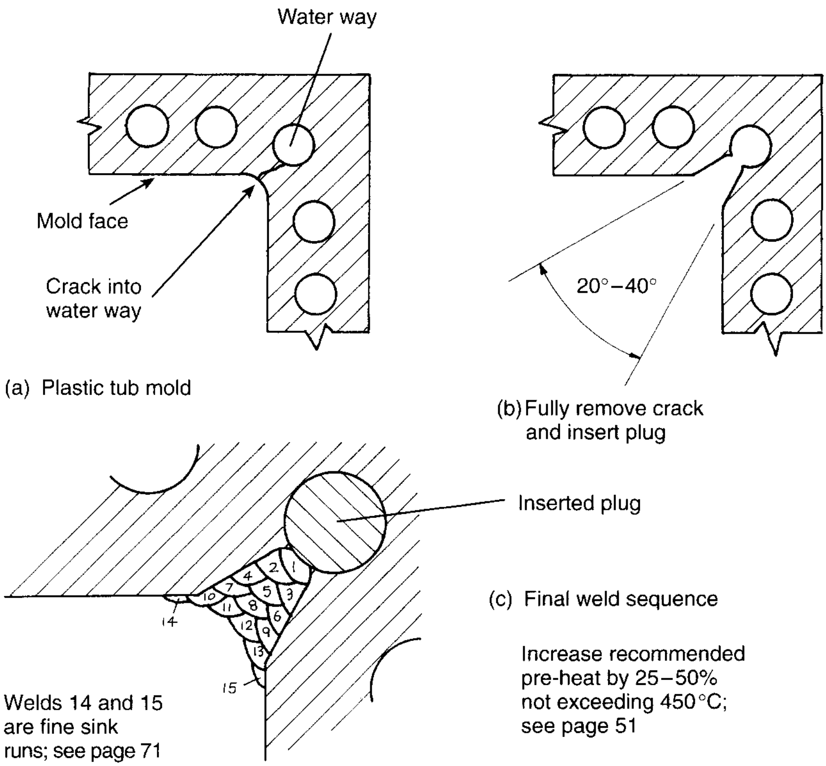


Fig. 6.15

Problem 8 Thin ribs on thick sections, on mold tools.

Solution 8a Remove and rebuild rib; see Fig. 6.16.

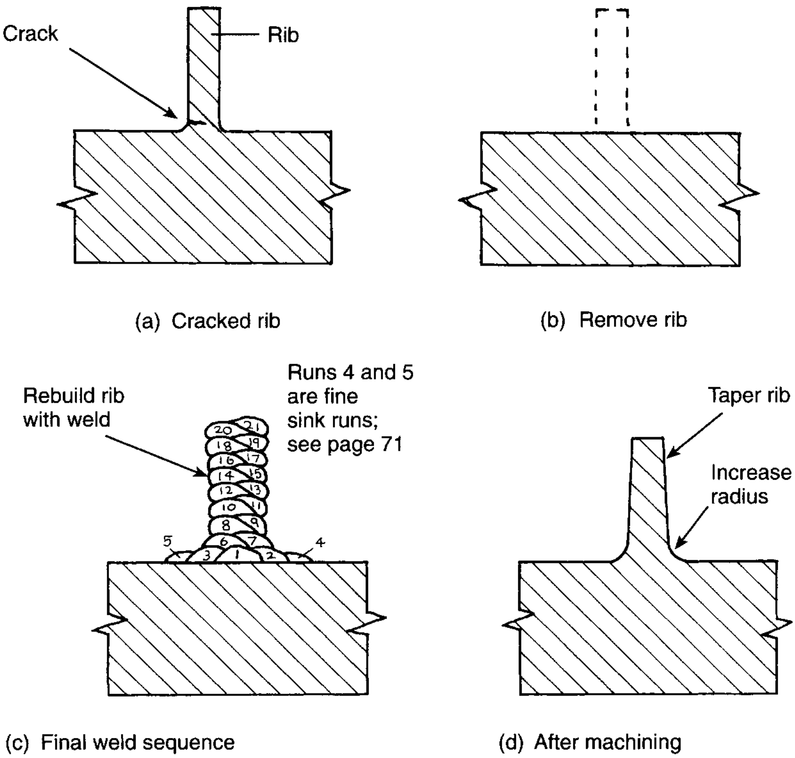


Fig. 6.16

Solution 8b Prepare and weld; see Fig. 6.17 and 6.18.

On repairs where large amounts of weld are needed, distortion may take place, so your tool may need to be restrained, see page 94, 'Using restraints'.

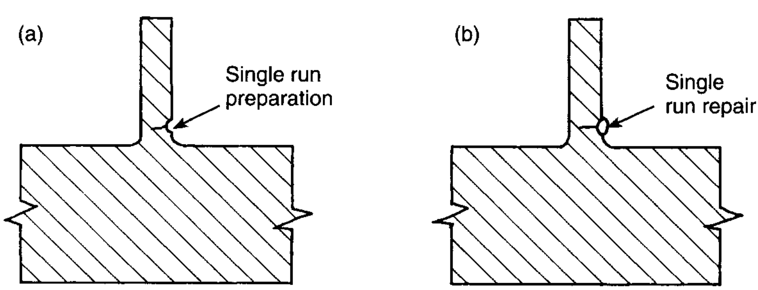


Fig. 6.17

If you think that the repair in Fig. 6.16 is a little extreme, then a temporary repair may be more suitable; see Fig. 6.17.

If you prepare the rib too much, the rib will distort during welding; see Fig. 6.18(b). You will then have to compensate; see Fig. 6.18(c).

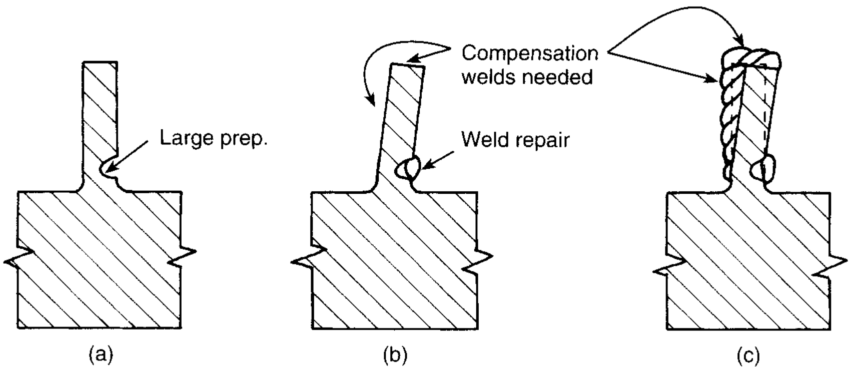


Fig. 6.18

Previous bad weld repairs

There are different types of bad weld, e.g. where no or insufficient pre-heat was used; bad welds where the parent metal around the weld area has cracked; where unsuitable filler wire has been used; where the weld has separated from the parent metal or the weld itself has cracked.

Problem 9 Cracking in the weld.

Solution 9 Remove all the old weld, see page 66, 'Excavating cracked material', and re-weld using correct weld procedure; see Chapter 2.

Problem 10 Cracking around the weld in the parent metal.

Solution 10a Temporary repair by preparing crack and welding; see Fig. 6.17.

Solution 10b Remove all of the crack and old weld, and weld as solution 9.

Problem 11 Weld too close to a sensitive area causing cracking to an inside corner.

Solution 11 Excavate crack and weld; see Fig. 6.14.

Sink

Sink (low areas around the weld) is unavoidable with standard welding processes such as TIG but it can be minimized.

Sink can be a major problem in the repair of plastic mold tools especially if a mold has to be welded, and it is under its original tolerance so no more parent metal can be removed; see Fig. 6.19.

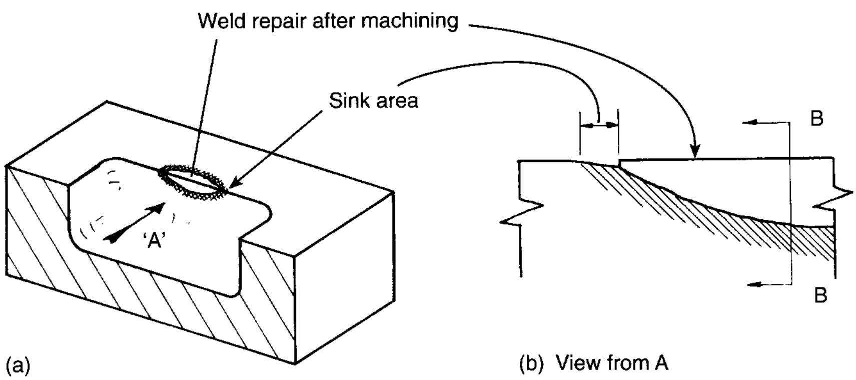


Fig. 6.19

To minimize the sink area during the TIG welding process, you need to reduce your amperage to lay down one or two fine sink runs; see Fig. 6.20.

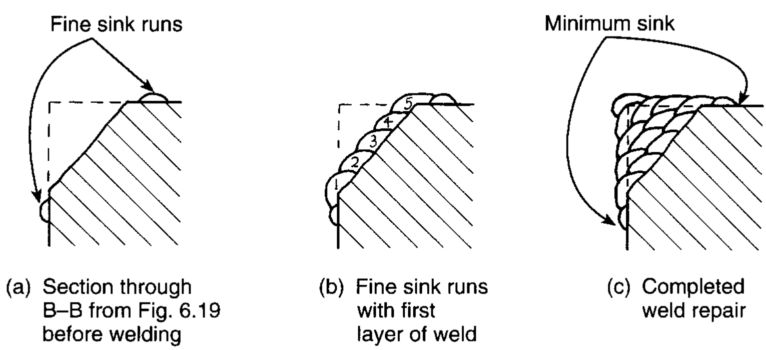
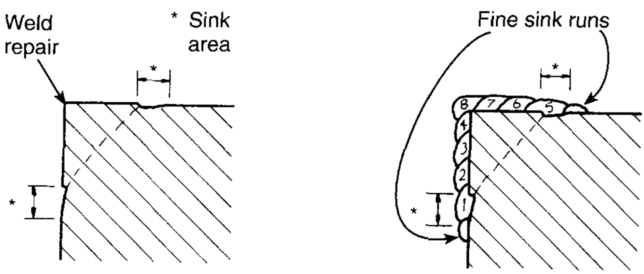


Fig. 6.20

The reason why it is best to lay down your sink runs first is because your tool is then at its cleanest and the most free from contamination. Also it is easier to overlap a larger weld onto a smaller than the other way round.

Repairing sink

If you have a tool that has been repaired and then machined back to tolerance but it is unacceptable because of sink, then the whole area needs to be re-worked; see Fig. 6.21.

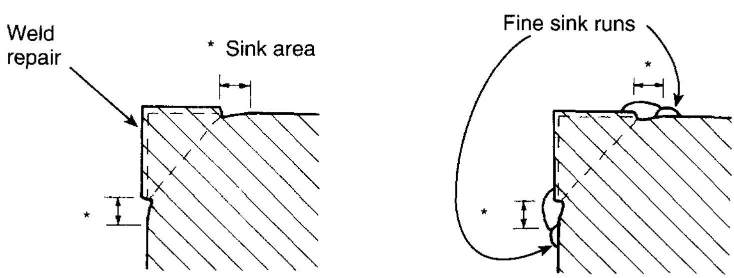


(a) Section through B–B from Fig. 6.19(b)

(b) Final run sequence to complete repair

Fig. 6.21

If you are aware that the weld repair area will not clean up when it is machined back to tolerance, then it only needs re-work in the sink area; see Fig. 6.22.



(a) Section through B–B from Fig. 6.19(b) after welding but not fully machined

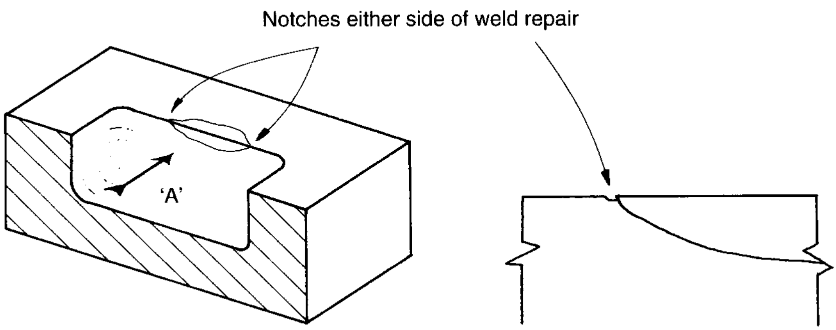
(b) Repair of sink only

Fig. 6.22

With the help of fine sink runs and a little practice, it is possible to reduce sink to 2 or 3 thou (0.05 or 0.075 mm).

Under cut (notches)

This is a problem which can be a lot worse than sink because it is much more difficult to control; see Fig. 6.23.



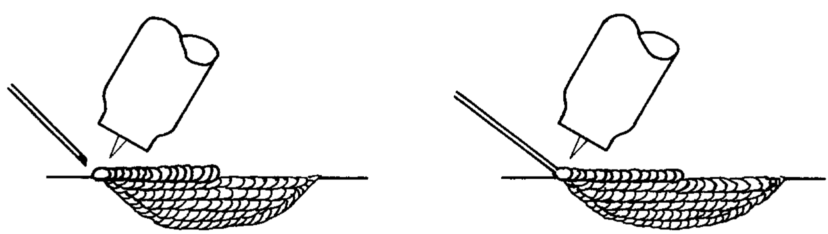
(a) Cut away section of a repaired mold tool

(b) View from A

Fig. 6.23

Although the surface of the mold has cleaned up leaving no sink, notches still remain either side of the weld. This could have been eliminated using a 'tug off' technique; see Fig. 6.24.

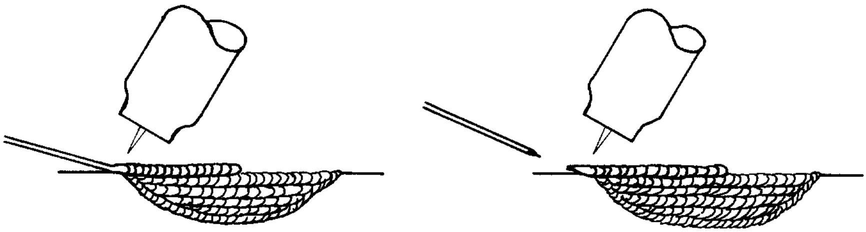
Before you start your final run on your weld repair, very carefully clean the area with a wire brush. Start your final run from the center of your weld repair and weld out over till you reach the outward edge of your sink area; see Fig. 6.24(a) and 6.19. Put your filler rod back



(a) Weld from the centre to edge of sink run

(b) Place rod back in pool and reduce amps

Fig. 6.24



(c) As pool turns plastic drag rod across unwelded edge

(d) Extinguish arc and tug off rod while still plastic

Fig. 6.24 cont'd

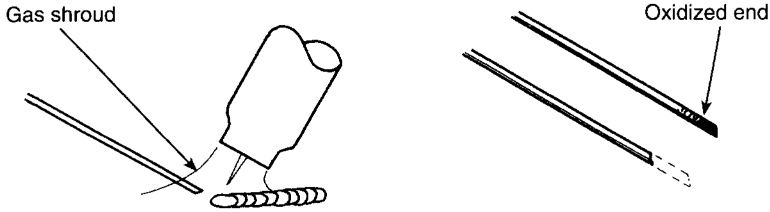
into the molten pool (b) and reduce your amps. (For this technique, a foot pedal is much easier to use than trying to work to your slope out on your weld set.) Keep your filler wire in the molten pool until it turns plastic (like molten glass), drag your filler wire across the previously untouched edge (c), extinguish your arc and tug off your filler wire while still plastic (d). Then turn the tool round and repeat the process again to complete the other half.

This is a very complicated weld maneuver even for an experienced welder, but a technique well worth practicing.

Building pads of weld

Oxidization (dirty welds due to scaling)

This is a problem that you might get when building pads of weld, mainly caused by bad weld sequence planning (see Fig. 6.26) and poor gas coverage due to holding a bad torch angle (see Fig. 6.31(b)). Also as you lift your filler wire out of the shrouded area created by the gas from your torch, it will oxidize causing small amounts of scale at the tip of your rod. So it is best to try to keep your filler rod in your gas shrouded area as much as possible and snip the oxidized end off in between runs; see Fig. 6.25.



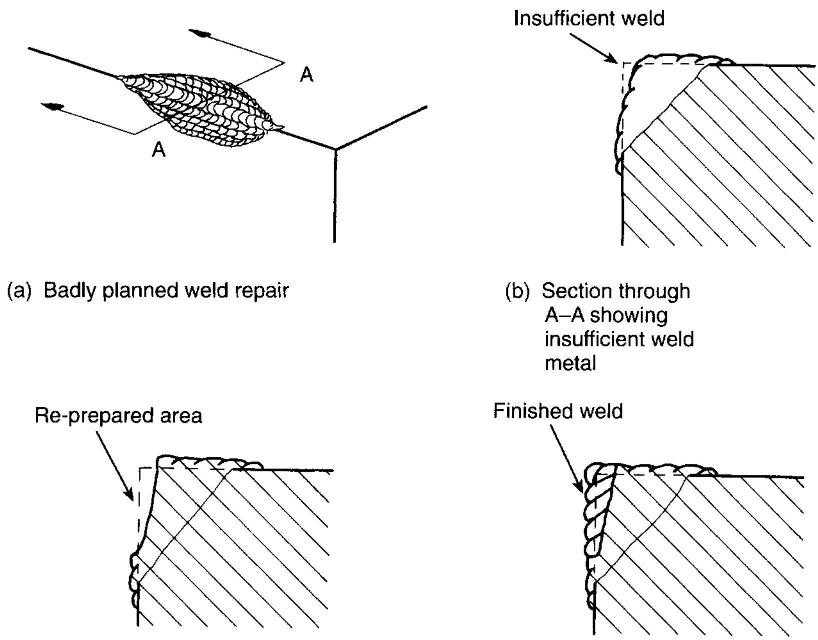
(a) Keep rod in gas shroud as much as possible

(b) Snip rod end between runs

Fig. 6.25

Bad weld sequence planning

Once you have started your weld, you should never go back over it to add a little bit more. It is very important that every weld you lay down completely covers the area that you want it to; see Fig. 6.26.



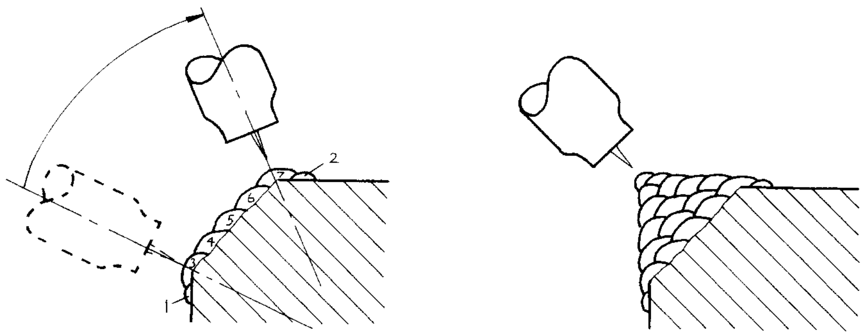
(a) Badly planned weld repair

(b) Section through A–A showing insufficient weld metal

(c) Re-prepare low area for additional weld

(d) Completed re-repair

Fig. 6.26



(e) Correct weld sequence and torch angle

(f) Correct weld shape and finishing torch angle

Fig. 6.26 cont'd

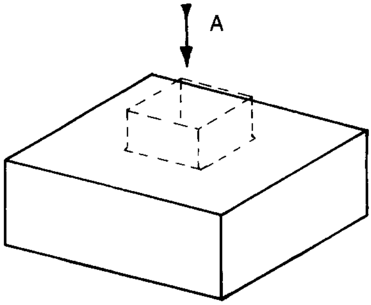
Figure 6.26(b) shows insufficient weld metal, which in itself is not a big problem because you can re-prepare the low area; see Fig. 6.26(c). The problem occurs when you try to weld over low areas of weld without cleaning. This can give you a contaminated weld which can cause scale entrapment or porosity.

Building a standard pad

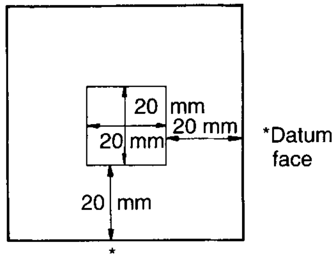
Building pads of weld on tools is a very common practice. There are two types of pads, standard pads and pedestal pads. Standard pads are built in the same way as any other build up of weld metal by planning your weld before you start and checking the shape of your pad at regular intervals; see Fig. 6.27 and 6.28. Pedestal pads are similar to standard pads but the first few runs are different; see Fig. 6.30.

The size of the pad after machining is to be 20 mm × 20 mm × 10 mm so the size of the pad that will have to be welded should be about 24 mm × 24 mm × 12 mm, allowing 2 mm of machining on all faces; see Fig. 6.27 and 6.28 for weld sequence.

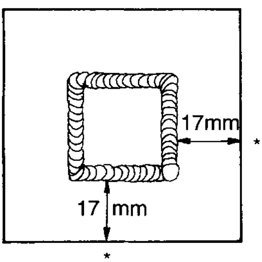
In Fig. 6.27 and 6.28, a datum face has been used to keep a check on the height and the width of the pad as it is being welded.



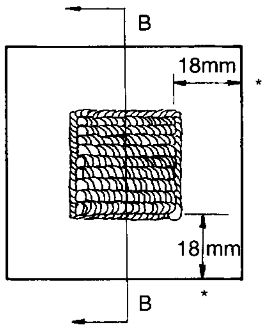
(a) Type of pad needed



(b) View from A.
Mark off pad size

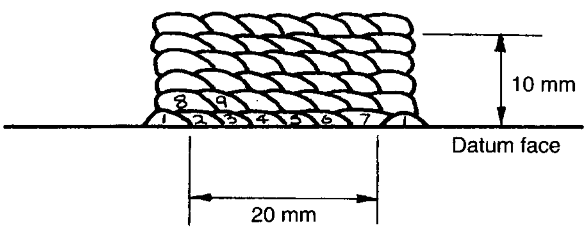


(c) First run is welded on the outside of marked off pad



(d) Fill in and overlap first run, then build to required height

Fig. 6.27

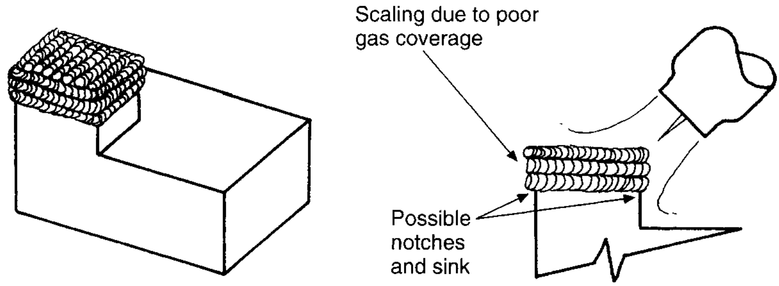


Section through B–B from Fig. 6.27(d)

Fig. 6.28

Preparing a tool for a pedestal pad

A pedestal pad is a pad on top of a pedestal or a rise. If the rise has become worn because it is a shut off face or the rise needs to be heightened because of re-design, then special care must be taken; see Fig. 6.29.

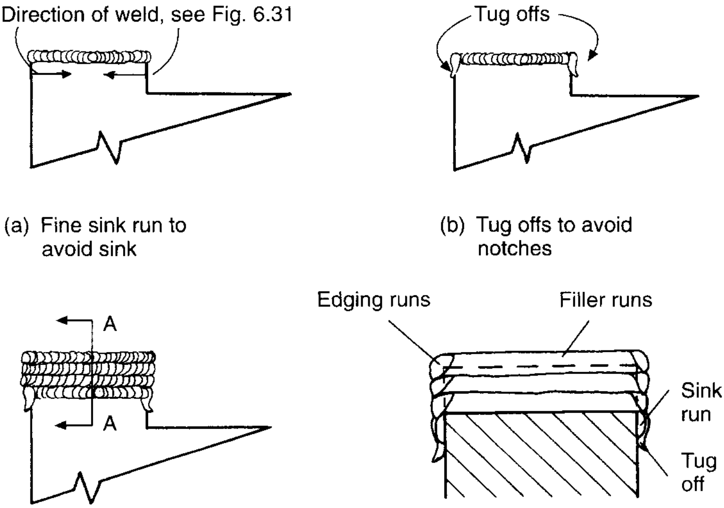


(a) A pedestal pad

(b) As one side is welded the other side will oxidize

Fig. 6.29

Under normal circumstances your 'tug offs' (see Fig. 6.30) would go on last but in this situation they will go on at the beginning because



(a) Fine sink run to avoid sink

(b) Tug offs to avoid notches

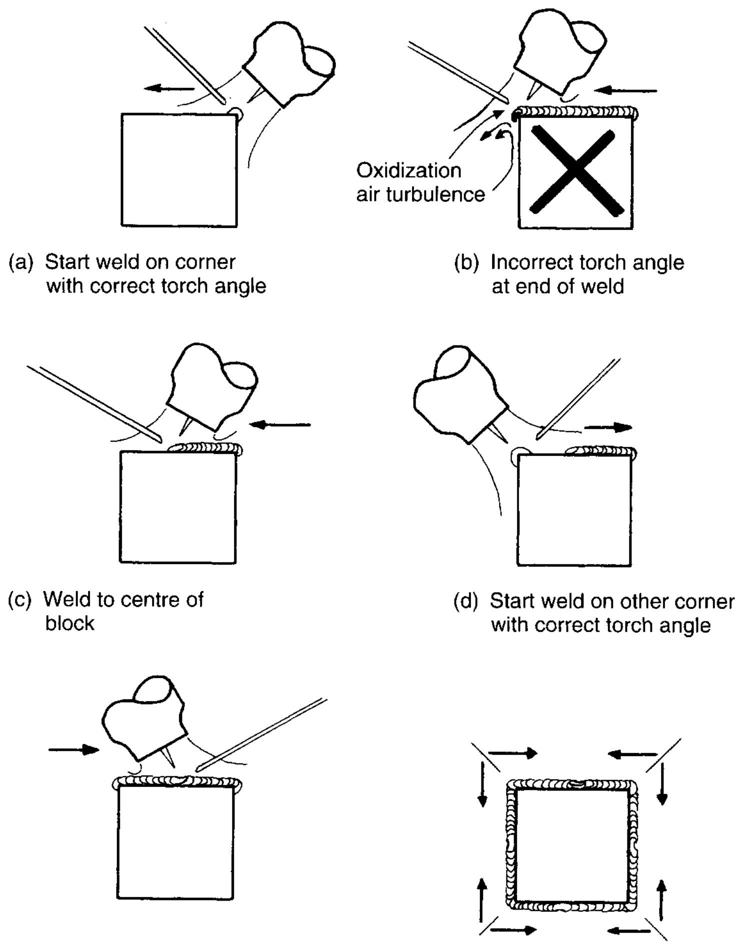
(c) Complete pedestal pad

(d) Section through A–A

Fig. 6.30

the weld in this area will overlap and oxidize due to poor gas coverage. As one side of the pad is welded, the other side will oxidize causing scaling, making any touching up to repair sink or notches very difficult; see Fig. 6.29(b). It is essential to make sure that every layer of weld that you build on your rise is sound; see Fig. 6.30.

In Fig. 6.30(a) you will see a 'direction of weld'. This is very important to stop oxidization on the adjacent face; see Fig. 6.31(b).



(a) Start weld on corner with correct torch angle

(b) Incorrect torch angle at end of weld

(c) Weld to centre of block

(d) Start weld on other corner with correct torch angle

(e) One side complete

(f) Four sides complete (fine sink run; see Fig. 6.30)

Plan view of pedestal from Fig. 6.30(a) **Fig. 6.31**

Porosity (pin/blow holes)

Porosity is caused by air or gas bubbles becoming trapped in the weld. There are three main causes of porosity:

1 Trapped air.
2 Contaminated weld area.
3 Faulty or badly set up equipment.

Trapped air

This is very common when welding over old engravings on mold tools and slots in general; see Fig. 6.32.

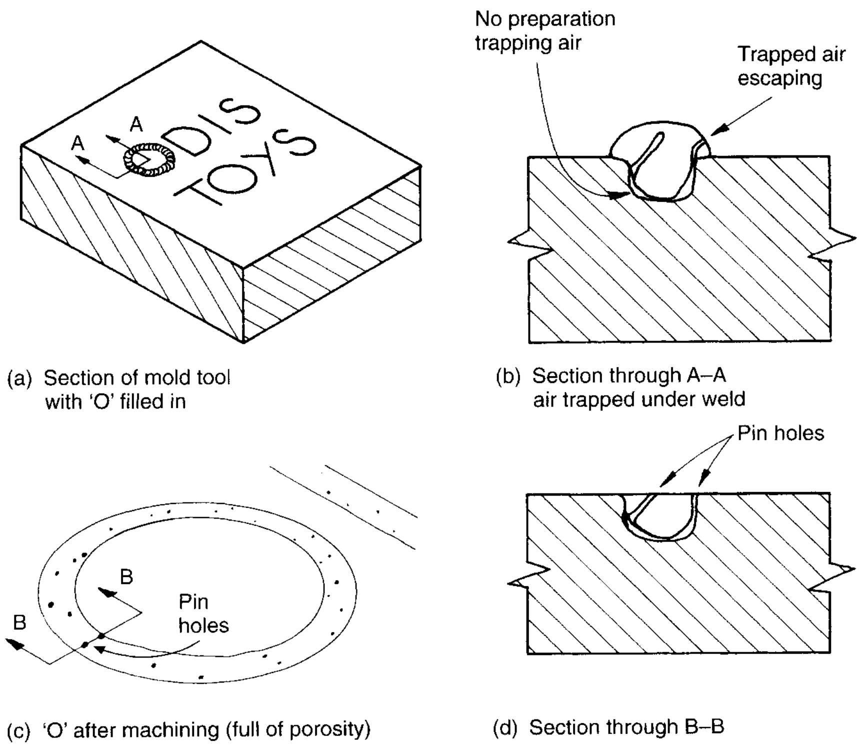
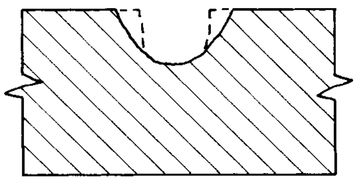
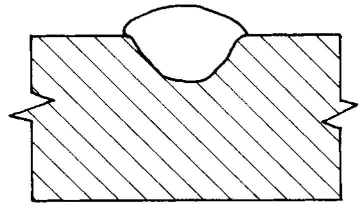


Fig. 6.32



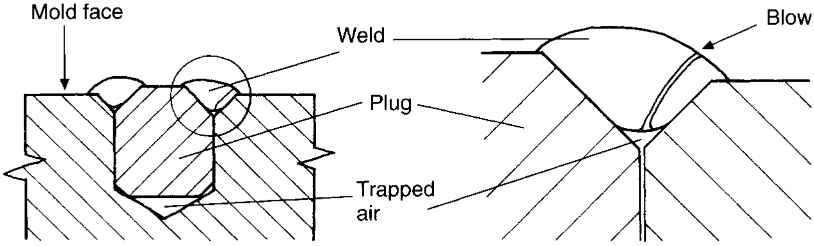
(e) Correct preparation



(f) Clean weld, free of blow holes

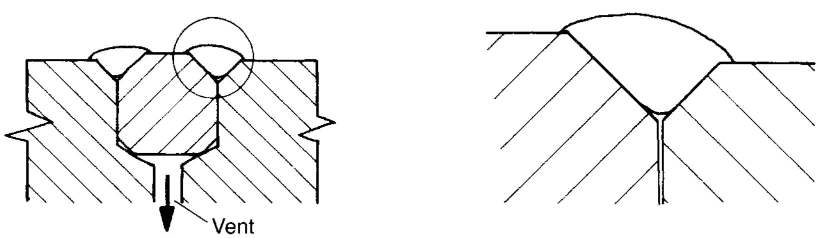
Fig. 6.32 cont'd

Air easily becomes trapped during the welding of inserts or pins to fill in holes; see Fig. 6.33.



