"FEASIBILITY OF AUTOMATING THE PRODUCTION OF CARBIDE-TIPPED MILLING CUTTERS"

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Feasibility of automating the production of carbide tipped milling cutters.

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SUMMARY

It is intended that this thesis describes, analyses and appraises the various techniques of automating the brazing of tungsten carbide tipped tools. It also investigates the control of parameters for the intended future automation of the helical forming of the tips prior to being brazed.

The first part involved performing a feasibility study into the various techniques of brazing, commonly available, that is, vacuum, furnace, induction, torch and bath brazing, and assessing the merits of each for the adaption to brazing tungsten carbide tips to tool bodies. The techniques were viewed in conjunction with the filler metal alloy, jigging arrangement, braze temperature, atmosphere, joint configuration and design, plus any mechanical properties that may be affected during the braze cycle (eg. cracking of tips due to different coefficients of expansion).

The second part of the thesis begins with a review of the production of helical tungsten carbide tips leading to experimental work undertaken to measure the parameters of the manual method (i.e., force, displacement, temperature), utilising a "Macsym" measurement and control system. A considerable amount of work was done to allow such parameters to be measured in hostile conditions (i.e., in an induction heating environment where RFI was present, and in conditions heavily affected by graphite dust). The experimental techniques used to solve these problems are discussed. Finally, graphs were plotted for Force versus Displacement and Force, Displacement, and Temperature versus Time for the various tests performed.

The study shows that brazing of tungsten carbide cutting tools can be automated using a torch brazing method, with pre-placement of filler in a modified tool body design.

Automation of the helical forming of the tips is very much dependent upon the efficient control of the difficult to measure parameters, although not impossible.

Keywords :- Carbide milling cutters, Automated brazing, Forming helical carbide tips.

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1 INTRODUCTION

Tungsten carbide tipped tools have found steadily increasing use in the machine tool industry, particularly over the last twenty five years. Over this period, with the increased demand particularly attributable to the aerospace industry, emphasis on increased productivity, and lower manufacturing costs, has brought the design and development of highly sophisticated numerical control machine tools. With the advent of these highly productive machines, and in order to fully utilise them, it was necessary to develop cutting tools with a much improved performance, enabling them to operate at optimum productivity. In recent years, research has resulted in the production of tungsten carbide helical fluted tools, with improved dimensional accuracy and consistency in shape, without limitations in length. These tools can now be produced to any helix angle up to 60 degrees, with any diameter from 6 mm to 200 mm and any direction of rotation and cut to an accuracy of plus or minus 0.05 mm per 25 mm helical form.

The introduction of these more complex tools has substantially increased the costs of production. The higher cost is acceptable since it gives better performance and reliability. But the demand for improved efficiency grows, because of the competition.

In order to produce the carbide tools more efficiently and economically the method of their production must be improved. As a result of a particular manufacturer of carbide cutting tools experiencing problems when trying to improve the production of these tools, collaboration between Aston University, Marwin Cutting Tools Ltd, and the Science and Engineering Research Council, led to a Teaching Company Programme being implemented.

Marwin Cutting Tools Ltd., produce a very diverse range of cutting tools for the machine tool industry. Of greatest current interest, the process of manufacturing a helical milling cutting tool of the type shown in Figure 1.1, begins with the production of the tool bodies, either by :

1. Machining from bar stock, or

2. Investment casting (with some subsequent machining)

Both processes provide a tool body into which the carbide tips, produced by a unique manual process, can be brazed, to give the finished cutting tool.

There are a number of areas in which difficulties are being experienced in the current methods of production of these particular cutting tools.

The production of the helical formed tungsten carbide tips, is performed concurrently with the preparation of the tool bodies, (see fig 1.2).

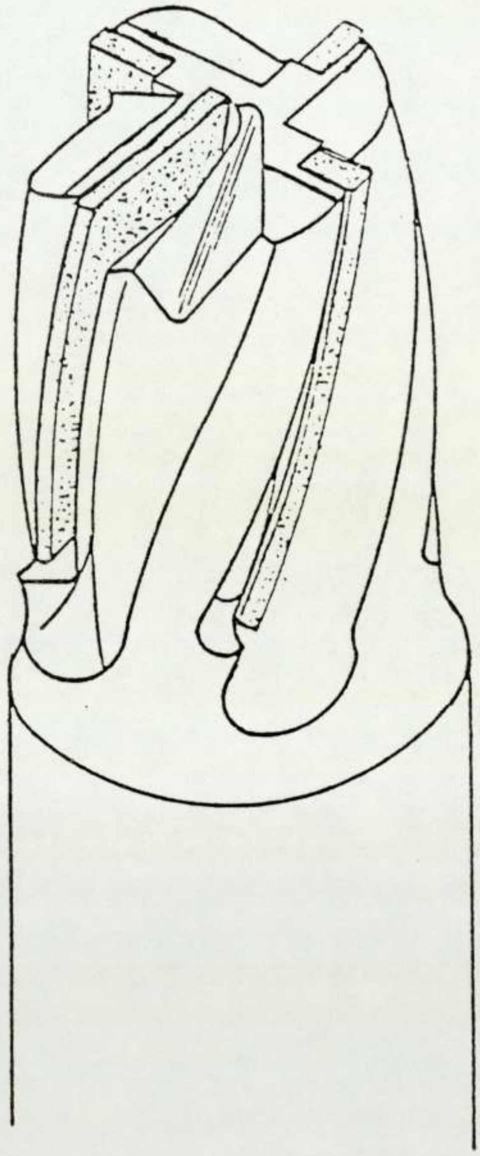


FIGURE 1.1 TYPICAL MILLING CUTTER

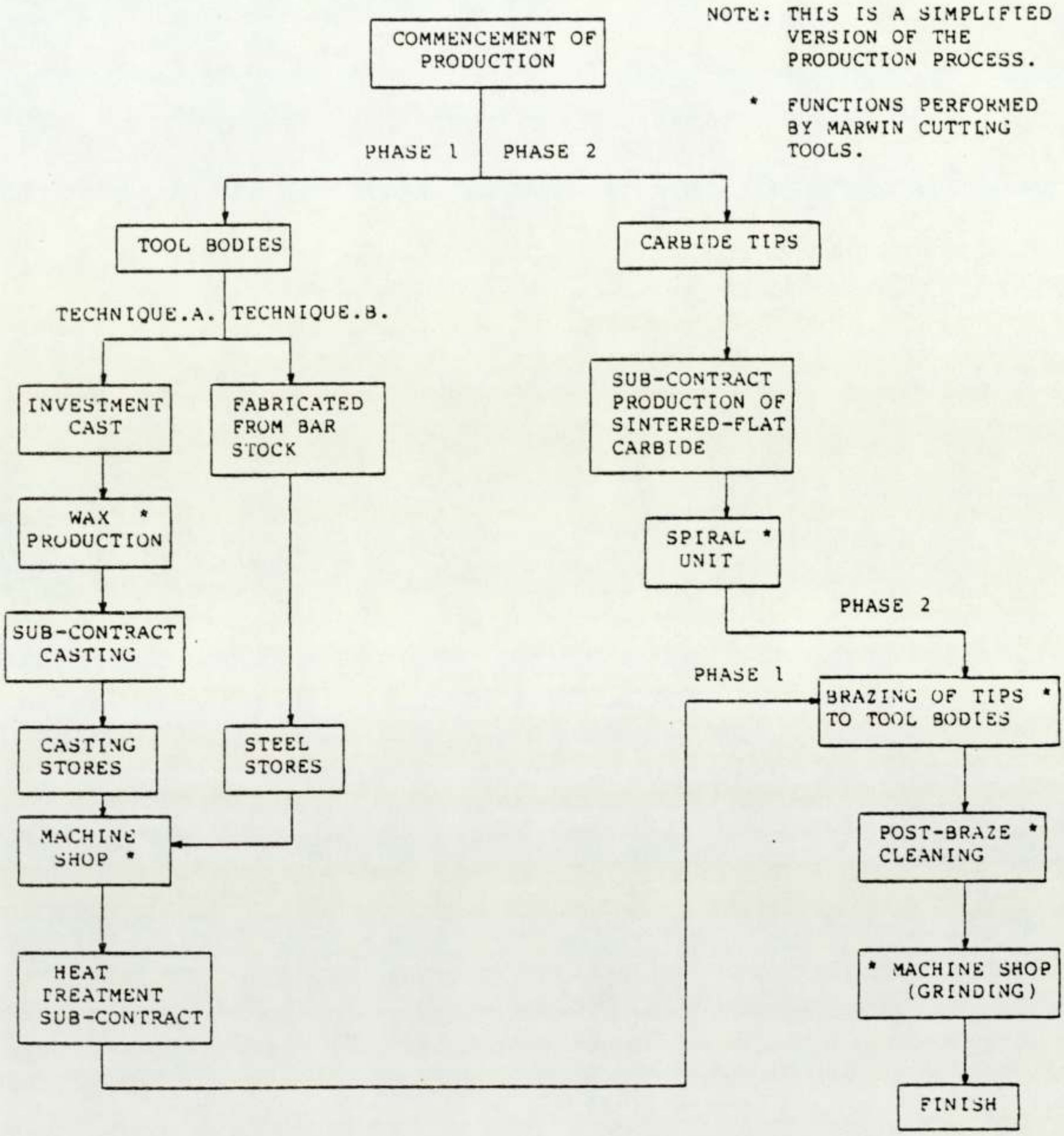


FIGURE 1.2 SCHEMATIC DIAGRAM OF CUTTING TOOL PRODUCTION

However, the tool bodies can be manufactured at a rate which far exceeds the production of the helical tips, since the helical forming is performed manually. Thus, there is a need to produce the tips at a more efficient rate than is currently being achieved.

Various steels are used for the manufacture of the tool bodies to which the tungsten carbide tips are brazed.

1. A2 (A.I.S.I.) Investment cast

2. M2 (A.I.S.I.) Machined from bar stock

3. 817M40 (B.S. 970) Machined from bar stock

4. 080M40 (B.S. 970) Machined from bar stock

The joining of the tips to the bodies is also performed manually by Torch Brazing. This inevitably reduces the through-put rate of the finished cutting tools.

Thus, two areas were identified as being in need of detailed study, with the objective of increasing the efficiency of production of carbide tipped tools, namely :-

1. Automation of joining carbide tips to bodies, and

2. Automation of the helical forming of the carbide tips

Initially a detailed feasibility study was made of the various techniques available for the automatic brazing of the preformed helical tungsten carbide inserts into the tool bodies. This entailed looking at the technical and economic implications of utilizing a particular technique, methods of application and the techniques of automation.

The other study examined the feasibility of developing an automated unit for the helical forming of the tungsten carbide inserts. The manually operated equipment was instrumented so that process parameters could be established. This formed a basis for appraising possible methods of automation, with the objectives of increased productivity and reduced tip rejection.

2 BRAZING SECTION

The object of this section is to discuss the advantages, disadvantages and consequences of various techniques reviewed for brazing tungsten carbide tool tips to tool bodies. It is done in the context of the complexity of shape, size, and numbers of components required to be brazed, in order to propose the most suitable method for automation.

2.1 FUNDAMENTALS OF BRAZING

The brazing process is defined as a means of joining two materials by heating them to a suitable temperature to melt a filler metal having a melting temperature lower than that of either of the parent materials. The filler metal flows between the closely fitting surfaces of the joint by capillary attraction. Where the melting temperature of the filler is above 450 C the process is called brazing, if, below 450 C the process is refered to as soldering [1]. For succesful brazing the surfaces being joined need to be free from "dirt" and oxide films. Degreasing is normally the first stage of the operation. To achieve the other requirement a flux is used, or the process is carried out in a furnace under reducing conditions, such as a vacuum, or a hydrogen containing atmosphere.

The braze alloy can be 'deposited' in the form of a shaped part on the gap to be brazed, or 'applied' by way of a continuously fed wire. The deposition of the shaped braze is done by hand with the flux usually being applied to the joint at the same time. If braze wire is applied to the gap, then in the case of mechanical brazing, this is done by means of special wire feed units. With the braze wire being applied by hand the joint can also be supplied with flux by hand at the time when the parts to be brazed are joined. It is, however, also possible to feed a flux-filled braze wire by means of a suitable feed unit to the joint to be brazed. It is also possible to arrange for the flux supply by means of special flux metering units.

In the case of torch brazing (see section 2.4.4) it is further possible to guide the fuel gas over a special flux, so that it is enriched with the flux which then reaches the gap to be brazed within the flame together with the fuel gas [1]. Whichever method 'deposited' or 'applied', is chosen depends upon the production figures, the shape of the gap to be brazed, the size of the workpiece and its material characteristics.

For each workpiece there is an optimum thermal cycle. This includes the shortest possible braze time, and the provision that neither the workpiece, flux or braze alloy is over-heated. If the parts to be brazed are heated too quickly, then there will be large temperature gradients within the workpiece which could prevent the achievement of a satisfactory brazed joint. If the workpiece is heated too slowly, and shaped braze alloy having a wide melting range is used, the braze alloy may be subject to segregation and the resultant primary melt may be prematurely drawn off by the capillary force into the gap to be brazed. This then causes the formation of a braze residue with a higher melting point which remains solid. In addition to the consideration of the optimum rate of heating it is important to use a braze alloy with a relatively narrow solidification range when shaped braze alloy is used for brazing. Here, braze alloys which have working temperatures within the mid 600 C range and a melting range of approximately 40 C have proven particularly suitable i.e. L-Ag 40 Cd, L-Ag 49, L-Ag 50 etc., (as can be seen in table 2.1). Thus, the small melting interval allows the braze to uniformly liquify and its total amount is involved in the brazing process [1]. Especially when shaped braze alloy is used, the braze should not be melted by the source of the heat but by the heat of the workpiece [1].

Equipment currently developed by manufacturers of brazing systems permits the automatic feeding of the braze wire, which can also be filled with flux, and the automatic feeding and metering of the flux in the form of paste, a liquid or a powder.

MANUF.	TRADE NAME	DIN 8513-1969	B.S. 1845-1977	% ELEMENTS Ag	Cu	Zn	Mn	Ni	Cd	Sn	P	Pb	Al	Si	others	Melting Range (°C)	Work Temp(°C)	Recomended Joint Gap (mm)	Shear Strength (N/mm²)	REMARKS
Degussa	4900	L-Ag49	Ag18	49	16	23	7.5	4.5	-	-	-	-	-	-	-	625-705	650	*	250-300	Brazing of
Degussa	49/Cu	-	-	49	27.5	20.5	2.5	0.5	-	-	-	-	-	-	-	670-690	650	*	150-300	Carbide_
Degussa	5009	L-Ag50	Ag9	50	15.5	15.5	-	3	16	-	-	-	-	-	-	645-690	660	*	*	tipped
Sheff.S.	MX18N	-	-	48	15.5	15.5	-	3	18	-	-	-	-	-	-	640-660	*	*	*	tools
Sheff.S.	MX20N	-	Ag6	50	15.5	15.5	-	3	16	-	-	-	-	-	-	635-655	*	*	*	
Sheff.S.	MX8N	-	-	38	19	18	-	3	22	-	-	-	-	-	-	640-670	*	*	*	
Sheff.S.	MX12	-	Ag2	42	17	16	-	-	25	-	-	-	-	-	-	610-620	*	*	*	Most Metals - except for
Sheff.S.	MX10	L-Ag40Cd	Ag10	40	19	21	-	-	20	-	-	-	-	-	-	595-630	*	*	*	Al,Zn, or Mn base alloys.
Sheff.S.	M15MN	L-Ag49	Ag18	49	16	23	7.5	4.5	-	-	-	-	-	-	-	625-705	690	*	*	Higher Residual Stress than M12MNT.
Sheff.S.	M12MNT	-	-	42	21	27	4	4	-	2	-	-	-	-	-	665-750	*	*	*	Higher Shear Strength than MX8,18,20N.
Sheff.S.	Plymetal	-	Cu between MX18N													640-660	*	*	*	Suitable only up to 40 mm Carbide.
Sheff.S.	H.O.T.	-	Ag6 1966	60	30	-	-	-	-	10	-	-	-	-	-	600-720	*	*	*	For joints which are exposed to
Sheff.S.	H12	L-Ag72	Ag7	72	28	-	-	-	-	-	-	-	-	-	-	780-780	780	*	*	Vacuum conditions.
Sif-Bronze	NO.2	L-Ms	CZ8	-	46-50	Rem	-	9	-	-	0.25	0.05	0.01	0.25	0.5	920-980	880	*	540	Cutting tips.
J.M.M.	Easyflo 2	-	Ag2	42	*	*	-	-	*	-	-	-	-	-	-	608-617	*	0.05-0.12	441	Very fluid -for small components.
J.M.M.	DIN Argofl	L-Ag40Cd	Ag10	40	*	*	-	-	*	-	-	-	-	-	-	595-630	*	*	456	Good flow.
J.M.M.	Silver fl 55	-	Ag14	55	*	*	-	-	-	*	-	-	-	-	-	630-660	*	0.05-0.12	415	
J.M.M.	Easyflo 3	L-Ag50CdNi	Ag9	50	*	*	-	*	*	-	-	-	-	-	-	634-656	*	0.1-0.3	490	General purpose good mech. properties.
J.M.M.	Argo-Braze 38	-	-	38	*	*	-	*	*	-	-	-	-	-	-	615-655	*	*	*	Economical alternative to No 3.
J.M.M.	Argo-Bze 49H	L-Ag49	Ag10	49	*	*	*	*	-	-	-	-	-	-	-	680-705	*	*	*	Cadmium free alt. to No 3 - Mn aids wetting.
J.M.M.	Argo-Bze 49LM	-	-	49	*	*	*	*	-	-	-	-	-	-	-	670-710	*	*	*	Good wetting -Suitable for small carbides.
J.M.M.	Argo-Bze 40	-	-	40	*	*	-	*	-	-	-	-	-	-	-	670-780	*	0.1-0.25	*	Higher melting point and
J.M.M.	Argo-Bze 25	-	-	25	*	*	*	*	-	-	-	-	-	-	-	710-810	*	*	*	good wettability.
J.M.M.	Easyflo Tri-Foil C	Easyflo bonded to both sides of a copper shim														620-630	*	*	*	For large carbides - stress absorbing.
J.M.M.	Easyflo Tri-Foil 'CN'	Easyflo bonded to both sides of a copper - nickel shim														620-630	*	*	*	For joints of high comp. stress during service.
J.M.M.	AB49 Tri-Foil	Argo-braze 49LM bonded to both sides of a copper shim														670-710	*	*	*	Cadmium free alternative to Tri-Foil 'C'.
A.W.S.	B Ag-8	-	-	71-73	Rem	-	-	-	-	-	-	-	-	-	0.15	779-779	*	*	*	
A.W.S.	B Ag-3	-	-	49-51	14-16	13-17	-	2.5-3.5	15-17	-	-	-	-	-	0.15	632-688	*	*	*	
A.W.S.	B Ag-4	-	-	39-41	29-31	26-30	-	1.5-2.5	-	-	-	-	-	-	0.15	671-779	*	*	*	
A.W.S.	B Cu	-	-	-	99.9	-	-	-	*	-	-	-	-	-	0.1	1083-1083	*	*	*	
A.W.S.	B Cu P	-	-	2-16	Rem	-	-	-	-	-	4.8-7.5	-	-	-	-	643-524	*	*	*	

* Data not available

TABLE 2.1 BRAZE FILLER CONSTITUENTS

2.2 CURRENT METHOD EMPLOYED BY MARWIN CUTTING TOOLS FOR THE BRAZING

At present the brazing of the tungsten carbide tips to the tool bodies is performed by Manual Torch Brazing. The operator uses his skill to control the braze cycle.

There are chiefly two areas to the brazing of the cutting tools (see fig 2.1).

1. the complete manufacture and brazing of the new cutting tools

2. re-tip brazing of old cutting tools

The current production output (including re-tips) for finished cutting tools is approximately 800 per week, but this figure can vary depending upon the number, size and complexity of the cutting tools required.

The normal size of the cutting tools produced can vary from a carbide length of 12 mm up to 200 mm and diameter of 9 mm up to 200 mm. These dimensions are flexible since Marwin's produce special cutting tools to customer's requirements.

2.2.1 Brazing Cycle For New Tools -

The newly produced tool body and helical inserts are passed to the brazing section. The operator coats the carbide insert with a Sif-bronze, usually performed at temperatures between 940 C and 960 C,

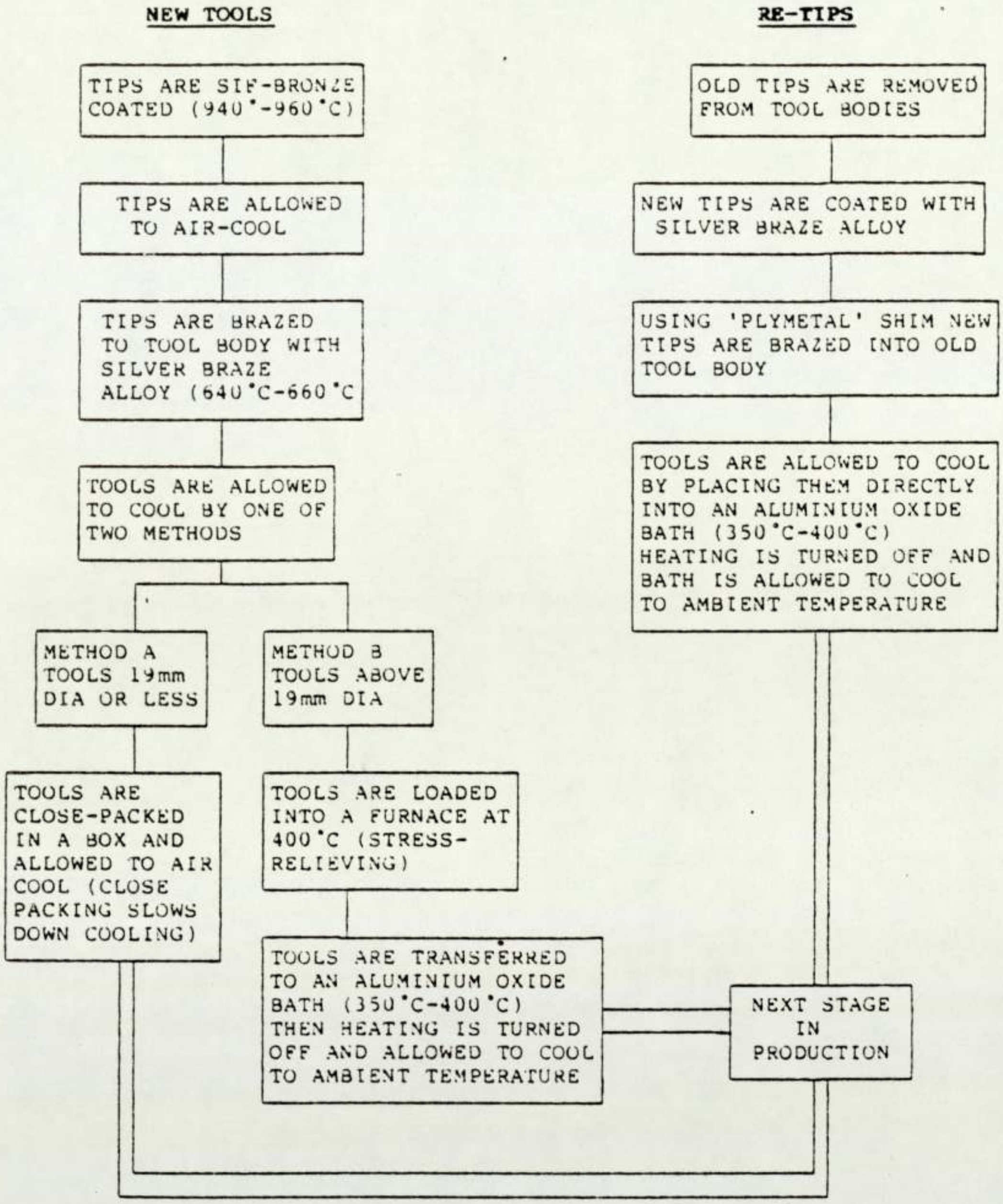


FIGURE 2.1 MANUFACTURING SEQUENCE FOR BRAZING OF TUNGSTEN CARBIDE TIPS TO TOOL BODY

with an oxy-acetylene torch. This is done so that the Sif-bronze absorbs any stresses that are induced in the joint, after the brazing of the carbide tip to the tool body. The stresses set-up by variations of expansion coefficient are sufficient to cause plastic deformation of the Sif-bronze which then relieves the stress, preventing fracture. Thus, the sif-bronze forms a 'buffer' between the two materials which have different coefficients of expansion.

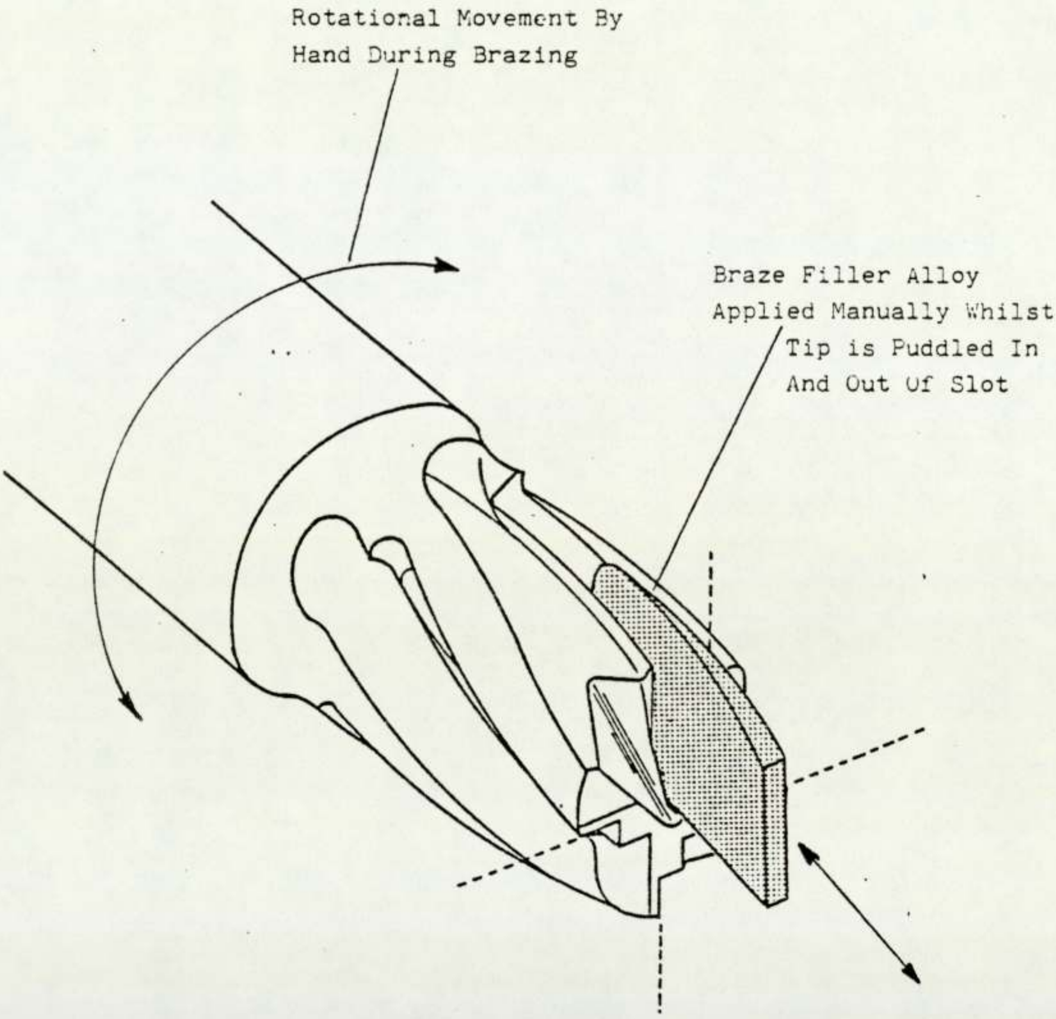
After sif-bronze coating, the carbides are allowed to air cool. Then using a silver brazing alloy rod (48% Ag, 15.5% Cu, 15.5% Zn, 3% Ni, 18% Cd) which has a narrow melting range of 640 C to 660 C, the operator brazes the tip into the tool body.

NOTE

> The temperature for brazing is controlled by the skill of the operator, due to the use of a hand torch providing the heat source. During the heat cycle, the operator actually 'puddles' the tip into place, in order to alleviate any problems of flux entrapment within the joint. (see fig 2.2)

The tools are then allowed to cool in one of two ways which is determined by the size of the tool.

Small cutting tools (19 mm diameter or less) are allowed to air cool in a box where they are closely-packed, and as a result of the close



MILLING CUTTER HELD AT A HORIZONTAL POSITION WHEN BRAZED MANUALLY - WITH ALLOWANCE FOR ROTATIONAL MOVEMENT OF TOOL BODY WHILST TIP IS PUDDLED INTO POSITION IN SLOT DURING BRAZING

FIGURE 2.2 TYPICAL CUTTER ARRANGEMENT FOR MANUAL BRAZING packing the cooling is slower than if cooled separately.

Large cutting tools (above 19 mm diameter) are slowly cooled by, initially loading them into a furnace which is held at a temperature of 400 C, to allow the stresses to be relieved in the brazed joint, tool body and carbide tips. They are kept in the furnace for approximately 1 hour. They are then transferred into an aluminium oxide bed which is at a temperature within 350 C to 400 C, the bath is then 'switched-off' and the tools are allowed to cool to ambient temperature. This can take up to 24 hours.

Once the cutting tools are cooled they receive any post-braze cleaning that is necessary and are then passed to the final stage in production, for grinding.

2.2.2 Re-tip Brazing -

Marwin Cutting Tools provide a service whereby they will re-tip old cutting tools, generally Marwin originals.

The old tool is heated up and the tip removed, thus the tool body is salvaged.

The new carbide tip is coated with a similar silver braze alloy which is used for new tools. A 'plymetal' shim (i.e., copper between silver braze alloy) is positioned in the old tool body and the new tip is then torch brazed into position. The 'plymetal' shim provides a similar interface between the tool body and the tip, as the sif-bronze does for new tools. (ie it relieves stress within the joint).

The re-tip tools are not put into the furnace, since the tool bodies have already been stress relieved when manufactured from new. Instead they go directly to the next stage of cooling which involves placing them into the aluminium oxide bath (350 C - 400 C) which is then 'switched-off' and the tools allowed to cool to ambient temperature.

The process of slowly cooling the tools after brazing is so that problems of carbide cracking are minimized.

2.3 AUTOMATION OF THE BRAZE CYCLE

Manual brazing involves the following operations :- the mounting of the workpiece, the application of flux, heating, the application of braze, cooling and removal of workpiece. This sequence applies to the use of solid, unsheathed braze wire, where the braze is applied to the joint from the outside. Where pre-placed 'shaped' braze is used, the application of flux and braze takes place during the mounting of the workpiece before heating. If flux-sheathed or flux-filled braze wires are used, the braze alloy and flux are applied simultaneously as soon as the work temperature has been reached within the workpiece.

In the automation of braze work, the main operations of the braze process can be arranged in a rising order of investment costs as follows [2] :- the heating of the workpiece, cooling by air, cooling with water, removal of simple workpieces, application of braze alloy, application of flux, removal of complex workpieces, feeding and mounting the workpieces. Depending upon the characteristics of a workpiece the order may be different. The main requirement for automation of brazing is "At least the time for heating , brazing and cooling should be an unpaid secondary time" [2]. Using this as a guide, the use of brazing techniques in which a number of workpieces can be heated manually simultaneously is not a first step towards the rationalization of the brazing process, since all the operations, including the heating of the workpieces are included in the paid primary time [2]. Whichever operations, other than the heating of the workpiece, are also mechanized or automated, will depend primarily upon the characteristics of the workpieces to be brazed and also upon the production figures. The extent by which automation is taken, is a matter of cost, since each step in the direction of full automation involves investment costs but, in turn, saves production costs.

Automation of brazing must therefore be preceded by an examination to find the most viable and rational degree of automation, since any investment must be amortized in a reasonable time [3].

In general it will be the mounting of the workpiece and the infeed of the workpiece to the automatic brazing machine which will be done by hand, since the mechanization (e.g robotics) of this step usually involves high investment costs. Since an automatic brazing machine does require one operator to monitor it, the mounting of the workpiece and the feeding of the workpieces to the automatic machine would present a logical occupation for the operator. Suitably shaped workpieces can, however, be brazed fully automatically (i.e. including all steps from the feeding of the workpieces and up to their removal). In such a case the operator is only required to ensure that the feeding devices are supplied with sufficient workpieces at all times. In this case, a number of automatic machines can be operated by one supervisor, obviously dependent upon the type of automatic system. Clearly the areas where robots or automation are to be used needs to be identified [4].

Whatever technique is employed, automation of the process has obvious advantages.

1. Efficiency

2. Control of the parameters

3. Economics - but related to efficiency

(1) Efficiency can be improved because production will be more consistent, since the variables can be controlled more effectively and the skill of the operator is eliminated.

(2) The parameters can be controlled and recorded more easily when brazing with automatic equipment. And, if any problems are encountered in future developments then it would be simpler to determine where they lie.

(3) There are many economic advantages which can be gained from automation. There is of course the initial Capital Investment, but

after a reasonable period (usually 24 months) this will be amortized, and it should run more profitably due to increased efficiency. A major cost advantage, is the saving in filler metal that automation provides. Instead of feeding a little extra filler metal "just to be sure", as can be the case with manual brazing, the equipment provides an exact and correct amount each and every time (whether using pre-placed or wire feeders) [5]. There is a tendency in hand brazing to use 50% extra filler metal, therefore with silver being a high braze constituent the cost saving can be quite considerable .

The improved efficiency (i.e., consistent high quality production) also affects the economics, since reworks or repairs are expensive and can require extra operations.

Considering the above benefits to be gained from automation, an investigation was undertaken to assess the various techniques of semi/full automatic brazing. This involved analysis of the following techniques.

- o Induction brazing
- o Vacuum brazing
- o Resistance brazing
- o Torch brazing

o Bath brazing

The most fundamental variables to be considered in the brazing process include, the braze temperature, time at temperature, the filler metal alloy, the braze atmosphere, the joint gap and jigging, together with any derivatives of the variables (e.g. capillary attraction).

Initially, each of the above techniques seemed to provide a reasonable case for consideration for the brazing of cutting tools. Therefore, each technique was reviewed independently and then comparisons made afterwards.

2.4 TECHNIQUES CONSIDERED FOR AUTOMATION

Each of the different processes reviewed provided a range of variables that required comparing before selecting a particular system which was worth pursuing further.

2.4.1 Induction Brazing -

This method produces a very rapid form of heating (compared to Furnace and Torch brazing) to the tool body by an alternating electric current induced by an adjacent coil. Heat is generated in the workpiece by the resistance to the passage of induced eddy currents. Ferrous base materials are most suitable for induction heating due to their ability to magnetise, as well as by high electrical resistance.

Non-ferrous materials can be induction brazed, but are heated less efficiently and require a greater input of energy or application for a longer period. In the instance for the materials listed in Table 2.2, the heat is generated in the base material (i.e., the tool body) and the heat is transferred by conduction to the filler metal to allow the capillary attraction to take place between the tool body and the tungsten carbide tips.

TYPE OF STEEL	% COMPOSITION							HARDNESS PRIOR TO BRAZING ROCKWELL 'C'
	C	Cr	Ni	Mo	V	Si	W	
A2 (AISI)	1.03	5.24	0.18	1.02	0.27	1.25	-	38–44
M2 (AISI)	1.0	4.0	_	5.0	2.0	_	6.0	62–65
817M40 (BS)	0.4	1.0	1.5	0.3	-	-	-	38–44
080M40 (BS)*	0.4	(0.9 Mn, 0.06 S, 0.06 P)						20

TABLE 2.2 : SPECIFICATION OF TOOL BODY MATERIAL

* Used mainly on large cutters therefore not too significant in selection process.

Factors affecting the production are ;

1. The frequency of the alternating current

2. The design of the heating coil (ie., the primary winding)

3. Jigging

4. Temperature

5. The type of filler used

1) Frequency - The higher the frequency , then the more rapid is the heating of the workpiece. In the brazing of cutting tools, this may produce localized burning at the edges of the carbide tips. Induction heating is a "surface phenomenon", with the heat being induced in the surface of the workpiece near to the induction coil. Transmission of heat to other regions of the workpiece then depends on conduction. Correct selection of frequency for controlled depth of penetration is important (see fig 2.3) [6], in order to obtain the optimum conditions and allow the heat to penetrate the carbide, filler and tool body, to provide sufficient joints without overheating a particular area of the cutting tool.

2) Design of coil - With reference to the design of the induction coil, there is no hard and fast rule. The optimum design will vary for different cutting tool designs, although this should not vary much in type, but only in size. Generally there would be no rapid changes of section in the workpiece (which can cause unacceptable overheating

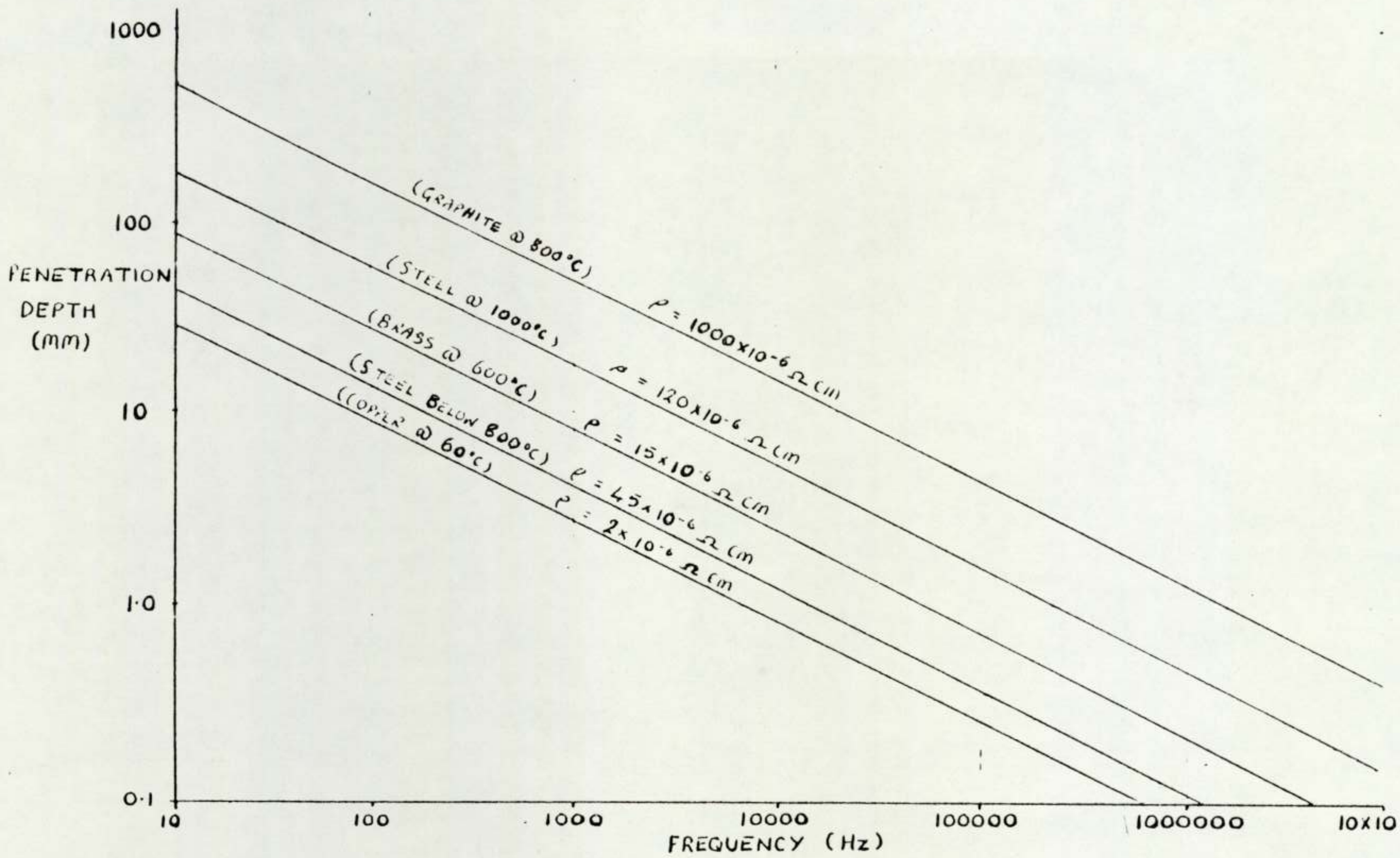


FIGURE 2.3 RELATIONSHIP BETWEEN PENETRATION DEPTH AND FREQUENCY OF INDUCTION HEATING FOR VARIOUS MATERIALS

if the coil is unsuitably designed or localized too close). The gap between the work coil and the workpiece is known as the COUPLE. For efficient heating, the gap needs to be as small as possible.

By varying the couple from a small gap to a wide gap over the workpiece, variations in the amount of heat input can be obtained. However, it would prove too difficult to control the couple intricately over the cross-section of cutting tools. Thus, single or multi-turn concentric coils would be used, making no allowance for the cut-away section caused by flute clearance. Fixturing and removal of completed parts from the heater coil must also be given consideration in coil design.

3) Jigging - During brazing, the carbide tips require to be held in position, since the tools do not have self-locating slots. Therefore some form of jig applied to the outside of the cutting tool requires to be added within the operation. However, the advance and removal of the workpiece into and out of the induction coil would be difficult with the jigs in the system. If possible, it may prove to be expensive, due to the number of diverse and infrequent range of cutting tools produced (especially if the 'couple' distance is to be optimized, since it would necessitate a sophisticated range of jigs). The most important aspect in brazing is to maintain the correct capillary spacing in the joint and because of the relatively high temperatures employed, thermal expansion effects must be allowed for since joint clearance could otherwise be eliminated.

If a high production rate is to be achieved it may be necessary to heat over several stations as single station heating would increase the timescale. This would obviously compound the problem of loading/ unloading with the jig held in position.

The application of the braze alloy would almost certainly require pre-placing, because with jigs and coils around the components, it would be difficult, perhaps even impossible (due to lack of access) for wire feeding. But pre-placement could lead to flux entrapment in the joint. This may be overcome by wiping/vibrating, but the risk of flux entrapment is still higher than when wire feeding.

The rise and fall of temperature may cause adverse movement of the jigging, mainly due to different coefficients of expansion and contraction. Consideration must always be given to the choice of materials chosen for the jig since magnetic materials should be avoided and preference given to non-reactive materials.

4) Temperature - Time at temperature is another important control feature of automatic induction brazing. The heating time is a function of desired production rate, it is controlled via the control of frequency and closeness of coupling. Although with high power input, care must be taken not to overheat the assembly.

Once the heating time of an assembly is determined, the number of heating stations and dwell time at each can be allocated among the total number of work stations relative to heating time, assemblies should be heated only to the point at which the filler metal is molten and flows. At some stage of the heating process, the tool body may tend to heat up at an astonishing rate. This may be when the braze metal has been melted by the carbide tip and forms a thermal bridge between the two. If heating is extended beyond this point then this will promote excess oxidation and even volatization of the filler metal constituents (dependent on the filler used). There is also the possibility of base metal erosion or intergranular penetration.

A distinct advantage of induction heating is that problems of liquation can be overcome with optimum heating time.

5) Filler metal alloys - The anomalies associated with 1) and 4) are similar for both controlled and non-controlled atmosphere brazing, apart from small differences. However, there is a significant difference when considering alloy selection.

The basic application of induction brazing is the same for controlled and non-controlled atmospheres, the main difference is that elimination of flux can only be considered when using a controlled atmosphere, thus necessitating a different filler alloy.

It is almost certain that if controlled atmosphere brazing is to be performed, the filler metal will need to be pre-placed on the joint before brazing and retained in the correct position during brazing. However, the components after brazing are clean and bright due to the prevention of oxidation at the joint area (given the term 'Bright Brazing') [7]. Although there will still be a need for some post-braze cleaning.

The low temperature silver brazing alloys normally used for joining tungsten carbide to steel, for fluxed brazing in air are generally not suitable for fluxless brazing due to certain effects within a protective atmosphere. If induction brazing was performed, for example inside a glass tube with a protective atmosphere, the deposition of metal vapour on the sides of the tube would be likely to present visibility problems - if volatile elements are within the filler metal alloy. Additionally certain elements such as zinc and cadmium may provide a health hazard, unless given environmental control [8].

Most low melting point alloys contain zinc or cadmium [Table 1]. These must be discounted from the selection process for a suitable alloy to braze tungsten carbide to steel in a controlled atmosphere, i.e. an inert or reducing atmosphere (due to the adverse affects of these elements). Due to different thermal expansion coefficients of the dissimilar materials that require brazing, it is necessary to retain low melting point alloys, since the use of low temperature silver brazing alloys helps to minimise distortion and stresses encountered on joining materials such as tungsten carbide and tool steel. Additionally, the low melting point alloys help to avoid excessive softening and grain growth when brazing heat treated alloys [9]. Alloys of the silver-copper (72/28) eutectic are available but usually melt around 778 C. This may be reduced, without using zinc and cadmium, by the addition of iridium, phosphorous, tin and manganese (one such type is the 60% silver 30% copper 10% tin alloy)

[10].

Phosphorous bearing alloys are not recommended for use on steel due to formation of brittle iron phosphide.

Tin and iridium reduce the melting temperature, but widen the melting range, (not so much of a problem with rapid heating where liquation is minimized) also iridium is very expensive (similar to silver) . Either element may be present when brazing under a protective atmosphere, without any problems.

Manganese is perhaps the least effective in lowering the melting point of copper-silver alloys. Under a protective atmosphere it does present problems - at low temperatures it is difficult to prevent the manganese oxidising, and at high temperatures , dew points of better than minus 50 C are needed to achieve reducing conditions (see fig 2.4). Therefore, small amounts of manganese may be added to improve wettability [11], but large amounts required to reduce brazing temperature need to be avoided.

Nickel is also added to the silver brazing alloys for use on tungsten carbide in order to improve wetting and reduce the fluidity of the alloy [12]. It appears to have no adverse effects on the performance of brazing alloys under a protective atmosphere.

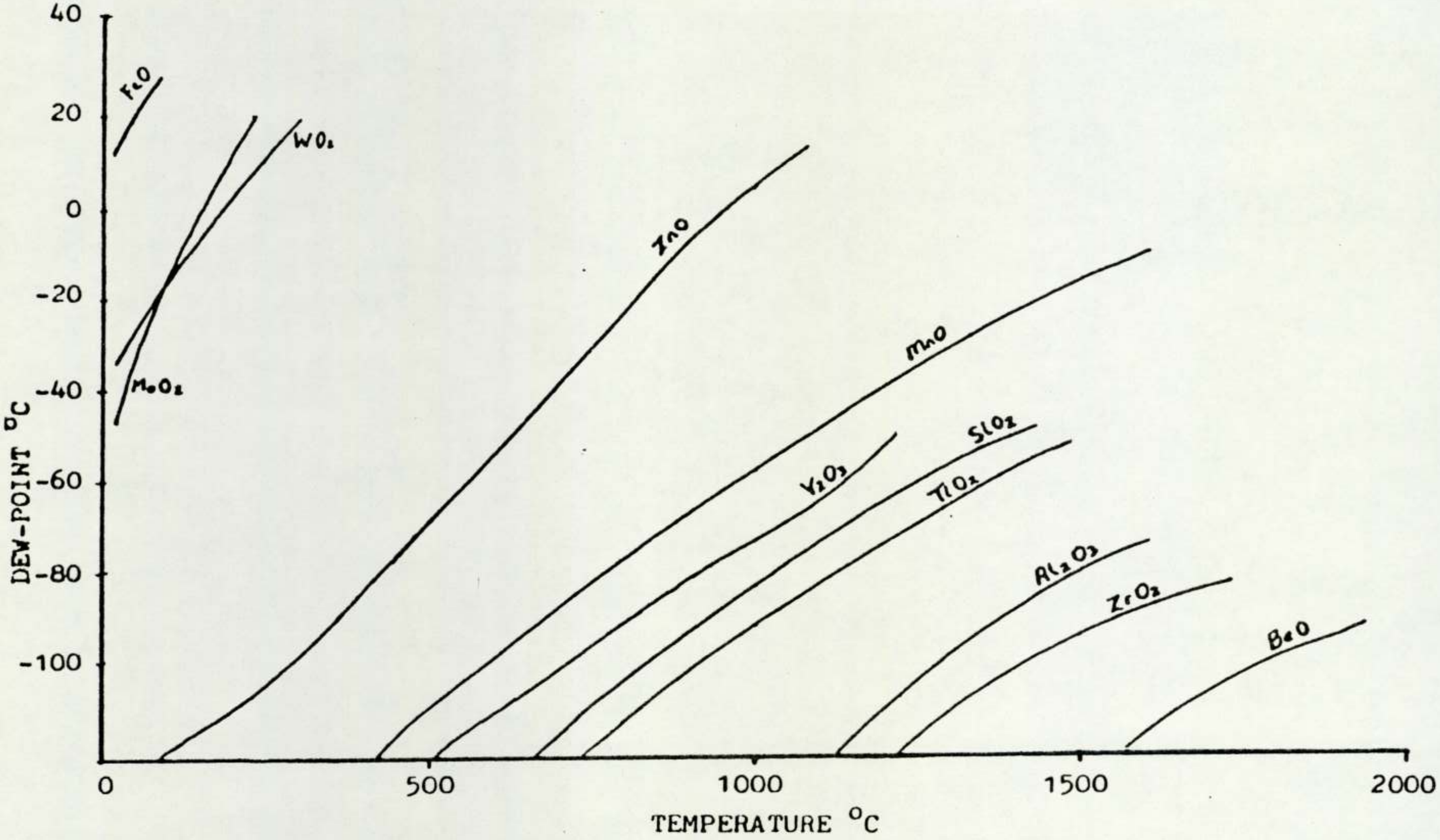


FIGURE 2.4 RELATIONSHIP OF DEW POINT TO EQUILIBRIUM TEMPERATURE FOR THE REDUCTION OF VARIOUS METAL OXIDES IN HYDROGEN

2.4.1.1 Types Of Protective Atmosphere Brazing -

The protective atmosphere used for brazing must be compatible with both the base and filler metal for satisfactory results, and equipment used to control the atmosphere must be designed so that the atmosphere is applied at brazing temperature without undesirable contamination.

It is also important to note that cleaning is not performed by the controlled atmosphere process and normal pre-braze cleaning operations dictated by the particular metals are still applicable.

Many types of protective atmosphere can be used for brazing which can be categorized into either gaseous or vacuum - the latter will be discussed in the section on vacuum brazing. Gaseous techniques can also be sub-divided into chemically active and chemically inert atmospheres. (see Appendix A)

Chemically inert atmospheres protect the parts being brazed from coming into contact with other gaseous elements, which might react with the metals being joined, to produce surface films which might inhibit flowing and wetting by the molten braze alloy.

Chemically active atmospheres will react during the braze cycle, with any surface films present on either the parts to be joined, or the brazing alloy, removing them in the process.

In the selection of a suitable active atmosphere (often termed 'reducing atmospheres'), careful consideration must be given to ensure that the elements in both the parent (base) metal and filler metal have oxides which will be reduced by the gas at a temperature below the solidus of the filler in order to attain oxide free surfaces at braze temperature. Various reducing atmosphere systems can be considered, for example hydrogen and cracked ammonia.

Hydrogen is an active agent for the reduction of many metal oxides at elevated temperatures and can be used in the 'bottled' or 'dry' form. It is however an element which possesses an affinity for carbon and will combine with carbon from the surface of steel to cause surface decarburization at elevated temperatures [13].

In the brazing of some steels in a hydrogen atmosphere, there is a possibility of embrittlement due to absorption of hydrogen, which is dependent upon temperature, composition of metals and pressure of applied atmosphere.

Hydrogen also forms the basis of atmospheres in the hydro-carbon series, but if any unburned hydro-carbides remain in the atmosphere, at certain temperatures it tends to carburize the surface of the steel.

When hydrogen is used in a furnace it will explode if air is allowed to mix with it, therefore, suitable precautions must be taken to prevent this from happening, usually by purging with nitrogen or other suitable gases.

Disassociated 'cracked' ammonia is widely used as a protective atmosphere for brazing. Although during the cracking process, in some instances there is a risk of residual uncracked ammonia which causes a certain degree of nitriding of steel. The cost of cracked ammonia is relatively high when compared with other gases.

Nitrogen is often present in a controlled atmosphere primarily as a purging agent - but again, consideration must be given to avoid objectionable nitriding.

Although Funk [14] demonstrates that brazing in a controlled atmosphere has significant advantages when brazing certain materials, for example, beryllium-copper assemblies, he does not refer to brazing tungsten carbide to steel.

Chemically inert (purified) atmospheres such as argon or helium form no compounds with metals and tend to inhibit evaporation of volatile components during brazing. In the UK argon has been utilized more often than helium for previous furnace brazing applications, mainly due to the limited availability and high cost of helium. (Helium, from natural gas, is cheap in the USA).

Inert atmospheres such as argon displace the amount of air when introduced in an air-filled chamber, thus reducing the oxygen level. By successive evacuation and introduction of argon the oxygen can be reduced throughout the brazing cycle in order to prevent the formation of oxide films. If the argon atmosphere remains stagnant, then any small residual amount of oxygen will combine to produce surface oxide films. Therefore, it is important to ensure there is a continuous flow of argon over the joint area.

2.4.2 Vacuum Brazing -

Vacuum brazing is primarily a batch process in which the charge of pre-assembled components is heated, usually using radiant electrical elements, in a vacuum chamber. However, during recent years a method incorporating vacuum heating into a continuously heated, fast cycling furnace for brazing has been produced [15]. By removal of gases which are evolved during heating to braze temperature, and the breakdown of existing surface films, very clean surfaces are obtainable. Once the braze metal has flowed, the charge is cooled back to ambient temperature by re-circulation of inert gas in conjunction with a water cooled external heat exchanger [16]. Although the process discussed refers to radiant electrical elements there are Induction heated vacuum furnaces available - as described later in the section.

No flux is required and the general appearance of vacuum brazed joints is such that no post braze treatment or cleaning is necessary.

The maximum tolerable pressure for successful brazing depends on a number of factors which are usually determined by; the composition of the base metals, the braze filler, and the gas that remains in the evacuated chamber. Most commercial vacuum brazing is carried out in pressures between 0.0005 and 0.5 mm of Hg, depending upon the factors mentioned, together with consideration of the area of brazed joint and the degree of which gases may be expelled throughout the operation [17].

Other important factors (in some instances similar to Induction brazing) which need to be considered when evaluating the choice of using a vacuum furnace for a particular brazing function are :

1. The types of filler used

2. Temperature and Time

3. Jigging

4. Process flexibility

1) The type of filler used - To ensure that brazing is carried out satisfactorily, special attention must be given to the selection of the actual constituent elements of the braze alloy, since conditions in the furnace must be such that all materials in the furnace chamber have extremely low vapour pressures (see fig 2.5). If any components in the system give off undesirable gas or vapour at any temperature encountered during the operation, it will denigrate the vacuum and may shorten the life of the device.

As can be seen in fig 2.5, such elements as zinc and cadmium have high vapour pressures at the temperature which would be reached during brazing and cannot be permitted as constituents of the filler metal alloy. This tends to eliminate the available low temperature silver brazing alloys which are usually used for fluxed brazing in open-air. Similar considerations, as mentioned in the discussion of the filler metal alloys for Induction brazing, can be applied in attempting to reduce the melting temperature for alloys (except for zinc or cadmium)

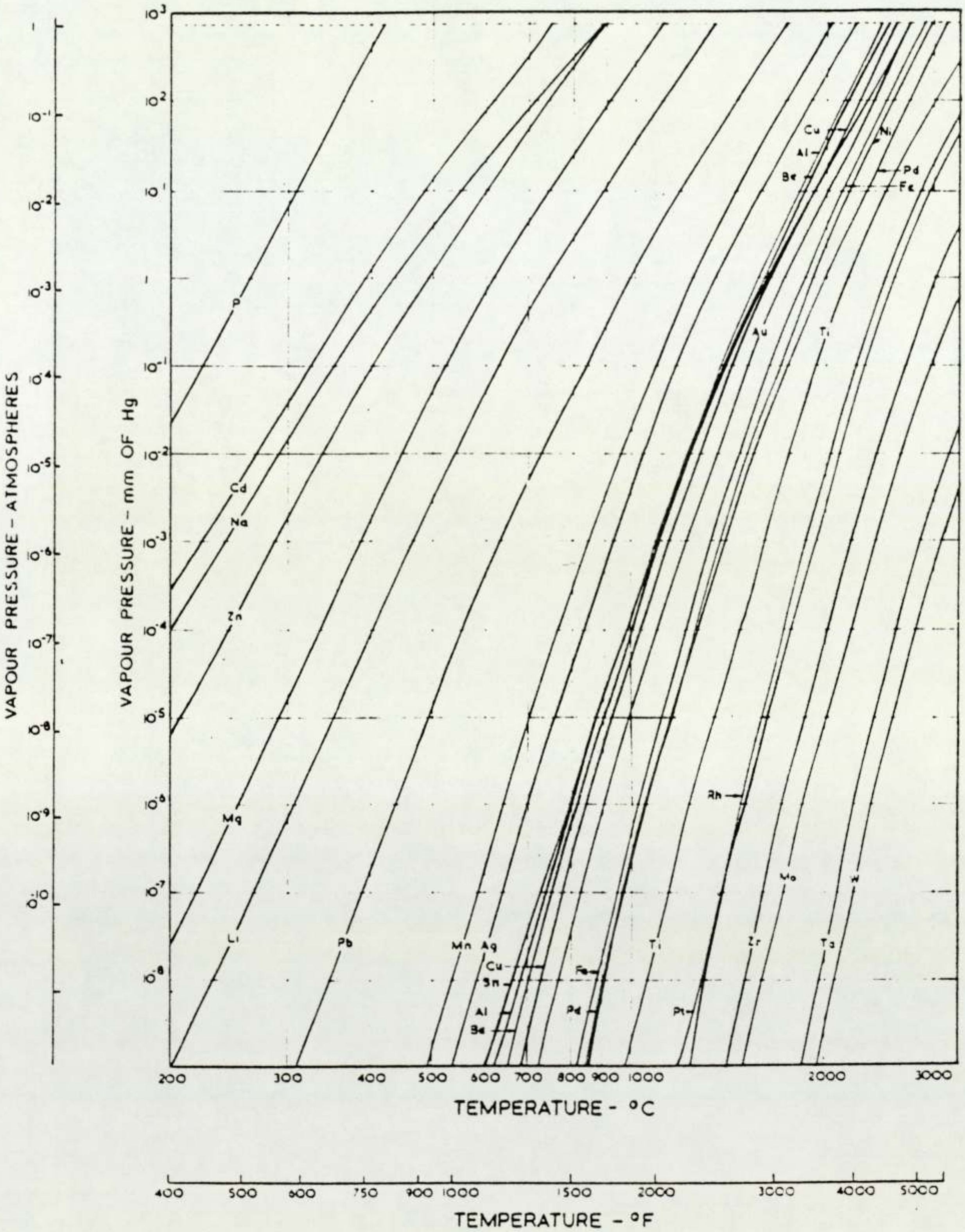


FIGURE 2.5 RELATIONSHIP BETWEEN VAPOUR PRESSURE AND TEMPERATURE OF ELEMENTS COMMONLY EMPLOYED IN BRAZING FILLER MATERIALS

in vacuum brazing. However, if any of the alloying elements such as manganese, iridium, tin and nickel were utilized to form a suitable alloy, there is a strong possibility that they would widen the temperature range between solidus and liquidus.