(a) Section through a plugged hole

(b) Blow hole formed by trapped air escaping



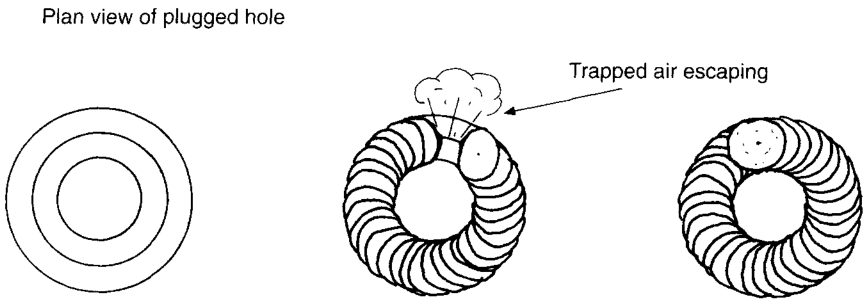
(c) Vent hole allows gases to escape

(d) Clean weld, free of blow holes

Fig. 6.33

If air is going to get trapped, it is better to drill a vent through the tool to allow air to escape or fill up the hole with weld only as in Fig. 6.32(e) and (f), which might cause other problems.

If the above solutions are not suitable, it is possible to reduce the chance of this type of porosity. Weld 90% of the insert, leaving a breather hole to allow trapped air to escape for two or three minutes and then finish your weld quickly. This technique is not always successful, but I have used it occasionally; see Fig. 6.34.



(a) Prepared plug (b) Partially welded (c) Finished weld

Fig. 6.34

Contaminated weld area

Most of the tools being repaired will have been in use so they are likely to be contaminated in some way. Some tools may have only surface contamination which must be cleaned off with a solvent, and then the solvent allowed to evaporate before welding. Other tool surfaces may be impregnated, and these must be removed, possibly by grinding, otherwise the contaminated surface layer will become gaseous, causing severe weld contamination (see also 'Welding case-hardened tools', page 97). It is important to look for contamination or surface conditions such as fine surface cracks that might hold contamination. Your weld may only be as good as your preparation.

Faulty or badly set up equipment

If you are having porosity problems all of the time, then it could be because of your own equipment. Find a piece of clean, uncontaminated steel and lay down a run of weld across it. If that weld still has porosity or any other type of contaminated finish, then it is probably caused by your equipment. Check your gas lines, from your gas source to the pressure as it comes out of your torch, see Chapter 7, 'Setting up your equipment' from page 115 up to and including 'Setting up your torch head equipment'.

Arc marks (earthing and protecting sensitive areas)

There are two main types of arc marks: arc marks caused by bad earthing and arc marks caused by stray torch arcs.

Arc marks caused by bad earthing

Unfortunately tools are not designed with earthing lugs, and any earthing to any tool will have its problems, so you need to improvise a connection to eliminate or minimize earthing arc marks.

My collection of improvised connectors and insulators contains the following:

- An 'auxiliary earth', which is two copper tipped, heavy duty crocodile clips held together by an 18″ (460 mm) length of light duty copper cable to hold and earth delicate tools; see Fig. 6.35. Small and delicate tools tend to suffer most from earthing arc marks because they do not have the weight to hold a good connection.

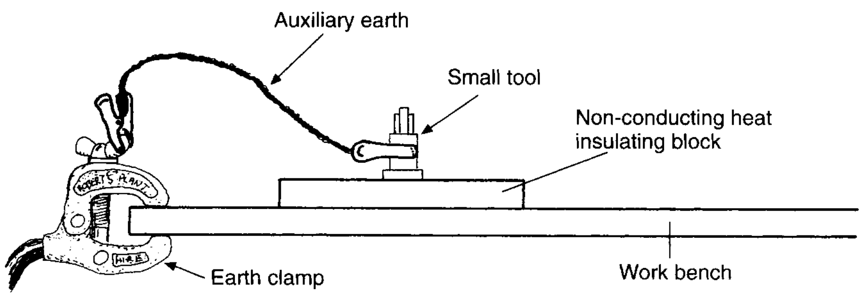
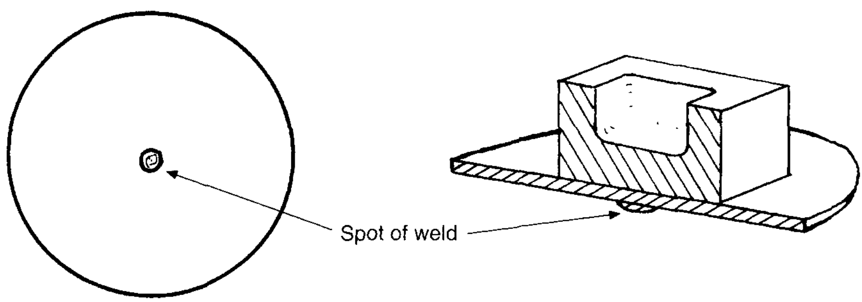


Fig. 6.35

- A pair of 'copper tipped mole grips', also to hold small tools but more firmly.
- A '4″ (100 mm) light duty machine vice' with shop-made aluminum jaws to eliminate any grip marks, also to hold smaller tools. The aluminum jaws also act as a heat soak when welding some small tools that are prone to over heating.
- A hard piece of non-conducting heat insulating material 6″ × 6″ × 1″ (150 mm × 150 mm × 25 mm) on which I rest tools when using the auxiliary earth to stop the tools earthing onto the work bench; see Fig. 6.35.
- A 6″ (152 mm) diameter, ¼″ (6 mm) thick 'aluminum disc' with a spot of weld in the center on the under side to act as a rotary table. This disc is very useful for tea cup and mug sized tools that need to be turned often to complete a weld repair minimizing arc marks to the base of the tool; see Fig. 6.36.



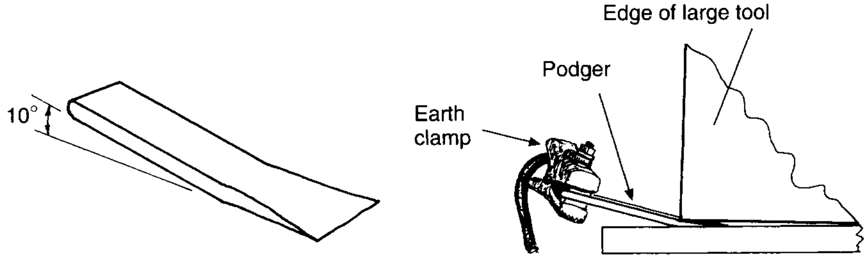
(a) Aluminum disc with spot of weld on base

(b) Section through disc and mold tool

Fig. 6.36

- A 12″ × 8″ × ½″ (300 mm × 200 mm × 12 mm) thick 'aluminum plate' on which to rest most of the tools that I weld. I rest this plate on top of my hot plate to give an even distribution of heat to the tool (see Chapter 5, Fig. 5.2, page 54) and also to minimize arc marks. As this plate is used continually the surface becomes oxidized and pitted and needs cleaning by removing the surface contamination from time to time.

- A 'podger' which is a shop-made earthing wedge, made to hammer under the bases of larger television sized tools that have no easy earthing points. The wedge is made from a piece of mild steel bar 1″ × ¼″ × 6″ (25 mm × 6 mm × 150 mm) long, flattened at one end; see Fig. 6.37.



(a) A podger wedge

(b) Podger hammered into place and earthed

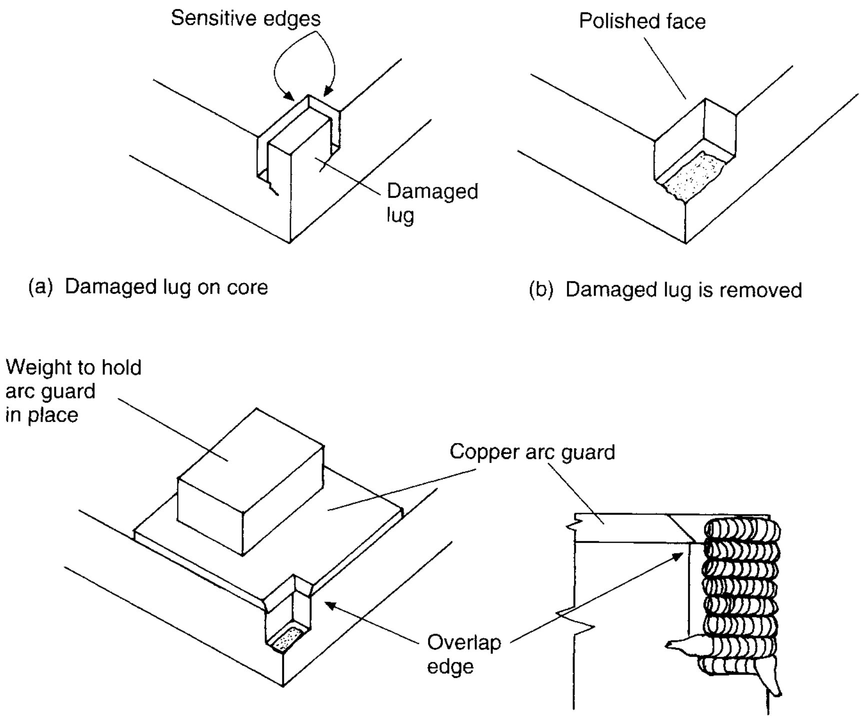
Fig. 6.37

Arc marks caused by stray torch arcs

Damaging sensitive areas while working on nearby areas can lead to major problems to the extent of scrapping what could be a very expensive tool. You need to look at the tool, identify all the sensitive areas and then decide which areas could be damaged and which would be the best way to protect them; see Fig. 6.38.

The core in Fig. 6.38 has a polished face and no more tolerance left on its height, so if the sensitive corners on the nearby polished face are damaged, they would also have to be weld repaired. The copper arc guard protects these sensitive corners from stray high frequency (HF) and accidents.

It is important to note that there must be no air gap between the guard and the tool because if HF or an accidental arc did stray onto the guard, it might then jump from the guard onto the tool causing stray arc damage. The copper arc guard is made from 2 or 3 mm thick copper plate, tailor-made to fit each individual situation; see Fig. 6.38(c), with a small overlap and chamfered for access; see Fig. 6.38(d).



(a) Damaged lug on core

(b) Damaged lug is removed

(c) Sensitive corners are masked by arc guard

(d) Finished weld repair

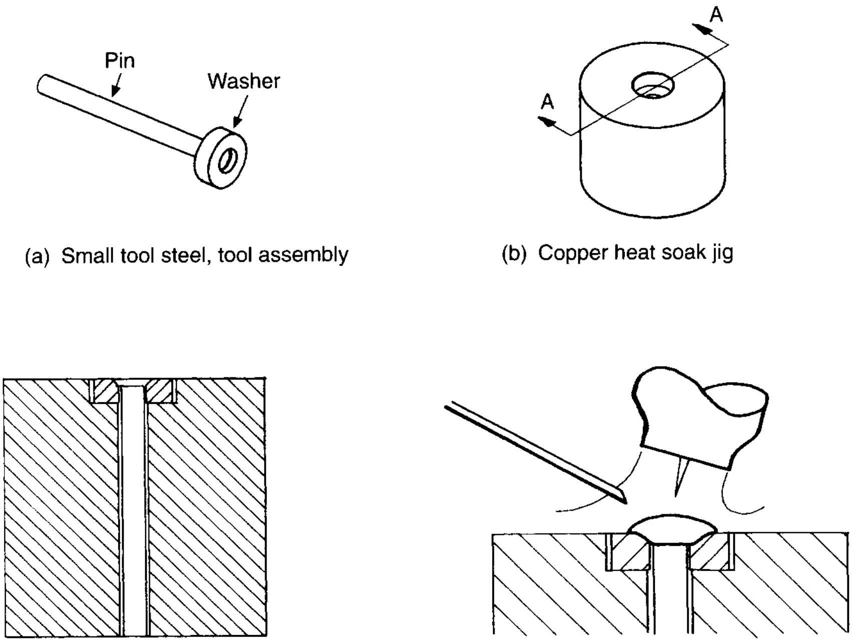
Fig. 6.38

Using heat soaks and flood supports

Heat soaks

Heat soaks, like arc guards, make very important additions to any tool welder's collection. Any small tools or small parts of large tools that will suffer from over heating can be protected with a little imagination. Figure 6.39 shows a heat soak jig used successfully to join two fine pieces of tool steel without heat damage.

The pin and washer are placed in the copper heat soak jig and welded. Using a long argon delay, place the two pieces in the jig, tap your foot pedal or HF button to set your argon gas flowing, move your torch to its welding position and allow the argon to fully immerse



(a) Small tool steel, tool assembly

(b) Copper heat soak jig

(c) Section through A–A pin and washer in jig

(d) Pin and washer welded together in jig

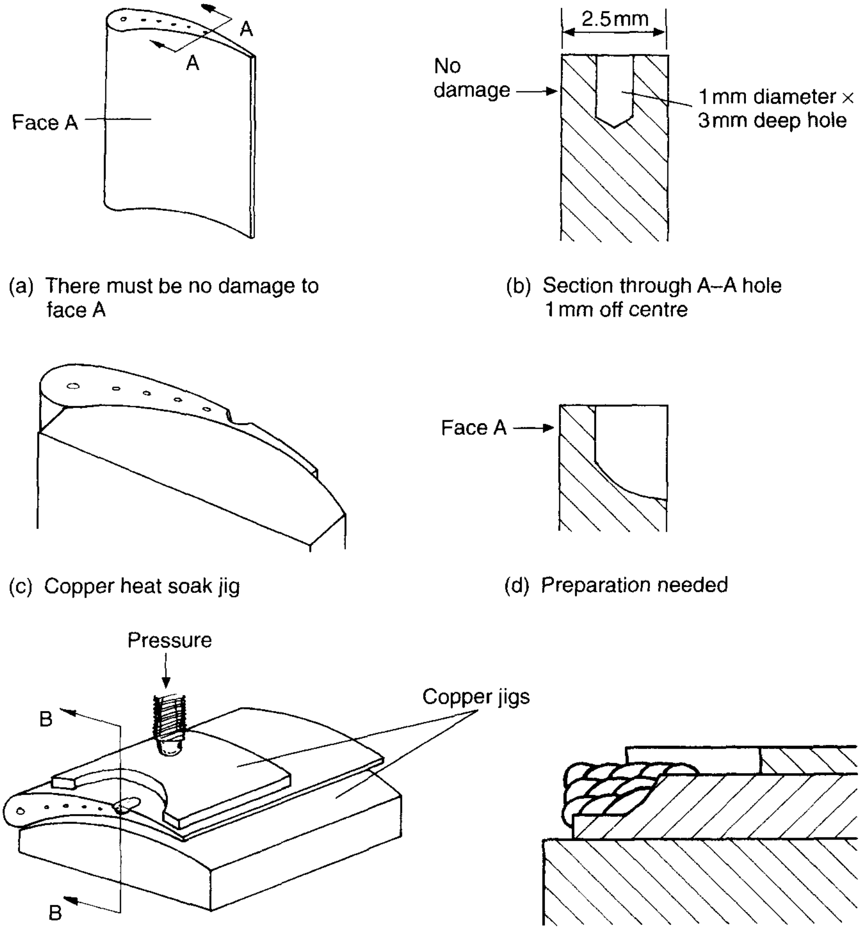
Fig. 6.39

the jig. Strike your arc, complete your weld and leave your torch over the weld area for 10 or 15 seconds. This will allow your tool to cool to a safe temperature before removing it from the jig so that no scaling and minimum oxidization occur.

An experimental turbine blade had a hole drilled off-center after weeks of expensive work, with only four days left for the delivery date. There was no time to make a new blade, so it was repair or nothing. Although the customer thought it impossible to repair, they got in touch with me anyway.

A heat soak was tailor made to fit the tool and the repair went ahead; see Fig. 6.40.

The tool was excavated on face B because there had to be no trace of the repair on face A. There had to be no distortion, so the blade was restrained in a copper heat soak jig. The preparation was filled with many small spots of weld and after each spot of weld, the



(a) There must be no damage to face A

(b) Section through A–A hole 1 mm off centre

(c) Copper heat soak jig

(d) Preparation needed

(e) Blade and heat soaks restrained under pressure

(f) Section through B–B weld complete

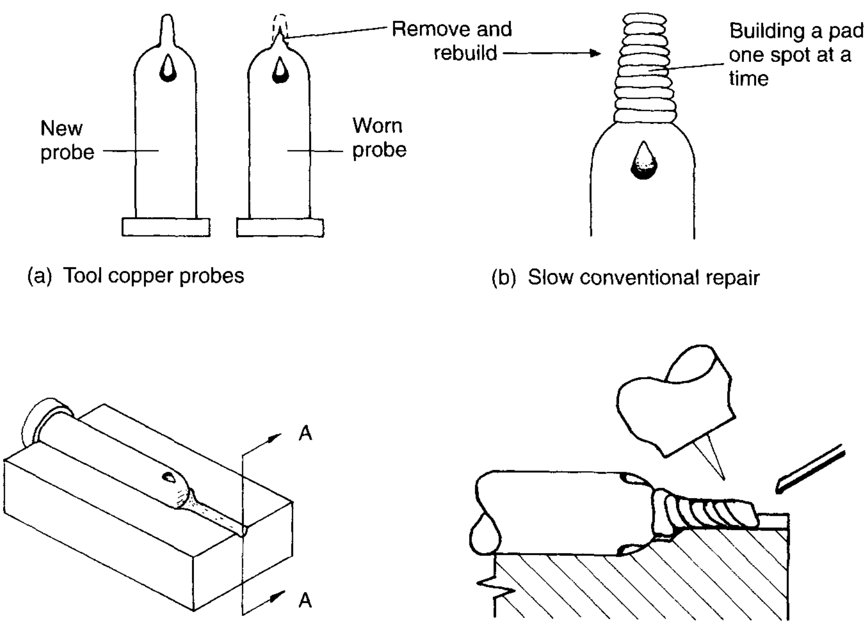
Fig. 6.40

blade was allowed to cool for 15 to 20 seconds in the cover of the argon gas flow. The preparation took two hours to fill, complete with fine sink runs and tug offs even though the whole repair was about the size of a peanut.

Flood supports

Flood supports and heat soaks are very similar in the type of operation they perform. The main difference between the two is that heat soaks are only designed to take away the heat from the weld area, and flood supports are designed to act like a mold to shape the molten metal and take the heat away at the same time.

Copper or aluminum flood supports can be very useful and time saving welding aids. Copper works best and lasts longer. When working with flood supports, it is very important to keep your direct heat on your weld metal and away from the support. Allow the molten pool to run onto the support because if the copper becomes too hot it will fuse with your weld metal. Figure 6.41 shows a worn copper probe which is being refurbished in an aluminum flood mold. An aluminum flood mold was used because the filler wire was thought to be to compatible with copper (410 stainless steel).



(a) Tool copper probes

(b) Slow conventional repair

(c) Prepared probe in flood mold

(d) Section through A–A: one fast and very clean continuous weld

Fig. 6.41

Building up thin gusset type features can be very time consuming and tedious. Sometimes there is no other solution but, as shown in Fig. 6.42, a flood support could be used producing a higher quality weld, free from the usual oxide problems associated with this type of repair and in a third of the time.

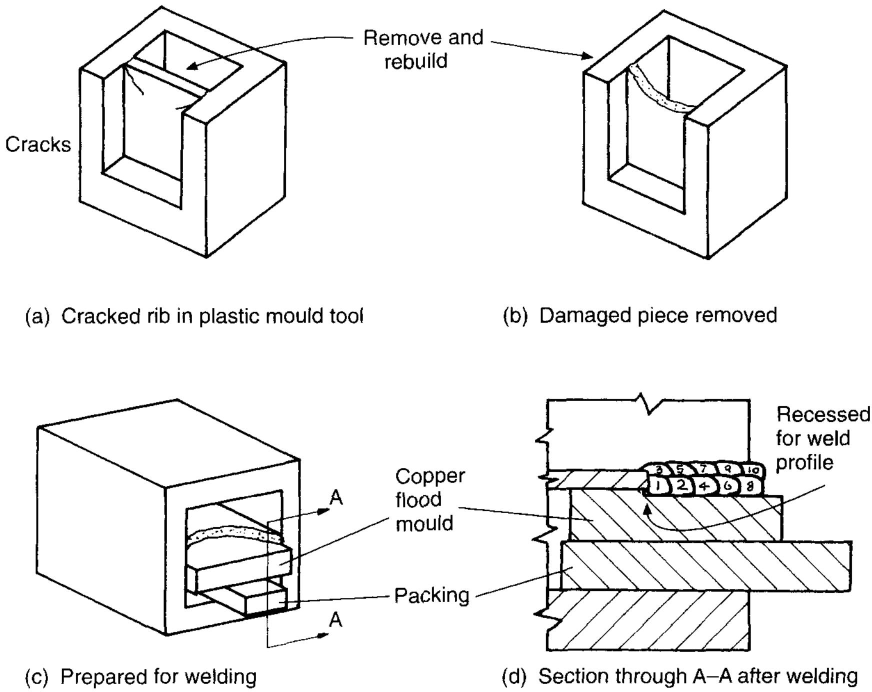


Fig. 6.42

Getting around bad access

There will be times when certain areas on a tool will be too difficult to weld because of poor access. This has always been a problem with molds, tools and dies because they are not designed to be weld friendly, so here are a few options and examples:

- Improvise with your own equipment.
- Remove material to improve access.
- Call in your local welding supplier to suggest any non-standard welding torches or torch head equipment.
- Scrap the tool.

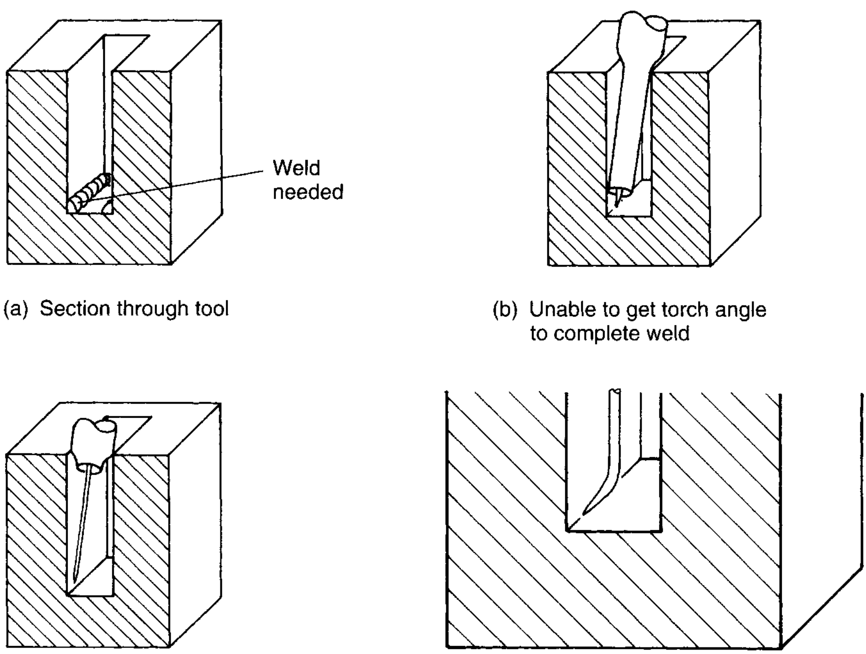
The first option, improvising, is always going to be the quickest and the cheapest. What follows are examples of some bad access problems and my own improvised solutions.

Problem 12 Deep narrow enclosed cavities.

Unfortunately, the weld needed in Fig. 6.43(a) is at an impossible angle even for a non-standard nozzle (b).

Solution 12 Because the cavity is enclosed, it is possible to fill the cavity with argon gas (because argon gas is heavier than air) and weld with a bare tungsten (c). If you find when using the bare tungsten that your angle is still not quite right, then bend the tungsten until it is (d). This gives you a perfect angle every time, see page 92, 'Bending tungsten'.

To fill your cavity with argon gas, set your gas delay to maximum and tap your foot pedal or HF button, switch to trigger your gas flow only (use only a standard gas flow; see Chapter 7, Fig. 7.5, page 117), move your torch to its welding position allowing the gas from your torch to fill the cavity. If you feel that the cavity may not have filled then just tap it again.



(a) Section through tool

(b) Unable to get torch angle to complete weld

(c) Extend tungsten

(d) Extend and bend tungsten

Fig. 6.43

Important: I have found it very important to build a mock cavity to practice on until I feel happy with my gas coverage, then I move on to the tool itself.

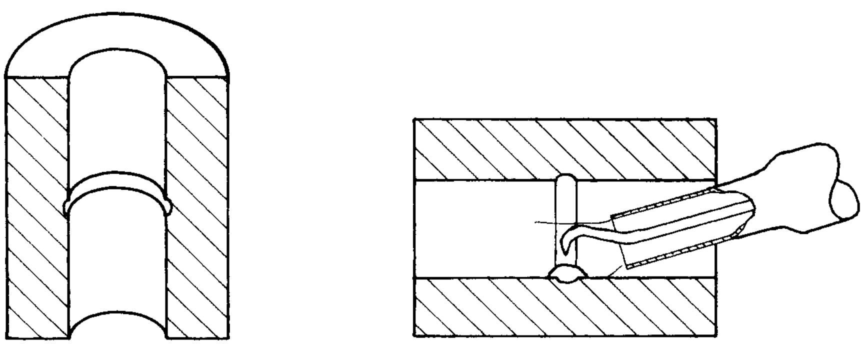
Bending tungsten

Bending tungsten is a technique I learned as a pipe welder. To bend a tungsten you need to strike your arc on a piece of scrap material and allow your tungsten to become white hot. Have a pair of snips (wire cutters) or pliers in your other hand and then quickly extinguish your arc and bend the tungsten with the snips before it cools. **Note**: sharpen the tungsten before you bend it!

Problem 13 Welding non-enclosed deep narrow cavities.

Solution 13 Welding non-enclosed deep narrow cavities can cause even more problems but these can be minimized by enclosing the cavity with all shapes and sizes of plate and bar, then welding as problem 12.

In some cases, the weld position dictates the setting up of the tool position; see Fig. 6.44. If it is necessary to use a narrow nozzle, e.g. 8 or even 6 mm, then bending your tungsten will probably position it out of the gas coverage, causing porosity. You need then to make a double bend as shown in Fig. 6.44(b).



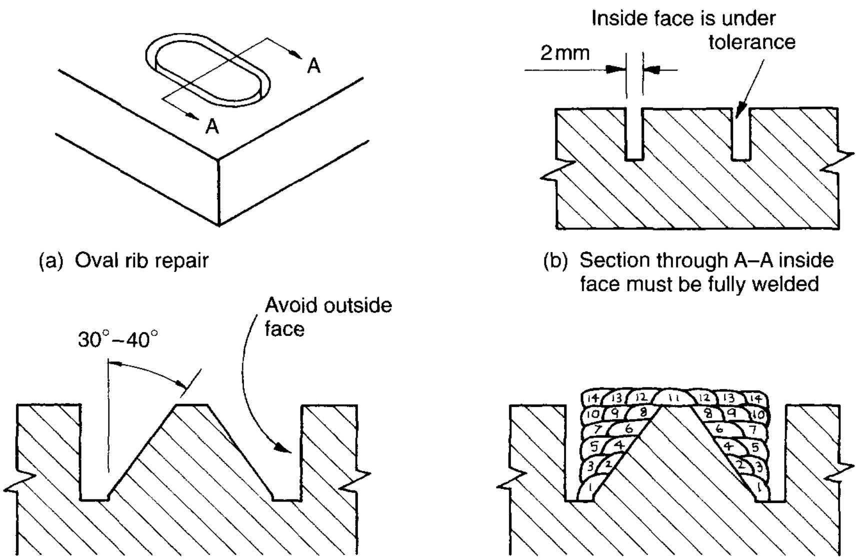
(a) Recess needs to be filled with no undercut

(b) Tool needs to be welded on the flat

Fig. 6.44

Problem 14 Welding deep narrow slots – Removing material to improve access. Unfortunately, there will be times when you will have to remove material to improve access, and this can be just as complicated as the welding itself.

Solution 14 In this example, the oval inner rise has too small a diameter so the inside rise diameter has to be increased by 0.2 mm (0.1 mm per side) see Fig. 6.45(a) and (b).



(a) Oval rib repair

(b) Section through A–A inside face must be fully welded

(c) Fully prepare rise to avoid damaging outside face

(d) Final weld sequence

Fig. 6.45

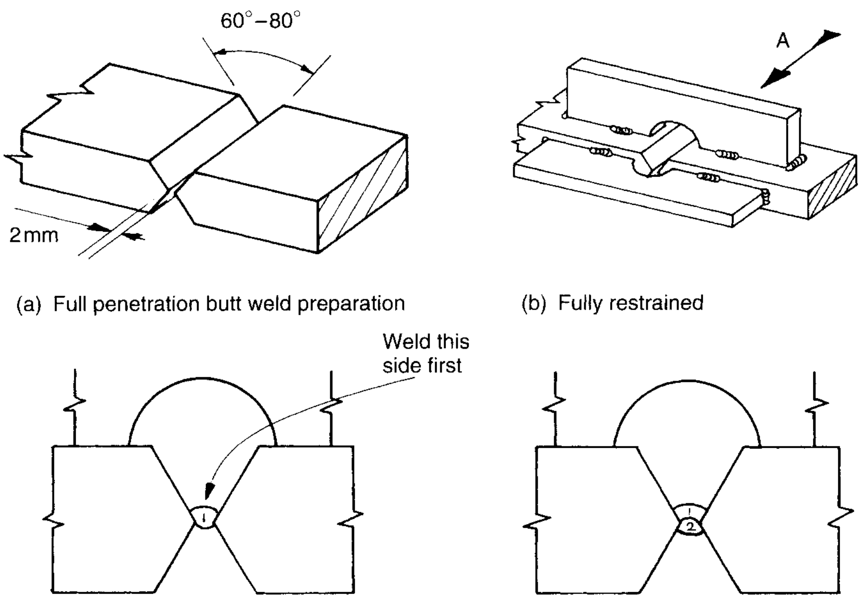
When removing material to improve access, it is very important to choose a preparation that you will find accessible or comfortable to weld (Fig. 6.45(c)). You will then need to plan a logical weld sequence which will ensure that every run is a good one because you will not be able to go back to touch it up (Fig. 6.45(d)).

Controlling distortion

It is very difficult to correct tools that have become distorted during welding, so prevention is better than cure. Most tools will distort during welding, and only experience will enable you to determine how much distortion will occur. Until you have that experience, you will have to do what I do – guess!

Using restraints

Repairing broken die plates, stripper plates and similar types of tools is a major operation of preparation, re-location of the broken pieces, restraining and planning your weld sequence, see page 59, 'Weld procedure 2, broken spoon die'. Weld procedure 2 will relate to most types of re-assembly on dimensionally tied tools. If the priority of a tool repair is its strength, and shrinkage is not a great problem, then a full penetration butt weld will be most suitable; see Fig. 6.46.



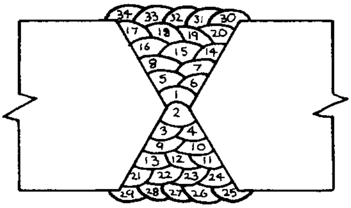
(a) Full penetration butt weld preparation

(b) Fully restrained

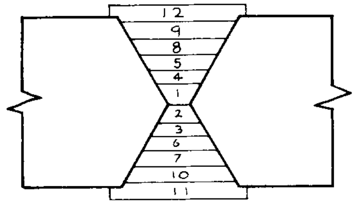
(c) View from A, full penetration on first run

(d) Back grind first run and complete root runs

Fig. 6.46



(e) Final run sequence, alternated to minimize weld distortion



(f) Simplified layer sequence to show order of layers

Fig. 6.46 cont'd

In Fig. 6.46(a) the damaged tool is prepared for welding by grinding a double chamfer on each face to be welded, creating a 60°–80° double 'V' preparation. Open up the preparation to form a 2 mm gap (which will probably be lost in shrinkage after the weld is finished), then restrain the tool from bending by tack welding two bars to the top and the side. Each bar has been cut away for better access; see (b).

In Fig. 6.46(c) run '1' is your first run which should be on the restraint side, then the tool will be turned over and back-ground to remove all the oxidized metal that penetrated the gap, leaving only clean metal so the root runs can be complete (d). Then the preparation is filled with weld in an alternate sequence to minimize distortion (e). This has been simplified in (f) to clearly show the alternated layers.

Pre-heats and cooling are not discussed in this chapter. For information on recommended pre-heats and specific filler wires see Chapters 4, 5 and Chapter 2, 'Weld procedure 2', page 9.

Restraining edge repairs

Repairing cutting edges like granulator blades and similar tools that are only welded along one edge can produce disastrous results if restraints are not used; see Fig. 6.47.

The damaged edge of the granulator blade should have a dye pen examination then be fully ground to remove all cracks and

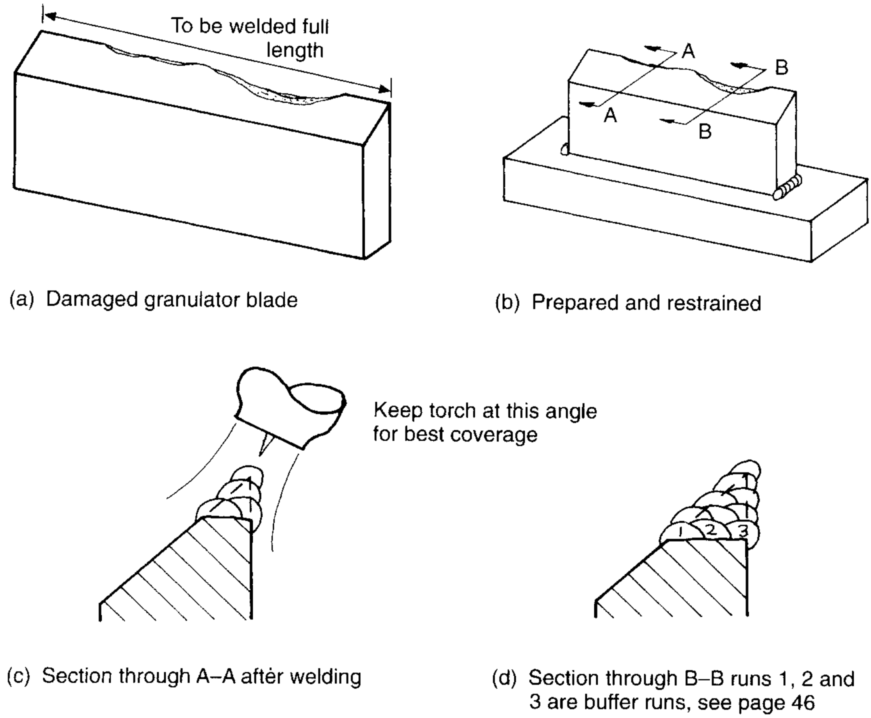


Fig. 6.47

contamination (Fig. 6.47(a)); see page 66, 'Excavating cracked material'. The prepared tool and its restraint should be pre-heated to the same temperature then tack welded together (b). The weld can then be completed. If there are only two or three layers of weld, then increase the pre-heat by 25% and only use a hard tool steel filler wire. If there are four or more layers, use a standard pre-heat and a single buffer layer, then finish with a hard tool steel filler; see (c) and (d).

Welding without full pre-heat

There are many tools that can be successfully welded without full pre-heat if sensible precautions are taken but this is not generally recommended.

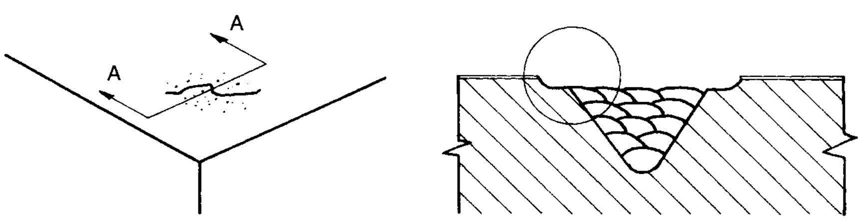
Materials such as P20, probably the most common type of tool steel available and generally used on larger plastic mold tools, can easily be repaired cold if care is taken, although I have seen many disasters. When it comes to welding without pre-heat, the bigger the weld, the greater the problem, the hotter the weld, the greater the problem, the quicker your weld cools, the greater the problem!

The answer to minimizing problems when welding tools cold is to use only short, narrow welds at first, allowing 10–15 seconds between each weld so the heat from each weld can soak into the weld area, naturally pre-heating as you weld. Welding hard, high carbon tools such as O1 and D2 without pre-heat can never be recommended because of the likelihood of cracking. At best it will be very damaging to the working life of the tool. There are, however, some companies that have developed medium carbon tools (0.6% carbon) which will harden up to 58 HRC and are recommended to be welded without pre-heat but the weld technique outlined above would have to be used.

Welding case-hardened tools

Case-hardened tools are repaired in much the same way as any other tool apart from the case hardening itself. The surface of a case-hardened tool cannot be welded with any great success so it must be removed. After the repair, the hard surface can be replaced with a hard filler wire; see Fig. 6.48.

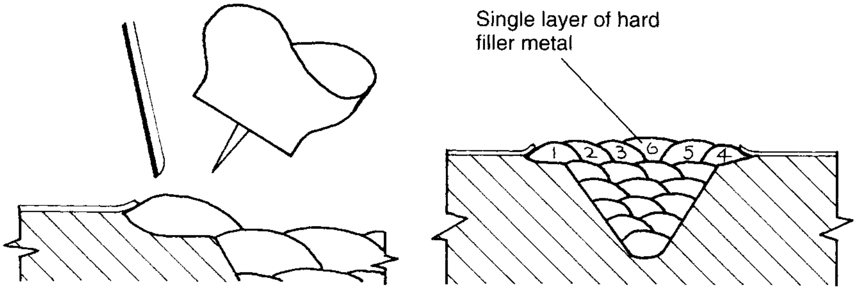
Keeping the tungsten away from the case-hardened skin, allow the pool to spread under the skin then push your filler wire into the pool



(a) Damaged surface on a case-hardened tool

(b) Repair main damage leaving room for one or two hard layers

Fig. 6.48



(c) Spread pool under skin and push in rod

(d) Final weld sequence. Three layers of hard filler metal will be needed for maximum hardness

Fig. 6.48 cont'd

lifting the skin (Fig. 6.48(c)), creating a continuous hard surface after machining (d). The first runs in (b) will be welded with a filler wire that matches the tool's base material and the final surface runs will be a hardness match.

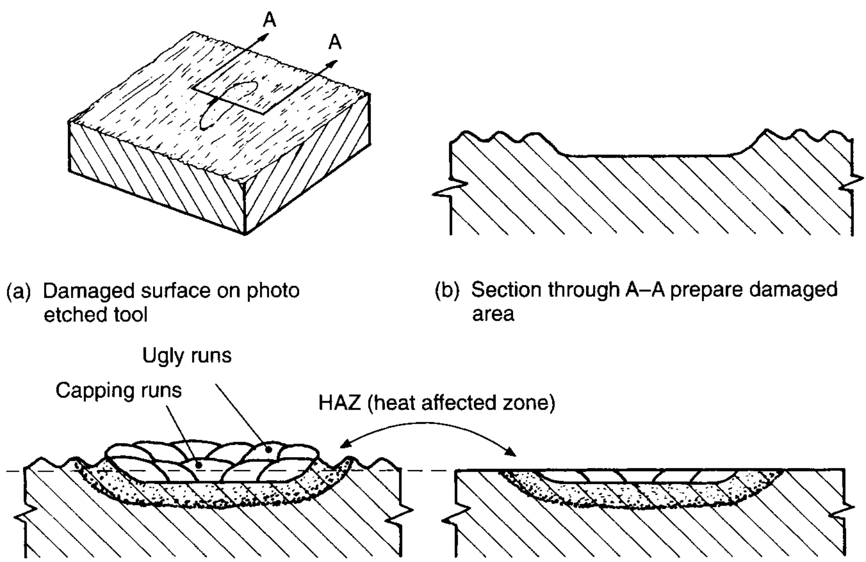
Welding photo/acid etched and polished tools

Most of the finish problems to plastic components caused by weld repairs can be minimized and in some cases completely eliminated.

First we need to understand photo/acid etching. Basically, this is a process of masking some areas with a protective coating and leaving the rest uncovered. When acid is poured over the surface, it eats into the areas that are not masked. Some materials are more resistant to acid erosion than others because of their chemical composition, so if you are going to undertake a repair on an acid etched surface, you must choose a filler wire that matches the chemical composition of the mold tool; see Chapter 4, Table 4.2, and 'Photo/acid etch' on page 45.

Unfortunately, chemical composition is not the only factor that determines the depth of acid etching. Grain structure also plays a part, so the harder the area, the greater the resistance to acid erosion.

To perform a surface repair, the repair area should be prepared for welding by grinding away any damaged material and cleaning to remove any contamination left over from the molding process; see Fig. 6.49(b). The welding repair should be completed and finished off with ugly runs (c). (The ugly runs are designed to reduce the inter-run hard lines on the final capping run and also to help reduce the severity of the HAZ (the halo effect).) The whole plane of the repair should then be removed by a polisher (d) and sent away to be re-etched.



(a) Damaged surface on photo etched tool

(b) Section through A–A prepare damaged area

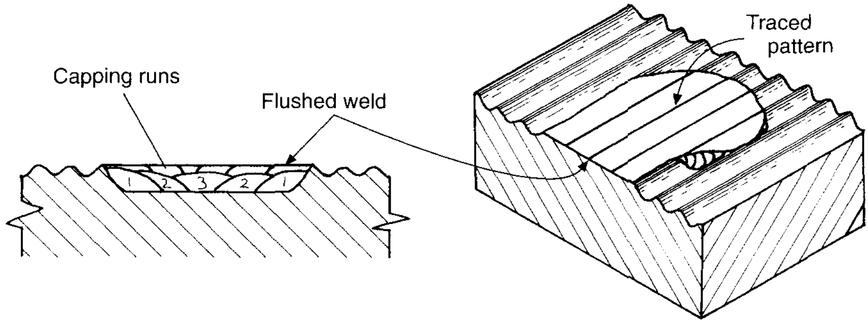
(c) Fill preparation with weld and add ugly runs

(d) Remove all etched surface, ugly runs and part of the capping runs

Fig. 6.49

If you only want a small repair in a discrete area and you do not want the expense of a polishing and re-etching, then follow steps (b) and (c) in Fig. 6.49, and steps (a) and (b) in Fig. 6.50.

It is very important for your weld to completely cover the damaged area so it must be cleanly flushed off level with the highest peaks of the engravings (Fig. 6.50(a)), or it will dimple. Then trace (using a piece of carbon paper, a piece of tracing paper and a piece of plain thin white paper) the pattern onto the flushed off surface (Fig. 6.50(b)) and hand etch away unwanted material.



(a) Flush weld to the peaks of the etch

(b) Trace etch pattern to the surface of the flushed weld, and hand etch away unwanted material

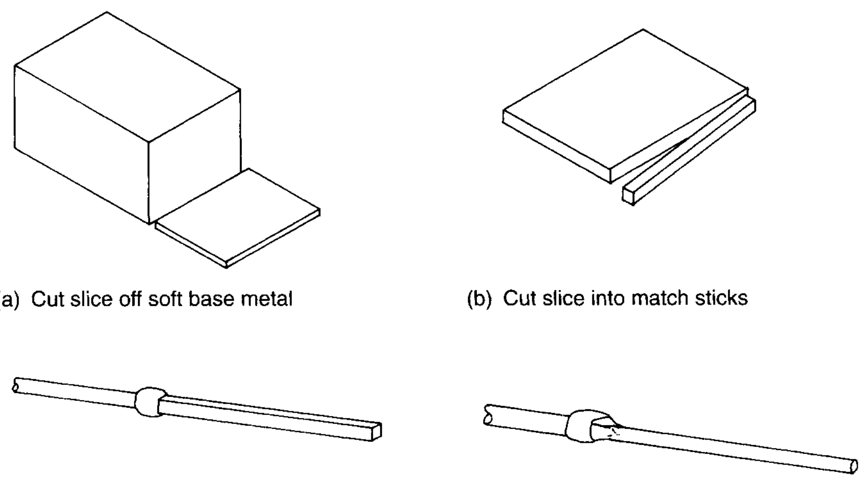
Fig. 6.50

1 Place your copy paper on to the etched surface where there is no damage, with the inked side facing up.
2 Place your tracing paper on top of that.
3 Hold flat and steady and rub something blunt over the paper like a brass rubbing, covering as much of the paper as possible. This should give you a good image on the underside of your tracing paper.
4 Cut your copy paper just bigger than the weld area.
5 Turn your copy paper ink-side down to cover the weld area.
6 Cut your white paper to the same size as your copy paper and place that on top of your copy paper.
7 Place your tracing paper on top of that and line up your pattern with the pattern around the weld.
8 Use a pen or pencil to line through each individual feature of the pattern onto the welded surface. Hopefully, enough of the pattern will have transferred through to the welded surface so you can hand etch away the unwanted material and possibly finish off with a bead blast.

Welding polished tools is very much the same as welding photo etched tools. It is important to choose a suitable pre-heat (see Chapter 5), a suitable filler wire (see Chapter 4) and a suitable weld technique using a fine sink run to minimize sink; see page 71. Also, use ugly runs, see page 99, to help minimize hard spots in the weld and to soften the halo effect (the HAZ) around the weld to make life easier for your polisher.

Using base metal as filler wire

Unfortunately, there are very few filler wires that actually match a particular base metal. Make your own filler wire by cutting a slice off some soft matching base metal and then cutting that slice into match sticks. Take a matchstick of base metal and weld that to a piece of filler wire. If you feel the need, you can grind the matchstick end round until it looks like one piece of filler wire, but this is not necessary; see Fig. 6.51.



(a) Cut slice off soft base metal

(b) Cut slice into match sticks

(c) Weld matchstick to filler wire

(d) Reduce filler wire by grinding if necessary; see next paragraph 'Welding fine details'

Fig. 6.51

Welding fine details

Normally when welding fine details, you would need a fine filler wire and a fine tungsten, e.g. 1.00 mm diameter, but personally I find

1.00 mm filler wires too thin to handle. What I normally do is grind a long thin point on my 1.6 mm diameter tungsten and grind down 1.6 mm filler wires because I find this quicker, cheaper and easier to use.

I generally use a pedestal grinder to reduce my filler wires and sharpen my tungstens. I use the side face to reduce my wires and to grind a rough point on my tungstens. I then use the front edge face to put a fine finish on my tungsten.

Important: *never* wear loose fitting clothing and *always* wear eye protection when grinding tungstens and filler wires; See Chapter 7, page 117, 'Sharpening tungstens', and see Fig. 6.52 for reducing filler wires.

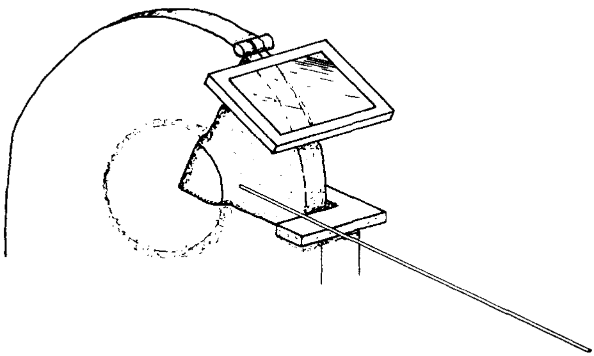


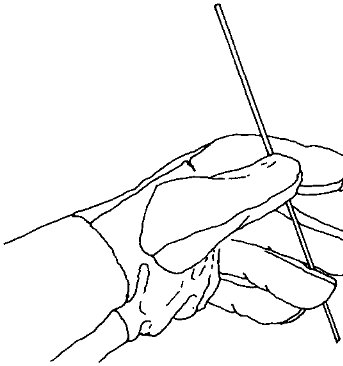
Fig. 6.52

Generally speaking, using the side of a grind stone is considered an unsafe practice because the stone can become worn on its flat side face, leaving the stone in a dangerous condition. If you intend to reduce filler wires in this way, always have a qualified person check your stone for uneven wear on a regular basis.

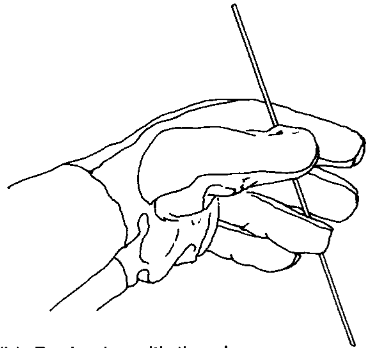
Filler wire

Hand feed technique

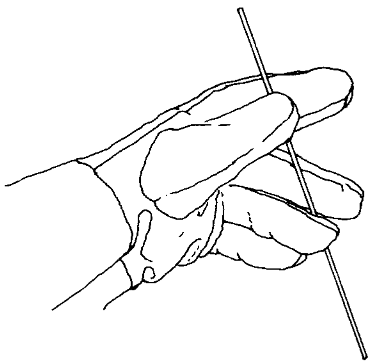
Every welder will hold and feed their filler in whichever way feels most comfortable to them so there is not a right way or a wrong way. See Fig. 6.53 for my way!



(a) Grip wire with thumb and index finger and hold wire with 2nd and 3rd fingers



(b) Push wire with thumb and index finger and guide with 2nd and 3rd fingers



(c) Hold wire with 2nd and 3rd fingers, loosely slide thumb and index finger back up the wire and start again

Fig. 6.53

Economical weld technique (bulking out)

This can be used to keep the cost of any large weld repairs as low as possible. If you have a large area of weld to build up and you want to keep your filler wire costs down, then building up most of that weld with a cheaper wire (bulking out) is a good option.

Suitable wires for bulking out

This technique is probably not regarded as technically correct but it is used and so I shall tell you about it!

Basically, you need to establish the chemical composition of the tool to be repaired (with the help of Chapter 3), and then contact your local filler wire suppliers and get them to find the closest, cheapest filler wire, see below

e.g. P20 Tool steel = 0.35 C, 0.30 Mn, 1.70 Cr, 0.40 Mo
A32 Filler wire = 0.10 C, 0.90 Mn, 1.20 Cr, 0.50 Mo
A33 Filler wire = 0.10 C, 1.00 Mn, 2.40 Cr, 1.00 Mo

e.g. H13 Tool steel = 0.35 C, 0.30 Mn, 5.10 Cr, 1.50 Mo, 1.00 V
A34 Filler wire = 0.07 C, 0.60 Mn, 5.80 Cr, 0.50 Mo,

e.g. D2 Tool steel = 1.50 C, 0.40 Mn, 12.0 Cr, 0.95 Mo
410 Filler wire = 0.10 C, 0.60 Mn, 12.0 Cr, 0.4 Ni

Although these filler wires are not an ideal match especially in the hardness area/carbon (C) content, I would consider them suitable for bulking out. It is important to note that you must allow for three finishing layers of your final matching filler wire in areas that you think important, e.g. areas to be photo etched, cutting edges and other areas that need a closer match. See also Chapter 4, Table 4.2, page 44, and the important issues that follow Table 4.2.

7

Equipment

Safety

Before getting involved with welding equipment, it is important to understand what welding safety is about, what safety equipment you will need and why you need it.

Like any other engineering trade, welding is usually very safe but it can be dangerous if proper precautions are not taken. Welding gives off ultra-violet radiation and exhaust gases which you need to be protected against. Although mold, tool and die repair TIG welding tends to use much lower amperages than other welding processes, making emission levels very low, safety must still be taken seriously. You will be dealing with electricity, high pressure gases, fuel gases, grinding tools and very hot materials, so please read this section carefully and **make safety a priority**.

Ultra-violet radiation

The bright light given off by welding is ultra-violet radiation, which you will need to be protected against. Ultra-violet rays are like intense sunlight so if your skin or eyes are not protected they will get severe sun burn. When this is on your skin it is called 'ray burn' and will take as long to go as bad sun burn. When it affects your eyes, it is called a 'flash', and it will make your eyes very sore for one or two days depending upon how long they were exposed. Like sun burn, constant over-exposure to ray burn over long periods of time may increase your risk of skin cancer, so the rule is: **Cover up**!

Not only should you cover up but you should also put screens up around your welding area to protect other people from irritating brightness and the effects of ultra-violet light.

Sparks

Grinding sparks can cause major problems for you and anybody in your vicinity. Sparks and particles can be travelling faster than 300 mph, so you must wear a grinding visor as well as your safety spectacles when preparing tools by grinding. You must also be considerate of others. People around you may not notice that you are about to grind until they are hit by a shower of sparks, so this is another reason to put screens up around your weld area.

When grinding you should always aim your sparks where they are going to do the least damage. Always be aware that sparks can start fires, especially with leaking fuel gas bottles.

Welding fumes

Even though the welding gases given off by TIG welding are very low, all welding rod containers tell you that welding gases are hazardous to your health, so you must protect yourself against their fumes wherever possible.

Always weld in a well-ventilated area. Nearly all welding fumes will rise because of the heat of the arc and be carried away in your shop's natural air movements. There are many different types of respiratory equipment available, such as disposable face masks, air fed masks and extraction units. See your local welding equipment supplier for more details. Respiratory equipment must be worn especially when welding beryllium copper, or in confined spaces, or at any time that you feel that the fume level is high, e.g. when using stick welding rods or flux cored MIG welding at high amperages.

You can get 'flu-like symptoms from inhaling high levels of fumes and their metal vapors, especially from zinc and copper. Fortunately these are short lasting. Inhaling high levels of fumes over long periods of time will, however, cause respiratory problems.

If you are going to be welding most of the time, always be aware of the way you feel, especially if you are working in a room with a gas heated hot plate or ovens where you may be pre-heating tools. In these conditions, oxygen levels will reduce, and if you feel drowsy, nauseous or dizzy, or if you start to get sore eyes, nose or throat, get some fresh air.

If you are concerned about the levels or concentrations of fumes in your work area, contact your local or national Health and Safety authority for more information on OELs (occupational exposure limits).

Highlighting these problems is not designed to discourage you from welding, only to encourage you to take safety seriously. I have been welding nearly every day for 25 years in heavy and light industries, and I still enjoy excellent health, so it is not necessarily what you do but the way that you do it!

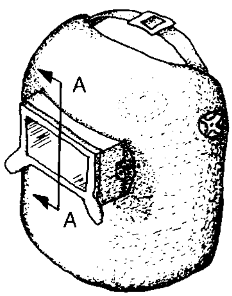
Safety wear

The type of safety wear that you use depends upon the type of work you will be doing. General requirements would be

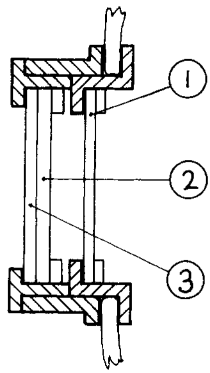
- Overalls: to protect your skin against ultra-violet light, sparks, burns and to protect your clothes.
- Safety boots: to protect your feet against hot and heavy objects.
- Safety spectacles: to protect your eyes from stray ultra-violet light, sparks and filler wire ends.
- Ear plugs or muffs: to protect your hearing from noise pollution. Constant over exposure to high levels of noise like grinding will result in an irretrievable reduction in the quality of hearing.

Welding head screens

There are many types of head screens ranging from a basic fixed visor to a super-fast reactor lens with built-in grinding visor and filter fed air stream. All head screens that come with a safety guarantee will be suitable, although some may be more comfortable than others, so try a few different types before you buy. I use a head screen with a flip-up visor. My screen contains three lenses as shown in Fig. 7.1.



(a) Welder's head screen with flip up visor



(b) Section through A–A: detail of flip up visor and inner safety cover lens

Fig. 7.1

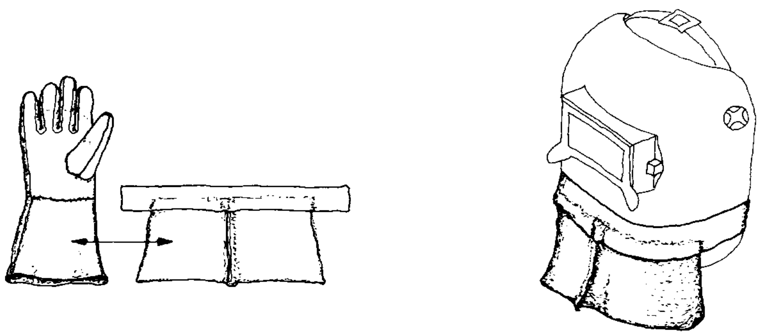
In Fig. 7.1(b), lens 1 is an inner safety cover lens (resin). This is important when your flip up visor is open and you are preparing your tools by grinding. For impact resistance, the inner safety cover lens should only be made from resin-based, plastic materials, and *never* from plain glass.

Lens 2 is a standard cover lens (resin or glass). This lens does not need the same impact resistance as the safety cover lens. The standard cover lens protects the more expensive shaded lens from grinding sparks when you are preparing tools for welding.

Lens 3 is a shaded lens (resin or glass). This lens acts like your sunglasses to reduce the brightness of your arc so you can see what you are welding. There are many different grades of shaded lens for arc welding, generally from a shade 6 to a shade 14. I use a shade 10 most of the time, but you should also try a shade 9 and 11 and find out which suits you best.

If you have a large repair for which you intend to use the stick or MIG welding process, I suggest you use a shade 10 or 11.

Handy tip: I have found with most of these head screens that you need to have your overall top button fastened all the time to avoid a ray burn triangle or 'Bermuda triangle' where your chest meets your throat. (Bermuda because that piece of skin looks as if it has been to Bermuda when the rest of you stayed at home!) To overcome this, try ripping off the gauntlet part of an old pair of TIG gloves and sticking it to the lower part of the screen, see Fig. 7.2.



(a) Remove gauntlet part from old glove, open out and fit to screen with masking tape

(b) Head screen with gauntlet fitted

Fig. 7.2

Partition screens

Partition screens are very important to protect other people around you from sparks and ultra-violet rays. They can be bought from your local welding supplier or you can make them yourself.

Welding gloves

There is more than one type of welding glove. The two main types are TIG and general-purpose welding gloves which are more suitable for stick and MIG welding. Both types will protect your hands from ultra-violet rays and a moderate amount of heat. TIG welding gloves are designed to be thinner so that you can feel your filler wire and have greater control of it when welding very fine tool work.

Hot gloves

To save your leather welding gloves from unnecessary damage, hot gloves should be used to handle hot tools. See your supplier for details.

Keeping your work place tidy

Being tidy will help you to keep your work place safe. Remove all non-essential materials from your working area, including rags and old cleaning cloths, especially solvent and oily wipes. Clear away any pressurized aerosol cans, and make sure that any fuel gas bottles are as far away as possible from any heat source, and heating torch hoses are kept away from direct heat.

Even if you do all this on a regular basis, still keep a vigilant eye on all of your flammable equipment, especially when you are grinding.

Gas bottles

Keep all bottles and cylinders as far away as possible from your working area. Bottles that are not in use should be stored in a special enclosure out of harm's way; see your local gas supplier for storage details. Bottles that are in use must be secured with ropes or chains so they cannot fall over.

Regularly check all the connections on your gas bottles and gas lines to ensure that they are not leaking and that all the hoses and gages are suitable for the job they have to do. High pressure hoses and gages must be fitted to high pressure bottles, and oxygen and fuel gas bottles should have suitable hoses and flash back arresters. See your local supplier for more details.