Due to the steady build-up of heat in the vacuum furnace, using furnaces with radiant electrical elements, the constituents of the filler metals tend to separate during the melting process. The low melting point constituents will flow, leaving behind a 'hard' phase of the high melting point constituents, thus liquation occurs, whereas in induction heating liquation is less likely to occur. The unmelted hard constituents will not contribute significantly to the braze joint. Although, where a wide joint is expected, a filler metal with a wide temperature range usually fills the joint more easily, but this may be to the detriment of a strong joint.

If a suitable alloy with a low melting point was found to be acceptable then maybe thought should be given to producing the alloy in paste form (or powder ready for mixing with a solvent) which can be applied manually or automatically. Powdered syringes have been developed to accommodate the need to dispense braze paste and fully automatic systems are in operation for many applications.

2) Temperature and Time - Both of these variables complement one another in their selection and are associated with the type of filler used. The filler metal alloy has a pre-determined melting range (i.e. temperature), which is controlled by the length of time that the

components are heated whilst in the vacuum chambers, subsequent to the time taken to attain the required operational pressure.

The time taken to 'pump-down' the chamber to the required level of vacuum for any particular operation is an important factor in the economics of vacuum brazing, because extended pumping times will increase the cost of processing parts which may only need short heating cycles, once the desired pressure is achieved.

However, as previously mentioned the alloys that appear to be available for the brazing of cutting tools have higher and wider melting range than perhaps desired. Therefore, the heating cycle is increased and this may lead to deleterious affects on the successful brazing of tungsten carbide to steel, due to the different coefficient of expansion rates and the liquation of the filler metal alloy - the higher the temperature the more time taken during heating, thus more susceptible to liquation for wide melting range alloys.

The braze temperature must not be above the hardening temperature of the tool bodies otherwise the heat treatment will be spoiled. If the filler metal alloy has a braze temperature above the hardening temperature, the brazing is best done prior to, or at the same time as the hardening operation. If the brazing is to be done prior to the hardening operation, the chosen filler metal alloy must have a solidus temperature well above the hardening temperature so that the hardening operation will not affect the previously brazed joint.

In a vacuum furnace high speed cooling using re-circulating gas has provided a reduction in cycle time, cost saving, since many heat treatment operations including quenching can be undertaken. If brazing and hardening are combined, i.e performed in the same cycle, a filler metal with a solidus near to the quench temperature is required. However, in the case of the cutting tools this procedure cannot be followed, due to the different thermal expansion rates of the tungsten and tool steel, which would undoubtedly cause severe cracking problems. Thus, this eliminates the possibility of post-braze heat treatment to the cutting tools.

3) Jigging - In many cases an assembly to be brazed must be maintained in the correct configuration by means of purpose-made jigs [18]. This is especially true when the filler metal alloy is applied as pre-formed shapes and the assembly is heated in a furnace. In Vacuum brazing the whole of the component is heated to the braze temperature, thus anything placed in the furnace hot zone will experience the same thermal cycle as the braze joints, i.e. the Jigs.

Brazing of metals with different coefficients of expansion can often create problems with tungsten carbide having a thermal expansion coefficient approximately one-third to one-half that of steel. In the brazing of cutting tools, this is more than enough to affect the success of the joint. With the additional expansion of any jigging around the components further problems will occur. To avoid component distortion the jig will need to be of similar coefficient of expansion as the component itself. This would be very difficult considering the cutting tool is built-up of two dissimilar materials of different expansion rates. Each cutting tool would need to be configured to obtain the expansion rate and a jig configured to provide the same rate.

Ideally components which are self-jigging are preferred for vacuum brazing, unfortunately, for cutting tools this is either difficult or impossible.

When jigging cannot be avoided the following features require consideration, the fixture must be easy to load and unload, sharp-thin transitions are reduced to a minimum, if screw threads are present then anti-seize agents need to be employed. The overall contact to the workpiece is kept to a minimum to reduce thermal sink, the energy and the space consumed by the jig must also be minimized otherwise it will constitute an increase in the cost. Also the components of the jig should be sited in such a way that they do not become attached to the assembly when the filler metal melts, or jig materials which are not wetted should be used (e.g. silicon nitride).

4) Process flexibility - The process is capable of a high degree of automation after the initial loading operation. Most equipment is designed to fulfil a pre-programmed thermal cycle from ambient temperature up to braze temperature and return to ambient temperature. Retention is only required for loading/unloading and 'switching-on' of the furnace. In some instances it may be even possible to automate the loading, but this could be relatively expensive since labour is still required to 'switch-on'. The ability to change programmes very

quickly to allow good process flexibility also demands some labour retention.

The overall size of the chamber controls the number of components that may be loaded in one operation (i.e. the larger the cutting tools, then the fewer number of components that may be loaded).

2.4.3 Resistance Brazing -

This process will be discussed briefly since it has limitations for adaptation to brazing cutting tools. Generally this type of brazing is more suitable for use with small components (where reproducible performances in large batches are required), producing consistent joints.

The heat is developed by passing at low voltage, a high current through the workpiece and the process is suitable for whole or part length heating, using close contacts. However, considerable sophistication of the electric circuits is necessary and require assessing for each different type of component, especially to control the heating in order to prevent burning at sharp edges.

The resistance heating technique using the I^2R heating method, is most readily applied to assemblies of various metals. Heating can be localized and high rates of heating can be achieved by using suitably adjusted currents. Where a simple lap type joint is being made, opposed carbon rod electrodes can be used but if brazing flux is employed it may interfere with the electrical conductivity at the interface. Very dilute fluxes are therefore necessary or, alternatively, a brief jet of hydrogen directed at the area being brazed must be used [1].

The three common methods of resistance heating are; Direct, Electrode and Interface resistance heating.

Direct resistance heating- This is used for relatively long sections of uniform cross section. The length should be a minimum of ten times the diameter, or even longer. Clamps are used for electrical connections with a good contact so as to reduce resistance between the clamp and the workpiece. The workpiece is made the higher resistance by ensuring that the conductors are of a cross-section such as to reduce the heat loss to a minimum. A uniform current is passed down the workpiece, to provide uniform heat, but long pieces tend to lose heat due to convection by the air and conduction of electrodes. Although, precautions can be taken to avoid this, either by shrouding or re-positioning of the electrode around the workpiece.

The change in cross section of any component alters the distribution of the heat path, consequently it is not often used for brazing.

Electrode resistance heating - This is mainly used for soft soldering. The mechanisms involved in this form of heating are more complicated than the direct heating. Heating is caused by the contact resistance of the electrode to the workpiece, and by the contact resistance in the joint area of the workpiece. It is desirable for electrodes to cover as much of the workpieces as possible in order that the workpiece receives maximum heat by thermal conduction from the electrodes, together with the heat generated by the resistance of the joints. This would be impossible to conform to in the brazing of the cutting tools.

Interface Resistance Heating - This is based on electrical resistance inherent in the surfaces brought together, usually requiring higher power ratings than the other two methods.

Resistance joining does have advantages in some cases, since the electrodes often form pressure jigs to hold the parts together and eliminate the requirement for other jigs. However it is difficult to implement for fixturing and brazing of the carbide tips.

2.4.4 Torch Brazing -

Torch brazing can be performed either by manual or automatic techniques, however in this discussion emphasis will be on the adaptation of fixed automated torch brazing.

There are machines available for mechanical torch brazing which vary from the simple sliding bed type to the more complex multi-station rotary indexing machines. The latter can incorporate many stations to allow the use of many devices which will provide automatic application of heating, flux, braze filler and quenching. Automatic removal from the jigs may be possible, but could prove difficult on certain applications.

During the brazing cycle the heat path developed with hand torch heating is completely dependent on the operator, therefore it is unlikely that the consistency of brazing will be achieved. However, with fixed torch brazing, once the optimum conditions have been established, only minimal skill would then be required to produce many consistent brazed joints.

The production rate is determined by the speed of loading and unloading, together with the time taken for each of the operations at the various work stations. The number of work stations can be increased to account for the slow brazing cycles.

The processing cycle can be divided into various categories;

1. Application of filler and flux

2. Heat control and heat time

3. Torch flame

1) Application of filler and flux - In developing an automated braze system the time that the machine remains at rest between successive indexes i.e. dwell time, is influenced by the automatic application of brazing materials which involves fluxes, braze alloy wire and braze paste.

Fluxes are available as powder, paste and liquid, and can be applied if necessary to very small areas, therefore, the application to cutting tools should not cause too many problems.

The wire is fed to the joint in the required quantity by control of feed speed, and the time interval during which the drive mechanism of the wire feeder is in operation. Careful adjustment of both parameters control the amount of filler placed, if multiple wire feeders are used, then adjustment/control is more difficult.

The use of braze alloy paste is considered to be more cost effective than wire feeders, but is usually only used on small joint areas.

2) Heating control and heating time - The heating control is important as it is in induction and vacuum brazing, but the advantage of torch brazing is that emphasis can be put on the direction of the heating flame. When components of different mass are brazed, it is necessary that both reach the braze temperature simultaneously. This would necessitate the heating of one part in preference to the other, which can be accomplished using a torch brazing method. The torch heat involves the use of a pre-set burner heat pattern positioned at one or more machine stations. Burners of various sizes, utilizing a choice of different fuel gases (i.e. town gas, propane or acetylene) mixed with air or oxygen may be used.

The heating time is also an important function which determines the desired production rate. When this is known, in conjunction with the time required for loading/unloading and indexing time (i.e. time to move between stations), then the number of workstations and direct time at each can be calculated.

3) Torch Flame - The correct adjustment of the torch flame is essential for a satisfactory effect on brazing, such adjustment can be made by suitable valves and monitored by the use of flow meters.

In addition to selective heating to offset the thermal conductivity of different base metals, it is important that the joint be brought to within a uniform temperature range so that the filler metal will flow freely and fill the joint. When a pinpoint localized flame is required, or where a hotter and faster heat is desired, oxygen may be used in place of or in combination with air. The use of oxygen will however increase operating costs and should only be considered when the extra cost can be justified by increased production rates.

The ongoing consideration for any of the brazing techniques is the problem of jigging, likewise for torch brazing. Each of the cutting tools require to be physically held in position throughout the brazing cycle.

If the jigging is complex, which would be the situation for locating the tungsten carbide tips in the tool bodies, the workstations must be stationary while the parts are loaded.

The actual choice of filler metal alloy is open to almost any type which is commercially available, since there are not the same adverse problems affected by vapour pressure of certain elements in torch brazing.

2.4.5 Bath Brazing -

Similar to electrical resistance brazing, this has restricted uses for the brazing of cutting tools. Therefore it is discussed only briefly.

Dipping baths - a technique by which brazing may sometimes be carried out by complete immersion in a bath of the molten metal, but is not as commonly used as is soldering. Assemblies may be completely immersed in a bath of molten braze alloy after coating with an aqueous flux and are slowly lowered through a layer of fused flux on the molten metal bath until completely immersed.

Salt bath brazing - Providing that an assembly is jigged with pre-placed filler metal, brazing may be carried out by heating the assembly by immersion in a bath of a suitable medium maintained above the melting point of the filler alloy. In brazing, a salt bath is used which simultaneously provides a fluxing action. After completion of the joining operation, the flux must be removed by suitable solvents, or by other means. Although after a few experiments the correct amount of brazing alloy can be selected to avoid the presence of excess metals at the joint. However, where frequent changes are made to the geometric shape of the component to be brazed, for example in the case of carbide tools, this experimental work could prove quite time consuming and costly.

The use of either of the bath brazing techniques applied to tungsten carbide cutting tools has adverse effects. Likewise, as in the furnace brazing jigs would be required and would experience the same thermal cycle as the component itself. A problem may also exist here, in that the jig would need to be critical in its design to avoid it from joining to the assembly when the filler metal melts, although less formidable in the salt bath technique. Usually the components undergo some preliminary heating prior to being dipped into the bath. This would severely compound the coefficient of expansion problems, discussed in other brazing considerations, due to the length of the heat cycle being increased.

It is not impossible to braze tungsten carbide to steel in a bath dipping technique (usually a salt bath), but it is not so viable for brazing tungsten carbide cutters due to the complexity of the problems of the jig arrangement (as described in the other brazing techniques) being further expanded on.

This completes the analysis of the Induction, Vacuum, Resistance, Torch and Bath brazing as an individual application. In some cases it may be possible to integrate partial aspects of each process. An example, is the mixing of induction heating within a vacuum chamber. If all the problems outlined within each of the processes were overcome and brazing under these conditions proved successful, i.e. satisfactory joints were achieved, the main problem area for automating the process would be the loading/unloading and jigging of the cutting tools. Nevertheless, electron beam welding performed in a vacuum chamber has been achieved with the use of a Rapid-Transfer-System (R.T.S.), which automatically loads, unloads and allows carriers to be used for holding the components which are to be welded. It may be possible to use an R.T.S., in conjunction with an induction furnace for the brazing of certain components, however, for cutting tools, the carriers need to locate and hold the tips in position, which would prove more difficult to hold than the conventional components used for electron beam welding.

2.4.6 Evaluation Of The Techniques Reviewed -

Each of the different processes discussed provides a range of variables that need comparing before selecting a particular system which is worth pursuing for future work.

Tungsten carbide tips can be brazed with Induction heating, Furnace brazing, Resistance, Torch brazing and Bath brazing - although neither provide or use identical design features (i.e. joint strength, configuration, filler materials, jigs etc). In most cases Furnace brazing is used when the parts are larger than those practical for the Induction and Resistance processes, however, furnaces can still be used for small detailed components. Torch brazing can be invariably performed on many different components, the machine can be designed to accept the necessary size.

In the past, the majority of tungsten carbide brazing has been on components with flat carbides inserts, thus the problem of different coefficient of expansion rates remain relatively less than on components with carbides of intricate shape.

At present, the method of alleviating expansion problems between the twisted carbides and the tool body is performed by using a sif-bronze coating, prior to being brazed to the tool body. The carbide is allowed to cool after sif-bronze coating at a temperature within 940 to 960 C. Then, the brazing is carried out within temperature range 640 to 660 C. Thus, the sif-bronze acts as a buffer between the carbide and the tool body.

The temperature is an important factor to be considered when moving towards an automated process. The temperature for hand torch brazing is dependent on the skill of the operator and automating can provide greater control of temperature.

If an Induction furnace is used for brazing the cutting tools in a controlled atmosphere, then one needs first decide upon the choice of atmosphere which must be compatible with the filler metal alloy and the base metal (e.g. A2, M2, 817M40 or 080M40). Up to a certain point hydrogen, nitrogen, cracked ammonia, argon and maybe other atmospheres will perform satisfactorily, but when brazing conditions require that the contaminants be reduced to an absolute minimum, vacuum heating is desirable.

NOTE

> Attention must be given to any objectionable effects of the atmosphere on the component. i.e Hydrogen embrittlement, decarburization or nitriding (albeit

The filler would need to be produced without volatile constituents for both Induction (controlled atmosphere) and vacuum brazing, and approval tests for various types of fillers are required. Various enquiries led to the possible use of a lower silver content Ag-Cu alloy than the eutectic or ternary alloy, containing nickel to facilitate wetting and a possible addition of manganese and/or tin which would possibly provide a suitable joint between tool steel and tungsten carbide. However, at present no such alloy is commercially available, and if required would necessitate commercial consideration, then if produced would require testing for correct wettability. It is also necessary to be produced in such a way that it may be pre-placed within the joint for both Induction and Vacuum brazing. If re-crystallization of the tungsten is undesirable, an excess of nickel needs to be avoided due to the interaction between tungsten and nickel.

There are in fact many commercial vacuum grade alloys available but they are mostly of high silver content - Ag-Cu alloys, thus increasing costs. Other alloys of multiple constituents require consideration of liquation effects, especially in vacuum furnace brazing where there is a slow build-up of heat. It is less likely to arise in Induction heating where a rapid form of heating takes place (but the high temperature of these alloys still remains a problem).

In the Torch brazing technique, retention of the cadmium-zinc braze alloys is possible, retaining a narrow solidus to liquidus range, therefore eliminating any problems of liquation. Whilst performed in relatively small when used with induction heating). The filler metal alloy will be required to be investigated as a separate venture to decide upon an alloy which will perform best provide a satisfactory joint under controlled atmosphere conditions. This would almost certainly result in the use of filler with a higher melting point, wider temperature range between solidus and liquidus, therefore, increasing braze temperature.

An increase in braze temperature leads to the investigation into the effect on the heat-treatment of the tool body, which is currently done prior to brazing. The use of a higher melting point braze alloy will require the braze temperature to be higher than the tool body heat treatment temperature. If heat treatment is to be performed after brazing, the temperature of heat treatment must be below the solidus of the filler metal alloys; or the heat treatment must be performed in parallel with brazing, i.e. at braze temperature and cooled accordingly to the heat-treatment requirements. However, the heat treatment cannot be done after brazing, primarily due to cracking of carbide tips (which would occur due to the heat treatment requirement of rapid/forced cooling). Additionally, the higher braze temperature compounds similar difficulties due to different coefficient of expansion between carbide and tool body material (even under a much slower cooling rate than required for heat treatment).

open-air there is no requirement to disregard high vapour pressure alloy elements with respect to technical issues, only for important safety aspects, which can be overcome with fume extractors. Brazing at lower temperatures can be maintained and the heat source can be localized and controlled more effectively, enabling the optimum conditions to be achieved to work against thermal expansion.

The overriding deterrent for consideration of a resistance brazing system is the complex study of the electric circuits and the affected heat pattern with changes in section. Since, the characteristics of the circuit resistance determines the heat within the components to be brazed.

Bath brazing is unsuitable for use with cutting tools primarily for the same reasons as furnace brazing, except for the dismissal of the cadmium and zinc content within the braze alloy. However, the reduced problem is counteracted by the additional heat source being required to prepare the components for dipping, furthermore increasing the problems of cracking due to thermal expansion rates of the material used (i.e., tungsten, steel, and jig material). The additional post-braze cleaning would also cause concern.

The process flexibility of each method is similar; the components are loaded individually and the brazing is on a singular basis, except for vacuum brazing which is a batch process. For cutting tools, the total production output for either technique would be acceptable for the current or even increased workload, i.e. if successful brazing can be achieved and is viable.

The overall problem for any method is the fixing and jigging of the carbide inserts in the tool bodies. The main deterrant for the use of jigs in the torch brazing technique is the limited access that would be available for automated filler application (i.e. wire feeders). This would not be a problem if the filler could be pre-placed. Compared with torch brazing there is more chance of jig distortion when used in conjunction with induction heating (where coil would almost certainly need to be wound around the jig fixture), where repeated contraction and expansion of the jig will take place (obviously relative to material used). A similar problem exists in the use of a Vacuum furnace and Salt bath brazing. With the nature of the tool design, the desired interference fit of the joint is difficult to achieve and in order to ensure successful wetting the jigs need to be designed to allow any wiping or vibration that may be required to consolidate the joint. This would prove very difficult with Induction heating, due to the limited accessibility of the joint area, caused by the positioning of the jigs inside the heating coil. For Vacuum brazing there would be zero access within the furnace.

A quick guide to the problems which may be encountered with any of the techniques discussed, can be seen in table 2.3, where a comparison of the unresolved problems can be seen for each method. From the comparison it is quite evident that the technique with the lowest score (i.e., least problems to be resolved) is the most suitable choice for future pursuit.

METHOD / FACTORS TO BE DETERMINED	INDUCTION	VACUUM	RESISTANCE	TORCH	INDUCTION/ VACUUM HYBRID	BATH
FILLER METAL ALLOY	YES	YES	YES	NO	YES	YES
TEMPERATURE	YES	YES	YES	NO	YES	YES
JIG	YES	YES	YES	YES	YES	YES
LIQUATION	NO	YES	NO	NO	NO	NO
ATMOSPHERE	YES	NO	NO	NO	NO	NO
EFFECT ON HEAT TREATMENT OF STEEL	YES	YES	NO	NO	YES	YES
HIGH VAPOURIZING ELEMENTS	YES	YES	NO	NO	YES	YES
STUDY OF ELECTRICITY	YES	NO	YES	NO	YES	NO
ACCESS FOR FILLER APPLICATION	NO	NO	YES	YES	NO	NO
SCORE	7	6	5	2	6	5

TABLE 2.3 : A 'quick' guide to the various problems of automating brazing which require proof testing before automation can be adopted for any particular method of brazing the cutting tools.

NOTE : The score is relative to the number of boxes filled with 'YES', the lower score necessitating fewer factors to be determined.

All methods have been investigated irrespective of cost, since initially one must decide if a particular method is viable - then if more than one method is possible - only then do costs need to be compared. However, it was decided that Torch brazing was pursued further as it scored less in the number of variables that require substantiating before automating. The only main deterring factorin adopting an automated system is the problem of jigging, when this is overcome Torch brazing will be possible to automate, since it would merely be the automating of an existing process, which is successful in producing satisfactory components. The other techniques require too many other technical avenues investigating before one can be consider the automation aspect e.g choice of filler, temperature, atmosphere etc.

With advantages and disadvantages of the various techniques being thoroughly compared, it was decided to set up an agreement with a specialist manufacture of automatic torch brazing systems, to develop a unit suitable for brazing cutting tools. This would then allow an experienced manufacturer, of brazing equipment, to run tests to determine whether the deterrants of jigging and filler application can be overcome, and thus automate the brazing. However, after considerable consultations with various manufacturers of torch brazing equipment, the viability was still a main problem. It was then decided, that if the filler could be pre-placed, then maybe a system could be developed.

2.5 EXPERIMENTAL TRIALS

During the investigation and feasibility study of the various methods, many companies were consulted regarding the assessment of systems available for the development of an automatic braze cycle. The most favourable response came from Degussa (UK) Ltd., who expressed their interest in assisting with trials.

On deciding that torch brazing was the best technique to consider further, DEGUSSA U.K. Ltd. was contacted with an aim to running some brazing trials, as previously agreed.

After considerable deliberations involving staff from ELGA, (Degussa's sister company), it was decided that the only possible method of automating the torch brazing technique would be based upon a modification to the existing cutting tool body design (see figure 2.2 and description earlier in text). Due to the range of design of cutting tools, it seemed impossible to develop a system to automate the brazing as currently performed manually. A modification to the existing design of the cutting tools was required, to avoid using a filler wire feed. Thus a modification to the tool body was designed, which involved producing a channel (groove) in the back face of the tip seat, to where the tungsten carbide tip is brazed (i.e., a longitudinal slot to follow the helical form of the existing tip seat) (see fig 2.6). The addition of a slot in the tip seat would then allow either an annealed braze rod, or braze paste to be pre-placed in the slot. The tungsten carbide tip could then be located and clamped into position. The next stage of the operation would be tested by Elga, i.e to place the cutting tools onto an automated unit where a heat source (provided by micro-torches) could be located at specific points on the cutting tools to determine whether capillary action would take place and hence braze the tips to the tool bodies.

Tool bodies were produced with the modification incorporated and passed onto Elga (via Degussa) for trials. At this stage, it was considered worthwhile to pursue brazing trials to see whether a suitable joint could be produced. If sucessful then additional work would be directed towards either a further change in design or change in the method of production. It is quite evident that a technique for automating the brazing cannot be adopted unless a change in the design or manufacture of the cutters can be tolerated.

However, in order to produce tool bodies to this new design, preliminary work was necessary to produce "waxes" with the groove in, in readiness for the investment casting process. For the purpose of the development stage, it was decided that the waxes would be produced (i.e., moulded) to the original design for a standard tool body and carefully machined afterwards to provide the groove in the tip seat of the cast body. Obviously, this proved a delicate task since the waxes were to be 'handled' with care.

The size of groove required in each carbide slot of the tool body was calculated precisely to contain the correct amount of filler, in order to provide sufficient braze alloy to completely fill the gap between

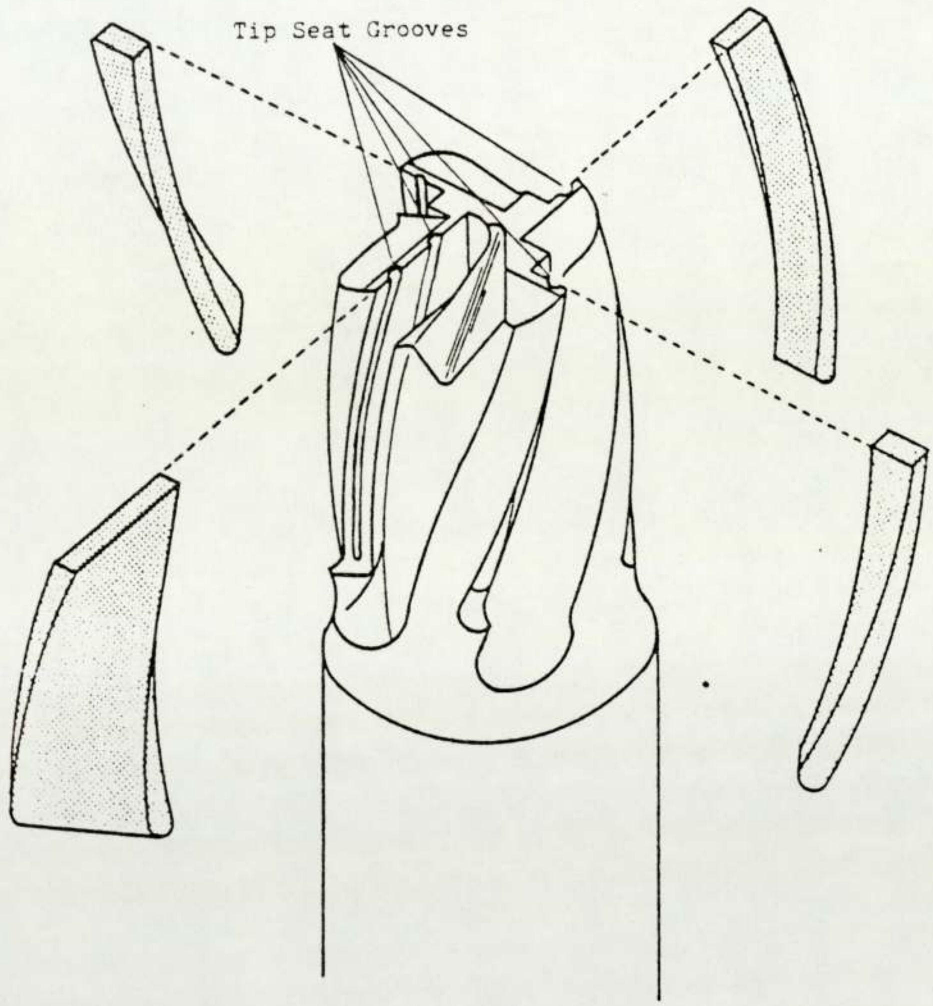


FIGURE 2.6 VIEW OF MILLING CUTTER SHOWING TIP SEAT GROOVES

the carbide and the tool body. (see Appendix B for skeletal model on how calculations were achieved).

On completion of the production of a set of six waxes for a chosen design of cutting tools (see below), they were passed to the foundry for investment casting of the bodies in A2 material.

The cast tool bodies were were forwarded to Elga, together with the helical tips, to be tested for automated brazing using pre-placed filler. Brazing was performed with tools located in a vertical position (see fig 2.7).

The type of cutter used for this experimental work is a three-flute semi helicon (approximately 25 mm in diameter and 50 mm on cut). For this type of cutter the clearance either side of the large tip is 0.33 mm. The volume of braze alloy required to fill the joint is 457 mm^3 . The size of braze rod to fill the joint over the carbide length would need to be 3.4 mm in diameter, this was unacceptable since the size of the groove necessary in the tip seat, to accommodate the rod would be detrimental to the tool strength. Therefore, it was decided that two grooves behind the carbide allowing two 2 mm diameter rods would be used , which would provide 312 mm^3 of filler.

A total amount of 312 mm^3 of filler was used, which was inserted in the form of 2 mm rods. The total volume that this was required to fill was 457 mm^3 - which may seem that there would not be sufficient filler for a good braze. However, at the point where the rods were inserted i.e. the groove, the filler could not remain there since the

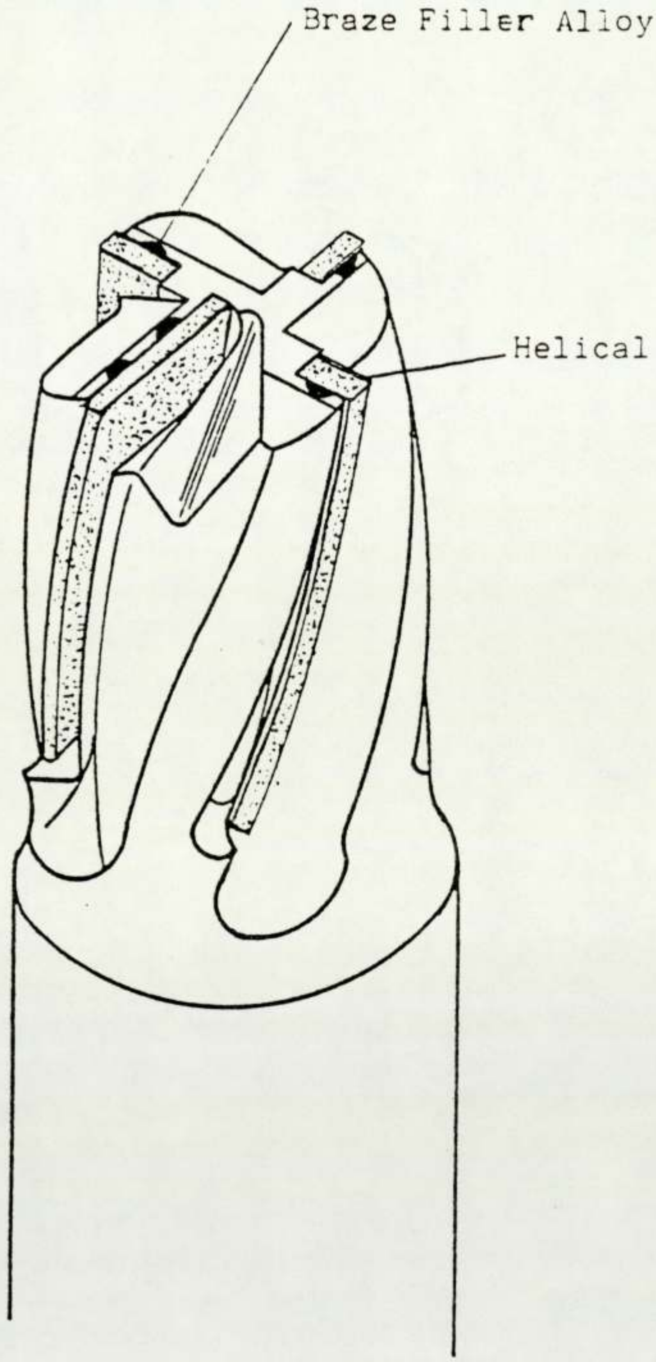


FIGURE 2.7 ASSEMBLED VIEW OF MILLING CUTTER WITH PRE-PLACED FILLER IN TIP SEAT GROOVE

groove was too large to allow it to remain there by way of capillary attraction. This allowed the total contact volume to be brazed to be reduced from 457 mm^3 to 375 mm^3. Another factor which further reduced the contact volume, was the direction of the filler towards the back face of the tip, since it is not necessary that the front face be brazed. Thus, the braze volume was reduced to almost the same as that of the filler, leading to a good joint.

The clearance on either side of the small tip is similar (0.33 mm) and a volume of filler required to fill the joint is 171 mm^3. A 2 mm dia. rod provides 156 mm^3 of filler - with the small tip there is minimal front face available. Thus, the tip needed brazing on the back face only, allowing a minimal clearance to be controlled by the accuracy of the helical form of the slot and carbide tip relative to each other. However, the groove reduces the surface area, to leave a joint volume of 136 mm^3 which is within the limit for this application.

It would be ideal to allow 30% excess filler to the joint clearance, but for this type of cutter the diameter of rod/rods would be greater than that which can be tolerated. Nevertheless, by concentrating on a sound brazed joint at the back face of the carbide, the joint-filler configuration can be rationalized to provide an excess of filler at the joint interface.

It is worth mentioning here that, although not part of intended study, investigations have also been performed to examine the possible technique of plasma coating the carbide tips with a silbraze (similar to sif-bronze) to provide a buffer as previously mentioned in section 2.1. This would allow retention of the joint design (i.e., bi-metal configuration) currently employed by Marwins. However, tests were disappointing due to the requirement of spraying a harder material (carbide) with a softer material (silbraze). Since the plasma coating relies on a mechanical bond and not a metallurgical bond.

The curent technique of Sif-bronze coating the carbide tip (as previously discussed) is performed with the use of a hand torch and filler rod, but this provides an uneven distribution of the Sif-bronze on to the tip.

Therefore brazing trials with ELGA GmbH were performed without the sif-bronze coating to determine whether an acceptable joint could be produced, (i.e., without subsequent problems of cracking). Using L-Ag 49 Cd braze filler alloy.

Subsequently at Marwins, cutting trials were undertaken to determine if the tool performed under the operating conditions (see figure 2.8) without detrimental effects. Tests were performed on a milling machine using a block of aluminium as the cutting medium. Results suggest that joints can be produced to give satisfactory performance in standard cutting tool operations, via a pre-placement technique.

However, the cutting tools which were produced did in fact have small voids at the ends where the grooves did not retain any of the braze filler. This did not prove to be a problem in the cutting tool trials, although it was envisaged that eventually these voids could

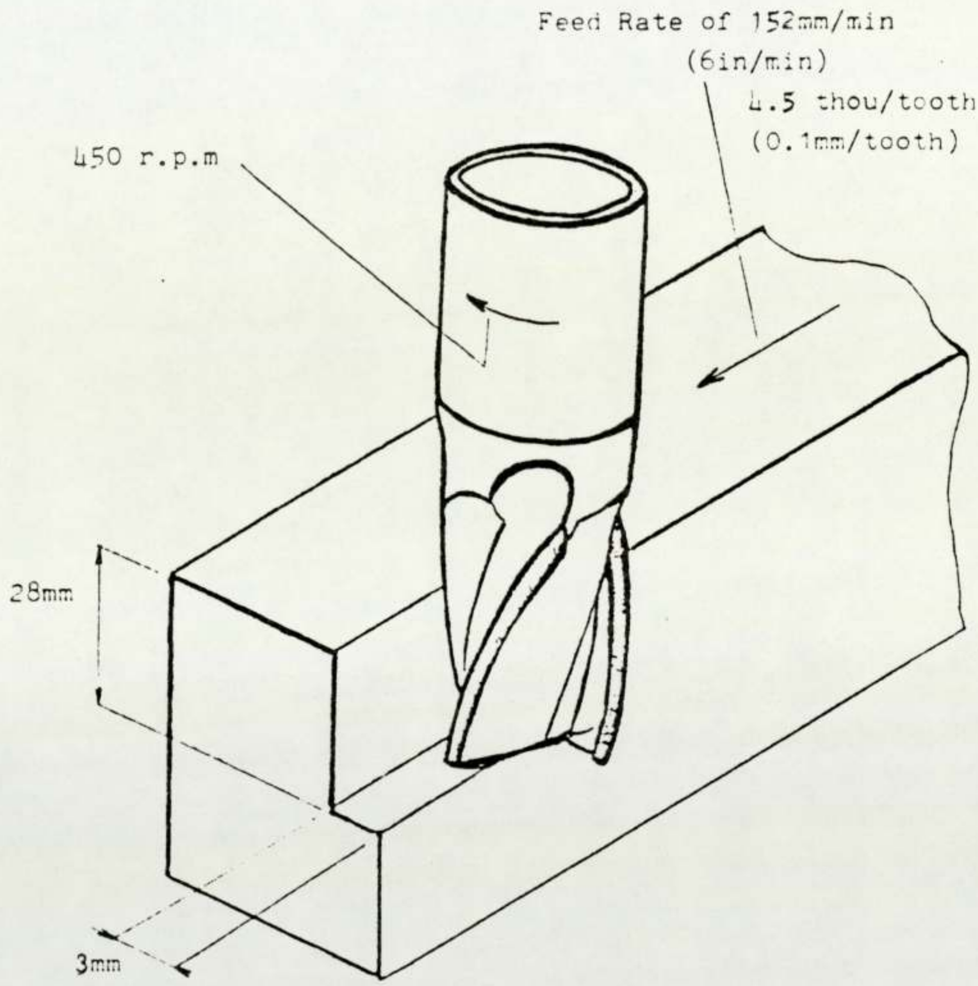


FIGURE 2.8 SPECIFICATION OF CUTTING TOOL TRIALS OF AUTOMATIC TORCH BRAZED CUTERS (For L.S. 512 028 cutters)

pick-up swarf or any other debris to cause stress raisers and the inevitable fracture of the tungsten carbide tips.

In order to improve this anticipated problem in the finished cutters it is suggested that further tests use automatic wire feeders to complement the braze filler application (see fig 2.9). This will then allow the braze filler alloy to completely fill the ends of the cutters where the braze flows away during the heating and subsequent brazing.

At the time of departure from the research associateship, a new set of cutters were being produced to verify and test further.

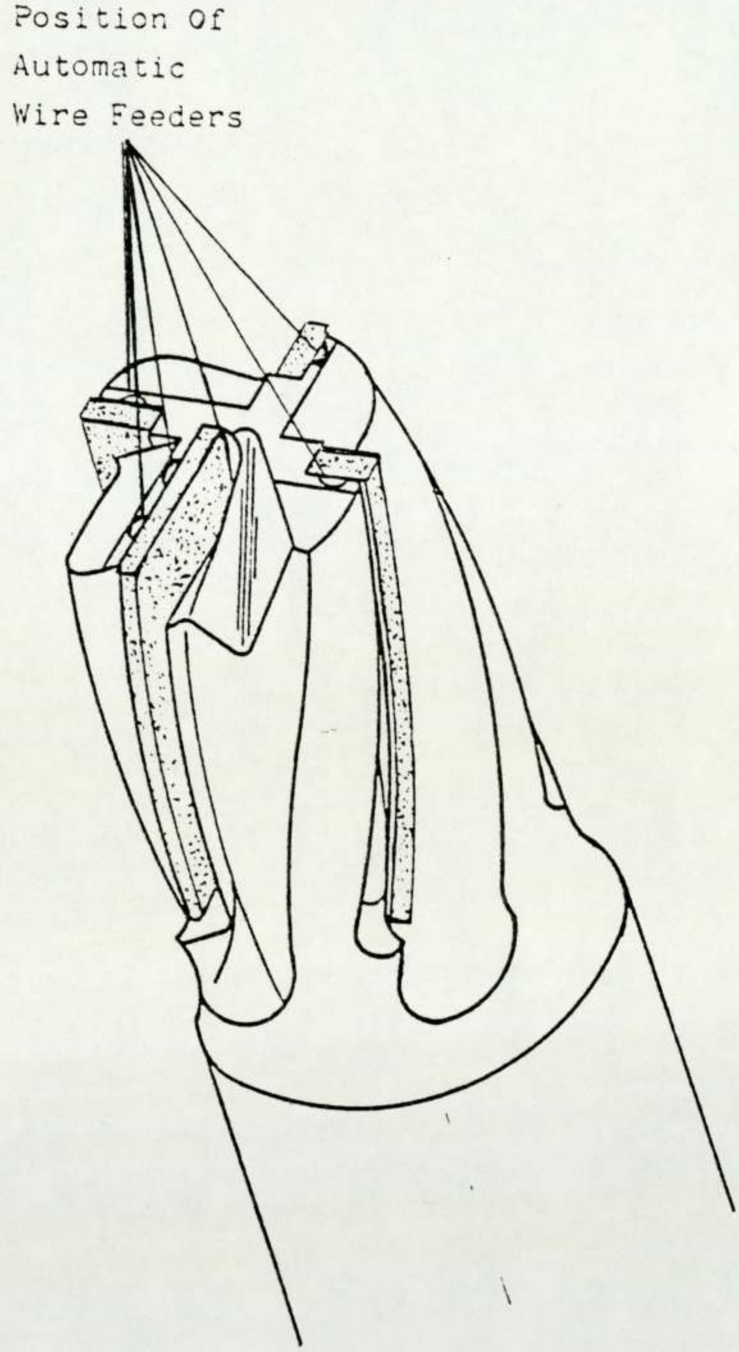


FIGURE 2.9 MILLING CUTTER HELD AT AN ANGLE TO ASSIST FLOW OF BRAZE FILLER ALLOY - (with additional wire feeders to improve joint finish)

3 CARBIDE HELICAL FORMING UNIT

The object of this section is to describe a study of the current manual technique of producing the helical formed tungsten carbide tips, with the aim of assessing the feasibility of automation to improve production. The instrumentation of the equipment to provide data, proved to be difficult and time consuming. Although insufficient time was available to fully analyse the results and instigate more critical experiments, it is considered that well founded proposals can be made.

3.1 MANUFACTURE AND PROPERTIES OF TUNGSTEN CARBIDE

Over half a century of research and development has produced compositions of cemented carbide to satisfy a wide range of industrial needs. One of the most important features of cemented carbide is the ability to be tailor-made to match a desired combination of hardness, wear resistance, high temperature strength, toughness and resistance to wet or dry corrosion. Combined with the shapes and sizes that can be produced, by the powder metallurgy process the engineering industry has tremendous scope to design cost effective solutions to virtually any wear problem. It is to these advantages that tungsten carbide is applied to the manufacture of tips for cutting tools.

The properties of cemented carbide arise from its manufacturing process, which is by powder metallurgy. The production procedures used to manufacture cemented carbide vary in detail according to the type and size of part required, but the main steps are as follows:

Tungsten powder is first produced by hydrogen reduction of chemically purified tungsten oxide ore. Reduction conditions can be altered to control the grain size of the tungsten powder, which is then carburized by mixing with carbon and heating with hydrogen at a temperature between 1400 and 1650 C (usually near to 1500 C). The temperature must be high enough to give full carburization within an acceptable time, and also to volatilize most of the residual impurities, but not so high as to induce grain growth in the newly formed carbide powder [19]. The reactants are mixed in the correct proportions to produce the mono-carbide (6.13 wt.%C), excess carbon being avoided as this has a marked influence on the properties of the final product [19]. The stoichiometric carbon content of 6.13% must be closely maintained to avoid either the presence of free graphite or the formation of W_2C, which leads to the presence of the brittle "eta" phase in the finally sintered carbide, (i.e., excess or deficiency of carbon respectively). The grain size of the tungsten carbide (WC) so produced can range from 0.5 to 7 µm. For certain grades of cemented carbides, the carbides of titanium, tantalum and niobium are used in addition to WC, and these are made in a very similar way. Fine control over the carbide grain size is applied during the next stage of the process, which involves adding fine cobalt powder and wet milling, (in a ball mill using hard metal balls) all the constituents which will make up the final powder, together with a lubricant to aid pressing. The prime object of mixing cobalt and carbide is to ensure that every carbide particle is coated with even finer particles of cobalt (the ball milling aids the reduction in the particle size of the cobalt powder). In most cases, long time milling appears to have very little effect on the ultimate grain size, being more likely in the absence of specific grain growth inhibitors to encourage grain growth rather than reduce their size. Nevertheless, extended milling up to periods of days, is considered necessary to promote reactions during final sintering and to reduce porosity to a satisfactory level [19].

After milling the powder is dried, ideally by spray drying, which produces free flowing spherical aggregates of powder. Pressing is carried out by a variety of methods; direct to shape in automatic presses, cold isostatic pressing, extrusion, or by pressing cylinders or blocks followed by pre-sintering and machining into shape.

Final sintering is carried out in a vacuum or reducing atmosphere at a suitable temperature, which, depends on the composition of the mixture, but does lie within the range of 1300 to 1600 C. Sintering involves the formation of a liquid phase, the cobalt-dissolving tungsten and carbon from the carbide and liquifying at about 1320 C. The parts shrink by about 20% on sintering, eliminating much of the porosity, reducing it from 50% in the pressed compact to less than 0.01% by volume in the final product [20]. The low porosity is attributable to the liquid being present during sintering. Porosity can be reduced even further by hot isostatic pressing after sintering, however, more beneficial to, for example, wire drawing rather than cutter tips, where small pores may be exposed during final polishing and hence mar the surface finish. On cooling, after sintering, the cobalt phase precipitates most of the dissolved tungsten and carbon, but the binder phase is much stronger than pure cobalt by virtue of the residual contents of these elements, which are sufficient to stabilise it in its cubic form. The merit of cobalt as the binding medium depends on the formation of the relatively low melting point liquid phase, which wets the carbide particles so that surface tension forces, help to densify the sintered compact , and on it dissolving some of the tungsten carbide to strengthen the binding phase.

The important properties of cemented carbides for the application in cutting tools are , the hardness, the transverse rupture strength, the compressive strength, Youngs modulus, and the impact strength - allowing the retention of the cutting edge at elevated temperatures. These properties can be controlled to a large extent by the composition and the manufacturing process, the principal factors affecting the properties being the proportion of cobalt and the particle size of the carbide. There are many commercial grades of the material and the range of properties differ according to the grades.

It should be noted that there is no internationally accepted classification of cemented carbides for wear parts, so each producer uses his own grading system.

The hardness of cemented carbide increases with the volume fraction of carbides and with reduction in the mean size of the particles. The relationship between cobalt content and particle size for tungsten carbide/cobalt alloys is shown in fig 3.1 [19]. The hardness range of cemented carbide begins where tool steels leave off, at about 900 Vickers Hardness Number, and goes up to over 2000 V.H.N. hard enough to scribe or cut glass [20]. Hardness is maintained to quite high temperatures, for example at 1000 C it can be equal to that of high speed steel at room temperature.

The transverse rupture strength also depends on the volume fraction of carbides and mean size of particles, rising to a maximum as one factor is varied whilst the other remains constant. Fig 3.2 shows a typical relationship of T.R.S. measured against cobalt content for various grades of carbide [20]. The fall off in T.R.S. with increasing cobalt content occurs because of the material actually bends before it breaks.

Comprehensive strength is higher with a lower binder content and smaller grain size , fine WC can reach a value of 7000 MN/m^2 [20].

The impact strength is directly related to the cobalt content of the alloy, increasing linearly with increase in cobalt as shown in fig 3.3 [20], for alloys with the particle size of the carbide in the range of 1.4 - 3.1 μm . This indicates that the impact resistance of the cemented carbides is good.

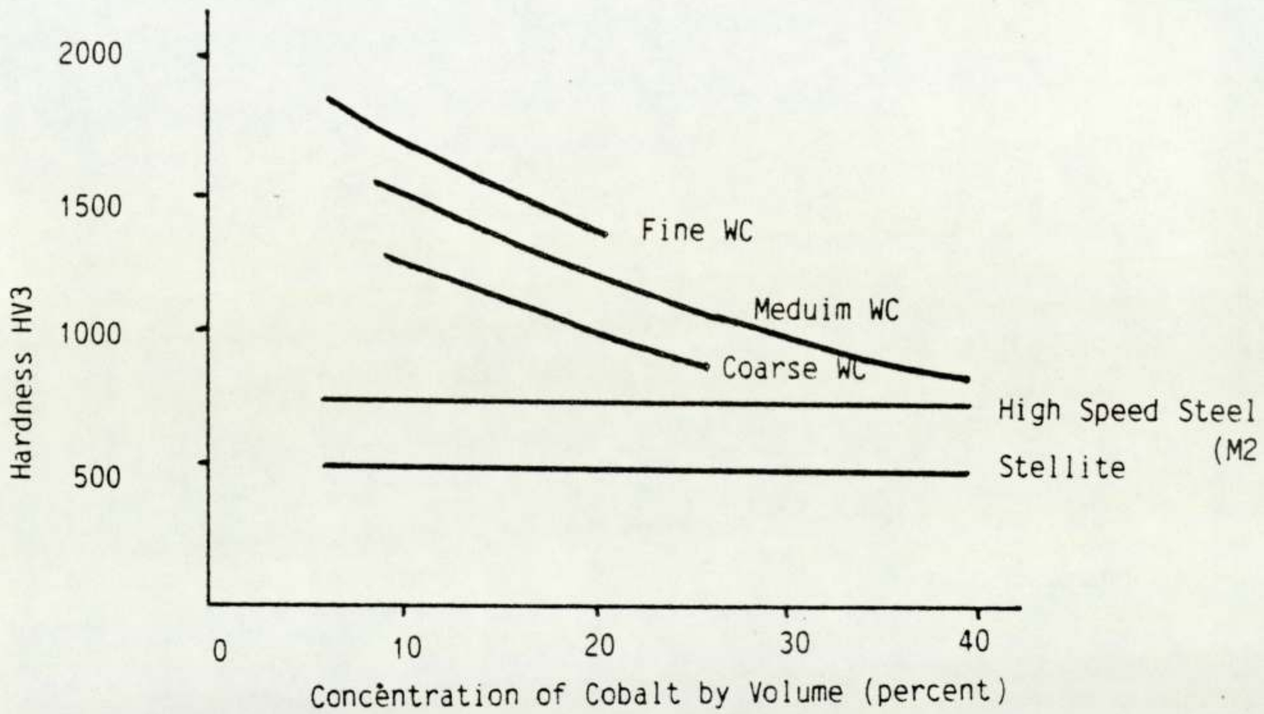


FIGURE 3.1 WC-Co CEMENTED CARBIDES HARDNESS INCREASES WITH DECREASING COBALT CONTENT AND WITH DECREASING WC GRAIN SIZE

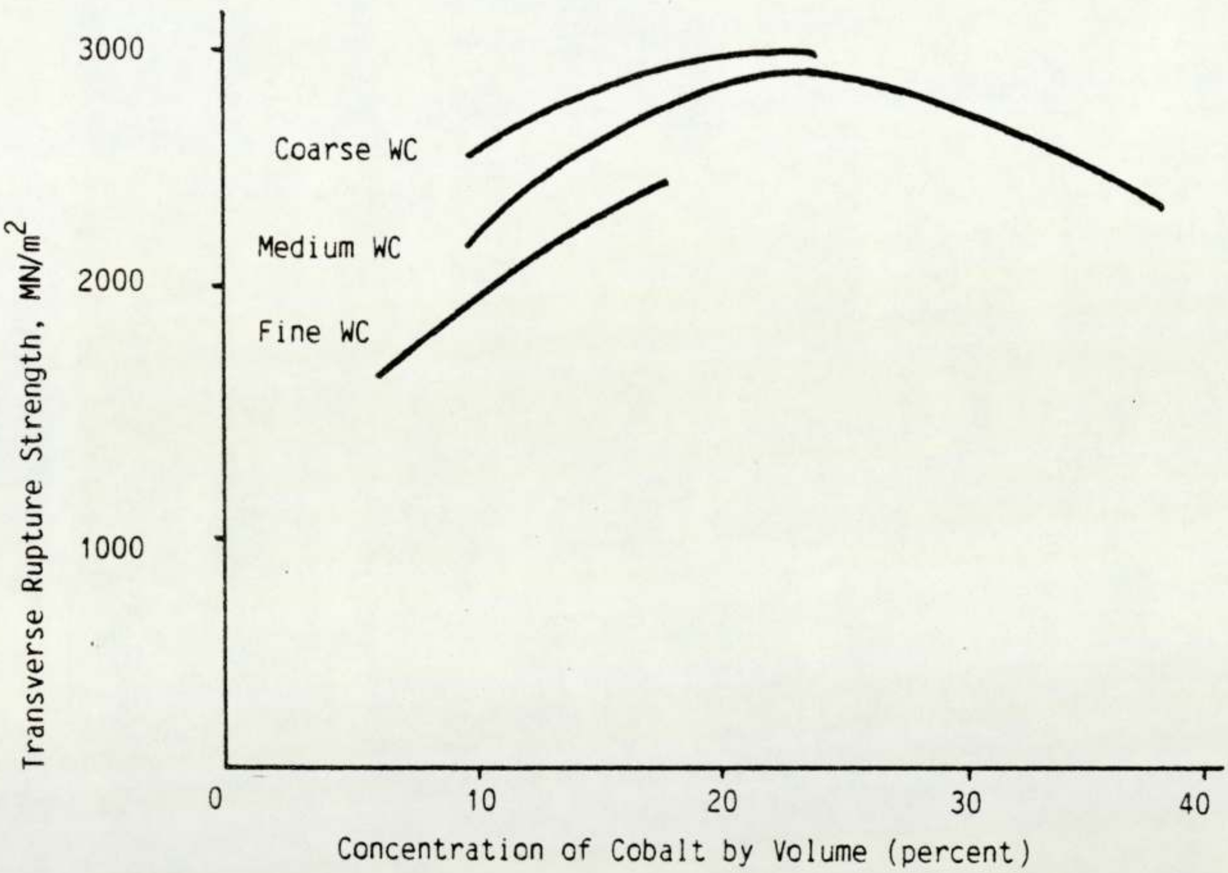


FIGURE 3.2 COARSE GRAIN SIZE WC GIVES CEMENTED CARBIDE ITS HIGHEST TRANSVERSE RUPTURE STRENGTHS

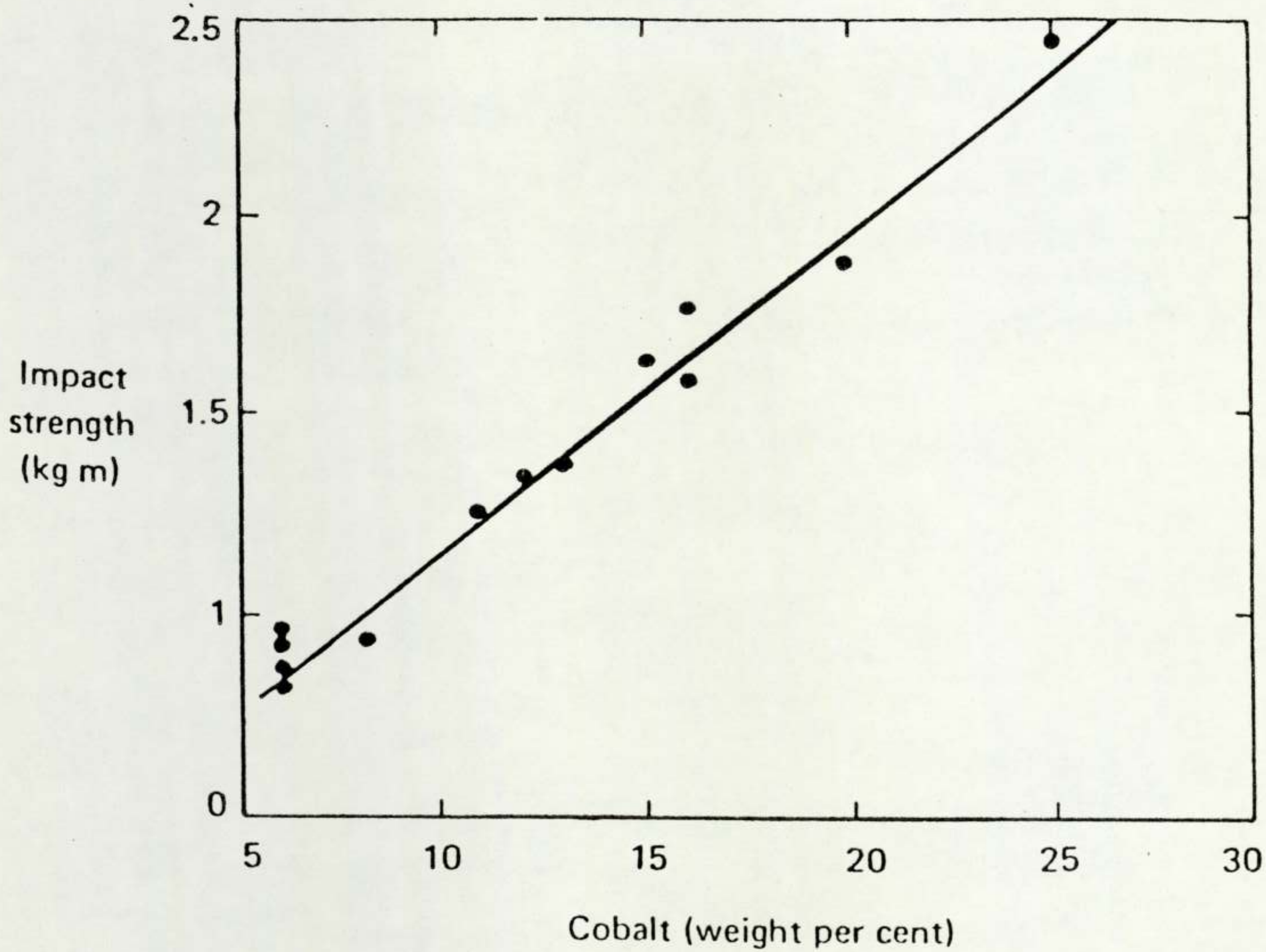


FIGURE 3.3 IMPACT STRENGTH OF WC-Co ALLOYS IN RELATION TO COBALT CONTENT, grain size of WC is 1.4 to 3.1 μm

Tungsten carbide has an extremely high rigidity, with a Young's Modulus of some three times that of steel. The modulus is independent of WC grain size ; and decreases with increasing cobalt content.

The density of WC-Co is normally 1.5 to 2.0 times that of steel, decreasing with increasing cobalt content.