Note: argon gas can kill! It has no smell and it is heavier than air. *Never* put yourself in a position where you will be breathing in high concentrations of argon because it will replace all the oxygen in your lungs and you will become asphyxiated.

Power tools

When using power tools, such as grinders, you should always follow the maker's recommendations and if you intend to change your own grinding discs, take a short training course before doing so. You should always wear eye protection when using power tools and you should not return a used disc to a grinder if there are no new discs available. Always unplug your grinder before changing discs.

You should never wear loose fitting clothing when holding tools, tungstens or anything else to be ground, because of the chance of getting pulled in to a revolving disc or stone. All power tools are dangerous: read the maker's recommendations and follow them for your own and other people's safety.

Welding equipment

The basis for every good set up is the appropriate equipment. There are many different types of welding equipment on the market and so many different companies to choose from, some of which are more interested in selling you their most expensive pieces of equipment rather than the most appropriate, so knowing what you want, or rather knowing what you do not want, could save you a lot of time and money. What follows is a guide to choosing the type of equipment that will most suit your needs.

Welding sets

When choosing your welding set, you must decide what category your type of work falls into, e.g.:

- Work type – light (steels only).
  Set type – 100–200 A, fan cooled DC inverter, TIG and MMA (manual metal arc).
- Work type – medium (steels and light copper only).
  Set type – 200–300 A, fan cooled DC inverter, TIG and MMA.
- Work type – medium (steels, light coppers and light aluminums).
  Set type – 200–300 A, fan cooled AC/DC inverter, TIG and MMA.

- Work type – heavy (steels and light to medium copper only).
  Set type – 300–400 A, water cooled TIG and MMA.
- Work type – Heavy (steels, light to medium coppers and aluminums).
  Set type – 300–400 A, water cooled AC/DC, TIG and MMA.

All the above sets must have an HF or lift start, about a 5 A start for fine mold tools, a slope in and out for *in situ* welding and the facility for a remote foot control for fine bench work.

Choosing your set can be more difficult if you expect to be welding pure copper or pure aluminum (because of their excellent conductivity), or if you will be welding continuously on a manipulator. For either of these, a higher amperage set would be recommended.

Torch head equipment

Your torch or torches should match the type of welding set that you buy complete with an HF switch or lift start for *in situ* welding if needed. Your torch should be as light and maneuverable as possible for fine tool work. If it is important for your weld to be as clean as possible (as in mold tool work), you will need a gas lens kit and a cupped ceramic as part of your torch head equipment. You must choose the most suitable sized tungstens to go with the type of work you intend to do; see Table 7.1.

DC TIG welding is used to weld all metals excluding aluminum and its alloys. AC TIG welding is used to weld aluminum and its alloys.

Table 7.1 Tungstens

DC thoriated or ciriated	AC zirconiated or ciriated
1.0 mm, up to 50 A	1.6 mm, up to 100 A
1.6 mm, up to 125 A	2.4 mm, 80–150 A
2.4 mm, 100–250 A	3.2 mm, 140–250 A
3.2 mm, 200–375 A	4.0 mm, 200–300 A
4.0 mm, 350–475 A,	5.0 mm, 250–350 A
	6.0 mm, 300–500 A

Thoriated and zirconiated tungstens give off low levels of radiation so ciriated tungstens are available as an alternative. However, these do not perform as well as thoriated or zirconiated tungstens.

It is also very important to choose the right gas lens to go with your tungsten, i.e. if you are going to use a 1.6 mm tungsten then you will need a 1.6 mm gas lens and so on. Unfortunately, there will be times when a gas lens kit and a cupped ceramic are just too bulky so you will then need an appropriate collet body and a selection of cupped ceramics of different lengths as shown in Fig. 7.3.

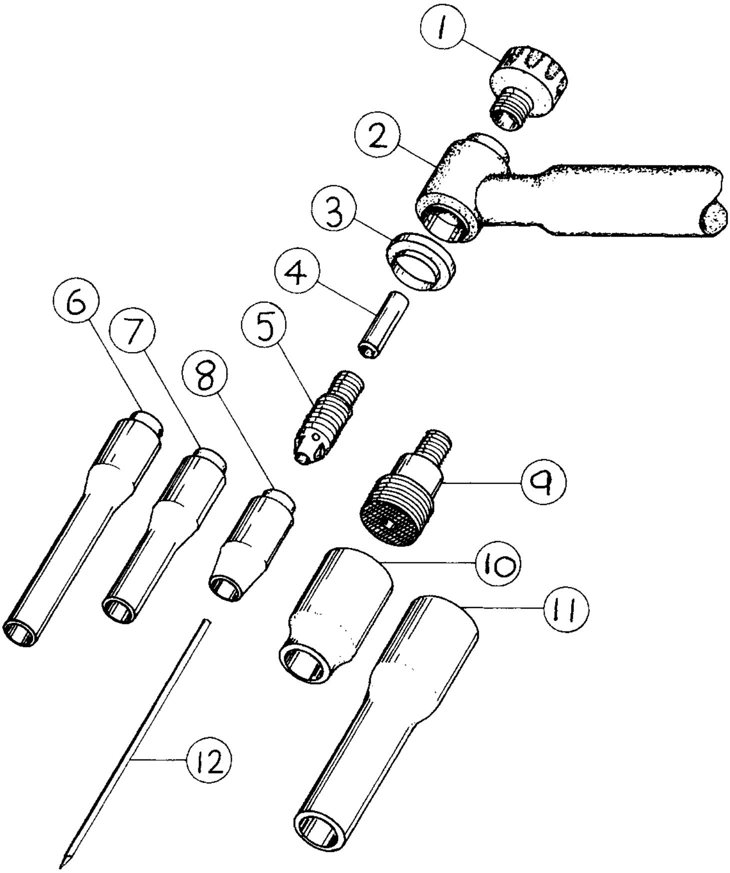
If you feel that the above torch is too light, then discuss a heavier torch with your supplier. You will find most standard torches have a similar range of torch head equipment to offer but the golden rule is **always use a gas lens when you can**.

TIG welding gases

For most TIG welding operations, high purity argon is the most suitable. If you intend to weld heavier copper and aluminum tools, you may find that argon/helium mixed gases are more suitable because helium increases the temperature of your arc without increasing its ferocity; see your gas supplier if you need more information.

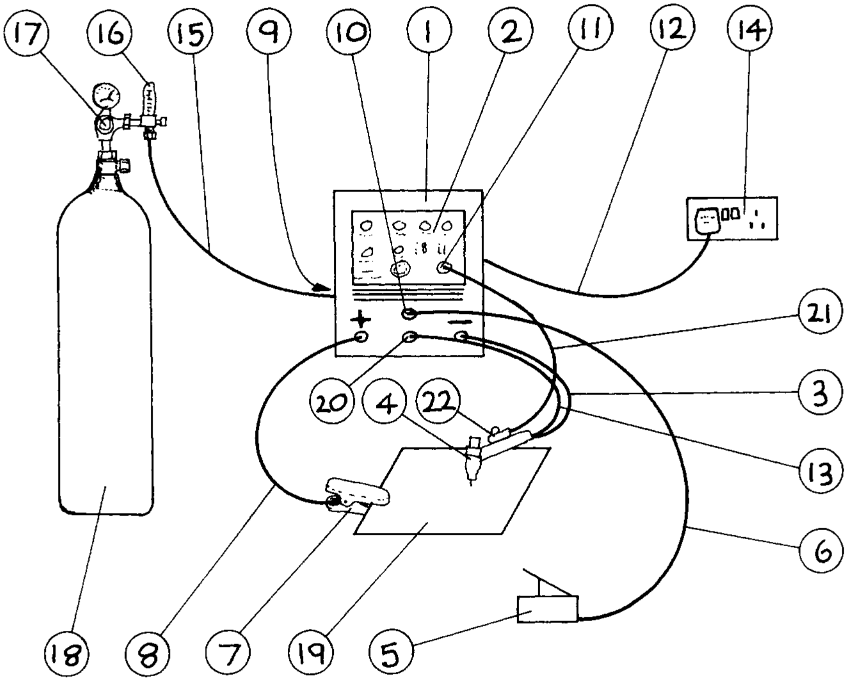
Hopefully by now, you and your suppliers will have decided upon the most suitable welding set, torch or torches and torch head equipment. For small to medium sized tools you will need a steel bench with plenty of leg room, with an 8 to 10 mm thick steel top to withstand all the heating and cooling which would badly distort a thinner topped table. The most important piece of equipment you will ever use will be your adjustable comfortable chair! It is very important to make yourself as comfortable as possible because you are more likely to produce tidy, accurate welds.

Once you have organized your equipment, you need to set it all up and make sure that everything is in the right place and that every connection is tight and leak free; see Fig. 7.4.



Light to medium duty torch with torch head equipment
1 Short back cap including O-ring
2 Torch body
3 Cup gasket
4 Collet 1.6 and 2.4mm
5 Collet body 1.6 and 2.4 mm
6 Extra long nozzle to fit collet body
7 Long nozzle to fit collet body
8 Standard nozzle to fit collet body
9 Gas lens 1.6 and 2.4mm
10 Standard nozzle to fit gas lens
11 Long nozzle to fit gas lens
12 Tungsten 1.6 and 2.4mm, thoriated for steels and copper, zicroniated for aluminum and aluminum alloys

Fig. 7.3



Welding equipment layout

1 Welding set	12 Mains cable to socket
2 Control panel	13 Argon hose to torch
3 Torch power cable	14 Mains socket
4 Torch	15 High pressure argon hose
5 Foot pedal	16 Argon flow metre
6 Foot pedal cable	17 Argon single stage regulator
7 Earth clamp	18 Bottle of argon gas
8 Earth cable	19 Work piece
9 Argon in	20 Argon out
10 Remote/current control socket	21 HF cable
11 Remote/switch socket	22 HF button

Fig. 7.4

Setting up your equipment

Before setting up your equipment make sure that you read and understand the section at the beginning of this chapter 'Safety'.

Although arc welding can be very safe, it has the potential to be very dangerous: it depends upon you. Look after yourself and others around you and take safety seriously.

You will be dealing with electrical equipment which will be supplied by 110V, 240V or 440V, all of which can kill. All mains supply cables should be checked regularly for loose connections and damage. Keep all mains cables out of harm's way, minimizing the chance of accidental damage.

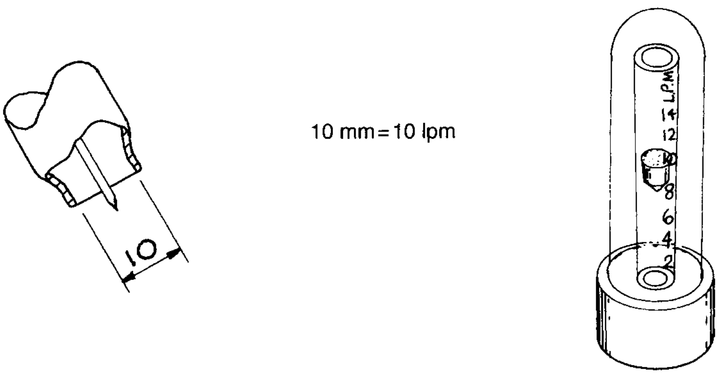
1 If you intend to be moving your set around your shop, have it fitted with an armored mains cable. This will decrease the likelihood of accidental damage especially if you intend to be welding well away from where you are plugged in.
2 Make sure that your argon bottle is tied up securely so it cannot be knocked over.
3 Before connecting the regulator to the argon bottle, release a half second blast of pressure to clean out any dust or foreign objects trapped in the valve neck.
4 Connect the single stage argon regulator to the argon bottle, connect the flow meter to the regulator, connect the high pressure argon hose to the flow meter and connect the high pressure argon hose to the 'argon in' on your weld set. Unfortunately, sometimes these connections are different sizes and sometimes you will find that you are trying to connect male to male and female to female connectors, which is very frustrating. Because of this, you might need some adaptors.
5 Turn on your argon bottle slowly to avoid a sudden burst of pressure and check to see if you have any leaks. If there is a leak, turn off the bottle, disconnect that connection and wind some plumber's tape clockwise up the threads, re-connect the joint and try again.

Hopefully your welding supplier will have set everything up for you to check that everything works. If they have not, and you have a problem, I would suggest that you bring them in because there are so many different types of torches, torch connections, welding sets and set connections that the guide layout given in Fig. 7.4 cannot cover all possibilities.

Setting your gas flow rate

I will assume that you have made all the necessary connections and switched on your equipment. Press the button/switch or foot pedal to start your gas flow; if there is no gas flow, check that everything is turned on, e.g. bottle, regulator (if the regulator has a control knob), flow meter and possibly your torch (because some torches have an economizer control). If you still have no gas flow, see your supplier.

Set your post-flow control to maximum, if you have this control (see Fig. 7.9), measure the orifice of your ceramic (8 mm diameter orifice = 8 litres per minute gas flow, etc.), tap your switch or pedal to initiate your gas flow and set your flow meter as shown in Fig. 7.5. Once you have set your gas flow rate, turn the post-flow control back to a sensible length, e.g. 4–8 seconds.



(a) Nozzle orifice is 10 mm

(b) Use the same number of litres per minute (lpm) as millimeters of orifice diameter

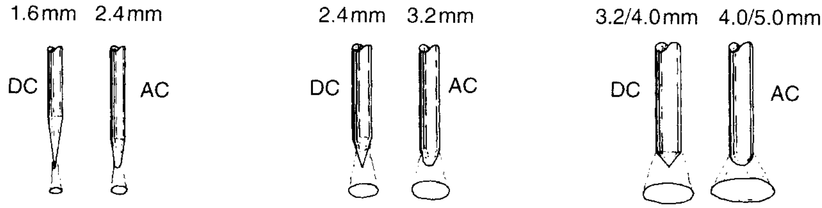
Torch gas flow rate

Fig. 7.5

If you have a big surge of gas when you start your gas flow and you find this a problem, you can move your flow meter from between the regulator and high pressure hose to between your set and the torch cables. Unfortunately this maneuver might also need some adaptor connections.

Sharpening your tungstens

There are many different schools of thought on how to sharpen tungstens – some are shown in Fig. 7.6.



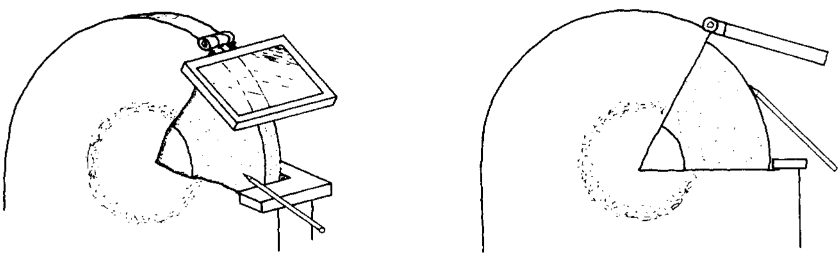
(a) Long fine points for fine welds (low amps). See Table 7.1

(b) Medium points for general welding (medium amps)

(c) Stubby points for heavy duty work (high amps)

Fig. 7.6

I always grind my point on the side of the grind stone and then finish it off on the edge; see Fig. 7.7. Never wear loose fitting clothing when sharpening tungstens and use a pin vice where possible. See your local tool supplier for a pin vice, which is a tool normally used to hold small drills for sharpening. **Always** wear safety eye and face protection when using grinders.



(a) Use side of stone to sharpen tungsten

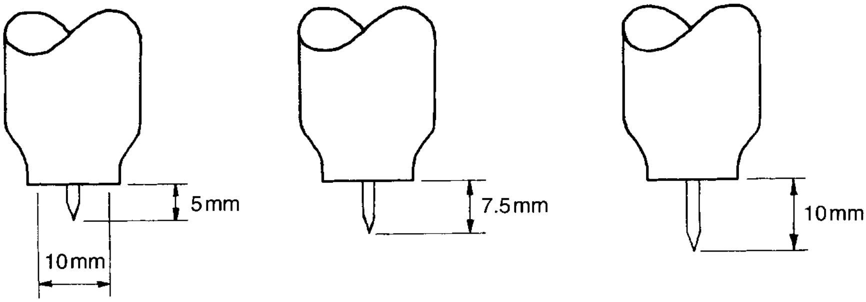
(b) Use front edge of stone to fine finish

Fig. 7.7

Setting your tungsten

As with sharpening, there are many different schools of thought on how far the tungsten should protrude. Figure 7.8 shows how and why I set my tungstens.

The further your tungsten protrudes, the more likely it is that you will get contamination problems. The less your tungsten protrudes,



(a) Minimum protrusion

(b) Standard protrusion

(c) Maximum protrusion (see below)

Fig. 7.8

the more difficult it is to see what you are doing; see Chapter 6, problems 12 and 13 for exceptions to this rule.

Setting your torch head equipment

This is a very common problem for welders and one which, unfortunately, leads to weld contamination. It is very important to check daily that your torch head equipment is always tightened in the correct sequence.

1 Tighten your gas lens/collet body with its heat barriers, first making sure that you are using the right size gas lens/collet body to suit your tungsten. See 'Torch head equipment', page 112.
2 Put on the ceramic/nozzle and tighten.
3 Insert your collet.
4 Screw in the end cap fully and take it back a few turns to allow your tungsten to be inserted.
5 Insert your sharpened tungsten to your required protrusion and tighten the end cap.

You should soon be set up and ready to go. If you are not and you feel that you have a problem, contact your welding supplier and ask them to send a technician. **Do not** attempt any electrical repairs yourself unless you are trained to do so. If you do have problems, it could just be something on your control panel that needs adjusting, so read through the next section first.

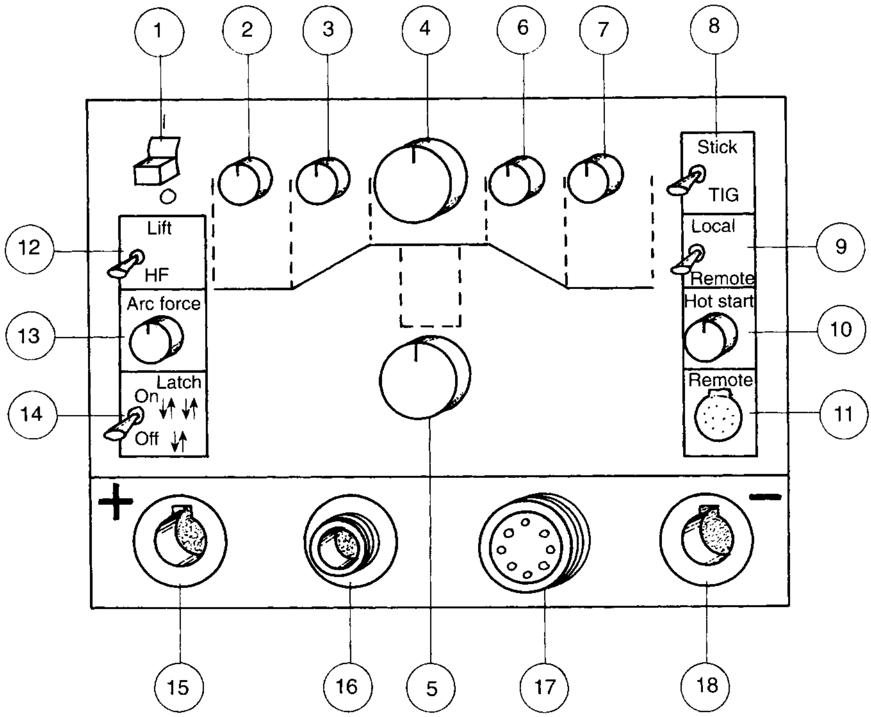
Control panels

Once you are happy with your set up, you will need to understand your control panel, what each knob, button and switch actually controls and which connection will go where and why. Figure 7.9 shows a selection of controls that you will find on most control panels. There are many different makes of welding set, all with different facilities and laid out in a different order, all using an assortment of buttons, knobs, switches and connections. Therefore, all the information now given is a general guide to the control panel on your welding set.

If you are not a welder, or you have little experience of welding, and you are about to strike an arc to try out your control panel, turn to Chapter 8. Chapter 8 will help you with the practical side of welding so you can try out your panel controls.

Control panel breakdown

1 **Mains switch** (DC or AC). This switch is your main on and off switch, and if your set is an AC/DC set this is generally where it is marked. So if you are welding aluminum or an aluminum alloy you would switch to AC and if you want to weld anything else you would switch to DC. Also, if you are welding an alloy that contains small amounts of aluminum, try both, and use the setting that works best. Just to help you remember which one is which, try to imagine AC as 'aluminum current'!
2 **Argon pre-flow**. This control allows you to have a flow of argon before your arc comes on.
3 **Slope in**. This control, allows you to gradually bring in your pre-set amps (slope out, below, allows you to gradually fade them out). This feature can be useful if you do not have a foot pedal.
4 **Main amperage control**. This control pre-sets your main amps.
5 **Trough amperage control**. This control pre-sets your trough amps. Trough amps are a feature which can be accessed by



Control panel

1 Mains switch (DC or AC)	10 Hot start
2 Argon pre-flow	11 On off switch, remote (socket)
3 Slope in	12 Lift or HF start
4 Main amperage control	13 Arc force
5 Trough amperage control	14 Latch or no latch
6 Slope out	15 Positive terminal
7 Argon post-flow	16 Gas out
8 Stick or TIG	17 Amperage and on off, remote
9 Remote or local	18 Negative terminal

Fig. 7.9

tapping your switch during welding to give you a choice of two different amperages, generally one high and one low. This feature can be useful if you do not have a foot pedal.

6 **Slope out**. This control allows you to control how fast or slow you want your amps to fade away.

7 **Argon post-flow**. This control allows you to have a flow of argon after your arc has been extinguished.

8 **Stick or TIG**. This is a two way selector switch giving you the facility of either stick (MMA) welding or TIG welding (argon welding, TAG welding, GTAW, TAW).

9 **Remote or local**. If your switch is in the local position, it will bring into action your HF button or your foot pedal, whichever you have connected. If your switch is in the remote position, your electrode (tungsten or stick rod) will be live at all times. This is only suitable for stick welding.

10 **Hot start**. This control is designed to stop your rod from sticking when you first strike your arc when you are stick welding.

11 **On off switch, remote (socket)**. This socket is where you plug in your HF cable.

12 **Lift or HF start**. This switch gives you the choice of either lift or HF starting. HF starting can cause interference with sensitive electrical equipment, e.g. telephones. Most modern TIG sets have a lift start facility which eliminates this problem. To use HF and lift starting, see Chapter 8, page 133, 'Striking your arc'.

13 **Arc force**. This control is used in conjunction with stick welding, increasing the voltage to give you a more powerful arc without increasing your amps.

14 **Latch or no latch**. The latch facility is for your HF or lift start. With the latch on, you can take your finger off your button during long continuous welds. This means, though, that you have to switch on, then switch off. Latch off means you have to keep your finger on your button during welding.

15 **Positive terminal**. When TIG welding, this is where you will plug in your earth (electrode negative). When general-purpose stick welding this is where you will plug in your stick rod holder (electrode positive).

16 **Gas out**. This is where you connect your argon hose connection from your TIG torch.

17 **Amperage and on off remote**. This socket is for your foot pedal.

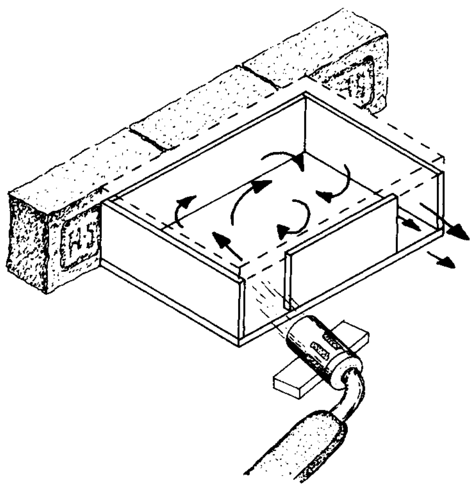
18 **Negative terminal**. When TIG welding, this is where you plug in your torch. When stick welding this is where you plug in your earth.

Other equipment

Other equipment is mainly non-standard, e.g. home made or slightly altered standard equipment, altered because such tools were not available or too expensive ready made.

Hot plate

A hot plate is an essential piece of equipment if you are going to be working on high carbon tools, such as D2 punches and dies, because it is very important to keep these tools above their pre-heat temperature at all times during welding. There will be many ways of making hot plates, gas or electric or you may prefer to buy one ready made. I have always used home made hot plates heated by a hand-held propane torch as shown in Fig. 7.10.



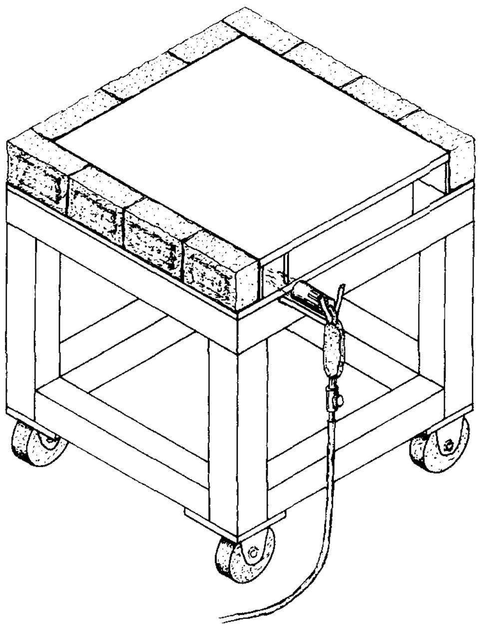
Propane heating torch heats
hot plate and fire bricks
help to shield operator

Home made hot plate

Fig. 7.10

Heavy duty portable hot bench

This piece of equipment was specially made for large television sized tools which are too heavy to move around from bench to bench. A tool can be lifted off a machine straight to the hot bench and easily moved to a welding area, pre-heated, welded, cooled and then moved to the machining area without leaving the bench. The heavy duty hot bench is based on exactly the same principle as the hot plate; see Fig. 7.11.



Heavy duty portable hot bench **Fig. 7.11**

Pre-heating oven

Although there are many different types of ovens available, I tend to use what is familiar: stick rod pre-heating ovens (fitted with a temperature gage). These are available from your local welding supplier.

Pre-heating torches

You will probably need two types of heating torch, large and small, for large and small tools. Fortunately there are some types of propane heating torches with interchangeable nozzles which saves you buying two torches. These should be available from your local supplier.

Vermiculite

Vermiculite is a light, granulated, heat-insulating material used in the building trade, so if you intend to slow cool your tools, get some from your local builders' merchant. Some tools need to be slow cooled; see Chapter 5, Table 5.1, page 50 and 'Cooling' from page 50. To slow cool your tools, you need a box, preferably made of wood, and filled with vermiculite so you can dig a hole and bury your tools after welding.

Power tools

When preparing tools for welding, you may need to use power tools such as grinders. For removing large amounts of material I would use a 7″ (180 mm) grinder (this is the diameter of the grinding disc used). For medium work, a 4″ (100 mm) grinder would be suitable and for fine work try a 58,000 rpm pneumatic die grinder with 3 mm rotary burrs or an electric die grinder. If you intend to buy a pneumatic grinder, you must buy a filter lubricator at the same time and fit it in line as close to the grinder as possible. It is recommended that a filter lubricator should be fitted in line and about a meter away from the grinder, but I find this a little bit of a restriction so mine is about 4 meters away.

Crack detection equipment

When dealing with high carbon tools such as D2, A2 and O1, where cracks could become a problem, crack detection equipment is essential. There are two types of crack detection equipment:

1 **Iron/steel filings**. These can be sprinkled onto a damaged area and the excess gently blown away to reveal any cracks.
2 **Dye penetrant examination kit**. This consists of three aerosol cans. You will also need some absorbent rags or paper roll; see Chapter 6, 'Excavating cracked material', page 66, for more information.

Wire cutters

Out of all of my hand tools, my spring loaded MIG welder wire cutters are the most used. Every time the end of my filler rod end becomes slightly oxidized, it can be snipped off, making sure that the rod end is always clean before welding again; see Chapter 6, 'Oxidization', page 74.

Wire brushes

When welding smaller tools, oxidization is a big problem, and wire brushing your tool at every interval could mean the difference between a successful weld or a contaminated weld. There are three types of wire brush in common use:

1 A standard three row soft stainless steel wire brush for general use.
2 A much smaller very soft brass wire brush, the type that would be used to brush suede shoes. This brush is very useful to clean welds in sensitive areas, e.g. on or close to a polished face on a injection mold tool.
3 A shop-made single tuft wire brush. This wire brush looks like a wire artist's paint-brush because it is a tuft of wires taken out of a stiff stainless steel wire brush, crimped in the end of a 150 mm length of 10 or 8 mm diameter tube. This wire brush is ideal for getting into little corners where your bigger wire brush will not reach.

Sash brush

This is just a 10–15 mm diameter soft brush, to help keep your tool free from dust and oxidized particles that generally build up as you weld and wire brush.

Copper tipped mole grips

These can be very helpful in holding and earthing very small tools that are susceptible to damage from bad earthing arc marks. Mole grips are also very useful just as an extra pair of hands. The copper-tipped jaws are there as a cushion to stop the mole grips from marking the tool and to provide a better earth connection.

Auxiliary earth

This is basically two large crocodile clips held together by a length of stiff copper cable. The crocodile clip jaws are also tipped with copper to help minimize earthing arc marks. This earth is specially for small tools as shown in Chapter 6, Fig. 6.35, page 83.

Podger

A podger is an earthing wedge which helps you to earth large tools that cannot fit on your bench and cannot be gripped by your earth clamp; see Chapter 6, Fig. 6.37, page 85.

Aluminum plates

Aluminum itself is a very useful aid because it is an excellent conductor and it is very soft, which makes it easier to earth to, minimizing earthing arc marks; see Chapter 5, Fig. 5.2, page 54.

Aluminum 'V' blocks

Obviously 'V' blocks are designed to support cylindrical tools like shafts and some cores and inserts. These 'V' blocks can be machined out of a solid block or fabricated out of pieces of machined plate.

Rotary discs

These are basically round pieces of aluminum or steel plate with a spot weld in the center. These discs are used for tools that need to be rotated several times during welding to help minimize earthing arc marks to the base; see Chapter 6, Fig. 6.36, page 84.

Restraints

Restraints are pieces of bar used to minimize distortion when welding tools. Restraints can be used to hold together pieces of broken tools or to keep tools straight during welding; see Chapter 6, page 94, 'Using restraints'.

Bent tungstens

There will be many occasions when access to your repair is very difficult, and bending the tungsten is one way to solve this; see Chapter 6, 'Bending tungsten', page 92, and Fig. 6.44.