Tungsten carbide has a very low coefficient of thermal expansion and a high thermal conductivity. This gives cemented carbides a coefficient of expansion of about half that of ferritic steels, and a conductivity of about twice that of steels, and a third that of copper. This combination gives the straight WC-Co grades an excellent thermal shock resistance, and an ability to conduct away heat generated by friction (e.g., in cutting tools)

Note; the low coefficient of thermal expansion must be taken into account when clamping or brazing (see brazing section)

However, the reliability of tungsten carbide parts also depends on a resistance to fracture.

For a material which is so hard, cemented carbide is exceptionally tough, but is still a relatively brittle material and fracture can start due to tensile stresses developed during bending or contact loading.

A strength measurement that better relates to the mode of stress applied in cemented carbide applications, and that is less sensitive to external test conditions, is "fracture toughness" [21]. Fracture toughness (K_{Ic}) is a measure of the tensile rupture strength of a specimen containing a flaw of critical size. K_{Ic} is the measure of toughness which is obtained from a test under plane strain conditions, which happens to be the most severe. Fracture toughness of a material is a good way of determining the minimum level of toughness commonly used by designers. Thus, for cutting tool applications fracture toughness should be a better indication of the strength of cemented tungsten carbide than the transverse rupture strength.

Typical fracture tests can be seen in fig 3.4 [20].

The failure of tungsten carbide is controlled by the propagation of cracks through the carbide phase. But the initiation of these cracks is due to plastic deformation in the cobalt [22,23]. Thus in addition to micro-structural contributions to the fracture toughness, the solid solution strengthening arising from the dissolution of WC in the binder will play an equally important role in determining the fracture toughness of the composite [21].

The quantity of cobalt binder can be measured by using the magnetic coercive force of the alloy.

It can thus be summarised that the properties of cemented carbides are influenced by;

1) Type of carbide

2) Choice of binder material

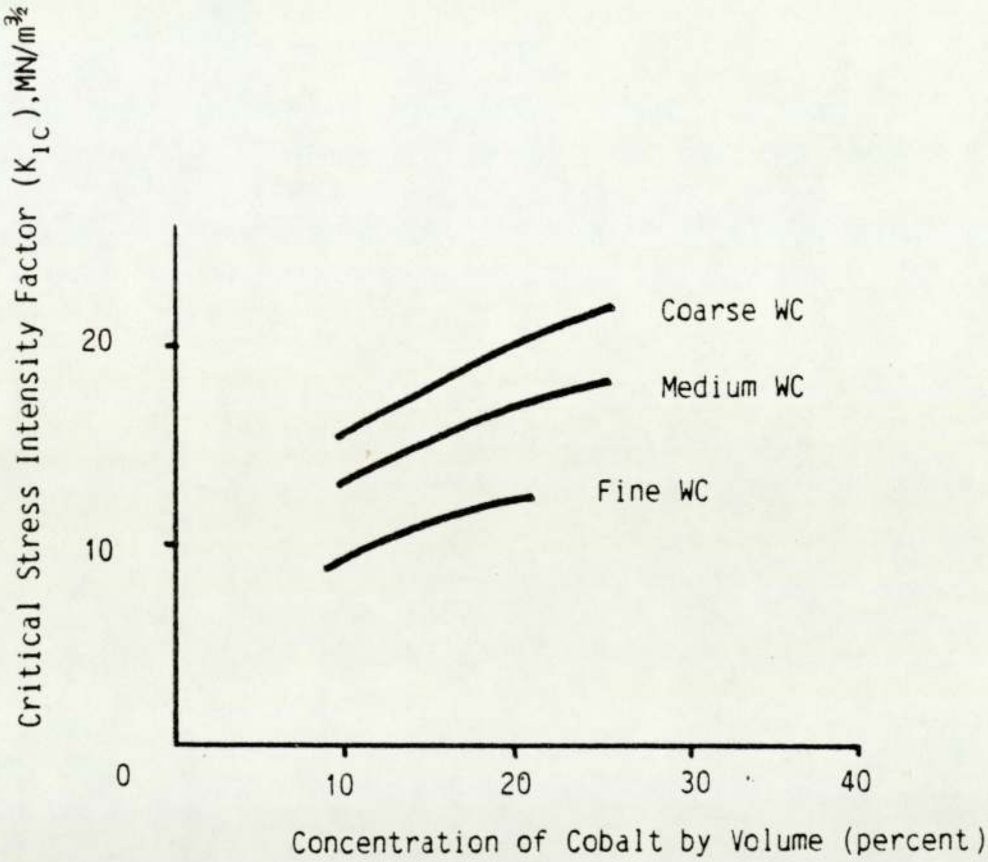


FIGURE 3.4 FRACTURE TOUGHNESS (K1c) IS INFLUENCED BY THE COBALT CONTENT AND THE WC GRAIN SIZE

3) Amount of binder material

4) Carbide grain size and distribution

5) Balance of carbon content

6) Porosity

It is considered at this point that the development of the forming process for the helical tips requires more than development of the equipment necessary to do the forming. It requires the development of a complete system, starting with the powder and ending with the finished part. New demands will be made on the sintered carbide and the powders now generally used may not be suitable for all forming applications. The helical forming part of the manufacturing process is intimately related to the powder used, and the object of all development efforts must be to the optimum combination of both for each part made.

However, the purpose of the study into the helical forming unit needed to be started with the measurement of the process parameters currently applied to produce the tips.

3.2 PRESENT TECHNIQUES OF PRODUCING THE HELICAL CARBIDE INSERTS

The tungsten carbide helical tips are manufactured in two stages, namely;

a) The production of the carbide blades

b) The forming of the tips

The flat carbide blades are produced in a similar way to that mentioned in section 2.1. The process commences with Marwin Hard Metals (M.H.M.) using a tungsten carbide, sub-micrion powder obtained from one of two suppliers (V.R. Wesson or Plansee).

Using the purchased carbide powder in the above form, the tungsten carbide cobalt (WC-Co + mix of wax) powder is pressed to shape at Marwin Hard Metals. The tungsten carbide pressing is carefully handled on removal from a press since its strength is mainly due to the wax compound which was previously added as a binder.

At present MHM employ two methods of producing the the sintered carbide after the pressing stage.

METHOD 1 : The compacts are loaded onto a tray covered with asbestos paper to prevent carburizing, and the tray is then fed into a furnace (with an atmosphere of natural gas or hydrogen) on a track driven through the furnace with an electric motor (similar to the pusher furnace discussed in a study by Read [24]). This part of the operation is to de-wax the pressings, usually at a temperature of

about 400 C, and to pre-sinter at approximately 700 C. The total time taken for this process is three hours. As the wax sublimes away, the cobalt dissolves the tungsten and carbon from the carbide to retain the binding of the pressing. After pre-sintering, the pressings are sufficiently strong for machining, if necessary, into intricate shapes.
The shaped carbide(i.e., the flat blade for the ultimate production of helical tips), is then placed into a furnace heavily insulated with carbon, (where the temperature is gauged by an optical pyrometer) and held within a range of 1360 to 1380 C, for four hours to finally sinter the pre-forms. After sintering the carbides are allowed to cool, without any forced cooling methods, which can sometimes take up to three days in the open air.

METHOD 2 : The compacts are placed on a tray and loaded into a recently acquired unit at MHM., a "CONSARC" vacuum furnace, which will de-wax, pre-sinter, and final sinter without any removal, i.e., a fully automated furnace. However, if additional shaping is required after initial pressing, then the carbide must be removed from the furnace after pre-sintering and returned to the furnace for final sintering, as described for method 1. After sintering, the carbides can be argon fan cooled in the furnace.

On observing the two methods, it is quite evident that since the "Consarc" furnace has been in operation, the sintering process is controlled more effectively. It also provides healthier working conditions, by eliminating excessive carbon dust, which was a problem with the old-type furnaces, as used in method 1.

Temperatures and times can be automatically controlled with the "Consarc" furnace, which reduces the "skill" used in reading the optical pyrometer, in sustaining controlled readings.

The use of method 2 helps produce flat blade carbides with consistent hardness and toughness characteristics, thus reducing the problems of cracking produced in the forming or brazing of the tips.

It is well known that chipping of the edges of cemented carbide tips is a serious problem in machining operations. Analytical approaches to this problem have been made by Usui, Ihara and Shirakashi [25], who performed work on the probablistic stress criterion of brittle fracture in carbide tool materials.

A study of crack initiation and crack growth could be performed to check the validity of the improved technique using the "Consarc" furnace, and a similar study has been carried out by Hong and Gurland [26] using a scanning electron microscope, for the observation of crack propagation on the surface of notched specimens.

However, it was not part of the brief for this particular research work that either of the above (i.e., stress criterion and crack initiation) should be studied to any depth. The work is intended to concentrate on the actual production of the formed tips, and not the fracture of completed tips already in use.

The technique currently used to form the helical inserts is illustrated in figure 3.5.

The operation is as follows:

With the aid of an induction unit, transformer, water pump and various fittings, a graphite former is heated to a sufficiently high temperature that a flat blade tungsten carbide tip may be pushed through the former, in order to form the helical shape. The feeding through of the carbide is accomplished with a rack and pinion system. The operator uses a pair of hand tongs to locate the flat tip at the entrance of the graphite former, and the rack and pinion device is hand wound to apply pressure on to the tip. The pressure (controlled by the touch of the operator) is then maintained, so that the carbide, (whilst being heated by conduction from the graphite former) will enter the former. Subsequent tips help push out the previously entered tips through the former until they drop out at the other end. The succesful production of the first helical tips represented a considerable "break through". Since then, the emphasis has been on utilizing the skills of certain operators to maintain a steady supply of tips, with as few failures as possible. However, total reliance is on the eye and "feel" of the operator and there is an urgent need to quantify the operations before any process developments are possible.

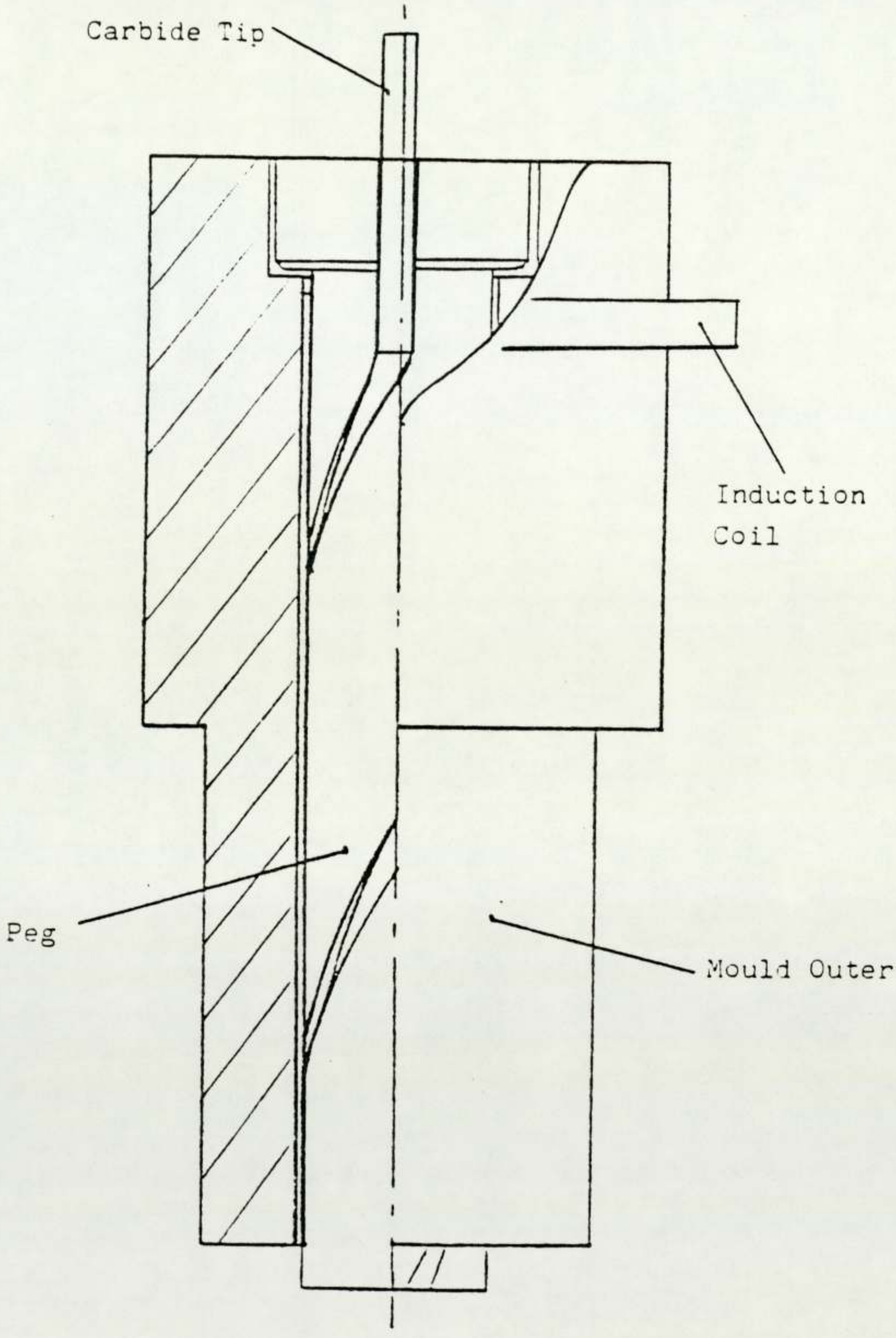


FIGURE 3.5 GRAPHITE FORMER (peg and mould outer) SHOWING LOCATIONS OF TUNGSTEN CARBIDE TIP PRIOR TO BEING PLUNGED THROUGH THE FORMER

3.3 SIGNIFICANCE OF THE AUTOMATION OF CARBIDE TWISTING

With the present method being performed by manual techniques, there are many advantages which can be gained from the introduction of a semi or fully automatic unit for helical tip forming.

There is of course, the high capital outlay required initially, once a suitable route for automation has been determined. This would involve critical assessment of the chosen technique, in order to provide a viable payback period for the introduction of the equipment.

After the economics of a system has been finalized and accepted, the benefits of automation can be categorized into the following :

(Obviously the automation of any system has similar advantages, as is the case in the previously discussed section on Brazing).

1) Removal of the skill of the operator

2) Consistency of production

3) Uniform production rate

4) Improved control of the parameters

The removal of the existing dependency of the operator skills is a prime consideration for automation. It removes the necessity to rely upon any one or small group of fully trained personnel to perform the operations required to produce the helical tips (i.e., providing a wider scope of personnel available to perform such tasks).

The consistency of production is maintained due to the ability to preset the data for each type of production batch, thus providing greater customer service and improved competitiveness.

The quality and quantity of the tips produced under automation will be manufactured at a uniform standard. The whims of the operators are removed.

While the operation remains a manual process, the parameters are entirely dependent upon the skill of the operator. Automation allows these parameters to be controlled and maintained more effectively (i.e once the optimum conditions for each type of production run can be determined, allowing the parameters to be pre-programmed).

3.4 EXPERIMENTAL WORK

The writer studied the manual method of producing helical formed tungsten carbide tips, with an aim to assessing the design features for an automated unit. In order to perform development work, an additional manual operated device (to avoid disruption to existing production requirements) was commissioned. The additional unit was obtained to allow the correlation of optimum conditions for producing the helical tips (i.e., pressure, temperature and displacement rates). (See fig 3.6 and 3.7).

However, the time available on the additional unit was limited due to increasing output requirements and necessitated time-sharing of the unit.

Initially, it was planned to use an ultra-violet recorder, in conjunction with thermocouples, load cells and displacement transducers, to determine the operating parameters. The decision to use an ultra-violet recorder required the need for a thermocouple amplifier (to increase the thermocouple current output) in order that a small amount of current could be taken to drive the galvonometers in the U.V. recorder. Problems were experienced in attempting to calibrate the thermocouple to the amplified voltage, due to various factors. The main problem was attributed to the presence of Radio Frequency Interference (R.F.I.) from the induction unit, used in the helical forming device. Subsequently, a mini-computer measurement and control system (i.e. 'Macsym' computer - see Appendix C and D for specification) was adapted to alleviate problems. This removed the need for the thermocouple amplifier - since a UV recorder was no longer to be used. The work performed and problems encountered in determining the operating parameters are now discussed.

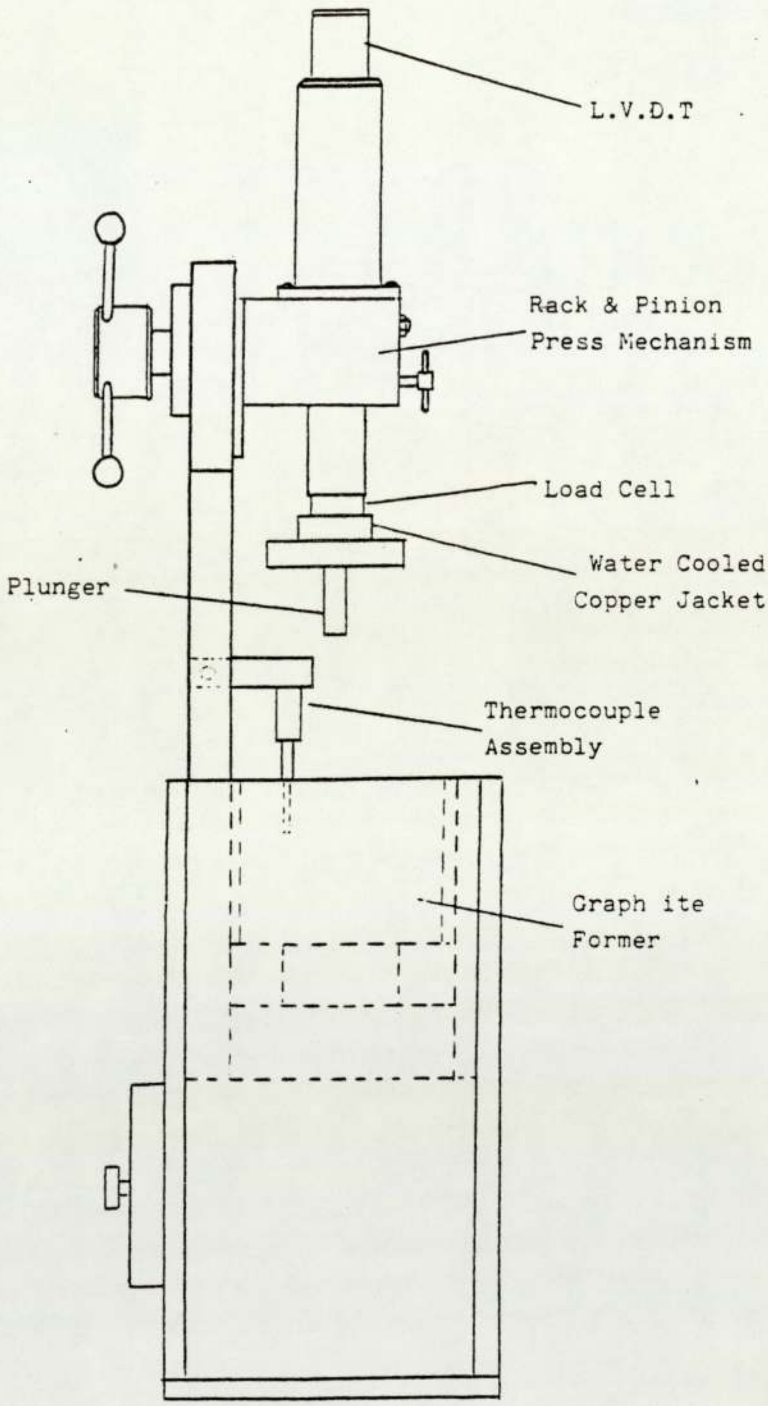


FIGURE 3.6 HELICAL FORMING UNIT - FRONT VIEW

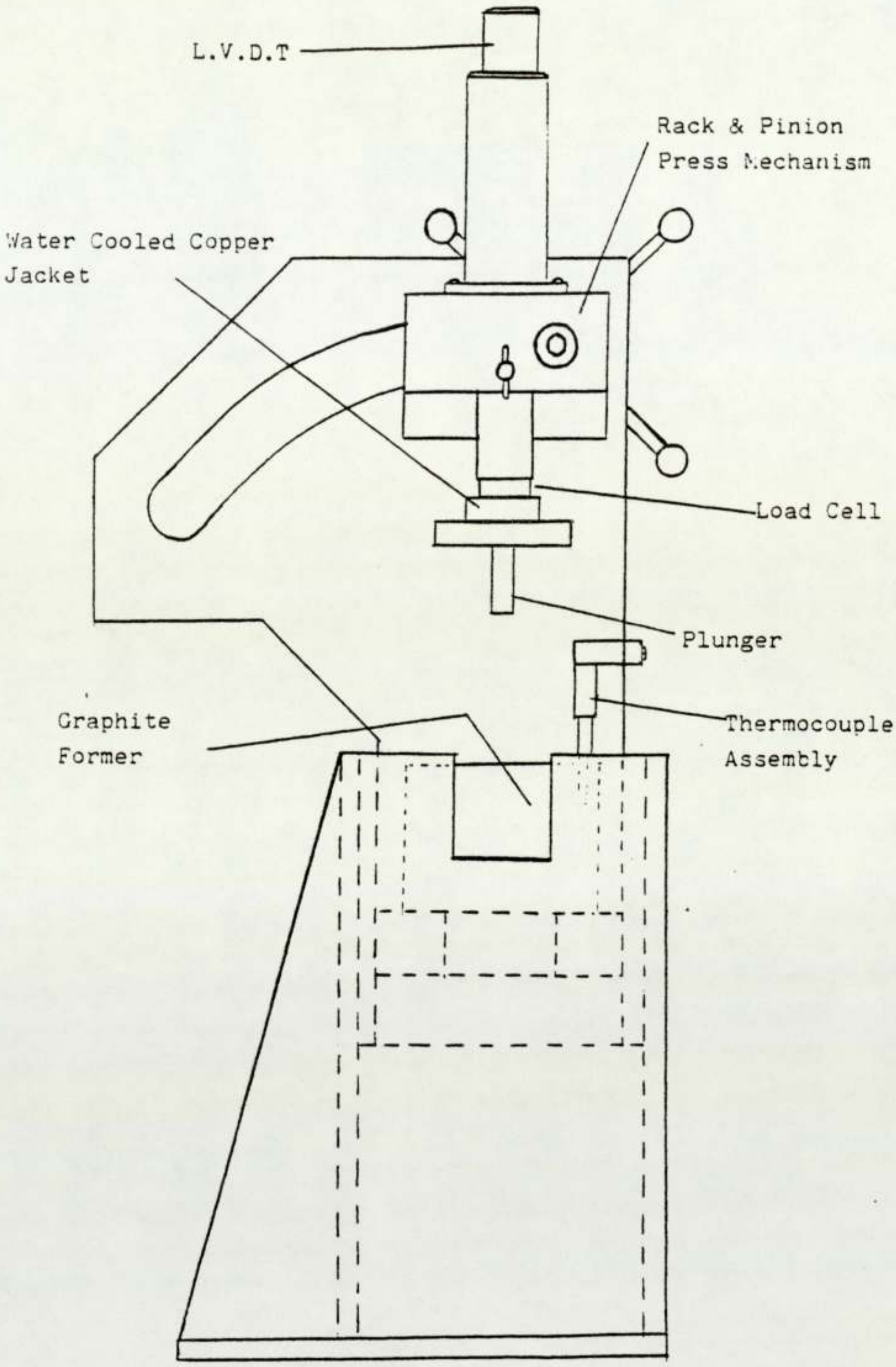


FIGURE 3.7 HELICAL FORMING UNIT - SIDE VIEW

3.4.1 Preliminary Investigations Into The Measurements -

3.4.1.1 Temperature Measurement -

Basically there are four main types of thermometer; liquid in glass; resistance thermometer; the thermocouple; and the radiation pyrometer.

The liquid in glass is commonly used for temperature measurement and in various forms can cover temperature ranges from about -200 to 600 C, with accuracies from 0.005 degrees C at room temperature, up to plus or minus 2 degrees C at the top of the range.

Resistance thermometers operate from absolute zero to above 1000 C. Semiconductors, thermistors, alloys and pure metals are all used to form stable temperature elements whose electrical resistance can be calibrated as a function of temperature.

Thermocouples are probably the most widely used thermometers in scientific and industrial applications. Their reasonably low cost, simplicity and low thermal mass make them ideal for multiple monitoring applications. They make use of the Seebeck (thermo-electric) effect, where an E.M.F. is developed between two different metals placed in contact [27]. It is important to recognise that the normal E.M.F., measured at the terminals of a thermocouple is generated not at the hot junction, but along the length of the wire in the temperature gradient between the junction and the terminals.

Thermocouples can be sub-divided into base, noble and refractory types. Base metal types with their elements of base metals or base metal alloys are generally used up to 1000 C, depending on the wire thickness. The noble metal thermocouples usually with platinum or a platinum-rhodium alloy can be useful up to temperatures of 1700 C. Refractory metal thermocouples have been developed for use above the noble metal range, e.g., tungsten-rhenium group, which can be used up to 2300 C. The choice of thermocouple depends on the task in hand.

Radiation pyrometry is widely used in industry to measure the surface temperatures of objects and materials mainly in two situations. When the surface moves, so making contact thermometry difficult, and when temperatures are too high or conditions too hostile for contact thermometers to survive very long. A radiation pyrometer basically measures spectral radiance of the radiation emitted from a surface at temperature. The pyrometer generally consists of a radiation detector with stops and lenses or mirrors to focus the radiation onto the detector. There are various types of pyrometers, e.g., infra-red and optical types. Infra-red is often used for temperatures of up to 800 C, and an optical pyrometer ranges from 800 to as high as 6000 C, with the aid of filters. An example of an optical type is the disappearing filament pyrometer which has an accuracy of 3 degrees at 1000 C to 10 degrees around 2500 C.

After considering the above types of thermometry methods, due to the environment in which the requirement of the temperature measurement is to be performed , the thermocouple was decided upon for use. Factors affecting the decision were, the requirement to measure the graphite internally (dismissing the use of an optical pyrometer) and the need to measure temperatures in the range 1300 to 1400 degrees C (thus inevitably eliminating the possible use of the liquid-glass type and the resistance thermometer).

Due to this high temperature range it was necessary to employ the use of the noble metal thermocouple of the R type (B.S.,4397:part 2), i.e., platinum 13% rhodium/platinum.

Various attempts were made to calibrate Platinum - 13% Rhodium/Platinum thermocouples, in conjunction with the thermocouple amplifier. Initial tasks were performed using a gas torch (oxy-acetylene) to heat up a graphite specimen with four thermocouples embedded in it, one being a control thermocouple and the other three being the thermocouples to be calibrated. Also, thermocouples were linked to a "Macsym" minicomputer measurement and control system. The control thermocouple was connected to an Isothermal Thermocouple Analog/Digital Input/Output (ADIO) card, which enables a direct temperature readout to be shown on the display unit. The calibration thermocouples were connected to a wide range solid state Analog Input card, where the voltages (i.e., amplified voltages) were collected and transmitted to the computer for calibrating against the control thermocouple.

The results obtained using a gas torch were very inconsistent, attributed to a thermal gradient across the graphite caused by the non-uniform heat source. Therefore, subsequent calibration tests were performed on site (i.e., at Marwin's) using the actual heat source (induction unit) used in the helical forming unit.

Initially a "Rika Denki" chart recorder was used in an attempt to calibrate the thermocouples, whilst using the induction unit to heat up the graphite specimen. The "Macsym" was not available for use at this point in time, since it was engaged in a research project at the University. The results produced using the chart recorder in conjunction with the induction furnace were inconclusive, due to spikes and saturation of the voltage signal caused by Radio Frequency (RF) Interference from the induction generator. Initially amplifiers were used with the chart recorder, designed to provide a current sufficient to drive the galvonometers on a U.V recorder, which was intended to be used (discarded at a later date). Although, this only proved to show the amplification of the errors compared to tests without the amplifier unit.

During the experimental work performed to calibrate and eradicate the problems of RF interference on the thermocouples, the 'Macsym' computer was commisioned to verify the problems (i.e., determine if the Macsym would detect a similar response to the RF environment). This was performed in order to determine if the Isothermal thermocouple card would help to eliminate the problems. The test provided results with a similar response to those obtained using the chart recorder.

A study of Macdonald [28] observed the generation of voltage spikes within ferromagnetic wires when the wires are placed in an alternating magnetic field. He revealed that this effect has implications for thermocouple thermometry. Where the voltage generated by this magnetic field will contaminate the thermocouple E.M.F., resulting in a temperature measurement error.

However, this work proved that only ferromagnetic wires exhibited a voltage and concluded that non-ferromagnetic wires such as platinum did not produce the voltage spikes.

Kollie [29] also performed a study of thermocouple thermometry errors caused by magnetic fields, concluding that changes in seebeck coefficient were small especially in non-ferrous thermocouples.

A substantial amount of work was undertaken to change the thermocouple configuration and set-up, in order to eliminate the R.F. pick-up. Advice was taken from various thermocouple manufacturers and further trials were performed using the following techniques.

a) Screening the thermocouple

b) Screening the thermocouple and earthing it to the graphite and amplifier.

c) Earthing positive wires of the thermocouple.

d) Using capacitors across the amplifier input to attempt to smooth the signal.

e) To use ground hot junction mineral insulated thermocouples.

f) To use hot junction mineral insulated metal-clad thermocouples (using Faraday's cage principle)

a) Macdonald [28] analysed the effects of ferromagnetic thermoelements and concluded that the amplitude of the voltage spikes was directly related to the amplitude of the alternating magnetic field between the threshold and saturation value. And also, showed that for a constant amplitude magnetic field, increasing the frequency of the field resulted in an increase in the amplitude of the voltage spikes.

However, whilst Macdonald was working on ferromagnetic thermoelements, a similar response was detected in the work performed at Marwins, although, platinum thermocouples were used.

Macdonald indicated that the thermocouples should be enclosed in a magnetic shield so as to minimise the temperature measurement error in the ferromagnetic thermocouple.

Thus, since a similar response to the work performed by Macdonald was experienced, it was worthwhile to use a similar technique to try and eradicate the temperature measurement error. Therefore the thermocouples were screened but unfortunately the cure was not analogous to Macdonald's study.

b) The method of screening the thermocouple was extended to earthing the graphite core, since the core is the object which has the E.M.F. induced. This was performed in order to allow the R.F. to be picked up in the screen to run to the same earth as the graphite core.

Again, however, it still produced the erroneous results.

c) During consultations with various suppliers of thermocouples, it was recommended that maybe the earthing of the positive wire of the thermocouple would eliminate the problem of R.F. interference. This was then implemented but again to no avail.

d) After numerous investigations into the R.F. interference, another technique of R.F. shielding was tried. This involved the use of passive elements in an attempt to filter the R.F. interference [30]. Capacitors were used across the amplifier input to attempt to eliminate the interference, but again it proved unsuccessful.

e) Similar to the technique used in c) i.e., earthing of the positive wire in the thermocouple, a ground hot junction mineral insulated thermocouple was used. The ground hot junction meaning that the thermocouple configuration inside the shield (which holds the mineral insulation) is grounded to the actual shield. However the results detected were no different to those obtained using method c).

f) Further discussions with thermocouple manufacturers gave rise to a completely different approach to the problem of R.F. interference. Where previously, the emphasis was put on the attempted earthing of the R.F. pick-up, it was decided to adopt a technique which would not earth the thermocouple, in fact it was an opposing strategy, i.e., to use a hot junction mineral insulated metal-clad thermocouple which would completely isolate the thermocouple from the graphite.

The last technique using metal-clad hot junction and mineral insulated thermocouples in conjunction with the 'Macsym' computer, eliminated the various R.F. interference previously 'picked up' from the Induction Unit and produced realistic temperature measurements. Due to the high cost of Platinum/Platinum-Rhodium (R-Type) thermocouples, the viability of this configuration was tested using Nickel-Chromium/Nickel-Aluminium (K-Type) thermocouples, up to a temperature of approximately 1000 degrees C. Since this proved sucessful, an R-Type thermocouple (sheathed in Platinum) was obtained to test up to operating temperatures of the helical forming unit (i.e., approx. 1400 degrees C). The results obtained using the Faraday's cage principle on the Platinum-Rhodium thermocouple proved reliable in measuring the temperature of the graphite whilst heated within an induction coil. However, after continual useage (i.e. heating up for different tests), the thermocouples decayed and became unserviceable. Discussions with the manufacturer indicated that a more stable thermocouple is required for future work (i.e a similar thermocouple to the above arrangement with a 5% Rhodium/Platinum sheath, opposed to the 100% Platinum sheath used). Due to the time available on the programme it was not possible to procure a thermocouple to this configuration and implement in any tests. Although the thermocouples used were serviceable long enough for a suitable set of results to be recorded.

3.4.1.2 Force Measurement -

Generally, measurements of Force/Pressure are taken for a number of reasons, e.g., to provide a local visual indication of Force/Pressure; to provide a local indication and Force/Pressure control capability at a pre-selected value; or to be transmitted, allowing for remote monitoring and control. It is for a combination of the above examples that the Force of pushing the tungsten carbide tips through the forming unit is to be measured.

There are various methods available for measuring such parameters, the most fundamental technique being the use of Manometers. Others include Bourdon tubes and various types of strain gauges. The former two methods i.e., Manometers and Bourdon tubes were considered unsuitable for the measurement of the Force incurred in pushing the tips through the graphite former, due to the hostile environment and complexity of the mechanics of the helical forming system. Additionally, due to the high temperature environment, strain gauges were not used, since the temperature would adversely effect the accuracy of the measurements obtained using the wheatstone bridge configuration.

Therefore, a Kistler load cell (type 9021) which was positioned inside the plunger of the helical forming device, was chosen to measure the force developed by the plunger when pushing the carbide tips through the former.

Various problems were experienced whilst trying to measure the load.

Early tests showed that the signal was being saturated above the expected values. This was due to a large voltage drop between the furnace transformer and measurement equipment earth (i.e., an earth loop). Mansfield [31] endorsed the problems of earth loops and demonstrated the use of low level ground points (LGP) which ensures the earthing is done at the same point for all equipment. The earth loop problem was eradicated (by 'shorting-out' the earth), but further problems were found due to the rising temperature causing a drift in the measured output from the load cell.

Due to the large amount of heat being generated in the helical forming unit, (1400 degrees C) the plunger device was conducting the heat to the load cell, as well as anticipated problem of radiated heat distorting the output signal from the load cell. A water-cooled jacket was designed and built, to isolate the load cell from the heat being conducted up the plunger.

Subsequent measurements of load still gave inconsistent results. Consultations were made with Kistler Instruments which led to in-house trials and trials performed away at Kistler Laboratories to identify the measurement problem. Initially the load cell was returned to Kistler Instruments for laboratory tests to check and correct insulation resistance (which did not cure the problem). Secondly, the load cell was again returned to Kistler (this time in situ with plunger unit and water-cooled jacket) for laboratory tests. This ascertained that the load cell produced acceptable results whilst on bench trials away from the Induction unit. But on site at Marwin's, placed in the Helical Forming unit, results were still erratic. It appeared that RFI from the induction unit was again the source. However, pressing on with measurements indicated that only in a few cases was serious interference encountered, and these could be identified and discounted. The errors produced coincided with temperature gradients (i.e. when graphite core was heated up by the Induction unit the errors were in line with the temperature build-up of the core) even though the load cell was completely isolated. Nevertheless, tests were performed to measure the Force of pushing the tips through the graphite former and the results obtained during problem free tests were able to be analysed.

3.4.1.3 Displacement Measurement -

A Linear Variable Differential Transformer (LVDT) Transducer (see Appendix E and F) type D5/3000A, was fitted to measure the displacement of the tips through the former, procured from RDP Electronics Ltd. An adaptor was made to secure the LVDT Transducer to the existing Manual helical forming unit. This held the LVDT and allowed the probe to follow the actual movement of the plunger as the carbide tips are pushed into the graphite former. No serious problems were experienced whilst using the LVDT, in conjunction with Transducer Indicator, within the induction (RF) environment.

3.4.2 Use Of "MACSYM" COMPUTER For Measuring Parameters -

The particular attributes of the "Macsym" computer were demonstrated during a research project at the University running concurrently with the Marwin project. Thus, when the Macsym became available, unfortunately at a rather late stage, it was adapted for use on the forming rig.

The "macsym" is a much more advanced system for measuring parameters than the U.V. recorder, and can also be utilized for process control (see Appendix C and D).

After programming the "macsym" (see Appendix G,H and I for programs used), bench trials were performed to test the ability to measure and manipulate the data recorded, in conjunction with a Hewlett Packard 7470A Graph Plotter. Subsequently, the "macsym" was enclosed in a dust proof cabinet to protect the system from the high graphite dust environment where the helical forming unit is situated.

Finally, numerous trials were undertaken to measure the operating parameters of the existing helical forming unit , using some of the above mentioned instruments.

3.4.3 Experimental Work -

A set of results were obtained using the equipment and resources listed below;

1. Macsym computer
2. L.V.D.T. transducer
3. Load cell
4. Thermocouple
5. Twisting unit
6. Flat carbide specimens
7. Graph plotter
8. Dust proof cabinet
9. Convoluted tube ducting
10. "Expellair" extractor fan
11. Trolley

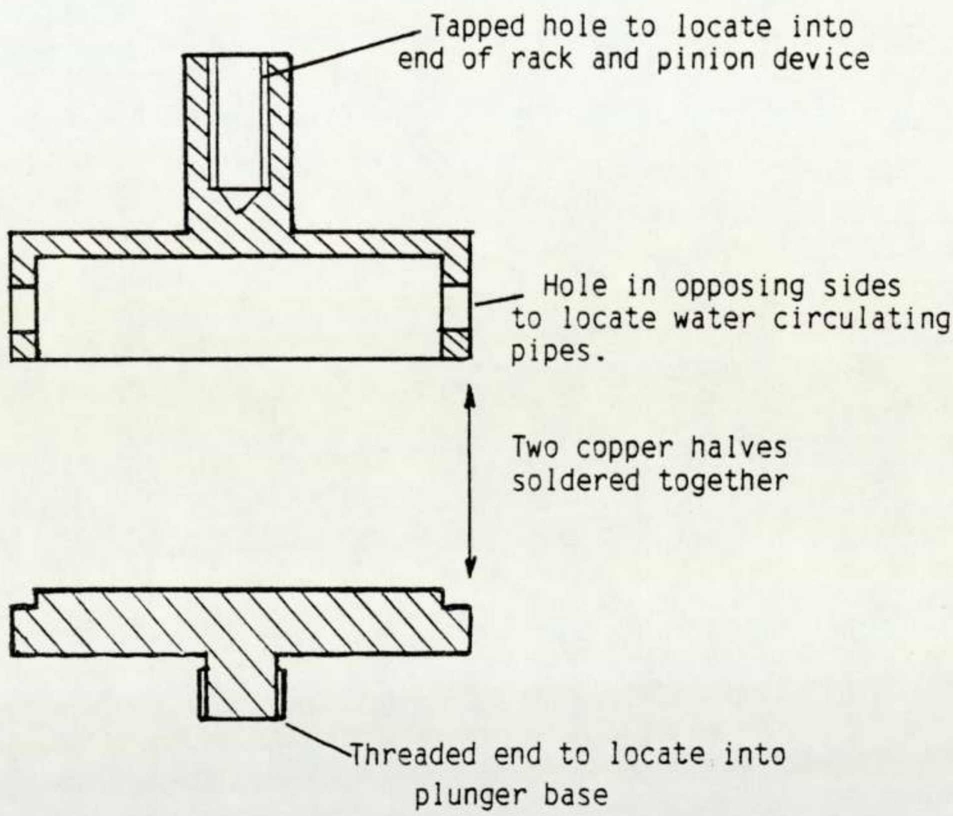
The Macsym computer was enclosed inside a special purpose-built dust proof cabinet, using an expellair fan to remove the hot air from inside the cabinet which had been generated by the computer itself (the computer had its own cooling extractor fan, but it could not cool the computer down since it was enclosed within the cabinet).

A convoluted tube tube was fixed with one end to the rear of the dust-proof cabinet, the other end lead to the open air, outside the factory in order to draw in cool air from outside the building. The encased Macsym computer was located on a trolley for ease of transportability and was positioned adjacent to the twisting unit.

The LVDT was positioned (using an attachment) at the top of the rack, on the forming unit (see fig 3.6 and 3.7). This allowed the transducer probe to move up and down, following the movement of the plunger as it pushed the carbide tip into the former.

The load was positioned on top of a water-cooled jacket located at the base of the rack and pinion unit (see figs 3.6 and 3.7). This acted as an interface between the load cell and the base of the plunger device (which became extremely hot as the tips were pushed through the former). The actual form of the water-cooled jacket can be seen in fig 3.8, which came about as a result of the development of various forms (see fig 3.9).

The thermocouple was positioned in the graphite former near to the centre, in order to obtain the optimum temperature reading of the graphite (which conducted the heat to the tungsten carbide tips as they were fed through the former itself). (see also figs 3.6 and 3.7 for diagram of assembly).



Both components machined from 38mm diameter copper bar.

FIGURE 3.8 WATER - COOLED JACKET WHICH WAS POSITIONED AT THE BASE OF THE PLUNGER DEVICE

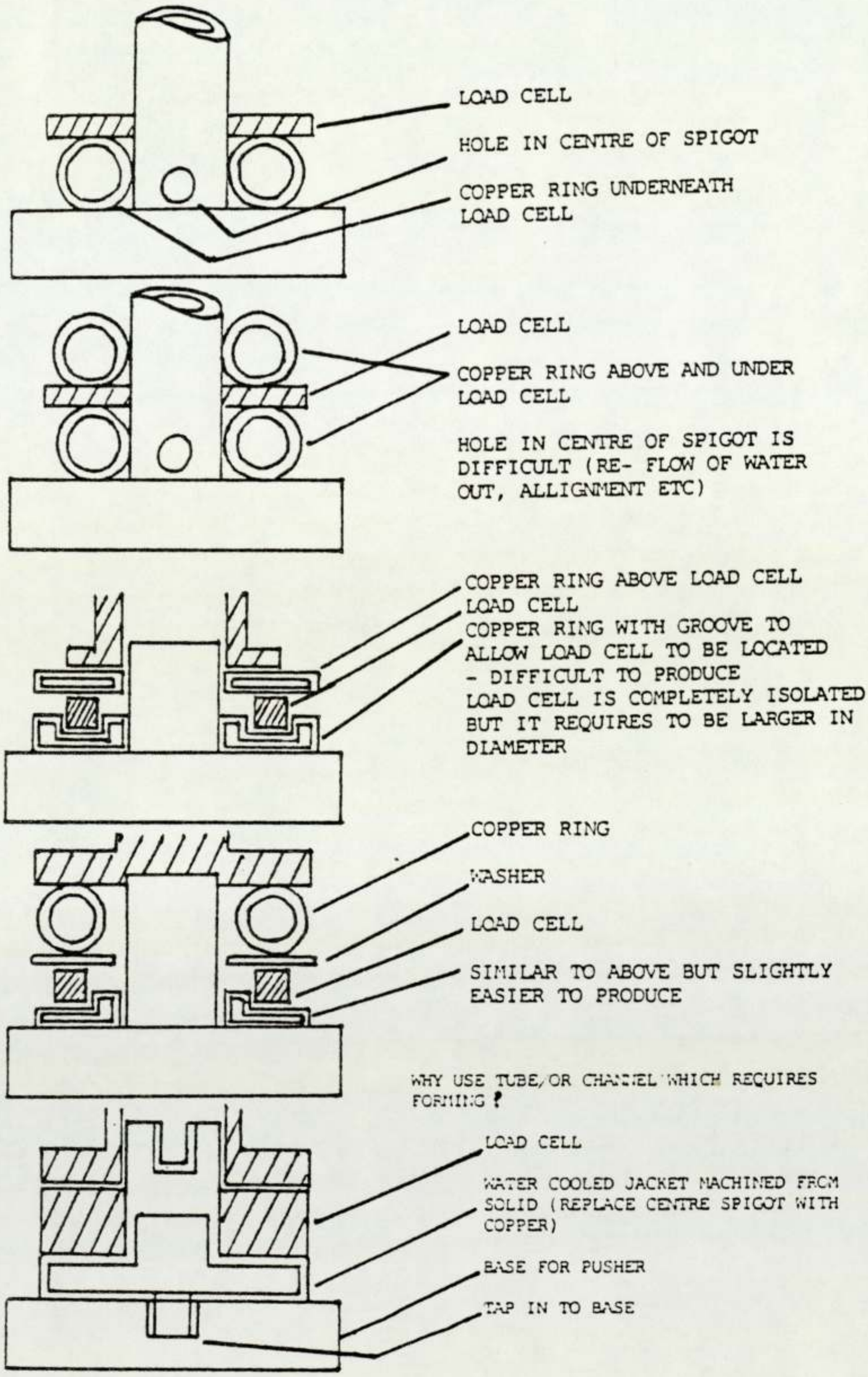


FIGURE 3.9 DEVELOPMENT OF THE WATER - COOLED JACKET FOR THE LOAD CELL

The Macsym computer was linked to; the thermocouple via an isothermal analog/digital input/output (ADIO) card, the LVDT transducer (type D5/3000A) via the LVDT digital transducer indicator (type E307-B see appendix F), and the Kistler load cell (type 9021 see appendix G and H) via the load cell charge amplifier unit (type 5006 appendix I). A full description and specifications of the Macsym computer can be seen in appendices C and D.

The twisting (helical forming) unit was thus adapted to measure the force, displacement and temperatures encountered in the operation of the forming of the helical tungsten carbide tips.

There were two types of carbide used in the procedures, these were:

a) H25T The type of H25T used is produced by Metallwerk Plansee (Austria). It is categorized as ISO code K30, with a high toughness offset against lower hardness (e.g., K20 carbide is likely to be harder but less shock-resistant than one of K30).

b) RAMET 1.

Ramet 1 is produced by V.R.Wesson (USA), and is a micro-grain carbide, having the strength of high speed steels and the hardness and wear resistance of coventional carbides , plus a high degree of shock resistance. It is also categorized as ISO K30 type.

For additional information on Ramet 1 see appendix M.

Both are usually used in cases where the carbide chips because of slow surface speeds. Thus, they are very suitable for machining high temperature, high strength alloys - the "aircraft" metals, as applied in the design of milling cutters which are produced by Marwin's.

The results were recorded and processed on the Macsym computer using the programs which can be seen in appendices J,K and L (for details of the recording program see appendix J). They were then analysed and checked for accuracy and consistency. Only a specimen set of results are included in this document, since it would not be practical to show them all. After obtaining results using the measurement program (appendix J) on the Macsym, they were printed using the program in appendix K. It was not possible to print the results simultaneously, as the tests were performed, since the time taken to print them would have severely slowed down, and reduced the sampling rate of the measurement.

Subsequently, the printed results were plotted on graphs of Displacement, Force and temperature versus Time, and Force versus Displacement, using a Hewlett Packard 7470A plotter (see Table 3.1 and 3.2 respectively). Examples of some of the graphs plotted can be seen in Figures 3.10 - 3.18 inclusive. The program used to plot these graphs can be seen in appendix L.

TEST	CARBIDE SIZE (mm)	CARBIDE TYPE	HARDNESS (VPN)	CUTTER DIA	HELIX ANGLE
M1	2.38 X 7.14 X 29.72	H25T	1478	22mm	25′
M2	2.38 X 13.9 X 29.72	H25T	1525	25mm	25′
M3	2.38 X 4.76 X 58.93	H25T	1525	25mm	30′
M4	3.18 X 6.35 X 58.93	H25T	1509	50mm	30′
M5	3.18 X 7.94 X 58.93	RAMET 1	1608	50mm	30′
M6	3.18 X 6.35 X 88.39	H25T	1525	38mm	30′
M7	3.18 X 7.94 X 88.39	H25T	1525	38mm	30′

TABLE 3.1 : SPECIFICATIONS OF CARBIDES USED IN THE TESTS

TEST	FORCE (N)	C.S.A. (mm^2)	STRESS (N/mm^2)
M1/1	8	17.00	0.47
M1/2	10	17.00	0.59
M2/1	10	33.00	0.30
M2/2	15	33.00	0.45
M2/3	15	33.00	0.45
M2/5	16	33.00	0.48
M2/8	14	33.00	0.42
M3/1	13	27.98	0.46
M3/3	7	27.98	0.25
M3/6	12	27.98	0.43
M4/2	7	20.19	0.35
M4/5	6	20.19	0.29
M4/6	6	20.19	0.29
M4/12	5	20.19	0.25
M4/17	7	20.19	0.35
M5/1	10	25.25	0.40
M5/7	15	25.25	0.59
M5/8	10	25.25	0.40
M5/10	25	25.25	0.99
M5/12	15	25.25	0.60
M5/14	15	25.25	0.60
M5/20	20	25.25	0.79
M6/1	7	20.19	0.35
M6/2	8	20.19	0.40
M6/7	5	20.19	0.25
M6/8	5	20.19	0.25
M6/9	4	20.19	0.20
M6/11	6	20.19	0.30
M6/12	5	20.19	0.25

TABLE 3.2 : MEASUREMENT OF THE OPTIMUM FORCE APPLIED TO THE INITIAL MOVEMENT OF THE TIP IN THE FORMER - obtained from graphs of Force V Displacement

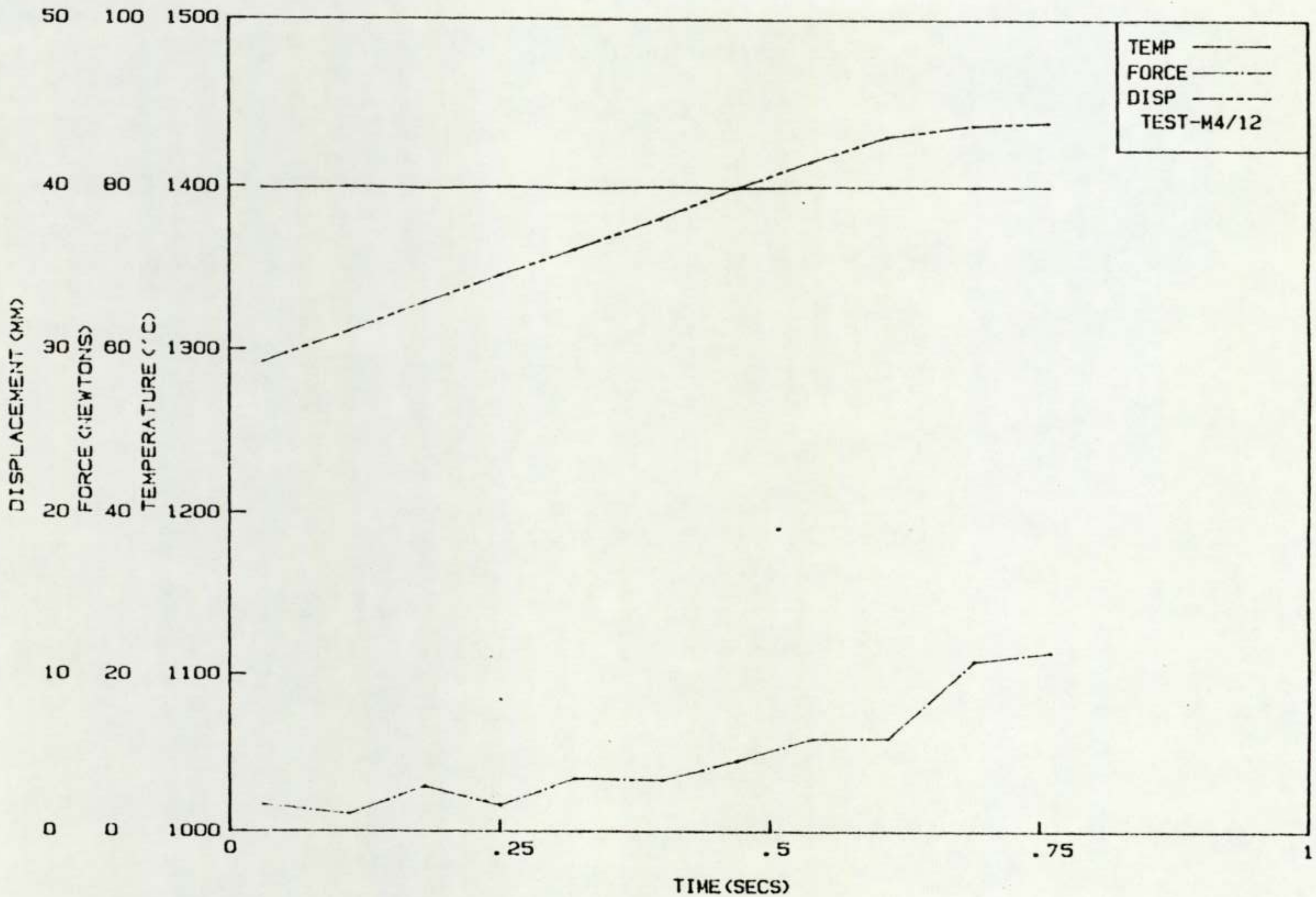


FIGURE 3.10 GRAPH OF FORCE, DISPLACEMENT, AND TEMPERATURE VERSUS TIME (for helical forming tests)

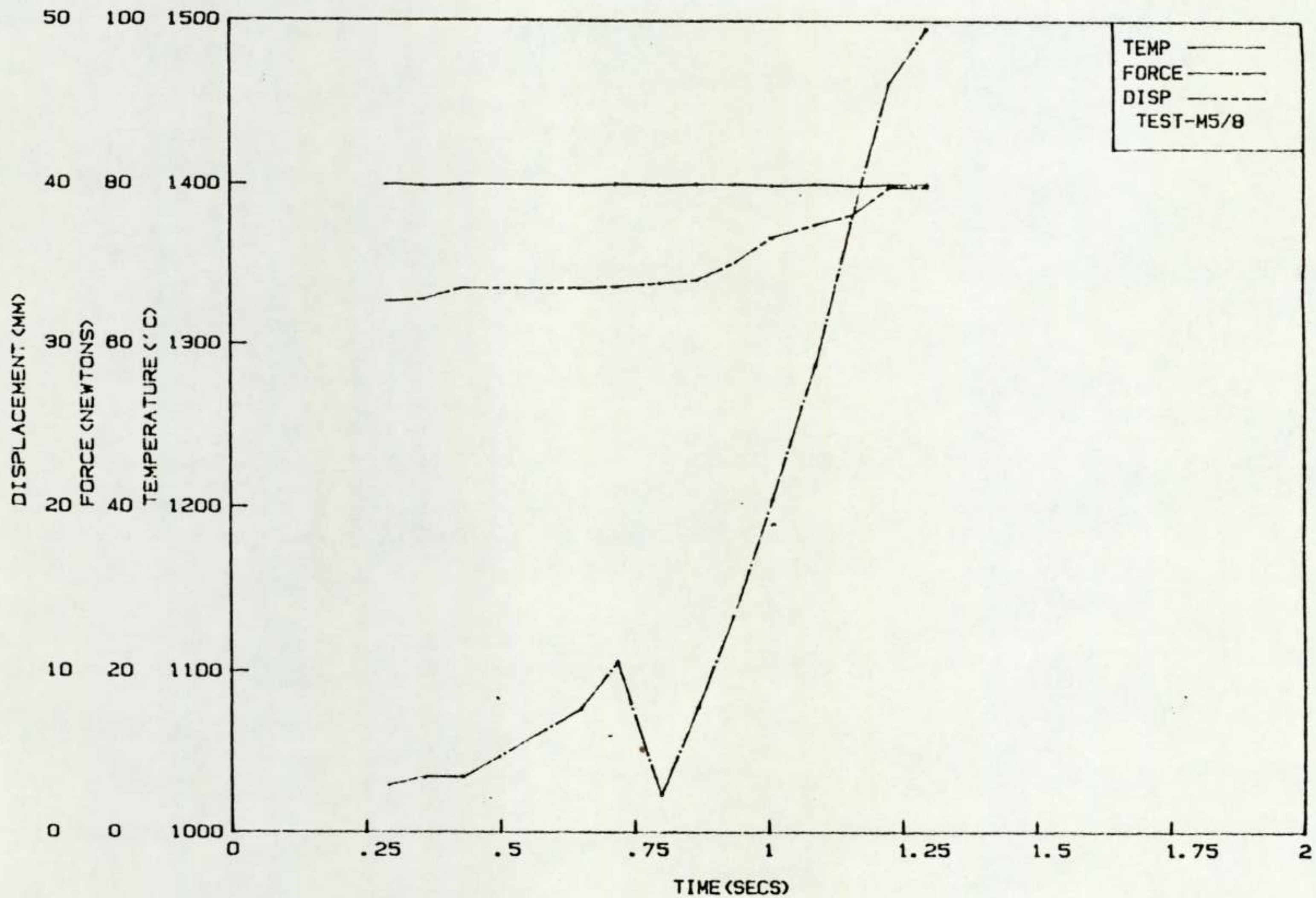


FIGURE 3.11 GRAPH OF FORCE, DISPLACEMENT, AND TEMPERATURE VERSUS TIME (for helical forming tests)