Scrap

Having to hand an assortment of scrap aluminum, copper and steel blocks, pieces of bar and plate makes all the difference when you need packing pieces, heat soaks, flood supports, etc.; see Chapter 6, 'Using heat soaks and flood supports', page 86.

8

Basic TIG welding for beginners

Although you can weld tools with the MIG and MMA (stick) welding processes, TIG welding seems to be the most complicated and difficult to master. This chapter introduces you to TIG welding so you can go on to understand the welding techniques in Chapter 6. This chapter also sets you tasks to help you to develop your hand skills.

TIG welding on fine tools needs a high degree of skill, and skillful practices take time to develop. The most important part of learning a new skill is to respect that skill and to take it one step at a time.

Before you go any further in this chapter, you must read through Chapter 7.

1 Understanding and implementing safe working practices.
2 Having the appropriate equipment, correctly set up and safely laid out.
3 Make yourself **comfortable**.

I have read many training manuals on welding and I find that most books overlook the skillful and practical side of welding, and concentrate on technical facts which makes them a little unfriendly to read. So with this in mind, I will try not to fall into the same trap.

I have found that there is only one rule in the practical side of welding, and that is that there are no rules! If something works for you, it works, and if it doesn't, it doesn't. All the welders that I have ever met have their own styles and techniques and they very rarely resemble anything described in a book. Obviously, technical instruction books have to be technically accurate, giving the student technically accurate information assuming ideal conditions. Your conditions may not be ideal, and my book takes account of that.

I will assume that you have read through Chapter 7 and that your welding set is in the DC position (if you have a choice), switched on and working. I will also assume that your bench is earthed and you have a piece of clean scrap steel and a length of filler wire standing by. For the moment we will ignore the filler wire and concentrate on the torch:

1 Students using a foot pedal, follow **FP** where indicated.
2 Students not using a foot pedal follow **HF** where indicated.
3 All students follow **Either**.

Note: **FP** If you have two controls on your foot pedal, one will probably control how low your amperage can go and the other will control how high your amperage can go. Set your low control to its lowest setting and set your high control to half way. If you have more than two controls, these will probably be slope in and slope out controls. If you have any problems with your controls, call in your supplier to explain what each control is for, and compare that with Fig. 7.9 on page 121.

Many foot pedals have no controls, which is simpler, but their amperage output may be governed by the controls on the main set, so 'experiment'. Your foot pedal acts in the same way as an accelerator pedal on a car – as you depress your pedal, your torch will switch on, then as you depress the pedal further, your amps will increase.

Note: **HF** Set your main amperage to 70–100 amps making sure that you are using a 1.6 mm or 2.4 mm, thoriated or ciriated tungsten, see Chapter 7, 'Torch head equipment', page 112. If you have slope in/slope out controls (see Fig. 7.9, page 121), set your slope in to 1–2 seconds and set your slope out to 2–4 seconds. If you do not have a slope out control and you have to extinguish your arc by pulling your torch away from the weld pool, then your equipment will probably not be suitable for molds or fine tools.

Either: Set your argon post-flow to 4–8 seconds and your pre-flow to 1 second. If you do not have these facilities on your welding set, it will be more difficult to weld fine tools to a high standard but it will not stop you learning to weld. Do not worry too much about these controls if you do not understand them, only time and frequent use will make you familiar with new equipment.

By now you are comfortable and ready to weld; if you are having problems consult your local welding supplier.

Holding your torch

Generally welders will hold their TIG torch like a pen or like a hammer as shown below in Fig. 8.1 and 8.2, but as with golf clubs, whichever style suits you is the right one.

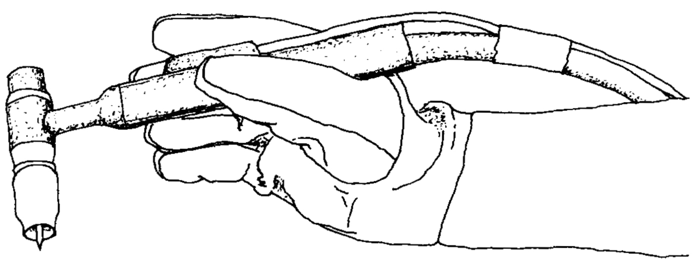


Fig. 8.1

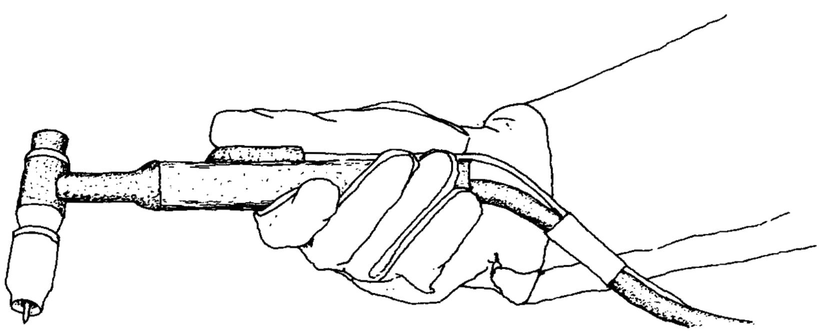


Fig. 8.2

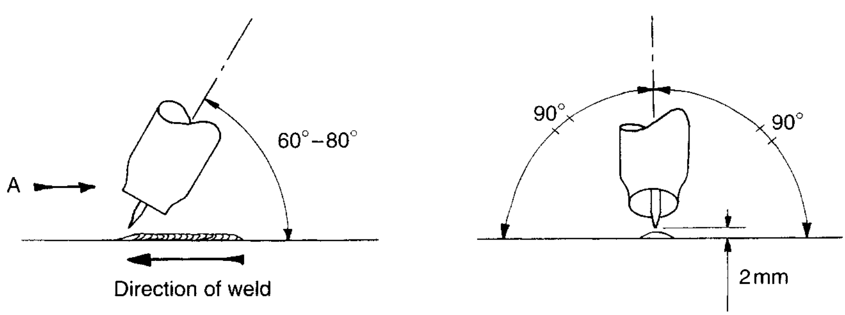
Figure 8.1 shows the torch held like a pen. This gives fine control of the torch head but restricted hand movement because your hand will always be rested. This style is better suited to bench work, especially on fine tools where close control is essential.

Figure 8.2 shows the torch held like a hammer. This is the type of hold for more general use because it gives free hand movement, although you will probably still rest your hand wherever possible.

HF: In Fig. 8.1, I would press my start button with my index finger and in Fig. 8.2, I would press my start button with my thumb.

Torch angles

Either: When you are welding, torch angle and the distance between your tungsten and the surface of your weld pool are very important to help you to maintain an even and clean gas coverage. I will assume that you have read 'Setting up your equipment' in Chapter 7 and that the piece of scrap steel in front of you is free from contamination, e.g. rust, oil, paint. Look at the ideal torch angles in Fig. 8.3 and practice holding them. Relax and ensure you are comfortable before you start welding.



(a) Ideal torch angle (b) View from A

Torch angles

Fig. 8.3

Striking your arc

I will assume that you have read through 'Safety' in Chapter 7 and that you are fully protected against the dangers of arc welding. Safety must be taken seriously. Rest your ceramic on your piece of scrap steel and, ignoring torch angles for a moment, lean your torch back so your tungsten is about 1 mm or 2 mm off your plate and gently strike your arc; see Fig. 8.4. Students using 'lift arc' should touch their tungsten onto the piece of scrap, press their button or foot pedal and then lift the point of the tungsten up 2 or 3 mm to start the arc.

(a) Rest ceramic on plate to assist arc strike

(b) Raise torch angle after arc is struck

Fig. 8.4

FP: Gently press your foot pedal down until your arc comes on. If you have set an argon pre-flow time it will be delayed by the seconds that you have set. Then lift your ceramic off the scrap steel and adjust the angle of your torch without breaking the arc until your torch is at a similar angle to that shown in Fig. 8.3. Once you have your arc established you should be able to increase your amperage by pressing your pedal further down and decreasing and stopping it by lifting it back up.

HF: Press the button on your torch and your arc should come on. If you have set a slope in, your arc should slope in over the duration that you have set. If you have set an argon pre-flow time, it will be delayed by the seconds that you have set. Then lift your ceramic off the scrap steel and adjust the angle of your torch without breaking the arc until your arc is at a similar angle to that shown in Fig. 8.3. If you have slope in and slope out controls on your welding set, you will be able to play about with these settings to help give you a more even control over your amperage. For example, if you set your slope in and slope out to 2 or 3 seconds you will be able to press your button on and off during welding.

Either: If you are having problems, go back over what we have discussed in this chapter and Chapter 7 because there are many things that can go wrong. If you have problems that you cannot solve, contact your local welding supplier for advice. Do not attempt any electrical repairs unless you are trained to do so.

Now it is time to experiment! Do not progress on to 'Using your filler wire' unless you feel confident to do so. Just try out what you have learned so far, practice using both the 'pen' and 'hammer' type grip on your torch. Why not play about with some of the settings on your welding set? This is a good time to find out what all those intimidating buttons, knobs and switches actually do; turn to page 121, Fig. 7.9, 'Control panels' and 'Control panel breakdown' and experiment. I would suggest that you make a note of all the settings that you have now so you can always get back to basics if you get out of your depth. Try to keep notes on the other settings you find in case you want to go back to them. This will help you to understand and to become familiar with your equipment. Also try writing your name on your piece of scrap steel with your molten pool as you are welding. Switch on and off for each letter and keep your torch in line with your direction of travel. This will help you get the feel of your torch especially if your parents have named you after every member of your local football team!

Using your filler wire

Filler wire in welding is added to your molten pool to create a build-up of metal. This is to replace metal that has been lost, e.g. to refurbish or rebuild a worn component, to add metal as an addition such as alterations and, bimetal cladding, or to join or reinforce a joint between two or more pieces of metal.

Holding your filler wire

You can hold your filler wire however you want, but there are techniques that are very useful; see Chapter 6, 'Hand feed technique', page 102, for my preferred technique.

Feeding in your filler wire

It is very important to feed your filler wire into the molten pool correctly; see Chapter 6, 'Oxidization' and 'Building pads of weld', page 74. The amount of filler wire you should feed into the molten pool depends upon how you want the finished weld to look; see Fig. 8.5.

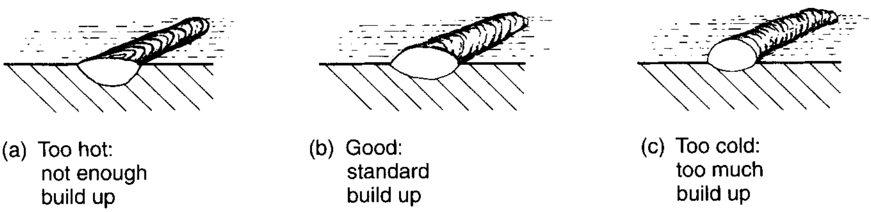


Fig. 8.5

Weld (a) is too hot, and generally not suitable for work on tool steels. This weld shape is the result of too high an amperage or not enough filler wire.

Weld (b) is the ideal weld shape.

Weld (c) is too cold for standard welding and is generally considered not suitable. This weld shape is the result of amperage too low or too much filler wire. Although this weld shape is generally not suitable, it is ideal for fine welding in delicate areas, e.g. shut off edges on mold tools, cutting edges on punches, dies, blades and knives.

So now it is time to experiment again: use what you have learned so far to re-create weld (b). Try to keep your welds even, tidy and straight. Also it is very important to make your weld width no wider than three times your filler wire diameter, e.g. 1.6 mm filler wire = 4.8 mm maximum weld width, etc.

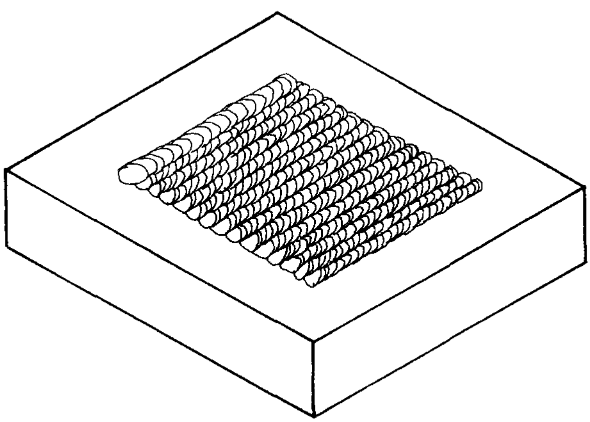
By now you should understand how to get a build-up of weld metal on your piece of scrap steel regardless of what it looks like! My first welds were looked upon as 'encouraging' by my unbearably optimistic welding instructor even though they looked a little like pigeon droppings, so do not be disheartened if you feel that you are getting nowhere. Welding for the first time is very similar to learning to drive because you have to perform several different skillful acts all at the same time. Any able-handed person can learn to weld if they have enough patience and persistence, so relax and find your own natural hand skill learning pace.

Welding exercises

Next in this chapter, I have laid out a series of exercises that will gradually challenge your new-found skills. As you try each exercise, you may encounter welding problems such as dirty welds (oxidization) or bubbles in your weld (porosity). These are common problems and are discussed in Chapter 6, to which I will refer you at appropriate times.

Exercise 1: A single level pad

This exercise is designed to help you practice laying one weld against another (overlaying) which is the first step in pad building; see Fig. 8.6.

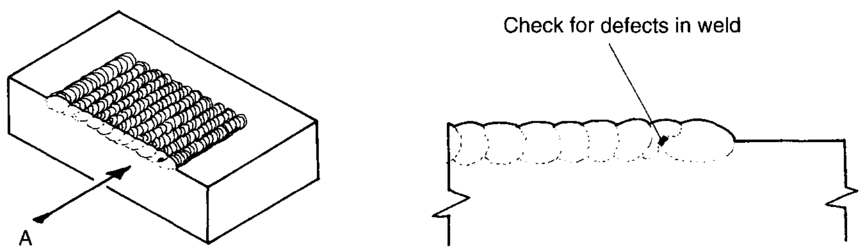


A single level pad **Fig. 8.6**

Use any size of weld you wish, taking into consideration the diameter of your tungsten, e.g. do not use too high an amperage for the diameter of your tungsten because it could melt; see Chapter 7,

Table 7.1, page 112. This table will give you a safe welding amperage for the diameter of tungsten you intend to use. Also, use whatever filler wire diameter you feel is right, e.g. 1 mm, 1.6 mm, 2.4 mm. I tend to use only 1.6 mm or 2.4 mm diameter filler wires on steels; see also Chapter 6, 'Welding fine details', page 101. Then weld a single level pad as shown in Fig. 8.6, using your wire brush to clean after each weld.

To check if your pad is all good metal (no contamination or weld defects) cut your pad in half as shown in Fig. 8.7, and clean up or polish the sectioned face. This type of inspection technique is called a macro inspection, and will show you if you are overlapping your welds properly.



(a) Sectioned pad, showing macro face (b) View from A

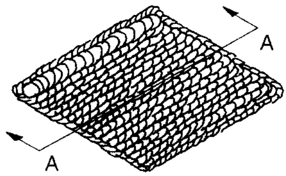
Fig. 8.7

Exercise 2: a standard pad

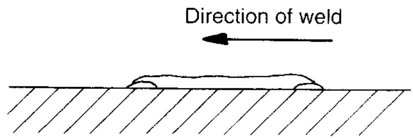
This exercise is basically the same as exercise 1 only using more than one layer. There is no one way to build a pad because everybody finds his or her own style and technique. The only important thing is to build a multi-layered pad of weld metal which, after machining, reveals a solid pad of metal that is free from defects and the right size. Figure 8.8 shows how you could build a pad.

(a) Mark off size of pad (b) Weld around edge of marking off

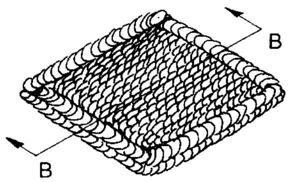
Fig. 8.8



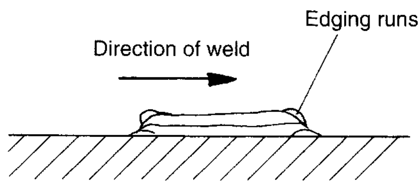
(c) Fill in pad area with overlapping runs to create single level pad



(d) Section through A–A weld from right to left



(e) Weld second layer of weld and edge with weld to keep shape

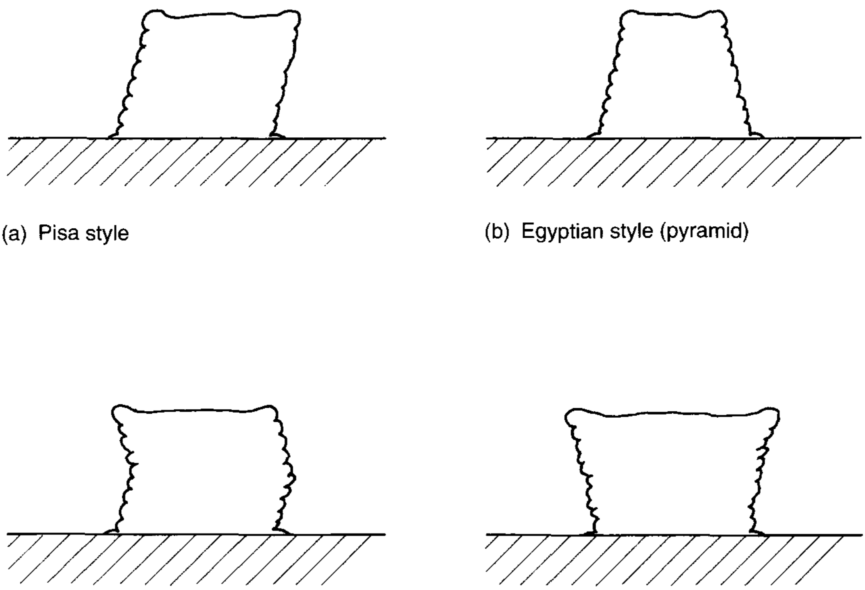


(f) Section through B–B weld in opposite direction to first layer

A standard pad

Fig. 8.8 cont'd

Once you have two layers of weld, all you need to do is repeat the same sequence over and over again until you reach your desired height. As you are building your pad, keep an eye on your pad shape because pads tend to have a life of their own and you need to keep them under control! See Fig. 8.9. Try to keep the sides of your pad as straight as possible because it is very difficult to touch them up after you have finished; see Chapter 6, Fig. 6.26, page 75, 'Bad weld



(a) Pisa style

(b) Egyptian style (pyramid)

(c) Wibbly wobbly

(d) Tornado style

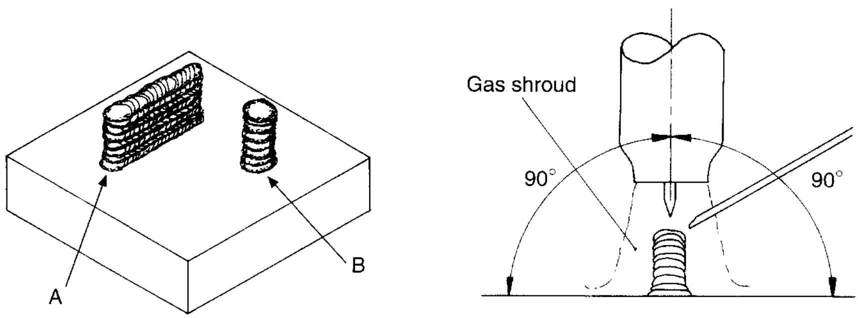
Wayward pads

Fig. 8.9

sequence planning'. As before in exercise 1, 'macro' your finished pad and check for weld defects.

Exercise 3: Stack pads

This exercise is designed to challenge your hand skills and amperage control. A stack pad is a single run pad generally used to repair fine features on mold tools; see Chapter 6, Fig. 6.41, page 89. Foot switches will perform better here than finger switches because of the greater amperage control. Use 1.6 mm filler wire and whatever amperage you think suitable. Turn your argon delay to 8–10 seconds, put your first run or spot on to your plate, extinguish your arc but do not move your torch away. Allow the argon gas from your torch to envelop your stack to minimize oxidization until your argon cuts off automatically, then keep on repeating this until you have a 10 mm high stack. Keep checking the shape of your stack as you progress to avoid straying off line. Avoid over-heating your stack, so stop and start wherever you think suitable and keep your torch directly over the stack at all times and for as long as possible after extinguishing your arc to avoid unnecessary oxidization. Do not worry if your stack collapses or becomes filled with air bubbles (porosity): this is not an easy exercise so do not expect to get it right first time. See Fig. 8.10.



(a) A is a rib stack, B is a pin stack

(b) Torch to be held at right angles to stack. Keep filler wire clean at all times. See Fig. 6.25

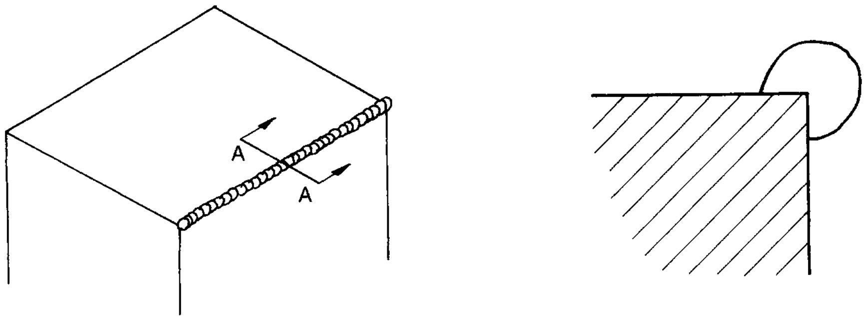
Stack pads

Fig. 8.10

A and B are both welded the same way, one single spot or one single run on top of another (with great patience).

Exercise 4: Edging welds

Edging welds are the most difficult and probably the most common especially on mold tool repairs. The mark of a good mold, tool and die repair welder is the quality of their finishing. Performing an edge weld is difficult, finishing an edge weld is very difficult even for an experienced welder; see Chapter 6, 'Under cut (notches)', page 73. Going back to Fig. 8.5, weld (c) is the type of weld required for an edge weld; see Fig. 8.11.



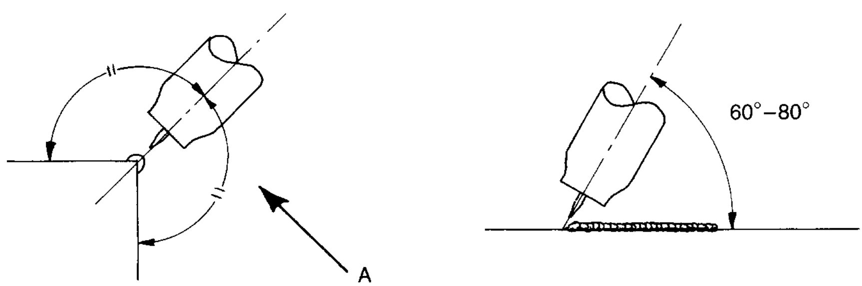
(a) Edging weld

(b) Section through A–A

Edging welds

Fig. 8.11

As before, keep your torch angle to about 60°–80° from the flat and evenly in line with travel for maximum gas coverage where possible; see Fig. 8.12.



(a) Torch angle evenly in line with weld for maximum gas coverage

(b) View from A

Edging weld torch angles

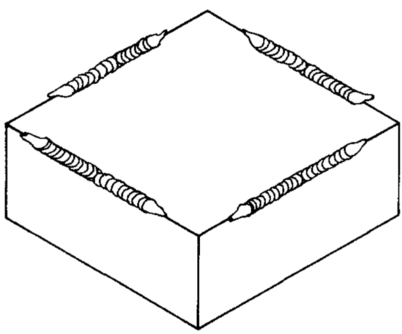
Fig. 8.12

To produce a good edge weld, it is important to concentrate on your gas coverage to keep your weld as clean and as free from oxides as possible. So relax in your chair and try to rest your hands on blocks of wood or bricks when you are welding to help give you good stability. Try to get into a rhythm of dipping or pushing your filler wire into your molten pool to help you produce tidy consistent welds.

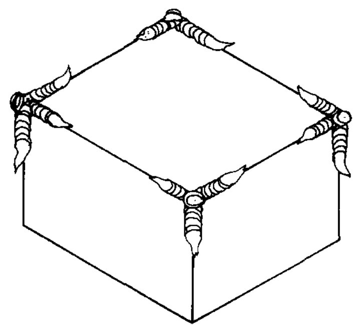
Exercise 5: Tug offs

A tug off is a technique that I have developed to minimize under cut (notches) at either side of an edge weld; see Chapter 6, 'Under cut' (notches), page 73.

Most of the repairs on molds, tools and dies tend to incorporate at least one edge, if not more. Any repair is only as good as its worst part, and that part is generally where the weld finishes onto an edge, so tug offs are very important. Use the techniques discussed in Chapter 6, page 74, Fig. 6.24, to practice your tug offs and edge welds.



(a) Edge welds with tug offs



(b) Corner welds with tug offs

Tug offs

Fig. 8.13

Perform the corner welds in exactly the same way as the edge welds. Start from the corner and work out over, do not weld down over! Always turn the block to make each weld as easy and comfortable as possible.

To inspect the quality of your tug offs, you will have to skim all surfaces with a surface grinder unless you feel confident enough to use a milling tool. If you do not have access to a milling machine or surface grinder, you will have to hand grind with a 4.5″ or 5″ (115 or 125 mm) angle grinder (grinderette) with the flat face of the disc.

Although exercise 5 is the last exercise in this book, I would suggest that if you have any practical difficulties with your welding skills, find out where your weakness lies and design an exercise to combat that short-fall.

Once you feel happy enough with your hand skills and you intend to attempt a tool repair, **Go to** Chapter 1 because you will need to decide pre-heats, cooling, types of filler wire, etc.

Appendix I
Other steels and tool steels

Other steels and tool steels, national and international, old and new with comparable AISI or Werkstoff numbers or a close matching chemical composition

Other tool steels		Comparison
0.9% carbon, 0.8% chromium		W5
0.9% carbon chrome		W5
09B		O1
1% carbon		W1
10% cobalt		T6
100 CD 6		1.2067
100 Cr 6		1.2067
100 MnCrW 4		1.2510
100 V 1		1.2833
1005	(SAE)	0.06C, 0.3Mn
1006	(SAE)	0.08C, 0.3Mn
1008	(SAE)	0.1C, 0.35Mn
100C6		1.2067
1010	(SAE)	0.1C, 0.45Mn
1011	(SAE)	0.1C, 0.75Mn
1012	(SAE)	0.12C, 0.45Mn
1013	(SAE)	0.13C, 0.65Mn
1015	(SAE)	0.15C, 0.45Mn
1016	(SAE)	0.15C, 0.75Mn
1017	(SAE)	0.17C, 0.45Mn
1018	(SAE)	0.17C, 0.75Mn
1019	(SAE)	0.17C, 0.85Mn
102 Cr 6 KU		1.2067

Other tool steels		Comparison
102 V 2 KU		1.2833
1020	(SAE)	0.2C, 0.45Mn
1021	(SAE)	0.2C, 0.75Mn
1022	(SAE)	0.2C, 0.85Mn
1023	(SAE)	0.2C, 0.45Mn
1024	(SAE)	0.22C, 1.5Mn
1025	(SAE)	0.25C, 0.45Mn
1026	(SAE)	0.25C, 0.75Mn
1027	(SAE)	0.26C, 1.35Mn
1029	(SAE)	0.28C, 0.75Mn
1030	(SAE)	0.31C, 0.75Mn
1035	(SAE)	0.35C, 0.75Mn
1036	(SAE)	0.34C, 1.35Mn
1037	(SAE)	0.35C, 0.85Mn
1038	(SAE)	0.38C, 0.75Mn
1039	(SAE)	0.4C, 0.85Mn
1040	(SAE)	0.4C, 0.75Mn
1041	(SAE)	0.4C, 1.5Mn
1042	(SAE)	0.43C, 0.75Mn
1043	(SAE)	0.43C, 0.85Mn
10-4-3-10		1.3207
1044	(SAE)	0.46C, 0.45Mn
1045	(SAE)	0.46C, 0.75Mn
1046	(SAE)	0.46C, 0.85Mn
1047	(SAE)	0.47C, 1.5Mn
1048	(SAE)	0.48C, 1.25Mn
1049	(SAE)	0.49C, 0.75Mn
105 C 6		1.2067
105 MV 01		1.2833
105 WC 13		1.2419
105 WCr 5		1.2419
105 WCr 6		1.2419
1050	(SAE)	0.51C, 0.75Mn
1051	(SAE)	0.5C, 1Mn
1052	(SAE)	0.51C, 1.3Mn
1053	(SAE)	0.51C, 0.85Mn
1055	(SAE)	0.55C, 0.75Mn
1060	(SAE)	0.6C, 0.75Mn
1061	(SAE)	0.6C, 0.9Mn
1064	(SAE)	0.65C, 0.65Mn
1065	(SAE)	0.65C, 0.75Mn
1066	(SAE)	0.65C, 0.1Mn
1069	(SAE)	0.7C, 0.55Mn
107 CrV 3 KU		1.2210

(Continued)

Other tool steels		Comparison
107 WCr 5 KU		1.2419
1070	(SAE)	0.7C, 0.75Mn
1072	(SAE)	0.7C, 1.15Mn
1074	(SAE)	0.75C, 0.65Mn
1075	(SAE)	0.75C, 0.55Mn
1078	(SAE)	0.78C, 0.45Mn
1080	(SAE)	0.81C, 0.75Mn
1084	(SAE)	0.86C, 0.75Mn
1085	(SAE)	0.86C, 0.85Mn
1086	(SAE)	0.86C, 0.4Mn
1090	(SAE)	0.91C, 0.75Mn
1095	(SAE)	0.96C, 0.4Mn
115 CrV 3		1.2210
12 Ch 13		1.4006
12 S		H21
120 C 2		1.2002
12-1-5-5		1.3202
12M		1.2C, 12Mn
1330 ~H	(SAE)	0.3C, 1.75Mn
1335 ~H	(SAE)	0.35C, 1.75Mn
1340 ~H	(SAE)	0.4C, 1.75Mn
1345 ~H	(SAE)	0.45C, 1.75Mn
14 Ch 17 N 2		1.4057
14% tungsten		0.65C, 4Cr, 14W, 0.5V
14/4/4		1.25C, 4Cr, 14W, 4V
145 Cr 6		1.2063
14HD		H24
1-5-1		A2
1513	(SAE)	0.13C, 1.25Mn
1518	(SAE)	0.18C, 1.25Mn
1522	(SAE)	0.21C, 1.25Mn
1524	(SAE)	0.22C, 1.5Mn
1525	(SAE)	0.26C, 0.95Mn
1525	(W. Nr)	1.1525
1526	(SAE)	0.25C, 1.25Mn
1527	(SAE)	0.25C, 1.35Mn
1536	(SAE)	0.33C, 1.35Mn
1541	(SAE)	0.4C, 1.5Mn
1545	(W. Nr)	1.1545
1547	(SAE)	0.47C, 1.5Mn
1548	(SAE)	0.48C, 1.25Mn
1551	(SAE)	0.5C, 1Mn
1552	(SAE)	0.51C, 1.35Mn
1561	(SAE)	0.6C, 0.9Mn

Other tool steels		Comparison
1566	(SAE)	0.65C, 1Mn
1572	(SAE)	0.7C, 1.15Mn
1625	(W. Nr)	1.1625
1645	(W. Nr)	1.1645
1663	(W. Nr)	1.1663
1673	(W. Nr)	1.1673
1730	(W. Nr)	1.1730
1740	(W. Nr)	1.1740
1750	(W. Nr)	1.1750
18 HD		H26
18% tungsten		T1
18-0-1		1.3355
18-0-2-10		1.3265
18-1-1-5		1.3255
1820	(W. Nr)	1.1820
1830	(W. Nr)	1.1830
1880	(SS)	1.1545
19F		O6
1C25		0.25C, 0.6Mn
1C35		0.35C, 0.65Mn
1C45		0.45C, 0.65Mn
1C55		0.55C, 0.75Mn
1C60		0.60C, 0.75Mn
1P		0.43C, 1Si, 1.4Cr
1U		1.9C, 12.5Cr, 0.75Mo, 0.25V
2P		S1
2% tungsten		S1
20 Ch 13		1.4021
20 Ch 17 N 2		1.4057
20 plus		P20
2002	(W. Nr)	1.2002
2008	(W. Nr)	1.2008
2057	(W. Nr)	1.2057
2067	(W. Nr)	1.2067
2080	(W. Nr)	1.2080
2082	(W. Nr)	1.2082
2083	(W. Nr)	1.2083
20S		H10
21 MnCr 5		1.2162
2-10-1-8		1.3247
2127	(W. Nr)	1.2127
2140		1.2510
2162	(W. Nr)	1.2162
22% tungsten		0.8C, 4.2Cr, 22W, 1.3V

(Continued)

Other tool steels		Comparison
2210	(W. Nr)	1.2210
2234	(SS)	1.2330
2241	(W. Nr)	1.2241
2242	(SS)	1.2344
2244	(SS)	1.2332
2260	(SS)	1.2363
227		H21
2302	(SS)	1.4006
2303	(SS)	1.4021
2303	(W. Nr)	1.2303
2304	(SS)	1.4028
2310	(SS)	1.2601
2311	(W. Nr)	1.2311
2312	(SIS)	1.2436
2312	(W. Nr)	1.2312
2316	(W. Nr)	1.2316
2321	(SS)	1.4057
2330	(W. Nr)	1.2330
2332	(W. Nr)	1.2332
2341	(W. Nr)	1.2341
2343	(W. Nr)	1.2343
2344	(W. Nr)	1.2344
2361	(W. Nr)	1.2361
2361	(W. Nr)	1.2361
2363	(W. Nr)	1.2363
2365	(W. Nr)	1.2365
2367	(W. Nr)	1.2367
2378	(W. Nr)	1.2378
2379	(W. Nr)	1.2379
23S		D3
2419	(W. Nr)	1.2419
2436	(W. Nr)	1.2436
2442	(W. Nr)	1.2442
24S		0.24C, 2.5Ni, 3Cr, 8.5W
2510	(W. Nr)	1.2510
2515	(W. Nr)	1.2515
2542	(W. Nr)	1.2542
2547	(W. Nr)	1.2547
2550	(W. Nr)	1.2550
2562	(W. Nr)	1.2562
2567	(W. Nr)	1.2567
2581	(W. Nr)	1.2581
25S		0.27C, 4.25Ni, 1.5Cr, 6.75W
2601	(W. Nr)	1.2601

Other tool steels		Comparison
2606	(W. Nr)	1.2606
2631	(W. Nr)	1.2631
2663	(W. Nr)	1.2663
2678	(W. Nr)	1.2678
2710	(SS)	1.2542
2711	(W. Nr)	1.2711
2713	(W. Nr)	1.2713
2714	(W. Nr)	1.2714
2718	(W. Nr)	1.2718
2721	(W. Nr)	1.2721
2722	(SS)	1.3343
2723	(SS)	1.3243
2735	(W. Nr)	1.2735
2744	(W. Nr)	1.2744
2762	(W. Nr)	1.2762
2764	(W. Nr)	1.2764
2766	(W. Nr)	1.2766
2767	(W. Nr)	1.2767
2770	(W. Nr)	1.2770
2782	(SS)	1.3348
2787	(W. Nr)	1.2787
2826	(W. Nr)	1.2826
2833	(W. Nr)	1.2833
2842	(W. Nr)	1.2842
2885	(W. Nr)	1.2885
28Mn6		0.28C, 1.5Mn
2-9-2		1.3348
2-9-2-8		1.3249
293		H21
2C25		0.25C, 0.6Mn
2C35		0.35C, 0.65Mn
2C45		0.45C, 0.65Mn
2C55		0.55C, 0.75Mn
2C60		0.60C, 0.75Mn
30 Ch 13		1.4028
30 CrMoV 12 27 KU		1.2365
30 CrMoV 12		1.2365
30CrNiMo8		0.30C, 2Cr, 0.4Mo, 2Ni
32 DCV 28		1.2365
32 NCD 16		1.2766
3202	(W. Nr)	1.3202
3207	(W. Nr)	1.3207
3243	(W. Nr)	1.3243
3246	(W. Nr)	1.3246

(Continued)

Other tool steels		Comparison
3247	(W. Nr)	1.3247
3249	(W. Nr)	1.3249
3255	(W. Nr)	1.3255
3265	(W. Nr)	1.3265
32B		A2
32CrMo12		0.32C, 3Cr, 0.4Mo, 0.3Ni
32S		A2
3342	(W. Nr)	1.3342
3346	(W. Nr)	1.3346
3348	(W. Nr)	1.3348
3355	(W. Nr)	1.3355
34 CD 4		1.2330
34Cr4		0.34C, 0.75Mn, 1Cr
34CrMo4		0.34C, 0.65Mn, 1Cr, 0.25Mo
34NiCrMo16		0.34C, 1.8Cr, 0.35Mo, 4Ni
35 B		A6
35 CrMo 4		1.2330
35 HM		1.2330
3505	(W. Nr)	1.3505
351		0.52C, 0.7Si, 1.1Cr, 1.9W, 0.3V
3551	(W. Nr)	1.3551
3554LW	(W. Nr)	1.3554LW
35CrNiMo6		0.35C, 0.65Mn, 1.5Cr, 0.25Mo, 1.5Ni
37Cr4		0.37C, 0.75Mn, 1Cr
38Cr2		0.38C, 0.65Mn, 0.5Cr
38Cr4		0.38C, 0.75Mn, 1Cr
39NiCrMo3		0.39C, 0.65Mn, 0.75Cr, 0.25Mo, 0.85Ni
3C25		0.25C, 0.6Mn
3C35		0.35C, 0.65Mn
3C45		0.45C, 0.65Mn
3C55		0.55C, 0.75Mn
3C60		0.60C, 0.75Mn
3Ch2W8F		1.2581
3Ch3M3F		1.2365
40 CDM 8		1.2311
40 CDM 8+S		1.2312
40 Ch 13		1.4034
40 CrMnMo 7		1.2311
40 CrMnMoS 8 6		1.2312
40 CrMo 4		1.2332
4005	(W. Nr)	1.4005
4006	(W. Nr)	1.4006
4012	(SAE)	0.11C, 0.85Mn, 0.2Mo
4014LW	(W. Nr)	1.4014LW

Other tool steels		Comparison
4021	(W. Nr)	1.4021
4023	(SAE)	0.22C, 0.8Mn, 0.25Mo
4024	(SAE)	0.22C, 0.8Mn, 0.25Mo
4027 ~H	(SAE)	0.27C, 0.8Mn, 0.25Mo
4028 ~H	(SAE)	0.27C, 0.8Mn, 0.25Mo
4028	(W. Nr)	1.4028
4032 ~H	(SAE)	0.32C, 0.8Mn, 0.25Mo
4034	(W. Nr)	1.4034
4037 ~H	(SAE)	0.37C, 0.8Mn, 0.25Mo
4042 ~H	(SAE)	0.42C, 0.8Mn, 0.25Mo
4047 ~H	(SAE)	0.47C, 0.8Mn, 0.25Mo
4057	(W. Nr)	1.4057
40Ch13		1.2083
40NiCrMo2		0.4C, 0.85Mn, 0.5Cr, 0.25Mo, 0.55Ni
40NiCrMo3		0.4C, 0.75Mn, 0.75Cr, 0.25Mo, 0.85Ni
410S21		1.4006
410S22		1.4006
4110	(W. Nr)	1.4110
4112	(W. Nr)	1.4112
4118 ~H	(SAE)	0.2C, 0.8Mn, 0.5Cr, 0.11Mo
4130 ~H	(SAE)	0.3C, 0.5Mn, 0.95Cr, 0.2Mo
4135 ~H	(SAE)	0.35C, 0.8Mn, 0.95Cr, 0.2Mo
4137 ~H	(SAE)	0.37C, 0.8Mn, 0.95Cr, 0.2Mo
4140 ~H	(SAE)	0.4C, 0.85Mn, 0.95Cr, 0.2Mo
4140	(W. Nr)	1.4140
4142 ~H	(SAE)	0.42C, 0.85Mn, 0.95Cr, 0.2Mo
4145 ~H	(SAE)	0.45C, 0.85Mn, 0.95Cr, 0.2Mo
4147 ~H	(SAE)	0.47C, 0.85Mn, 0.95Cr, 0.2Mo
4150 ~H	(SAE)	0.5C, 0.85Mn, 0.95Cr, 0.2Mo
416 Se		416
4161 ~H	(SAE)	0.6C, 0.85Mn, 0.8Cr, 0.3Mo
416S21		416
416S29		416
416S37		416
416S41		416
41Cr4		0.41C, 0.65Mn, 1Cr
41CrMo4		0.41C, 0.75Mn, 1Cr, 0.25Mo
42 CD 4		1.2332
420J2		1.2083
420S29		1.4021
420S37		420
420S45		1.4028
42CrMo4		0.42C, 0.65Mn, 1Cr, 0.25Mo
431 Se		431

(Continued)

Other tool steels		Comparison
4320 ~H	(SAE)	0.19C, 0.55Mn, 0.5Cr, 0.25Mo, 1.8Ni
4340 ~H	(SAE)	0.4C, 0.7Mn, 0.8Cr, 0.25Mo, 1.8Ni
4419 ~H	(SAE)	0.2C, 0.55Mn, 0.5Mo
441S49		431
4422	(SAE)	0.22C, 0.8Mn, 0.4Mo
4427	(SAE)	0.26C, 0.8Mn, 0.4Mo
45 NCD 17		1.2767
45 WcrSi 8		1.2542
45 WCrV 7		1.2542
45 WCrV 8 KU		1.2542
4528	(W. Nr)	1.4528
45Cr2		0.45C, 0.65Mn, 0.5Cr
4615	(SAE)	0.15C, 0.55Mn, 0.25Mo, 1.8Ni
4617	(SAE)	0.17C, 0.55Mn, 0.25Mo, 1.8Ni
4620 ~H	(SAE)	0.19C, 0.55Mn, 0.25Mo, 1.8Ni
4621 ~H	(SAE)	0.2C, 0.8Mn, 0.25Mo, 1.8Ni
4626 ~H	(SAE~AISI)	0.26C, 0.55Mn, 0.2Mo, 0.85Ni
46Cr2		0.46C, 0.65Mn, 0.5Cr
47 CrMo 4		1.2332
47 Prima		W1
4718 ~H	(SAE)	0.18C, 0.8Mn, 0.45Cr, 0.35Mo, 1.05Ni
4720 ~H	(SAE)	0.19C, 0.6Mn, 0.45Cr, 0.2Mo, 1.05Ni
476 Special	(Mo Type)	D4
476 Special	(W Type)	D6
476		D2
4815 ~H	(SAE)	0.15C, 0.5Mn, 0.25Mo, 3.5Ni
4817 ~H	(SAE)	0.17C, 0.5Mn, 0.25Mo, 3.5Ni
4820 ~H	(SAE)	0.2C, 0.6Mn, 0.25Mo, 3.5Ni
4Ch5MF1S		1.2344
4Ch5MFS		1.2343
4NHD		0.35C, 1.5Cr, 5.75W, 0.35V, 4Ni
4S28		1.5864
4WHD		0.35C, 1.1Si, 4W, 1.2Cr, 0.25V
5 CTDS		H12
5% cobalt		T4
50 CMV 4		1.2241
50 MCD 5		0.5C, 1.2Mn, 0.65Cr, 0.2Mo
50 NiCr 13		1.2721
50 WCV 22		1.2547
50100		1.05C, 0.35Mn, 0.5Cr
5015	(SAE)	0.14C, 0.4Mn, 0.4Cr
503A37		0.37C, 0.7Mn, 0.85Ni
503A42		0.42C, 0.7Mn, 0.85Ni
503H37		0.37C, 0.85Mn, 0.85Ni

Other tool steels		Comparison
503H42		0.42C, 0.85Mn, 0.85Ni
503M40		0.4C, 0.85Mn, 0.85Ni
5046 ~H	(SAE)	0.45C, 0.85Mn, 0.27Cr
5060 ~H	(SAE)	0.6C, 0.85Mn, 0.5Cr
50B40 ~H		0.4C, 0.85Mn, 0.5Cr
50B44 ~H		0.45C, 0.85Mn, 0.5Cr
50B46 ~H		0.46C, 0.85Mn, 0.25Cr
50B50 ~H		0.5C, 0.85Mn, 0.5Cr
50B60 ~H		0.6C, 0.85Mn, 0.5Cr
50CrV4		0.5C, 0.9Mn, 1Cr, 0.15V
51100		1.05C, 0.35Mn, 1Cr
5115 ~H	(SAE)	0.15C, 0.8Mn, 0.8Cr
5120 ~H	(SAE)	0.19C, 0.8Mn, 0.8Cr
5130 ~H	(SAE)	0.3C, 0.8Mn, 0.95Cr
5132 ~H	(SAE)	0.32C, 0.7Mn, 0.85Cr
5135 ~H	(SAE)	0.35C, 0.7Mn, 0.9Cr
5140 ~H	(SAE)	0.4C, 0.8Mn, 0.8Cr
51410		410
51416Se		416
51420		420
51420F		420
51420FSe		420
51431		431
51440A		440A
51440B		440B
51440C		440C
51440F		1.1C, 1.2Mn, 17Cr, 0.7Mo
51440FSe		1.1C, 1.2Mn, 17Cr, 0.7Mo
5145 ~H	(SAE)	0.45C, 0.8Mn, 0.8Cr
5147 ~H	(SAE)	0.48C, 0.85Mn, 1Cr
5150 ~H	(SAE)	0.5C, 0.8Mn, 0.8Cr
5155 ~H	(SAE)	0.55C, 0.8Mn, 0.8Cr
5160 ~H	(SAE)	0.6C, 0.85Mn, 0.8Cr
51B60 ~H		0.6C, 0.85Mn, 0.8Cr
52100		1.05C, 0.35Mn, 1.45Cr
526		M2
526M60		0.6C, 0.65Mn, 0.65Cr
530A30		0.3C, 0.7Mn, 1Cr
530A32		0.32C, 0.7Mn, 1Cr
530A36		0.36C, 0.7Mn, 1Cr
530A40		0.4C, 0.7Mn, 1Cr
530H30		0.3C, 0.7Mn, 1Cr
530H32		0.32C, 0.7Mn, 1Cr
530H36		0.36C, 0.7Mn, 1Cr

(Continued)

Other tool steels		Comparison
530H40		0.4C, 0.7Mn, 1Cr
530M40		0.4C, 0.75Mn, 1Cr
534A99		1C, 1.4Cr
535A99		1C, 0.6Mn, 1.4Cr
53S		H13
54 NiCrMo V6		1.2711
55 NCD 13		1.2721
55 NCDV 6		1.2711
55 NCDV 7		1.2713
55 NiCr 10		1.2718
55 NiCrMoV 6		1.2713
55 WC 20		1.2542
55 WCrV 8 KU		1.2550
56 NiCrMoV 7		1.2714
57 NiCrMoV 7 7		1.2744
58 S		H12
58 WCr9 KU		1.2550
5864	(W. Nr)	1.5864
5CC		A2
5ChNM		1.2713
6/5/2		M2
60 CrSi 8		1.2550
60 MnSiCr 4		1.2826
60 WCrV 7		1.2550
60 WCS 20		1.2550
605A32		0.32C, 1.5Mn, 0.27Mo
605A37		0.37C, 1.5Mn, 0.27Mo
605H32		0.32C, 1.5Mn, 0.27Mo
605H37		0.37C, 1.5Mn, 0.27Mo
605M30		0.3C, 1.5Mn, 0.27Mo
605M36		0.36C, 1.5Mn, 0.27Mo
606M36		0.36C, 1.5Mn, 0.27Mo
608H37		0.37C, 1.5Mn, 0.5Mo
608M38		0.38C, 1.5Mn, 0.5Mo
6118 ~H	(SAE)	0.18C, 0.6Mn, 0.6Cr, 0.12V
6150 ~H	(SAE)	0.5C, 0.8Mn, 0.95Cr, 0.15V
640A35		0.35C, 0.75Mn, 0.65Cr, 1.3Ni
640H35		0.35C, 0.75Mn, 0.65Cr, 1.25Ni
640M40		0.4C, 0.75Mn, 0.65Cr, 1.3Ni
65 NCD 6		1.2714
6-5-2		1.3343
6-5-2-5		1.3243
653M31		0.31C, 0.6Mn, 1Cr, 3Ni
6542 Molybdenum	(Cook)	M2

Other tool steels		Comparison
6582	(W. Nr)	1.6582
6747	(W. Nr)	1.6747
67S		F3
69S		D2
6ChV25		1.2550
7 PCR		W4
70 MDC 8		A6
708A37		0.37C, 0.85Mn, 1Cr, 0.2Mo
708A42		0.42C, 0.85Mn, 1Cr, 0.2Mo
708H37		0.37C, 0.85Mn, 1Cr, 0.2Mo
708H42		0.42C, 0.85Mn, 1Cr, 0.2Mo
708M40		0.4C, 0.85Mn, 1Cr, 0.2Mo
709M40		0.4C, 0.85Mn, 1Cr, 0.3Mo
722M24		0.24C, 0.6Mn, 3.25Cr, 0.55Mo
7-4-2-5		1.3246
74S		0.3C, 2.3Cr, 0.3Mo, 4.25W, 0.6V
75 CrMoNiW 6 7		1.2762
75		1.1750
785M19		0.19C, 1.6Mn, 0.25Mo, 0.55Ni
80		1.1625
8115	(SAE)	0.15C, 0.8Mn, 0.4Cr, 0.11Mo, 0.3Ni
816M40		0.4C, 0.6Mn, 1.2Cr, 0.15Mo, 1.5Ni
817M40		0.4C, 0.6Mn, 1.2Cr, 0.3Mo, 1.5Ni
81B45 ~H		0.45C, 0.85Mn, 0.45Cr, 0.11Mo, 0.3Ni
823M30		0.3C, 2Cr, 0.4Mo, 2Ni
826M31		0.31C, 0.65Cr, 0.55Mo, 2.5Ni
826M40		0.4C, 0.65Cr, 0.55Mo, 2.5Ni
82S		0.33C, 1Si, 3Cr, 2.8Co, 1W, 2.8Mo, 0.9V
830M31		0.31C, 1Cr, 0.3Mo, 3Ni
835M30		0.3C, 1.25Cr, 0.3Mo, 4.1Ni
85 NiV4		0.85C, 0.8Ni, 0.1V
8615	(SAE)	0.15C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8617 ~H	(SAE)	0.17C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8620 ~H	(SAE)	0.2C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8622 ~H	(SAE)	0.22C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8625 ~H	(SAE)	0.25C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8627 ~H	(SAE)	0.27C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8630 ~H	(SAE)	0.3C, 0.8Mn, 0.5Cr, 0.2Mo, 0.55Ni
8637 ~H	(SAE)	0.37C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
8640 ~H	(SAE)	0.4C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
8642 ~H	(SAE)	0.42C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
8645 ~H	(SAE)	0.45C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
8650 ~H	(SAE)	0.5C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
8655 ~H	(SAE)	0.55C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni

(Continued)

Other tool steels		Comparison
8660 ~H	(SAE)	0.6C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
86B30H		0.3C, 0.75Mn, 0.5Cr, 0.2Mo, 0.55Ni
86B45 ~H		0.45C, 0.85Mn, 0.5Cr, 0.2Mo, 0.55Ni
8720 ~H	(SAE)	0.2C, 0.8Mn, 0.5Cr, 0.25Mo, 0.55Ni
8740 ~H	(SAE)	0.4C, 0.85Mn, 0.5Cr, 0.25Mo, 0.55Ni
8822 ~H	(SAE)	0.22C, 0.85Mn, 0.5Cr, 0.35Mo, 0.55Ni
88HP		T1
897M39		0.39C, 3.25Cr, 1Mo, 0.2V
90 MCV 8		1.2842
90 MnCrV 8		1.2842
90 MnVCr 8 KU		1.2842
90 MV 8		1.2842
90 MWCV 5		1.2510
905M31		0.31C, 1.6Cr, 0.2Mo, 1.1Al
905M39		0.39C, 1.6Cr, 0.2Mo, 1.1Al
9254	(SAE)	0.55C, 1.4Si, 0.7Mn, 0.7Cr
9255	(SAE)	0.55C, 2Si, 0.8Mn
9257	(Cook)	W2
9260 ~H	(SAE)	0.6C, 2Si, 0.85Mn
9310 ~H	(SAE)	0.1C, 0.55Mn, 1.2Cr, 0.11Mo, 3.25Ni
945A40		0.4C, 1.4Mn, 0.5Cr, 0.2Mo, 0.75Ni
945M38		0.38C, 1.4Mn, 0.5Cr, 0.2Mo, 0.75Ni
94B15 ~H		0.15C, 0.85Mn, 0.4Cr, 0.11Mo, 0.45Ni
94B17 ~H		0.17C, 0.85Mn, 0.4Cr, 0.11Mo, 0.45Ni
94B30 ~H		0.3C, 0.85Mn, 0.4Cr, 0.11Mo, 0.45Ni
95 MCWV 5		1.2510
95 MnCrW 5		1.2510
95 MnWCr 5 KU		1.2510
9Ch1		1.2067
9Ch5VF		1.2363
9ChVG		1.2510
A 100		0.32C, 0.6Mn, 0.65Cr, 2.5Ni, 0.55Mo
A 13		0.4C, 1.15Cr, 1.5Ni, 0.3Mo, 0.6Mn
A11		D3
A25CrMo4		0.25C, 0.65Mn, 1Cr, 0.25Mo
A6		D2
AB 213		0.33C, 1Cr, 0.3Ni, 1.75W
AB 75		S4
ADIC		H13
ADS		H11
AGS		L1
AH chrome die		A2
AHA		1.2542
AHK		1.2550

Other tool steels		Comparison
Alloy C WPS		D3
Alloy mold		1.2766
Alum die mold		H11
ALZ		H13
AM1		0.35C, 1Si, 1.35W, 5Cr, 1.5Mo, 0.45V
AM3		0.4C, 1Si, 5Cr, 1.35Mo, 1V
Amutit S		1.2510
Amutit		1.2419
Ardho No 2		0.47C, 1.1Ni, 0.6Cr
ARH Medium		420
ARH Tough		420
Ark Superior Triumph Superb		T1
Ark Superlative Triumph Superb 1000		T4
ARL.GB		431
Arne		1.2510
ARW		410
ARWS.GB		416
ASP 23		1.27C, 0.5Si, 0.3Mn, 4.2Cr, 6.4W, 5Mo, 3.1V
Astra		0.55, 1Cr, 2W
AT		0.45C, 1.2Si, 0.7Mn, 3Ni, 0.5Cr
Austenite		0.65C, 14W, 4Cr, 0.5V
AW		0.73C, 14W, 4Cr, 1V
AZ		H21
B 20V		1.1545
B10		1.1730
B25CrMo4		0.25C, 0.65Mn, 1Cr, 0.25Mo
BA 2		1.2363
BA 500		0.33C, 1.15Cr, 0.25Mo, 4.15Ni
BA 6		0.7C, 2Mn, 1Cr, 1.4Mo
BCC	(Carr)	0.5C, 1Si, 1.2Cr, 2.25W, 0.25V
BCC	(Huntsman)	D5
BCD	(Carr)	S1
BCD	(Huntsman)	D3
BCD37		0.37C, 1.6Cr, 0.3V, 2W
BCHV		1.8C, 12.5Cr, 0.25V, 0.8Mo
BCRS		D1
BCW		D6
BD 2A		1.75C, 12.5Cr, 0.8Mo, 0.6V
BD 2		1.2379
BD 3		1.2080
BD2A		D2A
Benum		0.3C, 1.25Cr, 4.1Ni

(Continued)

Other tool steels	Comparison
Best Warranted Cast Steel	W1
BF 1	1.25C, 0.4Cr, 0.3V, 1.45W
BH 10	1.2365
BH 10A	H 10A
BH 11	1.2343
BH 12	1.2606
BH 13	1.2344
BH 19	0.4C, 4.25Co, 4.25Cr, 0.45Mo, 2.2V, 4.25W
BH 21 A	0.25C, 2.75Cr, 0.6Mo, 2.25Ni, 0.5V, 9.25W
BH 21	1.2581
BH 26	0.55C, 0.6Co, 4.1Cr, 0.6Mo, 1.25V, 18W
BKV	D3
BL 3	1.2067
Black Label Steels	W1
Blue Band Cast Steel	W1
Blue Label Steels	W1
Blue Label	W2
BM 1	1.3346
BM 15	1.50C, 5Co, 4.75Cr, 3Mo, 5V, 6.6W
BM 2	1.3343
BM 34	1.3249
BM 4	1.3C, 0.6Co, 4.1Cr, 4.75Mo, 4V, 6.1W
BM 42	1.3247
BO 1	1.2510
BO 2	1.2842
BR 1	L5
BS 1	1.2542
BS 2	0.5C, 1Si, 0.45Mo, 0.2V
BS 224	1.2711
BS 5	0.55C, 1.85Si, 0.7Mn, 0.45Mo, 0.2V
BS50 Extra	0.54C, 1.1Cr, 4Ni, 0.3Mo, 0.5W
BS50	0.5C, 1.1Cr, 3.3Ni
BSS	M1
BST	1.2767
BT 1	1.3355
BT 15	1.3202
BT 2	0.8C, 0.6Co, 4.1Cr, 0.7Mo, 1.9V, 18W
BT 20	0.8C, 0.6Co, 4.6Cr, 1Mo, 1.5V, 21.75W
BT 21	0.65C, 0.6Co, 3.8Cr, 0.7Mo, 0.5V, 14W
BT 4	1.3255
BT 42	1.3207
BT 5	1.3265
BT 6	0.8C, 11.75Co, 4.1Cr, 1Mo, 1.5V, 20.5W

Other tool steels	Comparison
BV	T6
BW 1A	1.1750
BW 1B	1.1625
BW 1C	1.20C, 0.15Cr, 0.1Mo, 0.2Ni
BW 2	1.2833
C 100 KU	1.1545
C 102	1.1645
C 105 W 1	1.1545
C 105 W 2	1.1645
C 120 KU	1.1663
C 120	1.1663
C 1215	D2
C 1220	D3
C 125 W	1.1663
C 135 W	1.1673
C 140 KU	1.1673
C 45 W	1.1730
C 60 W	1.1740
C 75 W	1.1750
C 80 KU	1.1525
C 80 W 1	1.1525
C 80 W 2	1.1625
C 80	1.1625
C 85 W	1.1830
C.M.V.	1.2344
C2–C6	W1
C36	0.36C, 0.65Mn
C46	0.46C, 0.65Mn
C53	0.53C, 0.6Mn
CA 510	A2
CA1220	2.1C, 1.2Cr, 0.7W
CA71215	1.65C, 12Cr, 0.5W, 0.7Mo
Calmax	0.6C, 0.8Mn, 4.5Cr, 0.5Mo, 0.2V
Capital 305	M1
Capital 398	M35
Capital 405	M42
Capital 50	M50
Capital 562	M2
Cast Steel	W1
CCM 10	T6
CCMP 15	0.81C, 22W, 4.75Cr, 1.6V, 15Co, 0.5Mo
CCR 350	0.75C, 3.5Cr
CCR 50	W5
CCR130	L1

(Continued)

Other tool steels	Comparison
CCR2	0.6C, 0.6Cr
CCV	0.4C, 0.65Mn, 1.25Cr, 0.15V
CCW	S1
CCZ	H10A
CD	D3
CD3	F2
CDD	1.9C, 0.6Cr, 6W
CDS2	H13
CDV 4	D5
CDV	H13
CDV1	D4
CDV2	D2
Celfor	W1
CGH	0.42C, 2.4Cr, 0.15V, 0.25Mo, 0.8Ni
Ch12	1.2080
Ch12F1	1.2379
Ch12M	1.2601
CHD 7	W1
CHD	H12
CHD2	H14
CHD3	H12
CHD4	0.65C, 3.75Cr, 0.45V, 0.6Mo
Chrom Special	1.2080
Chromo Triple Three	0.32C, 3Cr, 0.9V, 3Co, 2.8Mo, 1W
ChWG	1.2419
CJM	P20
CKK	L1
CL 15	0.4C, 3.25Ni
CL 222	0.35C, 0.8Cr, 0.5W, 0.7Mo
CL 225	0.25C, 1.25Ni, 0.5Cr, 0.25Mo
CL 244	0.55C, 1.5Ni, 0.75Cr, 0.3Mo
CL 40T	S4
CL 40X	S5
CL 444	H12
CL 45	L2
CL 562	M2
CL 60	0.6C, 0.7Mn, 0.6Cr
CL 99	0.4C, 1.2Cr, 0.25Mo, 4.2Ni
CM 1255	T15
CM Extra 150	0.55C, 0.65Mn, 0.65Cr, 0.3Mo, 1.5Ni
CM Extra 300	0.31C, 0.6Cr, 0.6Mo, 2.6Ni
CM Extra 450	0.41C, 0.6Cr, 0.6Mo, 2.55Ni
CM	0.4C, 1.15Cr, 0.27Mo, 1.55Ni
CM5	T4