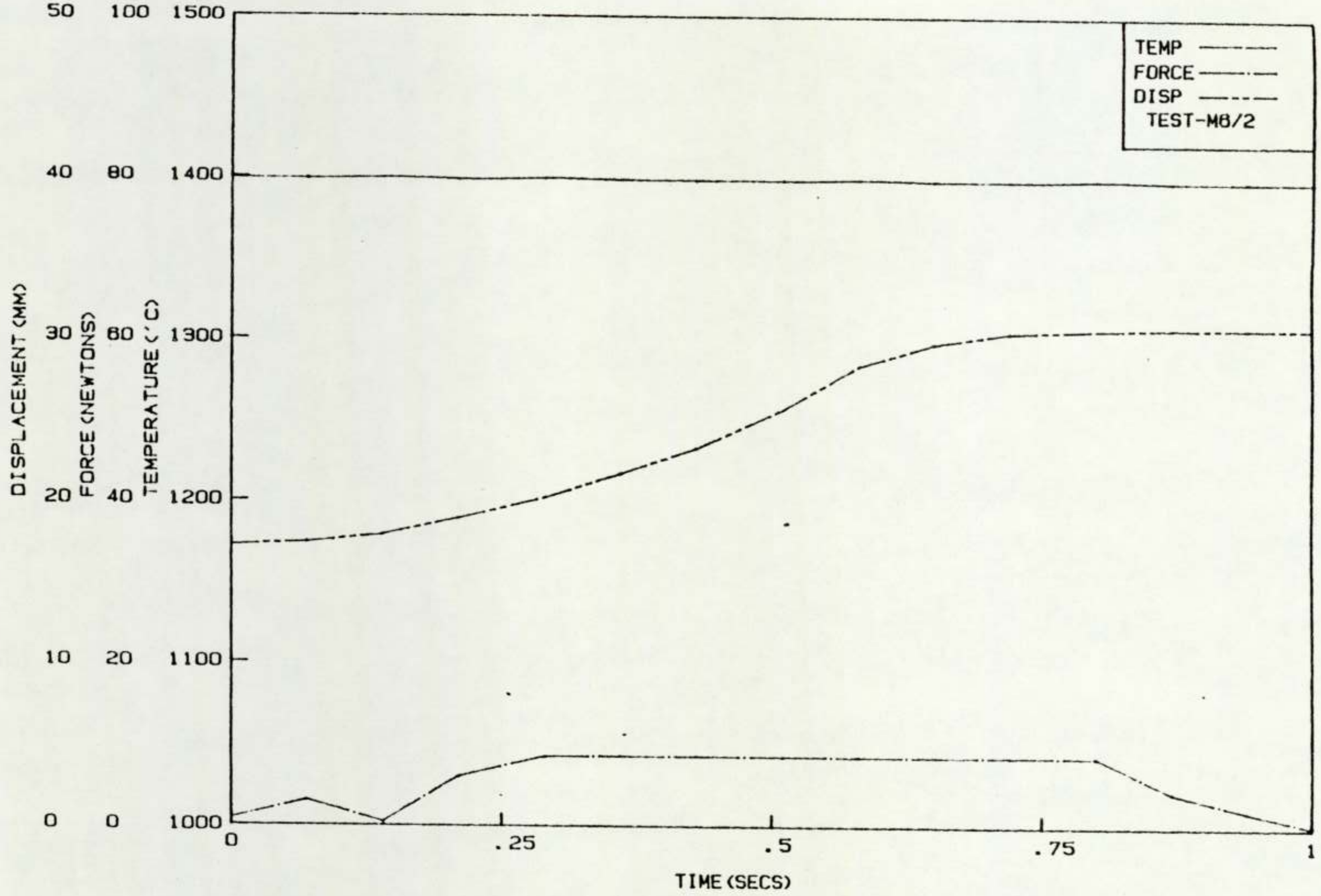


FIGURE 3.12 GRAPH OF FORCE, DISPLACEMENT, AND TEMPERATURE VERSUS TIME (for helical forming tests)

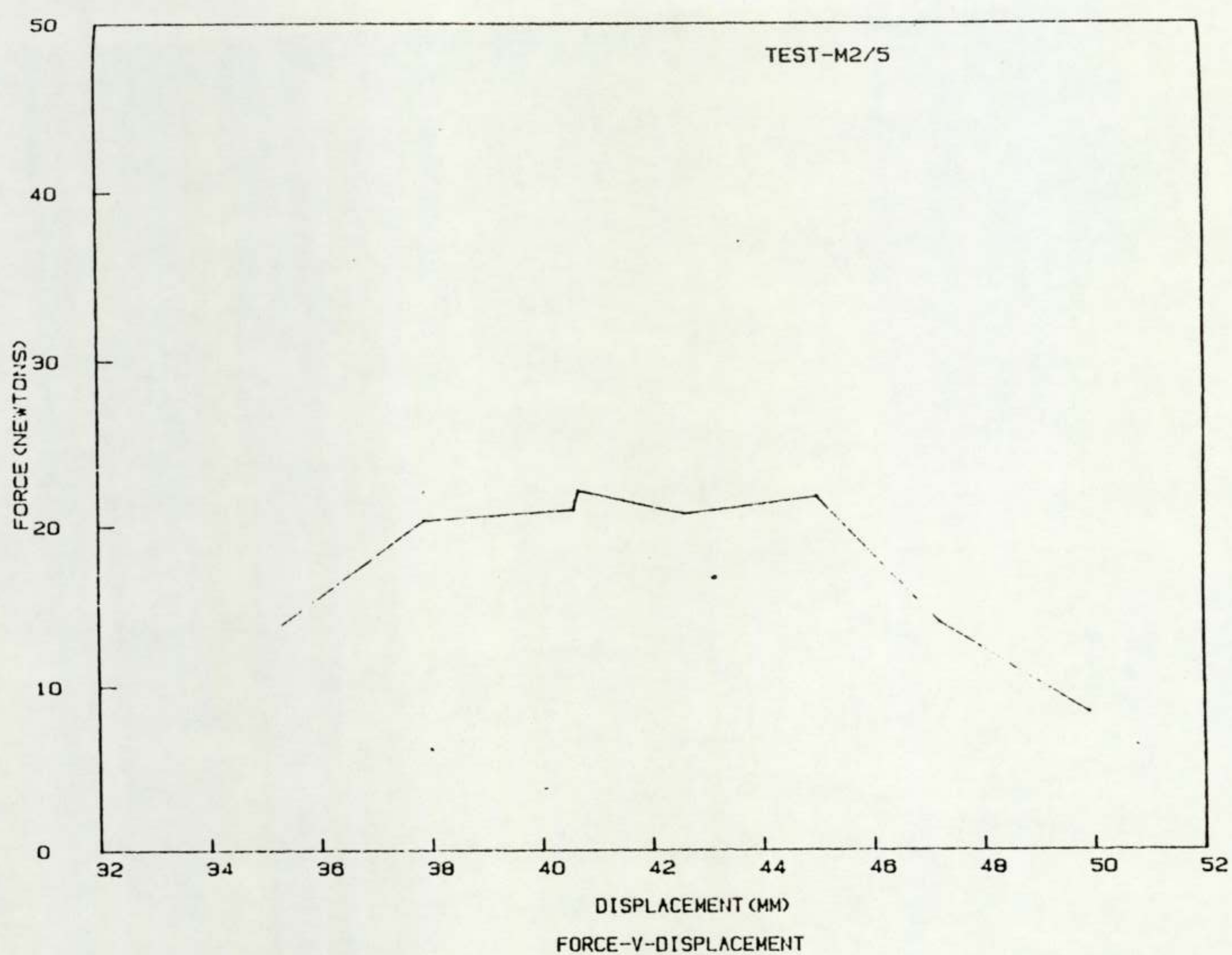


FIGURE 3.13 GRAPH OF FORCE VERSUS DISPLACEMENT (for helical forming tests)

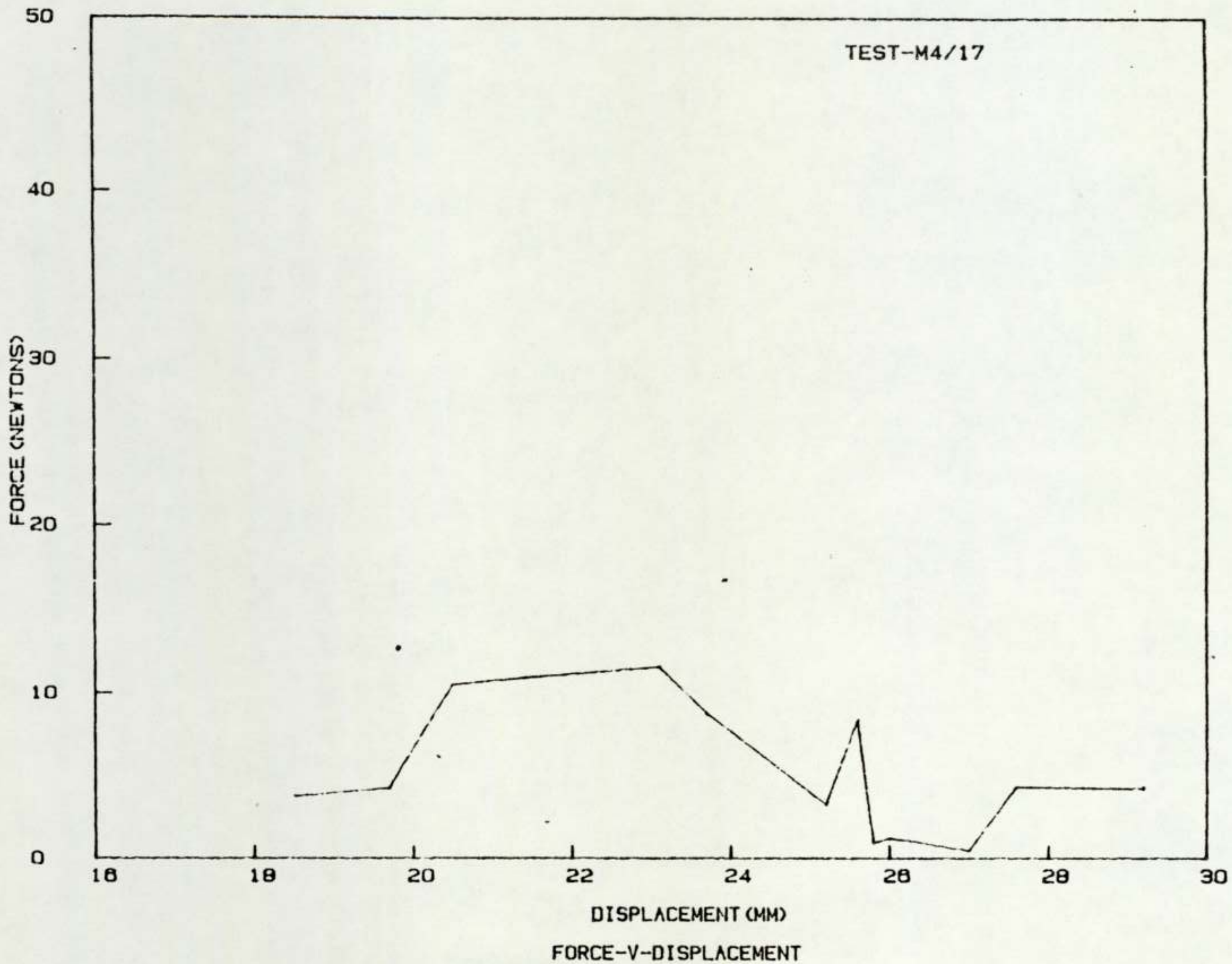


FIGURE 3.14 GRAPH OF FORCE VERSUS DISPLACEMENT (for helical forming tests)

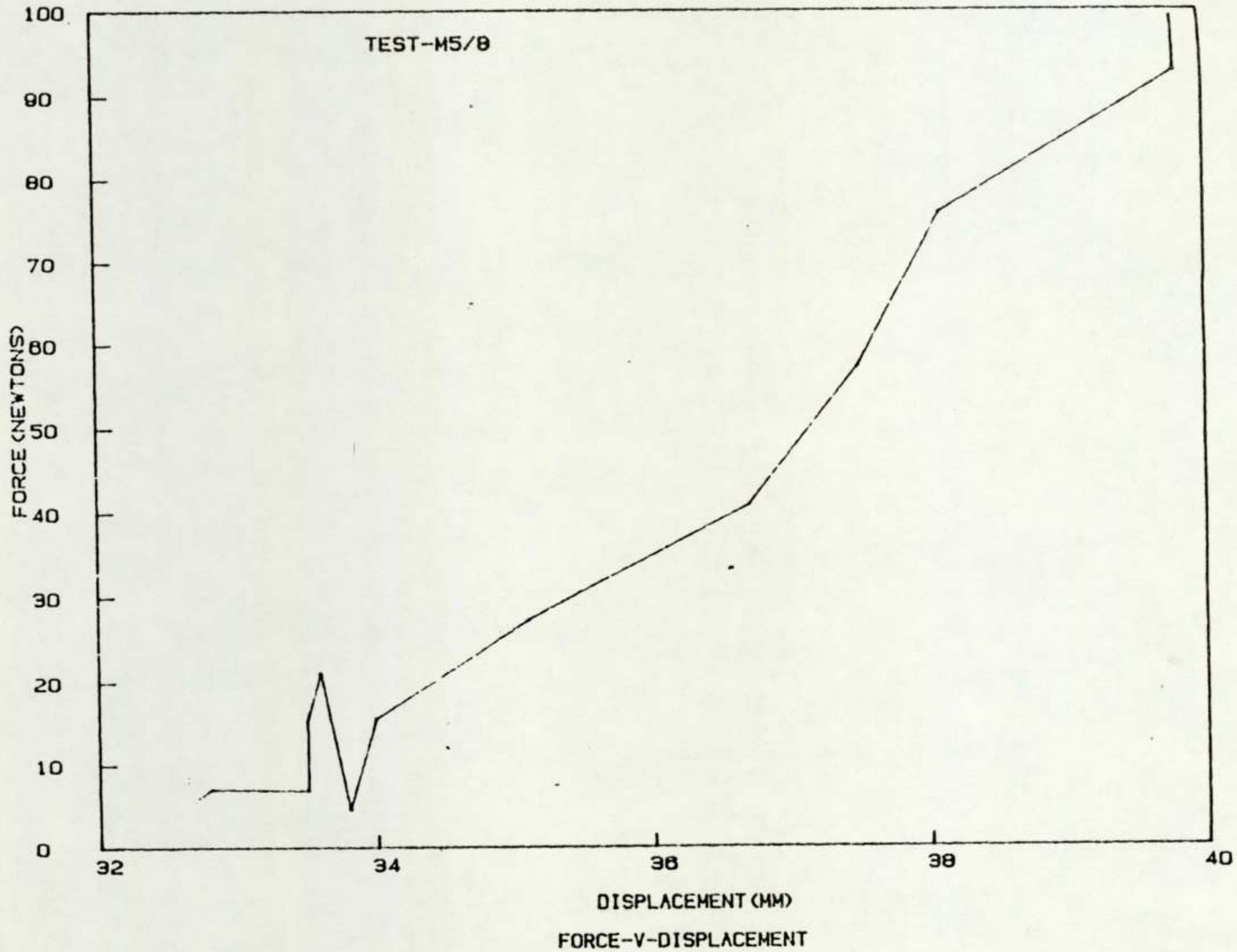


FIGURE 3.15 GRAPH OF FORCE VERSUS DISPLACEMENT (for helical forming tests)

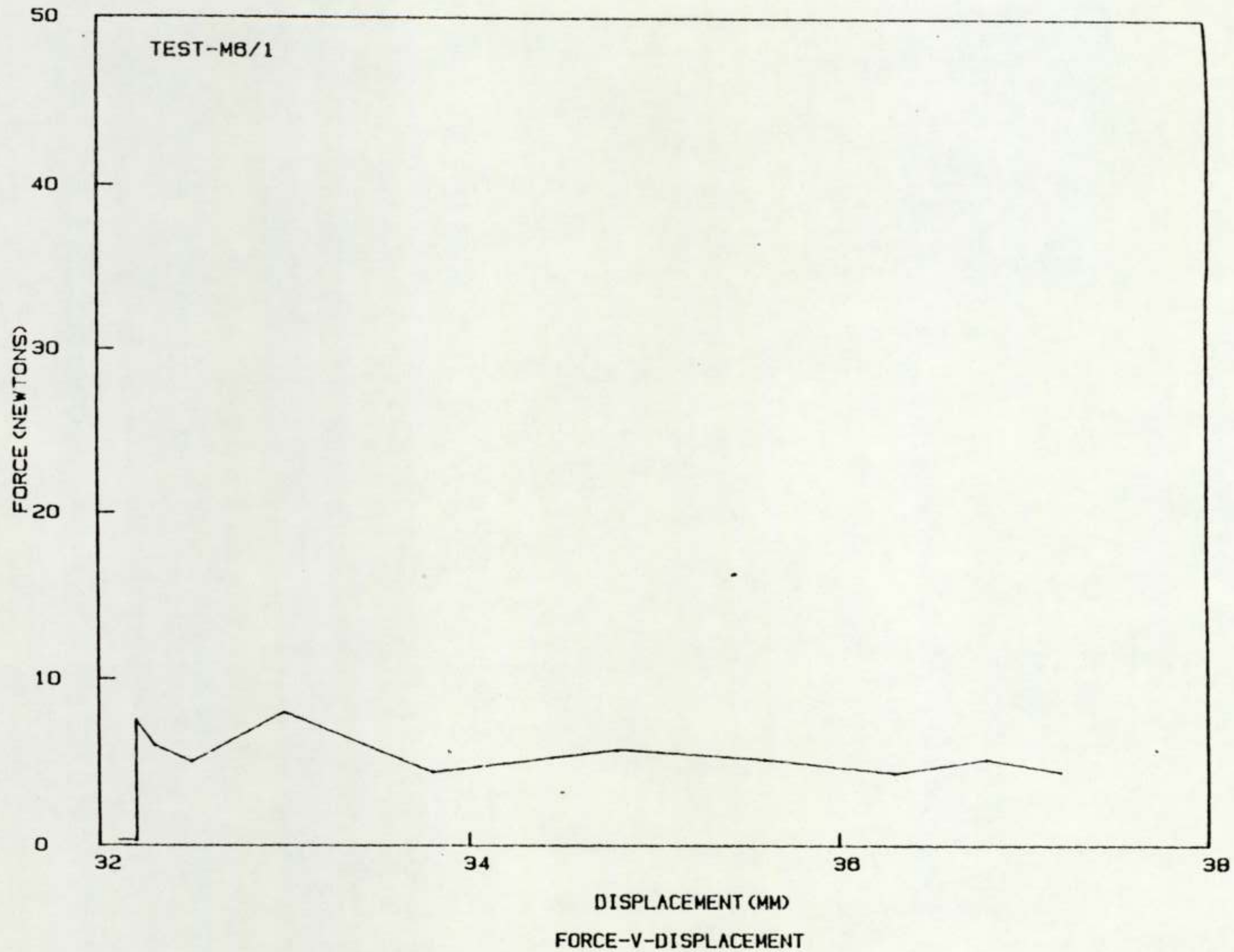


FIGURE 3.16 GRAPH OF FORCE VERSUS DISPLACEMENT (for helical forming tests)

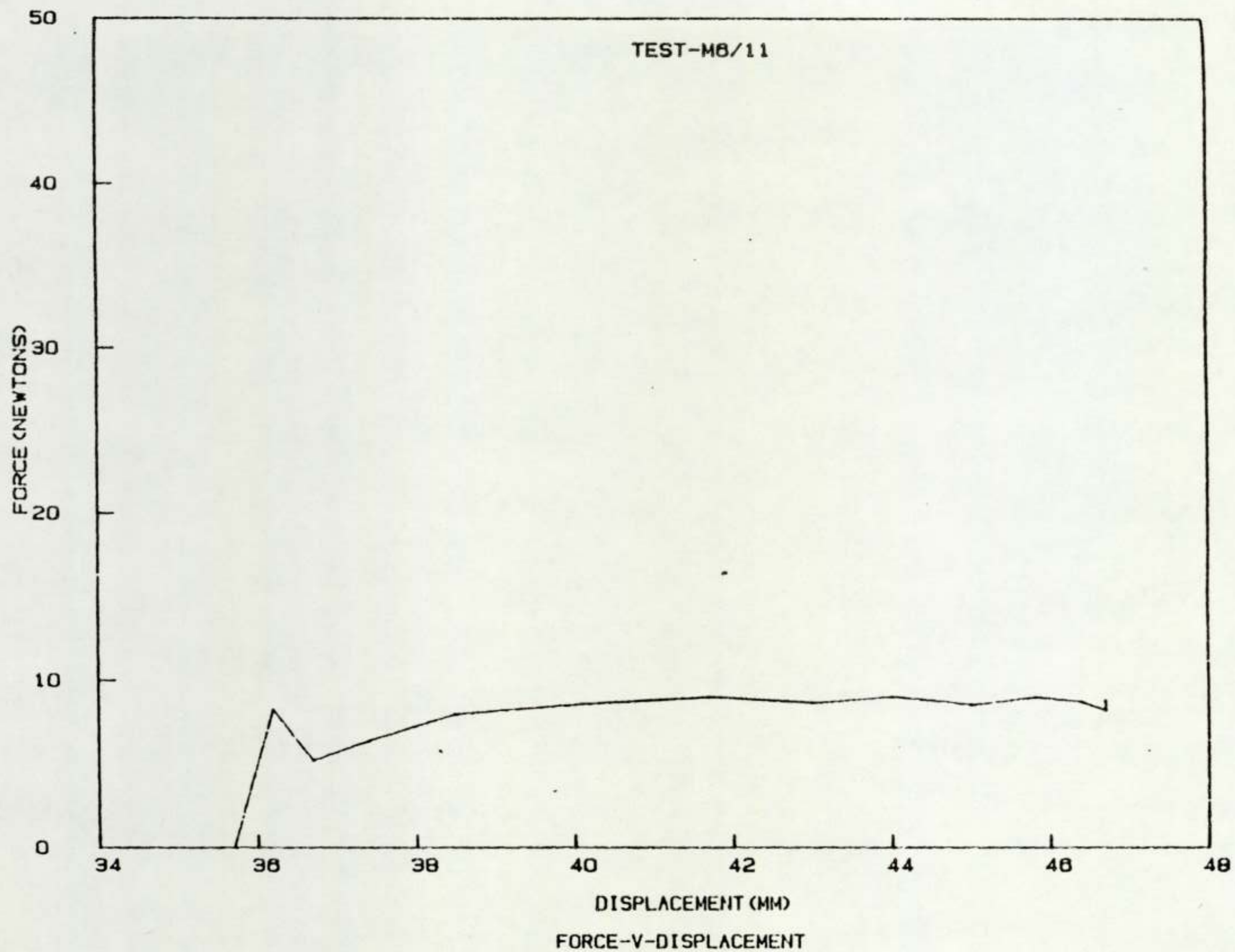


FIGURE 3.17 GRAPH OF FORCE VERSUS DISPLACEMENT (for helical forming tests)

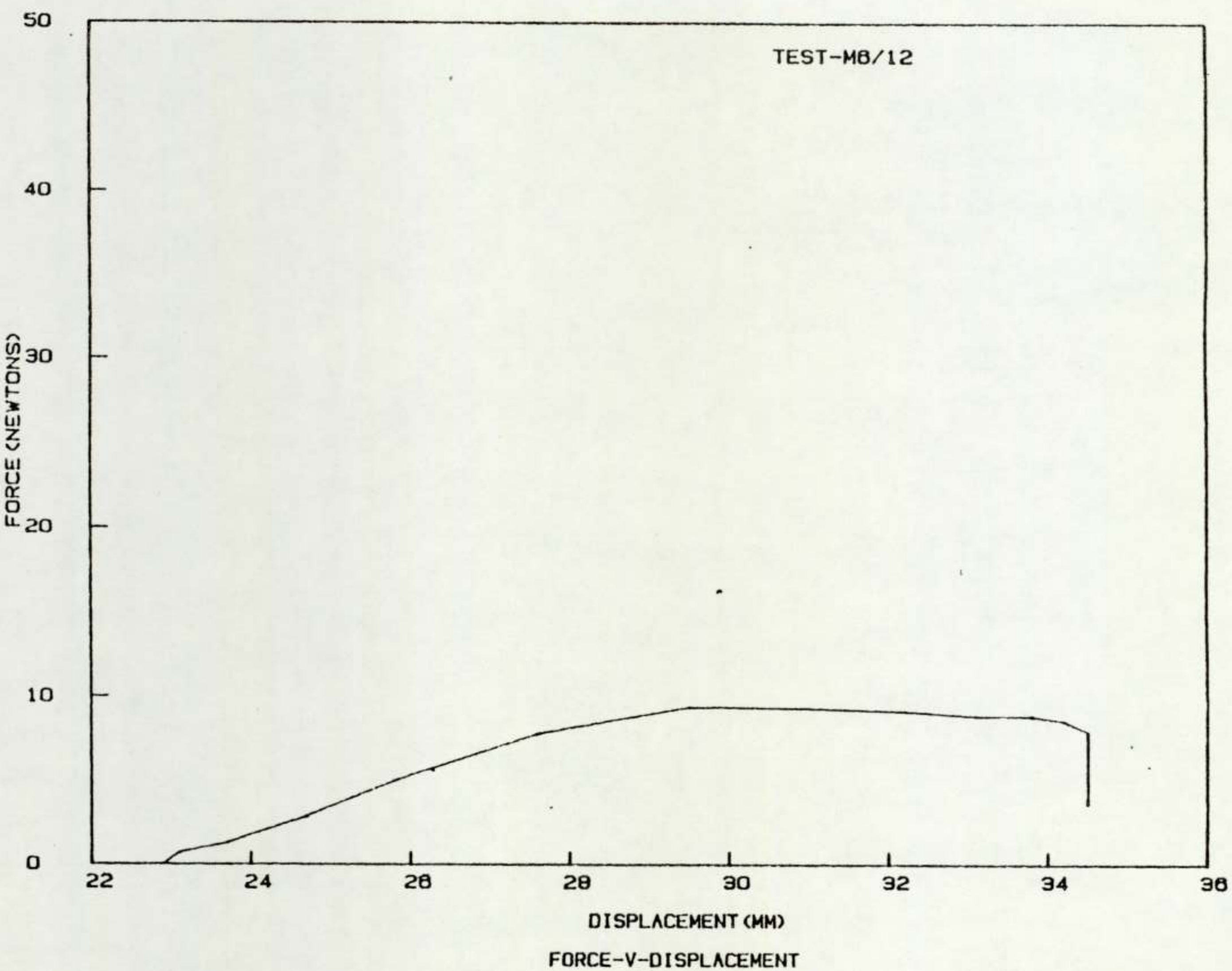


FIGURE 3.18 GRAPH OF FORCE VERSUS DISPLACEMENT (for helical forming tests)

3.4.4 Discussion Of Results -

Using the graphs plotted for Force, Displacement and Temperature versus Time, and Force versus Displacement the results for the various production runs were observed on the manual technique.

GRAPHS OF FORCE, DISPLACEMENT, TEMPERATURE versus TIME (see Fig 3.10 - 3.12 incl).

The temperature measurements proved consistent whilst the tips were helically formed (it remained around 1400 C plus or minus 5 C). It must be noted that the measurement was for the temperature of the core and not the actual tip. The tip reaches the desired temperature due to induction heating with conduction taking place from the graphite core. They were held at the entrance to the former, long enough for them to reach a temperature near to that of the former. A visual check ensures that the tip is only pushed into the former when this temperature is reached, and not allowing the tip to overheat. The end of the tip (that is, the first part to enter the former), must reach the correct temperature of around 1400 C, however the remaining part of the tip must not reach such a high temperature otherwise it would bend prior to entering the former.

The measurement of Force and Displacement against Time gave plots which were related. The displacement graph shows an increase in the rate of displacement with an increase in the force applied. However, the increase in force was not always tolerable, since it reached the point where the force was high enough to allow the feed through the former, before the correct temperature was attained, thus forcing the tips through at a reduced temperature (as can be seen in figure 3.11, where the displacement is maintained, only, by a sharp increase in the force applied). The pushing of the tips through, at a reduced temperature and increased force leads to problems of cracking in the helical formed tips. Although these cases, the increase in force did not produce tips with fractures, it is not recommended to continue to use a high level of force. The graphs and results show that for the tests done, the optimum force was usually in the range of 5 to 15 N., depending on the size, grade and hardness of the tips produced. It is evident that the control of the manual unit is difficult. The force often exceeded the tolerable limit, which was evident by the reduction in the rate of displacement, indicating that the force is too high. For example, the levelling off of the line of displacement necessitates an increase in the force to further displace the tips. At this point the tips are allowed to reach the temperature which will allow further displacement at the lower level of force.

The displacement of the tips through the former, often showed that if the force was maintained between 5 and 15 N , the rate of displacement need not be increased to allow a steady through put of the tips. This would allow the temperature to build up gradually throughout the tip as it fully enters the former.

The graphs also show that the timescale involved in the rate of displacement of the tips through the former is relatively short, for example, within the range of 10mm displacement the time taken is 0.5

seconds. The rate of displacement is difficult to interpret from the graphs, due to the high force often applied, which gives rise to a false indication. However, the rate at the optimum force, (5 to 15N), can be determined more effectively without erroneous conditions. Several results were calculated for the rate of displacement (i.e. distance divided by time) at the optimum force level. These provided a rate of displacement of approximately 20 mm/sec required to cause deformation. Thus, when the force is kept between 5 to 15 N (Newtons) and the rate of deformation is near to 20 mm/sec, the tips could be pushed through the former satisfactorily (allowing the temperature to build up in the tips sufficiently).

GRAPHS OF FORCE VERSUS DISPLACEMENT

The graphs plotted of Force against displacement give a clearer picture of the situation (see Fig 3.13 - 3.18 incl). They show that when a relatively low uniform force (about 5 to 15N) is applied (as opposed to the forces often reached) displacement took place. However, figure 3.15 shows that after an initial force level within the 5 to 15 N range displacement could still be maintained when an increase in force is applied. Note, that although the more consistent optimum force is within 5 to 15 N., the actual force used often was as high as 60 N.

However, due to the control of the plunger being dependent on the hand control, (via a rack and pinion device) of the operator, when less resistance to the feeding of the tips through the former was experienced, the tips could be passed through the former at a reduction of the initial force applied (see example of figure 3.13). Obviously, this can also be affected by the rate of heating of the tip. Conversely, an increase in the resistance often results in the operator applying a greater force in order to maintain displacement.