Other tool steels		Comparison
CMC	(Cook)	O2
CMC	(Thomas Turton)	M42
CMI		0.07C, 5Cr, 0.3V, 1Mo
CMV		H13
CMVM		0.5C, 0.65Mn, 0.95Cr, 0.2V
CMW		H12
Co 500		T4
Co 512		T8
Cobalt Extra Special		T6
Cobaltcrom		D5
Cobra		0.29C, 7W, 2.13Cr, 0.25V, 0.75Mo, 4.75Co
Common Hardening		0.55C, 0.7Mn
Conqueror 14%		T7
Conqueror LC		H24
Conqueror Tempers 1–6		W1
Constant Special		1.2842
Covas		T15
CPM 10V		2.45C, 5.25Cr, 10V, 1.3Mo
CPM 3V		0.8C, 7.5Cr, 1.3Mo, 2.75V
CPM 420V		2.2C, 13Cr, 1Mo, 9V
CPM 9V		1.8C, 0.5Mn, 0.9Si, 5.25Mo, 1.3Mo, 9V
CPM M2 HSHC		M2
CPM REX 20		M62
CPM REX 25		M61
CPM REX 76		M48
CPM REX M35S		M35
CPM REX M3HS		M3
CPM REX M42		M42
CPM REX M45		1.3C, 4Cr, 5Mo, 3V, 6.25W, 8Co
CPM REX M4HC HS		M4
CPM REX T15		T15
CPM T440V		2.15C, 0.4Mn, 17Cr, 0.4Mo, 5.5V
CR 80		D1
CRD Special		1.2601
CRD Supra		1.2379
CRD		1.2080
CRLS		1.2363
CRM2		0.6C, 0.6Cr, 0.3Mo
CRMI		A2
Cromax		0.45C, 1.30Mn, 0.7Cr, 0.2Mo
Cromodie HC		A2
Cromodie HCV		A7
Cromodie W		H12
Cromodie		H13

(Continued)

Other tool steels		Comparison
Crovaco 14		1.12C, 13.5W, 4.35Cr, 4.1V, 0.65Mo, 4.8Co
CRP		O1
CRU-Die 2		0.55C, 1.2Cr, 1.65Ni, 0.5Mo, 0.2V
CRV 14		0.68C, 14.5W, 3.75Cr, 0.65V
CRV 1444		1.2C, 13.75W, 4.4Cr, 3.75V, 0.5Mo
CS 13M Extra		D2
CS 13M		D3
CSM 420		1.2083
CSM2		P20
CSP		O1
CSV 4		0.38C, 1.5Cr, 0.1V, 1.5Si
CSV 5		0.45C, 1.5Cr, 0.1V, 1.5Si
CSV 6		0.61C, 1.2Cr, 0.1V, 0.9Si
CT 150		H12
CT		H20
CTU		0.37C, 1.1Si, 5Cr, 1.75W, 1V, 1.30Mo
CV	(Barworth)	0.45C, 2.5Cr, 0.2V
CV	(Osborne)	W2
CV	(Stone)	L2
CV 18		T1
CV 22		0.79C, 22W, 4.5Cr, 1.4V
CV Punch and Die		L2
CV1842		T2
CVHD		0.6C, 0.7Cr, 0.2V
CVM		H11
CVM2		H12
CVM3		H13
CVM4		0.58C, 0.9Si, 5Cr, 1.1V, 1.35Mo
CVM6		0.38C, 0.9Si, 2W, 5Cr, 0.95V, 1.75Mo
Cyclone 4V		M4
Cyclone 56		M2
Cyclone 92		M1
Cyclone 92CW		M1
Cyclone DG		T4
Cyclone MC33		M33
Cyclone MC42		M42
Cyclone MC46		M46
Cyclone MC50		M50
Cyclone MC6		M35
Cyclone MC7		M7
D 421		S1
DAC		1.2344
DBC		1.2606

Other tool steels	Comparison
DBS	1.2721
DC 1	1.2080
DC 11	1.2379
DC 3	1.2379
DC12	1.2363
DCM	A2
DDW	1.2567
DE-CP10V	1.2080
DE-CPPK	1.2601
DE-CPPU	1.2379
DE-CPR	1.2C, 12Cr, 1.2Mo
DE-CPV2	1.2378
DE-CPW	1.2436
DE-DMo5	1.3343
DE-EMo12	1.3207
DE-G42	1.1525
DE-G43	1.1545
DE-NHF	1.2542
DE-NHW	1.2550
DE-PS	1.2063
DE-VNC4M	1.2767
DE-WP7V	0.5C, 1Si, 0.8Mn, 8.3Cr, 0.3Ni
DE-Z1b	1.2842
DE-Z2T	1.2419
DH21	1.2344
DH2F	1.2344
DH4	1.2567
DH5	1.2581
DH6	1.2343
DH62	1.2606
DH72	1.2365
DHA1	1.2344
DHS	1.3343
Diehard HCD	D4
Diehard LC	0.8C, 12Cr, 0.5Mo, 0.5V
Diehard Standard	D2
DJS	1.3346
DJS	M1
DJSY	M7
DOH	0.9C, 1.7Mn
DOM 5	A2
DOM MW	D2A
DOM VM	D2
Dominant Extra Superb	T5

(Continued)

Other tool steels	Comparison
Dominant Hierom	D3
Dominant OH	0.95C, 1Cr, 1Mn, 0.5W
Dominant SA	0.4C, 1.75W, 1.75Cr, 0.3V
Dominant Special	0.68C, 14W, 3.5Cr, 0.5V
Dominant Superb	T4
Dominant SX	D4
Dominator	D3
Double Conqueror Vanadium	W2
Double Extra	W1
Double Griffin	0.35C, 1.75Cr, 3.5Ni
Double Horseman	T4
Double Rapid	T4
Double Seven	D5
Double Shear Temper	W1
Double Six	D3
Dreadnought 30BW	0.3C, 1.5Cr, 3.75, 0.3V, 5.75W
Dreadnought 5/6/2	M2
Dreadnought CTVM	M15
Dreadnought FP4T	0.3C, 2.3Cr, 0.3Mo, 0.6V, 4.3W
Dreadnought FPHD(N)	H21
Dreadnought FPHD	H21
Dreadnought M42	M42
Dreadnought Select	T1
Dreadnought Superior	T4
Dreadnought Supreme	T6
DS 122	D3
DS 133	D4
DS 144	D2
DS 200	O1
DS 400	L4
DS 600	O2
DUX 4	S1
DVS	M3
E	0.65C, 14.25W, 3.75Cr, 0.5V
E4340 ~H	0.4C, 0.75Mn, 0.8Cr, 0.25Mo, 1.8Ni
E51100	1.05C, 0.35Mn, 1Cr
E52100	1.05C, 0.35Mn, 1.45Cr
EE	H24
EF	O2
Electem	0.55C, 0.7Mn, 0.75Cr, 0.28Mo, 1.5Ni
EMS 45	1.1730
EMS 60	1.1740
EMS 85	1.1830
EN 100	0.38C, 1.4Mn, 0.5Cr, 0.2Mo, 0.75Ni

Other tool steels	Comparison
EN 100C	0.4C, 1.4Mn, 0.5Cr, 0.2Mo, 0.75Ni
EN 11	0.6C, 0.65Mn, 0.65Cr
EN 110	0.4C, 0.6Mn, 1.2Cr, 0.15Mo, 1.5Ni
EN 111	0.4C, 0.75Mn, 0.65Cr, 1.3Ni
EN 111A	0.35C, 0.75Mn, 0.65Cr, 1.3Ni
EN 12	0.4C, 0.85Mn, 0.85Ni
EN 12B	0.37C, 0.7Mn, 0.85Ni
EN 12C	0.42C, 0.7Mn, 0.85Ni
EN 13	0.19C, 1.6Mn, 0.25Mo, 0.55Ni
EN 16	0.36C, 1.5Mn, 0.27Mo
EN 16B	0.32C, 1.5Mn, 0.27Mo
EN 16C	0.37C, 1.5Mn, 0.27Mo
EN 16D	0.3C, 1.5Mn, 0.27Mo
EN 16M	0.36C, 1.5Mn, 0.27Mo
EN 17	0.38C, 1.5Mn, 0.5Mo
EN 18	0.4C, 0.75Mn, 1Cr
EN 18A	0.3C, 0.7Mn, 1Cr
EN 18B	0.32C, 0.7Mn, 1Cr
EN 18C	0.36C, 0.7Mn, 1Cr
EN 18D	0.4C, 0.7Mn, 1Cr
EN 19	0.4C, 0.85Mn, 1Cr, 0.3Mo
EN 19A	0.4C, 0.85Mn, 1Cr, 0.2Mo
EN 19B	0.37C, 0.85Mn, 1Cr, 0.2Mo
EN 19C	0.42C, 0.85Mn, 1Cr, 0.2Mo
EN 23	0.31C, 0.6Mn, 1Cr, 3Ni
EN 24	0.4C, 0.6Mn, 1.2Cr, 0.3Mo, 1.5Ni
EN 25	0.31C, 0.65Cr, 0.55Mo, 2.5Ni
EN 26	0.4C, 0.65Cr, 0.55Mo, 2.5Ni
EN 27	0.31C, 1Cr, 0.3Mo, 3Ni
EN 30B	0.3C, 1.25Cr, 0.3Mo, 4.1Ni
EN 31	1C, 1.4Cr
EN 40B	0.24C, 0.6Mn, 3.25Cr, 0.55Mo
EN 40C	0.39C, 3.25Cr, 1Mo, 0.2V
EN 41A	0.31C, 1.6Cr, 0.2Mo, 1.1Al
EN 41B	0.39C, 1.6Cr, 0.2Mo, 1.1Al
En 56A	410
En 56AM	416
En 56B	420
En 56BM	416
En 56C	420
En 56CM	416
En 56D	420
EN 57 Se	431
EN 9	0.55C, 0.7Mn

(Continued)

Other tool steels	Comparison
EN24	0.24C, 1Cr, 0.3Mo, 1.5Ni
ERCO 3	0.32C, 3Cr, 2.8Mo, 0.5V, 3Co
ETA	0.9C, 0.5W, 0.15V
ETH	W110
EW 15 Special	0.19C, 1.3Cr, 0.2Mo, 4Ni
EW 52 H	0.2C, 1.2Cr, 0.25Mo, 1Mn
EWPX	1.2581
EWX 40	0.07C, 4Cr, 0.5Mo
EXD 5	H23
EXD1	0.33C, 1.5Cr, 5.5W, 3.75Ni
Extra Double Horseman	T6
Extra Extra Special M	0.77C, 22W, 4.25Cr, 1.5V
Extra Quality Hard Temper Chrome	W5
Extra Quality Tough and Hard Temper	W2
Extra Tough	W1
Extra Triple Conqueror	1.55C, 0.55Cr, 5.5W
Extra Triple Griffin	1.5C, 0.25Cr, 6W
Extra Zah Special	1.1525
Extra Zah	1.1525
Extra Zahhart Special	1.1545
Extra Zahhart	1.1545
E-Z 85 WCDV 6	1.3554LW
F 2	0.58C, 0.8Mn, 0.75Cr, 0.2V
F 543	0.09C, 4.8Ni, 3.9Cr, 3Mo
F 5553	1.3207
F.5107	1.1625
F.5117	1.1645
F.5123	1.1663
F.5211	1.2601
F.5212	1.2080
F.5213	1.2436
F.5220	1.2510
F.5227	1.2363
F.5230	1.2067
F.5233	1.2419
F.5241	1.2542
F.5242	1.2550
F.5267	1.2316
F.5307	1.2711
F.5313	1.2365
F.5317	1.2343
F.5318	1.2344
F.5323	1.2581

Other tool steels	Comparison
F.5520	1.3355
F.5530	1.3255
F.5540	1.3265
F.5563	1.3202
F.5603	1.3343
F.5607	1.3348
F.5611	1.3249
F.5613	1.3243
F.5615	1.3246
F.5617	1.3247
Favorit	1.2842
FCW5	1.35C, 5W
FDAC	1.2343
Firthob	P3
Flashut	0.95C, 3.75Cr, 0.18V, 0.23Mo
FMP 035	W2
FMP 1850	0.55C, 18W, 4.1Cr, 0.7V, 1Mo
FMP 200	O1
FMP 328	H11
FMP 329	H13
FMP 336	D2
FMP 338	D3
FMP 348	0.42C, 1.55Cr, 0.3Mo, 4Ni
FMP 379	A2
FMP 399	S1
FMP 455	T4
FMP 470	0.8C, 22W, 4.5Cr, 1.5V, 1Mo
FMP 501	M1
FMP 504	M4
FMP 505	H21
FMP 507	0.3C, 9W, 3Cr, 0.3V, 0.5Mo, 2.5Ni
FMP 513	H12
FMP 526	M41
FMP 530	M30
FMP 536	M15
FMP 542	M42
FMP 555C	T15
FMP 563	M3
FMP 599	0.7C, 14W, 4.25Cr, 0.8V, 0.75Mo
FMP 622	T1
FMP 644	1.25C, 13.5W, 4.75Cr, 4V
FMP 682	H43
FMP 808	T6
FMP 828	T5

(Continued)

Other tool steels	Comparison
FMP 842	T2
FMP 922	M7
FMP 928	M34
FMP 929	M43
FMP 933	1.3C, 9.25W, 4.25Cr, 3.5V, 3.75Mo, 10Co
FMP 948	M10
FT 125	0.4C, 1.5Ni, 1.2Cr, 0.3Mo
FT 95V	W2
G 1 Special	0.32C, 1.3Cr, 0.3Mo, 4.1Ni
G 14C	0.44C, 1.5Cr, 0.4Mo, 3.5Ni
Geordie	W1
GFS	O1
Gigant 50	1.3355
Gigant M5	1.3343
Gigant M5Co	1.3243
Gigant M9	1.3346
GN	D2
GO 31	1.2419
GO3	1.2419
GOA	1.2510
Grandios Extra 655	1.3243
Grane	1.2721
Green Lable	W1
Ground Flat Stock	O1
GS	O1
GS3	1.2721
Guss. Stahl 3	1.1830
Guss. Stahl 5 H	1.1730
Guss. Stahl 4 W	1.1740
GZ	T4
H2	L1
H33	A2
H41	1.3346
H42	D2
H50	H13
H61	H10
Hammer & Zange 45	1.1730
Hammer & Zange 60	1.1740
Hardenite (CHD)	W1
HD 3MX	0.33C, 0.9Si, 1W, 3Cr, 0.9V, 2.8Mo, 3Co
HD10	H21
HD3	H21
HDB1	W1
HDB2	0.6C, 0.65Mn, 1.25Ni

Other tool steels	Comparison
HDB3	0.55C, 0.65Mn, 0.65Cr, 1.5Ni
HDB5	0.55C, 0.65Mn, 0.6Cr, 0.2Mo, 1.65Ni
HDC	1.2581
HDS	H13
HDZ	0.3C, 3.4Cr, 0.34V, 8.4W
Hecla 105	0.5C, 0.7Mn, 1Cr
Hecla 135	0.6C, 2Cr, 2Ni, 0.5Mo
Hecla 139	0.55C, 0.7Cr, 0.25Mo, 1.75Ni
Hecla 149C	H21
Hecla 15	O2
Hecla 150	0.4C, 0.7Mn, 1Cr, 0.2Mo
Hecla 159	D2
Hecla 174	H11
Hecla 175	A2
Hecla 177	H12
Hecla 18	W1
Hecla 28	W2
Hecla 67	0.3C, 1.3Cr, 4.25Ni
Hecla 67B	0.3C, 1.3Cr, 4.25Ni, 0.3Mo
Hecla D17	0.6C, 0.8Mn
HJS 202	0.11C, 0.5Cr, 1.25Ni
HJS 555	0.16, 1.15Cr, 0.3Mo, 4.25Ni
HJS 5-6-2	M2
HJS 626	T4
HJS M1	M1
HM3	H21
HMI	O2
Holdax	0.4C, 1.5Mn, 1.9Cr, 0.2Mo
Horseman Brand (14% W)	0.7C, 14W, 3.75Cr, 0.5V
Horseman Brand (22% W)	0.78C, 22W, 4.5Cr, 1V
Horseman	T1
HOV	H12
HP	H21
HRO 1243	1.2721
HRS	L1
HS 10-4-3-10	1.3207
HS 18-0-1	1.3355
HS 18-0-1-10	1.3265
HS 1-8-1	1.3346
HS 18-1-1-5	1.3255
HS 2-9-1-8	1.3247
HS 2-9-2	1.3348
HS 6-5-2	1.3343
HS 6-5-2-5	1.3243

(Continued)

Other tool steels	Comparison
HS 7-4-2-5	1.3246
HSB 1	0.85C, 0.6Mn
HSB 4 Special	0.8C, 0.5Cr, 0.3V
HSC 6-5-3	1.3342
HSM/W9A	H21
HV5	T15
HW 5	H12
HW2N	0.28C, 2.25Ni, 2.1W, 0.85Cr, 0.3V, 0.5Mo
HW4	0.3C, 4.5W, 2.5Cr, 0.55V, 0.3Mo
HWX	0.36C, 0.7Mn, 5.8Ni, 2.8W, 13.5Cr, 0.65V
Hyblade	S5
Hyform	W1
IAS	O7
IBD	0.32C, 1.25Cr, 0.35Mo, 4.25Ni
ICN	0.2C, 1Si, 1Mn, 14Cr, 1Ni
ICS	W1
ICW	D3
IDI	O1
Impax Supreme	0.37C, 1.4Mn, 2Cr, 1Ni, 0.2Mo
Inmanite	T4
Intra	F1
Intrinsic Special	H21
Invincible 18%	T1
Invincible 22%	0.75C, 4Cr, 22W, 1.25V
IR	D3
Iron Duke	0.4C, 0.3Cr, 3.25Ni
IU	1.9C, 12.5Cr, 0.75Mo, 0.3V
J24	M2
J28	H19
J34	M2
J35	M1
J36	T15
J37	1.3C, 9.5W, 4.5Cr, 3.5V, 4Mo, 10Co
J4 V	W2
J42	M42
JA	A2
JC 20	H20
Je	H13
JEM	W1
Jethete	0.14C, 0.7Mn, 12Cr, 0.35V, 1.8Mo, 2.4Ni
JG	0.5C, 1Mn, 1Cr, 0.3Mo
K 4 Special	O1
K 9	O1
K.E. 1006	1.2833

Other tool steels	Comparison
K.E. 1036	0.9C, 13Cr
K.E. 15	410
K.E. 160	1.05C, 0.5Cr
K.E. 169	0.14C, 0.85Cr, 3.4Ni, 0.15Mo
K.E. 200	1.4C, 13Cr, 0.6Mo, 3.5Co
K.E. 226	1.05C, 0.5Cr, 2.1W
K.E. 227	0.5C, 1.2Mn, 0.6Cr, 0.2Mo
K.E. 25	1.4021
K.E. 275	H21
K.E. 339	0.28C, 2.25Ni, 2.5Cr, 9.5W, 0.15V
K.E. 35	420
K.E. 355	1.2766
K.E. 396	1.2714
K.E. 40A	416
K.E. 43	431
K.E. 595	1.25C, 0.85Mn, 1.2Cr, 1.3W
K.E. 621	W5
K.E. 637	O1
K.E. 672	1.2510
K.E. 805	1.6582
K.E. 839	1.2067
K.E. 896	1.2241
K.E. 897	1.5864
K.E. 960	1.2547
K.E. 961	1.55C, 12.5Cr, 0.55W
K.E. 965	0.4C, 1.6Si, 13Cr, 2.75W, 0.55Mo
K.E. 970	1.2080
K.E. A203	440B
K.E. A207	440C
K.E. A28	0.43C, 13.25Cr, 1Ni
K.E. A505	431
K.E. A508	420
K.E. Diamond No. 10	1.5C, 0.6Cr, 5.75W
K.E.A. 108	1C, 0.55Mn
K.E.A. 138	H23
K.E.A. 145	1.2344
K.E.A. 162	1.2363
K.E.A. 172	A6
K.E.A. 180	1.2601
K.E.A. 205	1.4C, 3.45V
K.E.A. 220	1.2330
K.E.A. 222	H19
K.E.A. 227	0.5C, 1.2Mn, 0.65Cr, 0.2Mo
K.E.A. 275	H21

(Continued)

Other tool steels	Comparison
K.E.A. 28	0.45C, 13.25Cr, 1Ni
K.E.A. 476	1.2601
K.E.A. 505	431
K100	1.2080
K105	1.2601
K110	1.2379
K18	H12
K190	2.3C, 12.5Cr, 4V, 1.1Mo
K200	1.2067
K305	1.2363
K306	0.51C, 1Si, 5Cr, 1.4V, 1.4Mo
K4 Special KSA	O2
K455	1.2550
K460	1.2510
K5	T4
K5M	1.3243
K600	1.2767
K605	1.2721
K630	1.2770
K720	1.2842
K980	W1
K990	W110
KAO	F2
KAOC	F3
KAOK	1.3C, 5W
KCNM	1.2721
Kelock 1014	0.75C, 6Cr, 14.5W, 0.8Mo, 1.4V
Kelock 1021	T5
Kelock 237	1.3355
Kelock 795	0.7C, 4.1Cr, 14.25W, 0.6V
Kelock 873	T4
Kelock A157	1.3343
Kelock A182	1.3346
Kelock A229	M42
KK	M2
KKK	2.1C, 0.65Mn, 0.85Ni, 13Cr, 0.65Mo
KLAH	S1
KLD	1.2550
KM	1.2631
KMV	D2
KN90	1.2770
KNL	D2A
Komalp 3Herz	1.3355
Komalp MO	1.3346

Other tool steels	Comparison
Komalp WM	1.3343
Kova 57	1.25C, 4Cr, 10W, 3.5V, 3Mo, 9Co
KW10	410
KW30	420
KWB	431
L.T.A.H.	A6
LCHD	H21
LE	0.4C, 3.25Ni
LTAH	A6
LTTS	O7
M Brand	0.6C, 14.5W, 3.6Cr, 0.3V
M200	1.2312
M201	1.2311
M238	1.2378
M300	1.2316
M310	1.2083
M314	0.3C, 0.7Si, 1.1Mn, 16.8Cr, 0.15Mo
M390PM	1.9C, 20Cr, 1Mo, 4V, 0.6W
Malloy	0.6C, 1.1Si, 1.1Cr, 0.25Mo
Mammut Special	1.3355
Maxmith	0.4C, 0.6Mn, 3.25Ni
MC	M1
MCMO	A6
MCT	O1
MCV	0.5C, 1.25Mn, 0.55Cr, 0.25Mo, 0.55Ni
MIC 4	O1
MIC 8	O6
MIC	O2
Minerva HC	0.53C, 1.8Cr, 1.9W, 0.2V
Minerva LC	0.43C, 1.8Cr, 1.9W, 0.2V
MJW CR	1.25C, 0.5–3Cr
MJW LT	1.25C, 2.5W
MJW OH	O2
MJW	W1
MJWCV	W2
MKZ	H21
Mo 500	M2
Mo 53	M3
Mo 550 H	M41
Mo 550	M35
Mo 900	M1
Mo 92	M7
Mo 980 H	M42
MOG 111	0.45C, 1.5Cr, 0.8V, 0.5W, 0.5Mo

(Continued)

Other tool steels	Comparison
MOG 330	0.32C, 3Cr, 0.6V, 3Mo
MoG 510V	H13
MoG 510	H11
MoG 511	H12
MOHD	0.36C, 6Mo, 1W, 3.5Cr, 0.75V
Molycut 562	M2
Monarch (HCR)	D6
Monarch (OHB)	O1
Monarch (SSM-H)	0.75C, 22W, 7.5Cr, 1.30V
Monarch 652	M2
Monarch BLA	H13
Monarch DW8	0.3C, 7.75W, 2.75Cr, 0.45V
Monarch General Utility	0.6C, 0.7Mn, 0.7Cr
Monarch NCG	0.35C, 1.5Cr, 0.3Mo, 4Ni
Monarch PCS	0.8C, 1.25Cr, 0.5Ni, 1.9W
Monarch Special TAN	0.30C, 0.65Mn, 2.5Ni, 0.6Mo, 0.75Cr
Monarch TAN	L6
Morapid Extra 500	1.3243
Morapid Extra 9	1.3346
More 397	M7
More 500	M35
More 9S	M1
More V30	M3
Motor Magnus	M2
Motor Maximum	T1
Motor Special	0.68C, 4Cr, 14W, 0.25V
Movan Special	1.25C, 9.5W, 4.25Cr, 3.2V, 3.25Mo, 10Co
MOW 562	M2
MP	1.2721
MS	1.2419
MS1	1.2510
MST	1.2842
MT2	S1
MTDS	H21
Multitherm	H12
MY	0.55C, 0.95Cr, 0.95Si
Myextra	1.2542
N100	410
N316	416
N320	1.4021
N324	420
N350	1.4057
N530	1.4028
N540	1.4034

Other tool steels	Comparison
N555	0.6C, 14.1Cr, 0.7Mo, 0.1V
N685	1.2361
N690	1.4528
NAT	H11
NBS	1.2721
NC1510	0.4C, 1Cr, 1.5Ni
NC41M	0.3C, 1.25Cr, 0.3Mo, 4.25Ni
NCM	0.52C, 0.6Cr, 0.25Mo, 1.5Ni
NCM1	0.35C, 1.1Cr, 0.2Mo, 1.55Ni
NCM2	0.35C, 0.6Cr, 2.5Ni
NCM3	0.35C, 1.2Cr, 3.5Ni
NCM4	0.35C, 1.3Cr, 0.3Mo, 4.1Ni
ND	T1
New Capital	0.7C, 3.75Cr, 14.5W, 0.75V
Newhall	O1
NF	0.38C, 1.65Ni, 1.2Cr, 0.25Mo
NG	0.55C, 0.7Cr, 0.1V, 0.2Mo, 1.7Ni
NG2 Supra	0.55C, 1.1Cr, 0.1V, 0.5Mo, 1.7Ni
NH	0.31C, 4.1Ni, 1.3Cr, 0.3Mo
NHP	0.26C, 9W, 3Cr, 0.3V, 0.5Mo, 2.5Ni
Nita	0.53C, 1.5Cr, 0.21Mo, 1.1Al
No 0 Hardenite	W1
No 1 Hardenite	W1
No 1 Monarch	0.65C, 4Cr, 14W, 0.6V
No 1 Steel	0.6C, 0.7Mn
No 10 Hardenite	1.2C, 3Cr, 1W
No 2 Hardenite	W1
No 3 Hardenite	W1
No 4 Hardenite Van	1.4C, 0.4Cr, 3.6V, 0.4Mo
No 5 Hardenite	L1
No 5	H21
No 6 Hardenite	1C, 1Mn, 1.35Cr
No 7 Hardenite (70H)	O1
No 8 Hardenite	0.85C, 1W, 1.35Cr, 0.2V
Nonvar	O2
Novo 6/5/2	M2
Novo 9/2	M1
Novo C	0.75C, 13.5W, 6.25Cr, 1.25V, 0.75Mo
Novo Enormous	T6
Novo Max	T4
Novo Superb	1.2C, 10.5W, 4.25Cr, 3.25V, 3.75Mo, 10Co
Novo Superior SS	0.75C, 21W, 4.5Cr, 1.25V
Novo Superior	T1
Novo TCV	1.5C, 11W, 5Cr, 5V

(Continued)

Other tool steels		Comparison
Novo V		T15
Novo VHC		M42
Novo		0.7C, 14W, 0.4Cr, 0.5V
NRM		D2
NRW		D3
NS 12		W5
NSC		1C, 1.1Mn, 1.4Cr
NSCD		O2
NSCM1 (HC)		0.6C, 0.95Cr, 0.3Mo, 1.4Ni
NSCT		L1
NSS 3		O2
NTC	(Barworth)	0.5C, 1Mn, 1Cr, 0.35Mo
NTC	(Huntsman)	0.4C, 0.5W, 0.4Cr
Nu-Die Xtra		H13
NV		H12
Nyblade		0.47C, 1Si, 3Ni, 0.6Cr, 0.2Mo
O		0.35C, 1.5Mn
O6S		W2
O9B		O1
OHD		1C, 1.6Cr, 0.5W
OK Crown		S1
OO		0.6C, 0.7Si, 1.1Cr, 1.9W, 0.3V
Optimax		0.38C, 0.9Si, 0.5Mn, 13.6Cr, 0.3V
Orvar Supreme		0.37C, 1Si, 0.4Mn, 5.3Cr, 1.4Mo, 0.9V
P 704		O2
P 720		L1
P1008		1.2083
P1009		1.2316
P256		0.55C, 0.7Mn
P280		0.6C, 0.6Cr
P552		0.3C, 4.25Ni, 1.25Cr, 0.3Mo
P553		0.4C, 1.5Ni, 1.1Cr, 0.3Mo
P558		0.3C, 2.5Ni, 0.7Cr, 0.5Mo
P564		0.3C, 3Ni, 0.74Cr
P576		1.2767
P602		0.4C, 0.65Mn, 1.1Cr, 0.3Mo
P609		0.4C, 0.8Mn, 1Cr
P618		0.4C, 0.3Ni, 3Cr, 1Mo, 0.25V
P973		1.2770
PAC		H19
Pax No. 2		1.2547
Pax Non-break No 2		S1
PCS		H12
PCSK		S1

Other tool steels	Comparison
PDS1	1.1740
PDX	0.28C, 0.85Cr, 2.25W, 0.5Mo, 0.3V, 2.25Ni
PE655	1.3243
PGT	O7
Pitho	O1
Plain Carbon Steels	W1
Plasmould	0.35C, 4.3Ni, 1.3Cr, 0.3V
PLMB/1	0.55C, 0.65Mn, 1.63Ni, 0.7Cr, 0.28Mo
PLMC/1	0.42C, 2.6Ni, 0.65Cr, 0.6Mo
PLMC/2	0.4C, 4.25Ni, 1.4Cr, 0.25Mo
Pluto Paramount	0.78C, 4.5Cr, 0.7Mo, 18.75W, 1.25V, 10Co
Pluto Perfectum	T4
Pluto Plus	M42
Pluto Premier	M15
Plutocrat	0.78C, 4.25Cr, 0.5Mo, 22W, 1Co
Plutog	1.3355
PN1	S5
Pneumo	0.45C, 0.75Si, 1.25Cr, 2W
Pnusnap OH	0.43C, 1Si, 1.8W, 1Cr
Pnusnap WH	0.35C, 1Cr, 1.8W
Premo	0.5C, 4Cr, 0.5Mo
Prima Mittel	1.1645
Prima Zah	1.1625
Prima Zahhart	1.1645
PRN2.DCCM	1.05C, 1.3Mn, 1.3Cr
PWE 893	0.25C, 8.25W, 2.4Cr, 0.18V, 0.4Mo, 2.35Ni
Q	0.4C, 0.8Mn
R 9030	0.35C, 0.75Cr, 0.5Mo, 2.75Ni
R18	1.3355
R18K5F2	1.3255
R6AM5	1.3343
R6M5	1.3554LW
R6M5K5	1.3243
RAB 420ESR	0.37C, 0.5Mn, 0.75Si, 13.5Cr, 0.3V
RAB1	0.4C, 4.1Ni, 1.3Cr, 0.3Mo
RAB20	0.4C, 1.5Mn, 2Cr, 0.2Mo
Ramax S	0.33C, 1.4Mn, 16.7Cr
RB 10	1.1645
RBD	H21
RCC Spezial	1.2601
RCC Supra	1.2379
RCC	1.2080
RCW2H	1.2581
RDC1	1.2606

(Continued)

Other tool steels	Comparison
RDC2	1.2343
RDC2V	1.2344
Red Band Cast Steel	W1
Red Lable	W1
REGIN 3	1.2542
Regor	A2
Remount	W1
RHB-E	0.22C, 2.25Ni, 10W, 2.25Cr, 0.45Mo, 0.20V
Rigor	A2
RKCM	1.2363
ROP 57	1.2601
ROP19	1.2344
ROP21	1.2363
RPG3	1.2365
RSD 13	A2
RT 10	1.1545
RT 1733	1.2510
RT 8	1.1525
RTO912	1.2542
RTW2H	1.2542
RTWK	1.2550
RUS	1.2842
RUS3	1.2510
RUS4	1.2419
RV	L3
RWA	1.2567
RWS	1.2510
S 10-4-3-10	1.3207
S 12-1-4-5	1.3202
S 18-0-1	1.3355
S 18-1-2-10	1.3265
S 18-1-2-5	1.3255
S 2-10-1-8	1.3247
S 2-9-1	1.3346
S 2-9-2	1.3348
S 2-9-2-8	1.3249
S 6-5-2	1.3343
S 6-5-2-5	1.3243
S 6-5-3	1.3344
S 7-4-2-5	1.3246
S.K. Silver Steel	1.2002
S.R.E.	T1
S200	1.3355

Other tool steels	Comparison
S305	1.3255
S400	M7
S401	1.3346
S402	M1 Special
S500	1.3247
S600	1.3343
S605	M3
S690	M4
S705	1.3243
SA1	1.2419
Saban Extra	T1
Saben 6-5-2	1.3343
Saben 652	M2
Saben HC	1.25C, 13.5W, 4.6Cr, 3.75V, 0.3Mo
Saben Kerau	0.75C, 22W, 4.25Cr, 1.5V, 0.25Mo
Saben Tenco	T5
Saben Wunda	T4
Sabex	0.3C, 9.5W, 2.25Cr, 0.15V, 1.75Ni
SBM	0.58C, 1Cr, 0.25V
SBR	1.1830
SC 13 NEOR	D3
SC 25	D2
SC 26	D3
SC 38	1.5C, 12Cr, 1.1V, 0.75Mo
SC 40	0.4C, 12Cr, 0.5Ni
SC 45 168	0.75C, 17Cr
SC 6-5-2	1.3342
SC	S4
SC90	1.5C, 1.1Mn, 0.9Cr
SCD	1.2363
SCH 3	1.4028
SCR1	0.47C, 1Si, 1.4Cr
SCS 2	1.4021
SCV 5	A2
SCV	L2
SD 20	0.35C, 1.2Cr, 1.75Ni
Senator A	H11
Senator B	H14
Senator C	H21
SG	H21
SGHV	1.2581
SGT	1.2419
SHC1	0.44C, 1Si, 0.65Mn, 0.65Cr, 3Ni
SICV	1.15C, 0.7Cr, 0.1V

(Continued)

Other tool steels		Comparison
Silver Steel		1.2002
SIW	(Balfour)	0.67C, 1.15Si, 0.7Mn, 0.6Cr, 1.3W
SIW	(Fortuna)	1.20C, 0.1V, 1W
SK 1		1.1673
SK 2		1.1663
SK 3		1.1645
SK 4		0.95C
SK 5		1.1625
SK 53		1.2510
SK 6		1.1625
SK 7		1.1740
SKC 11		1.2057
SKC 24		0.38C, 0.7Mn, 0.5Cr, 0.3Mo, 3Ni
SKC 3		1.1625
SKC 31		0.2C, 0.9Mn, 1.5Cr, 0.55Mo, 3Ni
SKD 1		1.2080
SKD 11		1.5C, 12Cr, 1Mo, 0.35V
SKD 12		1.2363
SKD 4		1.2567
SKD 5		1.2581
SKD 6		1.2343
SKD 61		1.2344
SKD 62		1.2606
SKD 7		0.33C, 3Cr, 2.75Mo, 0.55V
SKD 8		0.4C, 4.15Co, 4.35Cr, 0.4Mo, 2V, 4.15W
SKH 10		1.5C, 4.7Co, 4.1Cr, 4.7V, 12.5W
SKH 2		1.3355
SKH 3		1.3255
SKH 4		1.3265
SKH 4A		1.3265
SKH 51		1.3343
SKH 52		1.3344
SKH 53		1.3344
SKH 54		1.3C, 4.1Cr, 4.2V, 5.9W
SKH 55		1.3243
SKH 56		0.9C, 8Co, 4.1Cr, 5Mo, 1.95V, 6.2W
SKH 57		1.3207
SKH 58		1C, 4Cr, 8.7Mo, 1.95V, 1.8W
SKH 59		1.1C, 8Co, 4Cr, 9.5Mo, 1.2V, 1.5W
SKS 11		1.2562
SKS 2		1.2419
SKS 21		1.2515
SKS 3		1.2419
SKS 31		1.2419

Other tool steels	Comparison
SKS 4	0.5C, 0.75Cr, 0.75W
SKS 41	0.4C, 1.25Cr, 3W
SKS 43	1.2833
SKS 44	0.85C, 0.2V
SKS 5	0.8C, 0.35Cr, 1Ni
SKS 51	0.8C, 0.35Cr, 1.65Ni
SKS 7	1.2442
SKS 8	1.2008
SKS 93	1C, 0.95Mn, 0.4Cr
SKS 94	0.95C, 0.95Mn, 0.4Cr
SKS 95	0.85C, 0.95Mn, 0.4Cr
SKT 3	0.4C, 0.8Mn, 1Cr, 0.4Mo, 0.4Ni, 0.2V
SKT 4	1.2713
SLD 2	1.2379
SLD	1.2379
SLZ	0.36C, 1.75Si, 13Cr, 2.75W, 0.65V, 5.75Ni
SMN	S4
SMO	S5
SMV 200	O2
SND	W2
SNK	1.2770
SNSC	O1
Somcold	D2
Somdie	0.48C, 1Si, 0.5Mo, 1.20Cr, 0.07V, 1Ni
Somtuf	?C, 2Ni, 2W
SP3	1.1830
SP5W	1.1740
SP6W	1.1730
SPCR	O1
Spear 5/6/2	M2
Spear 50	0.55C, 0.6Mn
Spear 75	S1
Spear 9/2/1	M1
Spear AHC	S1
Spear B1	0.32C, 1.25Cr, 4.25Ni
Spear B2	0.20C, 13Cr
Spear D1	L4
Spear D12	D3
Spear D13	D4
Spear D14	D5
Spear D15	A2
Spear D16	D2
Spear D17	D2
Spear D5	H13

(Continued)

Other tool steels	Comparison
Spear D7	H12
Spear D9	H21
Spear DX	0.28C, 2.2W, 2.25Ni, 0.85Cr
Spear Leapfrog	0.65C, 14W
Spear M42	M42
Spear Mermaid	T1
Spear No 2 Vanadium	W2
Spear No 2	W1
Spear NS	O1
Spear PS	L2
Spear Superior	T6
Spear Triple Mermaid	T4
Special Ardho	0.35C, 3.2Ni, 0.78Cr
Special BB/HDS	H21
Special Cold Pressing Vanadium Steel	W2
Special Conqueror Vanadium	W2
Special HW	H21
Special K	D3
Special M	T1
Speedicut Leda	T4
Speedicut Maximum 18	T1
Speedicut Superleda	T5
Speedicut Vanleda	T15
Spenard	O2
Spezial K	1.2080
Spezial K5	1.2363
Spezial K8	1.2631
Spezial KMV	1.2379
Spezial KNL	1.2601
SPG Extra V	1.2344
SPG Extra	1.2343
SPG Special W	1.2606
SPM	O1
SPS	0.5C, 0.75Si, 0.2V, 0.7Mn, 2W, 0.9Cr
Spur 6/5/2	M2
Spur 9/2/1	M1
SPW	0.25C, 13Cr
SRE 500	T4
Sremo	M2
SS652	1.3343
SS921	1.3346
SSC	0.58C, 1.05Cr, 0.3V
ST	0.7C

Other tool steels	Comparison
Stag Extra Special	T4
Stag Major	T6
Stag Mo 562	M2
Stag V55	T15
Stag Vanco	1.52C, 17.5W, 5Cr, 8.75Co, 0.5Mo
Stage Special	T1
Stagmold	0.32C, 4.1Ni, 1.3Cr, 0.3Mo
Stamold H.T.	0.36C, 1Si, 1Mn, 16Cr, 1.2Mo
Statos CRD Spezial	1.2601
Statos CRD Supra	1.2379
Statos CRLS	1.2363
Statos Extra	1.2842
Statos Spezial	1.2080
Statos Superior	1.2419
Stavax ESR	0.38C, 0.9Si, 0.5Mn, 13.6Cr, 0.3V
STNS	O1
Stora 16	O1
Stora 18	S1
Stora 214	W2
Stora 25	T1
Stora 27	T4
Stora 29	M2
Stora 30	1.2C, 6.5W, 4Cr, 3.4V, 5Mo, 10Co
Stora 323	0.3C, 5.3W, 1.5Cr, 0.1V, 0.6Mo, 4.8Co
Stora 364	D2
Stora 424	M35
Stora 431	M1
Stora 433	M7
Stora 62 G	D3
Stora 62	D6
Stora 65	A2
Stora 67	H13
Stora 85	0.55C, 1Cr, 3Ni, 0.3Mo
SUJ 1	1.2057
SUJ 2	1.3505
SUJ 3	1.2127
SUJ 4	1.3505
SUJ 5	1C, 1Mn, 1Cr, 0.2Mo
Super Austenite	T1
Super AW23	0.3C, 4.1Ni, 1.25Cr, 0.25Mo
Super C12	D2
Super Capital	1.3C, 4.25Cr, 9W, 3.5V, 8.5Co, 3Mo
Super Chromium	D3
Super CS	D5

(Continued)

Other tool steels	Comparison
Super Dominant	T1
Super Inmanite	0.8C, 22W, 4.5Cr, 1.5V, 1Mo, 10Co
Super Invincible 5% Cobalt	T4
Super Invincible Advance 10% Cobalt	T5
Super Invincible TB	T8
Super Maxel	0.5C, 1.25Mn, 0.65Cr, 0.18Mo
Super Monarch	T1
Super Rapid Extra Mo	1.3343
Super Rapid	T1
Super Super Monarch (E1)	T4
Super TKL	S1
Superapid Extra	1.3355
Superior Spur	T1
Supermax 98	M42
Superwear	A7
SUS 403	1.4006
SUS 410	1.4006
SUS 420 J 1	1.4021
SUS 420 J 2	1.4028
SUS 431	1.4057
SUS 440 B	440 B
Sverker 21	D2
Sverker 3	D6
SW 111	1.05C, 1Cr, 1Mn, 1.2W
SW 55	O1
SW1	1.2419
SWS	1.2510
T 1040	W4
T Quality	W1
T4 (Rochling)	1.1730
T5 (Rochling)	1.1740
T6 (Rochling)	1.1740
TA	W1
TB	W1
TD	W1
TDC	F1
Tenax C1	L1
Tenax C2	0.6C, 0.7Mn, 0.7Cr
Tenax C9/5	W5
Tenax CTS	S1
Tenax CV	0.5C, 0.7Mn, 1Cr, 0.25V
Tenax DCB	0.3C, 4.25Ni, 1.25Cr, 0.3Mo
Tenax FPC 5	H11

Other tool steels	Comparison
Tenax FPCT	H12
Tenax FPDD	F2
Tenax K 250	D3
Tenax K250 CN	D5
Tenax K250MV	D2
Tenax PNS	O1
Tenitkl Special	1.2550
Tenitw Special	1.2542
Thermodie	0.55C, 0.9Cr, 0.75Mo, 2.15Ni
Thremalloy	0.27C, 8.5Cr, 0.55V, 9.5Co, 4Mo
Thyrapid 3243	1.3243
Thyrapid 3343	1.3343
Thyrapid 3346	1.3346
Thyrapid 3355	1.3355
Thyrodur 1525	1.1525
Thyrodur 1545	1.1545
Thyrodur 1625	1.1625
Thyrodur 1645	1.1645
Thyrodur 1730	1.1730
Thyrodur 1740	1.1740
Thyrodur 1830	1.1830
Thyrodur 2067	1.2067
Thyrodur 2080	1.2080
Thyrodur 2363	1.2363
Thyrodur 2379	1.2379
Thyrodur 2419	1.2419
Thyrodur 2436	1.2436
Thyrodur 2510	1.2510
Thyrodur 2542	1.2542
Thyrodur 2550	1.2550
Thyrodur 2601	1.2601
Thyrodur 2606	1.2606
Thyrodur 2718	1.2718
Thyrodur 2721	1.2721
Thyrodur 2762	1.2762
Thyrodur 2767	1.2767
Thyrodur 2826	1.2826
Thyrodur 2833	1.2833
Thyrodur 2842	1.2842
Thyroplast 2083	1.2083
Thyroplast 2162	1.2162
Thyroplast 2311	1.2311
Thyroplast 2312	1.2312
Thyroplast 2316	1.2316

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Other tool steels	Comparison
Thyroplast 2341	1.2341
Thyroplast 2711	1.2711
Thyroplast 2764	1.2764
Thyrotherm 2343	1.2343
Thyrotherm 2344	1.2344
Thyrotherm 2365	1.2365
Thyrotherm 2367	1.2367
Thyrotherm 2567	1.2567
Thyrotherm 2581	1.2581
Thyrotherm 2713	1.2713
Thyrotherm 2714	1.2714
Thyrotherm 2744	1.2744
Thyrotherm 2885	1.2885
TI	T1
TKL	S1
TM	W1
TMS	O2
Toba	0.4C, 0.7Mn, 1Cr, 0.2V, 0.5Ni
TOH	O1
Toughard	0.4C, 0.45Cr, 0.5W
TPM	O1
Treble Extra Cast Steel	W1
Treble Super Monarch (E4)	T6
TRG	W1
Triple 5 Monarch	T15
Triple Conqueror	F3
Triple Crescent	1.25C, 1.25Cr, 4.3W, 0.3V
Triple Griffin	1.35C, 0.25Cr, 2.75W
Triple Spur	T6
Triple Velos	T4
Triumphator 5	1.2363
Triumphator MW	1.2601
Triumphator VM	1.2379
Triumphator	1.2080
TTQ Triumph Superb Double Thousand	T6
Tufdie	?C, 13Cr, 3W, ?Ni, ?V
Tungsten Diamond	F3
Two Spur	T4
Tyrann Extra V	1.2542
U10	1.1645
U10A	1.1545
U13	1.1663
U3	1.2550

Other tool steels	Comparison
U8	1.1625
U8A	1.1525
UHB 11	0.5C
UHB 16	1.1525
UHB 19 Va	W2
UHB 20	1.1545
UHB 29	1.3343
UHB 424	1.3243
UHB 431	1.3346
UHB 9	1.1730
UHB Special	1.2606
UHB20	W1
Ultra Capital 22	0.76C, 4.25Cr, 22W, 3.5V, 8.5Co, 3Mo
Ultra Capital 395	M4
Ultra Capital Plus 1	T4
Ultra Capital Plus 2	T6
Ultra Capital	T1
US Ultra 2	1.2344
US Ultra 4	1.2606
US Ultra	1.2343
V 175	T2
V6N	1.2770
VALAND1	1.2581
Vamox	0.3C, 2.25W, 0.8Cr, 0.3V, 0.5Mo, 2.25Ni
VAP	T1
VC 12	T6
Velos 42	M42
Velos UR	T1
Velos	M2
VF	H19
VG	M15
Viaduct 15	0.45C, 0.7Si, 1.1Cr, 1.9W, 0.3V
Vigilant	0.55C, 0.7Mn
VMC (H)	0.33C, 3Cr, 0.13V, 0.5Mo
VMC	H13
VWMC	H12
W 10 Extra	1C
W 10 Prima	1C
W 11 Prima	1.1C
W 1230	H23
W 182	T2
W 63 K	0.65C, 1Mn
W 63	0.6C
W 85 K	0.8C, 1Mn

(Continued)

Other tool steels	Comparison
W 93 K	0.9C, 1Mn
W100	1.2581
W108	1.2678
W10V	1C, 0.1V
W14 MO	O6
W18	T1
W2N	1.2770
W300	1.2343
W302	1.2344
W304	H12
W320	1.2365
W321	1.2885
W324	H15
W43	0.45C
W500	1.2711
W8N	0.85C, 0.1V, 0.8Ni
WA 235	0.35C, 1Cr, 0.2V, 2W, 1Si
WA 245	0.45C, 1Cr, 0.2V, 2W, 1Si
WA 250	S1
WA 255	0.6C, 1Cr, 0.2V, 2W
WA 530	0.30C, 2.5Cr, 0.6V, 4.5W
WA 930	H20
WAMV	1.2567
Warranted Crucible Cast Steel	W1
WATCO	0.33, 0.9Cr, 0.7Mn, 0.12V
WCD	1.2606
WCD2	1.2343
WCDV	1.2344
WCM Co	H10A
WCM	1.2365
WCO	H19
WCPS	0.48C, 0.7Si, 1.2W, 1.5Cr, 0.15V, 0.25Mo, 0.7Ni
WEL	L1
WF 8	0.62C, 1Mn, 0.6Cr, 1Si
WGKL	1C, 1.5Cr
WH2	1.3355
WHC	0.58C, 0.5Mn
White Band Cast Steel	W1
White Label	W2
Wing 111 A	1C, 1Cr, 1Mn
Wing 111 B	1C, 0.5Cr, 1.5Mn, 0.25V
Wing's Double Shear Temper	W1
WK5K	1.2567

Other tool steels	Comparison
WKM33	1.2365
WKZ	1.2581
WKZ50	1.2567
WL	A7
WM 13	0.4C, 13Cr
WMD Extra	H10A
WMD	1.2365
WMEV	1.2344
WMN	0.28C, 3Cr, 9.5W, 2Ni, 0.15V
WMO	1.2365
WMS	1.2606
WMWH	1.2581
WO 3	0.6C
Wolfram	S1
WS	1.07C, 1.2Mn, 1.7W, 1.1Cr
WSB Extra	1.15C, 2W
WSMA	1.2343
WVC	H19
WZ	0.4C, 3Cr, 0.25V, 0.4Mo, 11W
X 10 Cr 13	1.4006
X 100 CrMoV 5 1 KU	1.2363
X 100 CrMoV 5 1	1.2363
X 100 CrMoV 5	1.2363
X 105 CrCoMo 18 2	1.4528
X 12 Cr 13	1.4006
X 155 CrVMo 12 1 KU	1.2379
X 155 CrVMo 12 1	1.2379
X 16 CrNi 16	1.4057
X 160 CrMoV 12	1.2601
X 165 CrMo	1.2601
X 165 CrMoV 12	1.2601
X 165 CrMoW 12 KU	1.2601
X 19 NiCrMo 4	1.2764
X 20 Cr 13	1.4021
X 205 Cr 12 KU	1.2080
X 21 Cr 13 KU	1.4021
X 210 Cr 12	1.2080
X 210 CrW 12	1.2436
X 215 CrW 12 1 KU	1.2436
X 22 CrNi 17	1.4057
X 220 CrVMo 12 2	1.2378
X 30 Cr 13	1.4028
X 30 NiCrMo 16 6	1.6747
X 30 WCrV 5 3 KU	1.2567

(Continued)

Other tool steels	Comparison
X 30 WCrV 5 3	1.2567
X 30 WCrV 9 3 KU	1.2581
X 30 WCrV 9 3	1.2581
X 30 WCrV 9	1.2581
X 31 Cr 13 KU	1.4028
X 32 CrMoCoV 3 3 3	1.2885
X 32 CrMoV 3 3	1.2365
X 36 CrMo 17	1.2316
X 37 CrMoV 5 1 KU	1.2343
X 37 CrMoV 5	1.2343
X 37 CrMoW 5 1	1.2606
X 38 CrMo 16 1	1.2316
X 38 CrMo 16	1.2316
X 38 CrMoV 5 1	1.2343
X 40 Cr 13	1.4034
X 40 Cr 14	1.4034
X 40 CrMoV 5 1 1 KU	1.2344
X 40 CrMoV 5 1	1.2344
X 40 CrMoV 5 3	1.2367
X 40 CrMoV 5	1.2344
X 41 Cr 13 KU	1.2083
X 42 Cr 13	1.2083
X 45 Cr 13	1.4034
X 45 NiCrMo 4	1.2767
X 50 CrMoW 9 11	1.2631
X 55 CrMo 14	1.4110
X 6 CrMo 4	1.2341
X 82 WMoV 6 5	1.3343
X 91 CrMoV 18	1.2361
XC 100	1.1545
Y 100 C 6	1.2067
Y_1 105 V	1.2833
Y_1 105	1.1545
Y_1 80	1.1525
Y_1 90	1.1525
Y100C6	1.2067
Y1120	1.2631
Y_2 120	1.1663
Y_2 140	1.1673
Y_3 45	1.1730
Y_3 60	1.1740
YC3	1.1545
YC5	1.1830
YCK2	1.2631

Other tool steels	Comparison
YDC	1.2567
Yellow Label Steels	W1
Yellow Label	W1
YEM	1.2365
YHX2	1.3355
YK3	1.1545
YK5	1.1830
YK50	1.2842
YXM1	1.3343
YXM4	1.3243
YXMT	1.3346
Z 10 C 13	1.4006
Z 100 CDV 5	1.2363
Z 100 DCWV 09-04-02-02	1.3348
Z 110 DKCWV 09-08-04-02-01	1.3247
Z 110 WKCDV 07-05-04-04-02	1.3246
Z 12 C 13	1.4006
Z 120 WDCV 06-05-04-03	1.3344
Z 130 WDCV 06-05-04-04	1.3344
Z 130 WKCDV 10-10-04-04-03	1.3207
Z 15 CN 16-02	1.4057
Z 155 CDV 12	1.2601
Z 155 CVD 12-1	1.2379
Z 160 CDV 12	1.3279
Z 20 C 13	1.4021
Z 200 C 12	1.2080
Z 200 C 13	1.2080
Z 210 CV 13	1.2080
Z 210 CW 12	1.2436
Z 25 WCNV 9	0.28C, 2.25Ni, 2.5Cr, 9.5W, 0.15V
Z 30 C 13	1.4028
Z 30 CDV 12-28	1.2365
Z 30 WCV 9	1.2581
Z 30 WCV 9-3	1.2581
Z 32 WCV 5	1.2567
Z 35 CDV 5	1.2344
Z 35 CWDV 5	1.2606
Z 38 CDV 5	1.2343
Z 38 CDV 5-3	1.2367
Z 40 C 14	1.4034
Z 40 CDV 5	1.2344
Z 40 CDV 5-1	1.2344
Z 75 WV 18-01	1.3355
Z 8 WDCV 6	1.3343

(Continued)

Other tool steels	Comparison
Z 80 WCV 18-04-01	1.3355
Z 80 WDV 06 05	1.3343
Z 80 WKCV 18-05-04-01	1.3255
Z 85 DCWV 08-04-02-01	1.3346
Z 85 WDCV 06-05-04-02	1.3343
Z 85 WDKCV 06-05-05-04-02	1.3243
Z 90 WDCV 06-05-04-02	1.3342
Z 90 WDKCV 06-05-05-04-02	1.3243
ZN	0.25C, 8.5W, 3Cr, 0.25V, 2.25Ni

-H May include the letter 'H'.

This is my list of tool steels and what I consider to be comparable AISI, Werkstoff or chemical compositions. I had been adding to this list over many years until I was recommended to purchase a book called 'Stahlschussel' (Key to steel). This book contains more than 45,000 standards and steel-brands of approx. 250 steel works and suppliers from 22 different countries. If you feel that you need to continually update your tool steel list I would strongly recommend the purchase of this book. Contact Mito Construction and Engineering Limited, Adams Wharf, 19 Yeoman Street, London SE8 5DT, Tel. 0171 2310918.

Appendix II
Elements and their symbols

Symbol	Element	Melting point °C	Properties and uses
Al	Aluminum	660	Widely used light metal
Ar	Argon		An inert gas used in TIG welding
Be	Beryllium	1,285	A light metal used to toughen copper
C	Carbon		An essential element in steel, especially in hardenable steels
Cr	Chromium	1,900	A corrosion resistant material which increases hardenability and resistance to wear. An essential element in stainless steel and heat resistant steels
Co	Cobalt	1,495	Used mainly in high-speed steels and permanent magnets
Cu	Copper	1,083	A metal of high electrical and heat conductivity and alloyed with other metals to give brasses and bronzes
Fe	Iron	1,536	A fairly soft white metal when pure. A major element in steel
He	Helium		A light gas generally used together with argon gas to weld heavier sections of aluminum and copper
Mg	Magnesium	651	Used as an alloy in aluminum to increase its work hardening ability and corrosion resistance to sea water
Mn	Manganese	1,260	Used in steel making as a deoxidant, it also increases the hardenability and tensile strength but decreases

(Continued)

Symbol	Element	Melting point °C	Properties and uses
			ductility. Also added to non-heat treatable aluminum to improve its mechanical properties
Mo	Molybdenum	2,620	Increases hardenability in steels. Used in high speed steels and also used in stainless to increase resistance to corrosion
Ni	Nickel	1,458	A widely used metal in steels, coppers and aluminums to improve toughness
Pb	Lead	327	A heavy metal used as an alloy to improve machinability in many metals. Higher levels (1% plus) may cause weldability problems
Si	Silicon	1,427	Generally used as a powerful deoxidizer in steels. It also increases strength and ductility in aluminums and if combined with magnesium in aluminum it allows precipitation hardening
W	Tungsten	3,410	Generally the main constituent in high-speed steel. Also used as the electrode in TIG welding
V	Vanadium	1,720	Added to steels to increase hardenability and also to give a greater resistance to shock loading
Z	Zinc	419	Widely used for galvanizing mild steel and when alloyed with copper makes brass. Also used as a basis for some die-casting alloys and when added to aluminum drastically increases strength and allows precipitation hardening

Appendix III
Millimeters to inches conversion table

mm	inches	mm	inches
1	0.0394	90	3.8076
2	0.0787	100	3.9370
3	0.1181	110	4.3307
4	0.1575	120	4.7244
5	0.1968	130	5.1181
6	0.2362	140	5.5118
7	0.2756	150	5.9055
8	0.3150	160	6.2992
9	0.3543	170	6.6929
10	0.3937	180	7.0866
20	0.7874	190	7.4803
30	1.1811	200	7.8740
40	1.5748	210	8.2677
50	1.9685	220	8.6614
60	2.3622	230	9.0551
70	2.7559	240	9.4488
80	3.1496	250	9.8425

Appendix IV
Temperature conversion table

Centigrade-Fahrenheit		Fahrenheit-Centigrade	
50	122	120	49
60	140	140	60
70	158	160	71
80	176	180	83
90	194	200	93
100	212	220	104
110	230	240	115
120	248	260	127
130	266	280	138
140	284	300	149
150	302	320	160
160	320	340	171
170	338	360	182
180	356	380	193
190	374	400	204
200	392	420	215
210	410	440	226
220	428	460	238
230	446	480	249
240	464	500	260
250	482	520	271
260	500	540	282
270	518	560	293
280	536	580	304
290	554	600	315
300	572	660	349
350	662	710	376
400	752	750	399
450	842	840	449
500	932	930	498
550	1,022	1,020	549
600	1,112	1,110	598

Appendix V
Hardness conversion chart

Vickers, HV	Rockwell C	Brinell	Vickers, HV	Rockwell C	Brinell
940	68	–	410	41	388
920	67	–	400	40	379
900	67	–	390	39	369
880	66	767	380	38	360
860	65	757	370	37	350
840	65	745	360	36	341
820	64	733	350	35	331
800	64	722	340	34	322
780	63	710	330	33	313
760	62	698	320	32	303
740	61	684	310	31	294
720	61	680	300	29	284
700	60	656	295	29	280
690	59	647	290	28	275
680	59	638	285	27	270
670	58	630	280	27	265
660	58	620	275	26	261
650	57	611	270	25	256
640	57	601	265	24	252
630	56	591	260	24	252
620	56	582	255	23	243
610	55	573	250	22	238
600	55	564	245	21	233
590	54	554	240	20	228
580	54	545	230	18	219
570	53	535	220	15	209
560	53	525	210	13	200

(Continued)

Vickers, HV	Rockwell C	Brinell	Vickers, HV	Rockwell C	Brinell
550	52	517	200	11	190
540	51	507	190	9	181
530	51	497	180	6	171
520	50	488	170	3	162
510	49	479	160	0	152
500	49	471	150	–	143
490	48	460	140	–	133
480	47	452	130	–	124
470	46	442	120	–	114
460	46	433	110	–	105
450	45	425	100	–	95
440	44	415	95	–	90
430	43	405	90	–	86
420	42	397	85	–	81

Job no.	Company	Description	Date
Contact	Material	HRC	Quantity
Instruction sketch		Preparation sketch	
Pre-inspection			
Visual		Dye pen	
Weld process		Pre-heat	
Consumable 1			
2			
3			
Gas		Backing gas	
Other requirements			
Operation:	Quantity	Sign	Date
Preparation			
Weld			
Weld			
Cooling:	Heat insulating material	Air	
Final inspection			
Dye pen		Visual	

Job no.	Company	Description	Date
Contact	Material	HRC	Quantity

Instruction sketch	Preparation sketch

Pre-inspection					
Visual			Dye pen		
Weld process			Pre-heat		
Consumable	1				
	2				
	3				
Gas			Backing gas		
Other requirements					

Operation:	Quantity	Sign	Date
Preparation			
Weld			
Weld			

Cooling:	Heat insulating material		Air	

Final inspection					
Dye pen			Visual		

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