The results show that although the hardness of the tips altered slightly (i.e., 1478 VPN for H25T to 1600 VPN for RAMET 1), the force applied at the optimum rate of displacement was quite low in relation to what the force often reached.

This clearly indicates that as long as the force remained within the range of 5 to 15 N., the displacement rate was ideal to allow the tip to build up to the correct temperature at a suitable rate, whilst being fed through the former. An increase in the force above 15 N. implied that the tip was being pushed too hastily through the former, before reaching the correct temperature at the point of deformation, which would mean that the tip was at too low a temperature to be produced effectively.

However, the relationships of force applied in the different tests is affected by the cross-sectional area of the tip. Thus stresses were calculated to show that within the range of 0.2 to 0.6 $N./mm^2$ they were sufficient to cause deformation of the tips at the optimum conditions.

The results identify that as long as the front end of the tip (whilst embedded in the entrance to the former), is at the deformation temperature, only a steady application of force is required to produce the tips in the helical form. Obviously the techniques currently in operation rely on the patience of the operator, and therefore it is easy to apply the force in bursts, rather than at a consistently low level.

The main observations that can be generally obtained from the graphs is that the earlier portion of the lines produced is more indicative of the actual force required. Thus the emphasis for discussing the results is within the force range of 5 to 15 N., that is, before the excess force disrupts any true relationships.

4 CONCLUDING SUMMARY

The results from both sections have provided interesting conclusions, however, due to the nature of the study, they will be dealt with under two sub-headings, as in the main text.

4.1 AUTOMATION OF THE BRAZING

1. All of the processes studied initially, i.e.,induction heating, furnace brazing, resistance, bath and torch brazing, gave reason for consideration in the automating of the brazing of tha tungsten carbide tips to the tool bodies.

2. One of the major problems of brazing tungsten carbide tips, is the overriding concern for the problems of the different coefficients of expansion between the tool body and the tungsten carbide tips. The expansion coefficient is further affected by the brazing of intricately formed helical tips, as opposed to the more common requirement to braze flat blades to tool bodies.

3. The present method of alleviating stresses set up in the brazing, using the Sif-bronze buffer can possibly be discarded if the correct choice of filler is used under strict brazing conditions (i.e.,control of braze temperatures with optimum joint clearance).

4. The rise in temperature of the brazing operation also affects the heat treatment of the tool body, which is performed prior to brazing.

Any post braze heat treatment will adversely affect the coefficient of expansion problems.

5. In order to retain the low temperature braze alloy, with cadmium and zinc elements, furnace brazing using both induction under controlled atmosphere and vacuum methods cannot be used, due to these volatile constituents.

6. Due to the helical shape of the tips, there is the extreme problem of producing and implementing suitable jigs to hold the tips in situ whilst brazing to the tool body, for any automated technique.

7. The jigging also has its high cost in affecting the expansion problems due to additional expansion in the jig itself. Thus, an automated method which utilizes jigs and pre-placed filler with the ultimate submersing of the total assembly in a heat retort (i.e., in furnace, bath and in some cases induction) is impossible.

8. Bath brazing provides similar problems to those in furnace brazing. The total assembly is heated up to the braze temperature, thus, again affecting the expansion problems.

9. Resistance brazing proves to be difficult to braze cutting tools due to the complexity of the tool design. It would be difficult to achieve the desired heat pattern and produce suitable contact electrodes.

10. The desired localized heating of the tool body, filler and tungsten carbide tip assembly would prove extremely difficult if

induction heating is used (i.e., where the heating coil is critically wound round the assembly to provide to provide optimum couple distance at the joint area only).

11. It remains that the most viable technique of automating the brazing of the tool tips is by the torch braze method. Using torch brazing the heat can be localized to the joint area, the filler metal alloy can contain Cadmium and zinc (used with suitable furnace extraction equipment).

12. The problem of stress cracking is helped by dividing the total surface contact area of the braze joint (i.e., separating the joint interface into smaller areas over the same total area - but with spaces between each interface area). This segregation of the joint interface became apparent in the trials undertaken to braze the tips to the tool bodies, using a pre-placed filler in a 'groove' on the back face of the tip seat in the tool body.

13. The temperature of the brazing could only be kept at the current low level of 650 to 700 C if the braze filler retained the cadmium and zinc content, since any increase in the braze temperature would severely affect the cracking of the tips due to expansion problems. Thus, a change in the filler constituents is not possible when brazing tungsten carbide to tool steel at temperatures between 650-700'C and retain the correct wettability.

14. The automated torch brazing method using pre-placed rods in the tip seat groove provided tools which gave satisfactory results under

cutting tool operations

4.2 AUTOMATION OF THE HELICAL FORMING OF THE TIPS

1. The intended automation of the forming of the helical tungsten carbide tips is very much dependent on the control of the operation parameters.

2. The temperature of the tips whilst being formed must attain a temperature near to that of the sintering temperature of 1400 C, but not above it.

3. In order to achieve this in the current method of forming the tips, the former , (i.e., the graphite core) must not rise above 1400 C.

4. The tips must be displaced through the former at a rate which would not allow the exposed end of the tip (still not in the former) to conduct the high temperature, preventing the tip to be pushed (i.e., causing the tips to bend before fully entering the former).

5. The displacement rate needs to be controlled in conjunction with the force applied in pushing the tips through the former.

6. A steady application of the force in the range of 5 to 15 N will allow the tips to reach the correct deformation temperature, and the displacement rate needs to be varied so as to retain the constant level of force.

7. Special attention needs to be given at the start of the application of the force in order to plunge the tips. The force must only be applied when the tips have been allowed to reach the required level of temperature at the front of the tip. Although the tip must not be static long enough for it to overheat, which would cause the tip to deform and swell inside the plunger.

8. The results of the graphs plotted for Force, Temperature, Displacement v's Time and Force v Displacement indicate that the earlier portion of the graph shows the optimum force required to push the tips at the optimum temperature.

9. The latter portion of the plot tends to indicate that the force is being increased above the optimum to retain a similar displacement rate, therefore, the force generally reaches a point where the plunging is suspended, to allow the tip to reach the correct temperature at the point where the deformation first occurs.

Note, the tips are heated whilst embedded in the former, but the initial deformation takes place near to the entrance of the former. Therefore, the tips must be allowed to reach the correct temperature before hastily applying the force on the plunging device.

10. The temperature gradient over the length of each tip can vary considerably, since the front end will be in the hot zone (at 1400 C) and the back section still exposed outside the former will be at a temperature between 1400 C and ambient temperature caused by the conduction through the tip.

11. A displacement rate of approximately 20 mm/sec (at optimum force) gave an indication of a satisfactory rate of forming, if continuous motion could be maintained using an automatic system, rather than the stop - start technique used in the hand operated device. Although, some scope for variation in displacement rate is needed if force range is restricted.

5 RECOMMENDATIONS FOR FUTURE WORK

This will also be discussed under two discrete headings.

5.1 FUTURE WORK ON THE BRAZING TECHNIQUE

Development of an automated brazing system for brazing the pre-formed helical tungsten carbide inserts to the tool bodies

If the existing technique of producing a "groove" in the tip seat, to allow pre-placement of filler, cannot be tolerated in production an alternative must be considered.

An alternative method would be to produce a groove on the back face of the carbide, as opposed to the groove in the tip seat of the tool body. This would have a two-fold advantage ;

a) To reduce the amount of filler needed to secure a sufficient joint.

b) To reduce the effect of the different expansion rates between the tool body and the tip, to minimise problems of cracking, by dividing the area of bond interface.

Further trials need to be initiated to test the viability of the above, in order that the development of the automated unit can be continued with Elga.

In attempting to braze cutting tools the problems of brazing in variable degrees of freedom for each type of cutting tool, e.g., the change in diameter, different helical angles, deep or shallow tips, different numbers of flutes etc., need to be viewed in accordance with additional trials. Discussions with Elga reinforced decisions to pursue trials with a new design, otherwise, there would not appear to be any viable route to automate the brazing of cutting tools. A proposal was made to Marwin's to continue the work with automation of the brazing technique in order to develop a system for the automated brazing of the tips.

5.2 FUTURE WORK ON THE HELICAL FORMING UNIT

Further investigation of parameters needs to be carried out before the optimum conditions for automation can be confirmed, this would involve the determination of many different values for each type of helical tip produced. Only when this task has been completed could design work begin on the automation of the forming unit.

It is proposed that for automation, the use of a Programmable Logic Controlled (P.L.C.) hydraulic plunger device should be considered, in conjunction with a "Pick and Place" Robot (which would locate the tips at the entrance of the former, in readiness for the plunger to be activated).

A hydraulic device is recommended in preference to a pneumatic device, the reasons being as follows ; (without being over simplistic), in the use of pneumatic equipment there appears to be less need for systems with a high degree of accuracy, when related to feedback or detection. That is, when considering the possible automatic feeding of tungsten carbide tips into a helical form where the pressure is critical. When sensors are used in these pneumatic devices, they only determine when a resistance is encountered, and either terminate or delay the action of a particular operator. More often, than not, the operational requirements of these devices are to provide a positive action or movement to a fixed orientation and distance, that is, action or no action. Obviously the degree of accuracy for controlling the pressure (measuring resistance accurately) is higher when using hydraulic systems, since fluids readily transmit accurate data as they are incompressible.

Further considerations towards the automation of the helical forming unit can be directed at the supply of the tips to the forming unit itself. This could include the use of variable controlled resistor systems (which relate to the speed/feed of the tip into the former). This may also provide a means of transporting tips to maybe, a hopper device to locate the forming unit, or perhaps to a robot order picker which would pick and place the tip at the entrance of the forming unit.

It is difficult for companies to produce the whole system required for the automation of the forming cycle, thus advice from manufacturers of proprietary equipment which is readily available must be used on the integration of individual manufacturers equipment for a system.

APPENDIX A

TYPICAL BRAZING ATMOSPHERES

The types of protective atmosphere which may be considered for use in brazing with an induction unit.

A) GASEOUS:

There are two types of gaseous atmosphere:

i) Chemically active (reducing), it should be noted that elements in base metals and fillers must have oxides which reduce at temperatures below solidus of filler in order to achieve oxide-free surfaces at braze temperature. Typical atmospheres are; Hydrogen and Dissociated ammonia.

ii) Chemically non-active (inert), this is used to prevent oxides, it forms no compounds with metals and tends to inhibit the evaporation of volatile components. Examples are; Argon (the most commonly used inert gas) and Helium (which has limited availability and is more costly than argon)

B) VACUUM:

TYPICAL BRAZING ATMOSPHERES

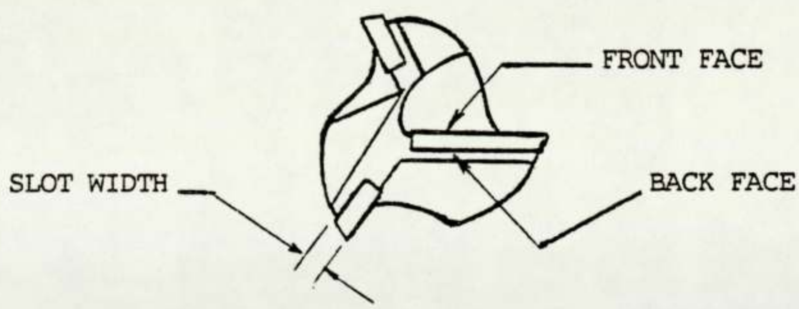
This involves the removal of all gases to a suitably low pressure. It is generally done at pressures varying from 0.5 to 0.0005 mm of Hg., (65 to 0.065 Pa).

APPENDIX B

BRAZE FILLER CALCULATIONS MODEL

CUTTER TYPE:

NO. OF FLUTES:



N.B. The number of flutes can vary

TYPICAL SECTION OF A CUTTING TOOL

LARGE TIP

Back face cutter depth

Tool body dia. =   Radius =   Cutter depth below centre line =

BRAZE FILLER CALCULATIONS MODEL

Cutter depth =

Front face cutter depth

Core dia. = Core radius = Cutter depth =

Width of slot =

Total area of joint = Back face cutter depth + front face cutter depth + slot width X length of cut minus overhang

Clearance Between Tip and Slot

slot width =

tip width =

Clearance = slot width - tip width =

Clearance either side of tip =

Volume of joint = total area X clearance either side of tip

Calculation For Diameter of Rod (filler) required to fill the joint

Volume = (Pi x R x R) X length of slot

$$R = \sqrt{\frac{\text{Volume}}{\text{length of slot X Pi}}}$$

Dia required for Interference Fit =

Dia of rod with 30% excess =

Is dia above acceptable limit for tool ?

If yes, what combinations of dia's can be used to fill the joint

SMALL TIP

Back Face of Cutter

BRAZE FILLER CALCULATIONS MODEL

Tool body dia. = Radius = Cutter depth = to centre line

Cutter depth =

Front Face of Cutter Depth

Core dia = Core Radius =

Cutter depth = core radius - cutter depth to centre line

Width of slot =

Total area of joint = Back face cutter depth + front face cutter depth + slot width X length of cut minus overhang

Clearance between slot and tip

slot width =

tip width =

clearance = slot width - tip width =

Clearance either side of tip =

Volume of joint = Total area X Clearance either side of tip

Calculation for dia. of rod (filler) required to fill the joint

Volume = (Pi x R x R) X length of slot

$$R = \sqrt{\frac{\text{Volume}}{\text{length of slot X Pi}}}$$

Dia required for interference fit =

Dia of rod with 30% excess =

Is dia above acceptable limit for tool ?

If yes, what combination of dia's can be used to fill the joint

APPENDIX C

MACSYM MEASUREMENT AND CONTROL SYSTEM

HARDWARE - DESCRIPTION

"MACSYM 2" is a fully integrated Measurement And Control System developed specifically to acquire, reduce, store, present and output real-time information in laboratory, process control and discrete manufacturing applications. Integrated programming and hardware design enables the user to install and operate the MACSYM 2 relatively easily, regardless of previous systems experience.

The complete MACSYM 2 system with integral signal conditioning is packaged in a compact desk top unit. The system includes a high speed 16-bit processor, keyboard, display, tape cartridge storage and data aquisition sub-system. Available is a large library of Analog/Digital Input/Output (ADIO) Cards, to allow the user to configure a system to specific requirements. These can be plugged into any of the 16 card slots in MACSYM 2's chassis and external signals connected via screw-type terminal boards.

Programs written in MACBASIC, a multi-tasking real-time BASIC is a high level interactive language which provides user interface and allows program development through simple English-like phrases. It is a super set of Dartmouth BASIC (Beginners All Purpose Symbolic Instruction Code) with enhancements including multi-tasking and process 1/0 (ADIO card) statements.

MACSYM ARCHITECTURE (see fig C-1)

PROCESSOR BOARD (CPU)- The central processor unit is a 16-bit, general purpose, digital mini-computer, built on Schottky TTL and integrated injection logic, bit-slice technology for optimum speed and low power consumption. Special features include byte manipulation instructions and floating point mathematics.

MEMORY BOARD (MEM)- Addressable Random Access Memory with controller to handle chip selection, buffering, etc. It is expandable from 64K bytes to 128K bytes. Battery back-up retains memory data during power transients and brief outages.

AUDIO CONTROLLER BOARD (CIU)- Provides the interface between CPU and the ADIO Cards, including timing and receiving and transmitting signals to and from the Cards (i.e., serves as the data aquisition sub-system). The CIU contains analog to digital conversion facilities, eliminating the need to implement these on the ADIO Cards. On command from the CPU board, the CIU selects input and output channels, controls analog and digital signal multi-plexing and transfers data to and from the ADIO Cards over the ADIO BUS.

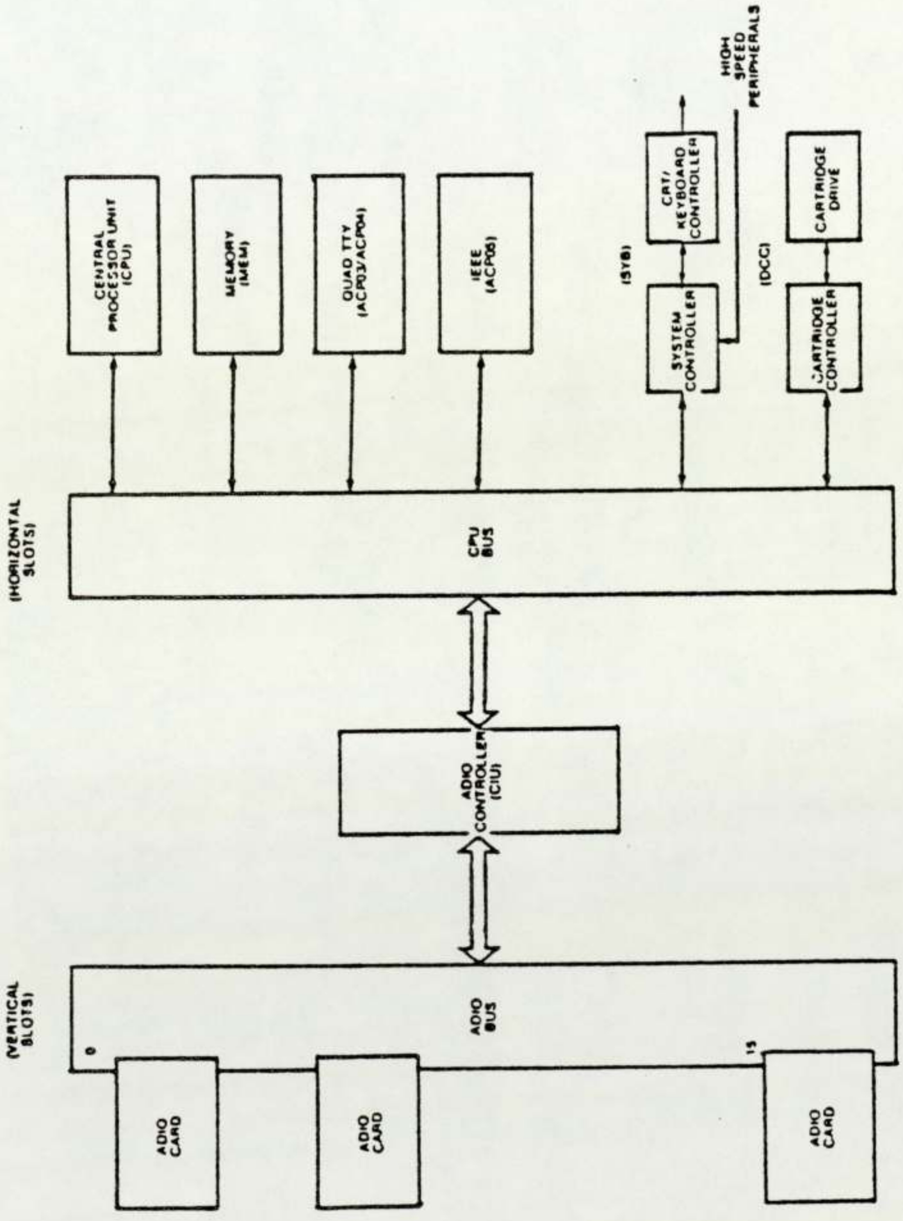


Figure C-1. MACSYM 2 Architecture

ADIO BUS- Part of the back plane of the MACSYM 2 chassis, this bus accomodates up to 16 ADIO Cards, which can be installed in any card slot as desired (except CKL01 pacer card, which must be located in slot 7, if used). The ADIO bus is for interfacing the ADIO Cards to the ADIO controller. It is isolated from the noisy, high speed processor bus for high quality analog measurements. The bus carries both analog and digital signals.

CPU BUS- Provides a conventional computer bus for communication between the CPU, memory and high speed peripherals.

SYSTEM CONTROLLER (SYB)- The system controller provides several utility functions for overall systems control, sequencing and buffering. A bus buffer provides an interface to peripherals such as the floppy disc or 9 track tape. The line frequency controlled real-time clock and the console (teletype) interface are functions of the system controller board. Power fail and power-up sequences are also controlled by this board.

DATA CARTRIDGE CONTROLLER (DCC)- The standard MACSYM 2 uses a magnetic tape cartridge for data and system program storage. The DCC provides DMA control, data buffering, encoding and decoding, motion control and status reporting to interface the data cartridge unit to the CPU bus.

DUAL (ACP03) and QUAD (ACP04)- Port asynchronous communications cards provide the means to interface MACSYM 2 with a wide range of devices that operate via the standard RS232 or 20MA current loop asynchronous communications protocol. These boards are options: devices supported by them include terminals, printer, plotter, intelligent instruments and other computers. Up to twelve fully programmable input and output ports are supported by the software.

THE IEEE -488 (ACP05)- This card has an option which enables the MACSYM 2 to function as a controller to the general purpose bus defined in IEE Standard 488.

The MACSYM keyboard features a full ASCII keyboard and a CRT display. Display format (16 lines of 32 characters, or 16 lines of 64 characters) is a keyboard selectable option.

APPENDIX D

MACSYM SPECIFICATIONS

PROCESSOR SPECIFICATIONS

ARCHITECTURE- 16 bit word CPU with hardware floating point (8 bit bytes)

MEMORY- 64K bytes (expandable to 128 bytes) RAM

MEMORY READ CYCLE- 0.8 us

SYSTEM CONTROL

REAL TIME CLOCK- 24 hour with 10 ms resolution

POWER MONITOR

CONSOLE SERIAL INTERFACE- RS232 or 20MA current loop, 110-9600 Baud rate data transfer.

ADIO CONTROLLER

RESOLUTION- 12 bit

CONVERSION TIME- 25 us

INPUT RANGE- plus or minus 10 V

GAINS (programmable amplifier)- 1, 2, 4, 8.

INPUT IMPEDENCE- Greater than 10,000,000,000 OHMS

SAMPLE AND HOLD- 90 ns maximum aperture time

DISPLAY

INTEGRAL CRT- Viewing area 5" diagonal (12.7 cm)

MACSYM SPECIFICATIONS

FORMAT- 16 lines of 32 or 64 characters

REMOTE CRT- (optional) RS-17075 ohm connector

KEYBOARD- Full ASCII keyboard (upper case)

CARTRIDGE DRIVE UNIT

CARTRIDGE- 3M DC100A Data cartridge

CAPACITY- 60K bytes

OPERATING SPEED- 30 ips (76.2 cmps) for read/write, 60 ips (152.4 cmps) for search.

TAPE HEAD- Single channel, single gap, full width .

FORMAT- Variable cell width recording

SYSTEM ELECTRICAL SPECIFICATIONS

INPUT POWER- 115 V ac, 230 V ac (plus or minus 10%), 50/60 Hz 500 W max.

PHYSICAL CHARACTERISTICS

DIMENSIONS- 9.5" H x 17.5" W x 32.5" D (24.13cm x 44.5cm x 82.55cm)

WEIGHT- 85 lbs (38.25 Kg) with 16 ADIO Cards

OPERATING TEMPERATURE- 41 - 104 degrees F (5-41 degrees C)

RELATIVE HUMIDITY- Up to 90% non-condensing

APPENDIX E

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER TRANSDUCER

PRINCIPLE OF OPERATION

Basically the LVDT (linear variable differential transformer) consists of two parts:

a) A primary winding and two identical secondary windings on a common former, and

b) A moveable magnetic armature.

The primary winding is excited by an A/C supply. The two secondary windings are connected so that their combined output represents the difference in the voltage induced in them. With the armature in the central position, the output is zero. Movement of the armature from this position produces an output (at carrier frequency) which is proportional in phase and magnitude to the armature displacement. (see fig E-1)

For correct operation, the LVDT requires some special electronics (consisting of an oscillator normally 5v at 5KHz to energise the

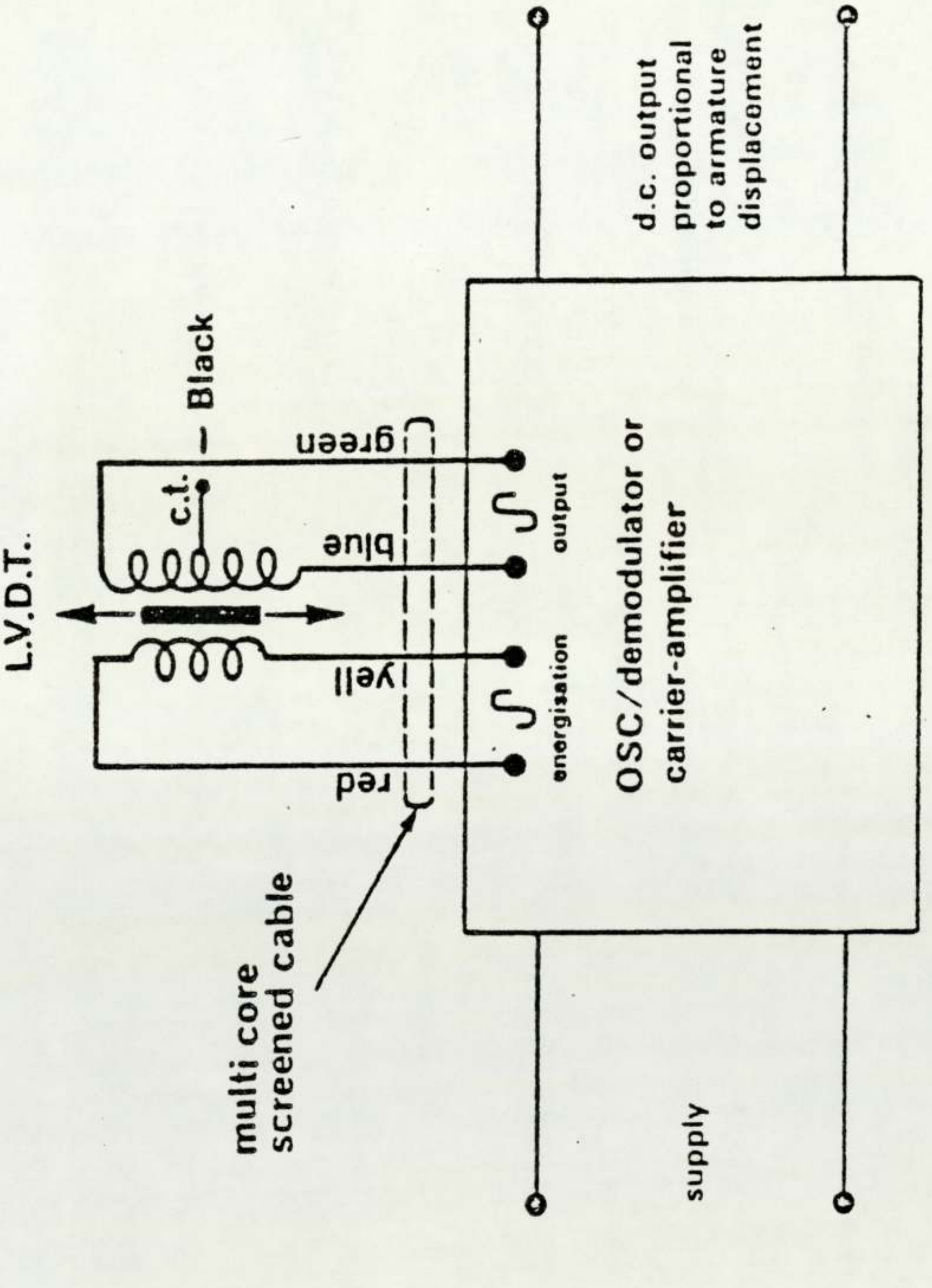


FIGURE E-1 SCHEMATIC DIAGRAM ILLUSTRATING THE BASIC ELEMENTS OF L.V.D.T TRANSDUCER primary winding, a phase-sensitive demodulator and an amplifier) to provide a smoothed DC output voltage which is proportional in magnitude and of the appropriate sign to the armature displacement. This output signal may be utilized to drive analogue or digital indicators, recorders or DC data logging systems (e.g., "Macsym" computers).

APPENDIX F

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER TRANSDUCER

TRANSDUCER INDICATOR

Used in conjunction with the appropriate inductive transducer, the indicator provides an effective means for measuring either force, load, displacement, strain etc., with direct digital readout in the correct engineering units.

The display is a 3.5 or 4.5 digit brightness LED type with 11mm high characters and optional decimal point, positioned by means of an internal link. In addition to display, it provides a full scale output of plus or minus 2v D/C for driving an external plotter or device (e.g., output to the "Macsym" computer) plus an additional output. When used with displacement transducers, the course zero control may be used to "back off" up to 100% of the transducer output, thus enabling a device with a range of plus or minus 75mm to be used to measure 0 to 150mm in one direction only.

Weighing approximately 1.5 Kg, the indicators may be panel mounted or used as free standing for bench use. Connections are made to plug-in terminal blocks on the rear of the panel.

APPENDIX G

LOAD CELL - DESCRIPTION

Quartz load washers are piezo electric force transducers, their purpose being to convert a mechanical force into an electrostatic charge signal, which can be transformed in a charge amplifier to an electric output voltage, and transmitted to an indicating or recording instrument.

By reason of their nature and purpose, these force transducers are built very rigidly and have a high natural frequency. They can, therefore be used without altering the elastic behaviour of the objects to be measured. Because of their design, (in the shape of a washer) and their comparatively small dimensions, they are suited to a variety of applications, and are easy to install. Standard accessories are available for special applications.

OPERATING PRINCIPLE: see fig G-1

The force to be measured, uniformly distributed, is exerted on one or two quartz discs. The mechanical load develops in the quartz discs and an electrostatic charge which is directly proportional to the

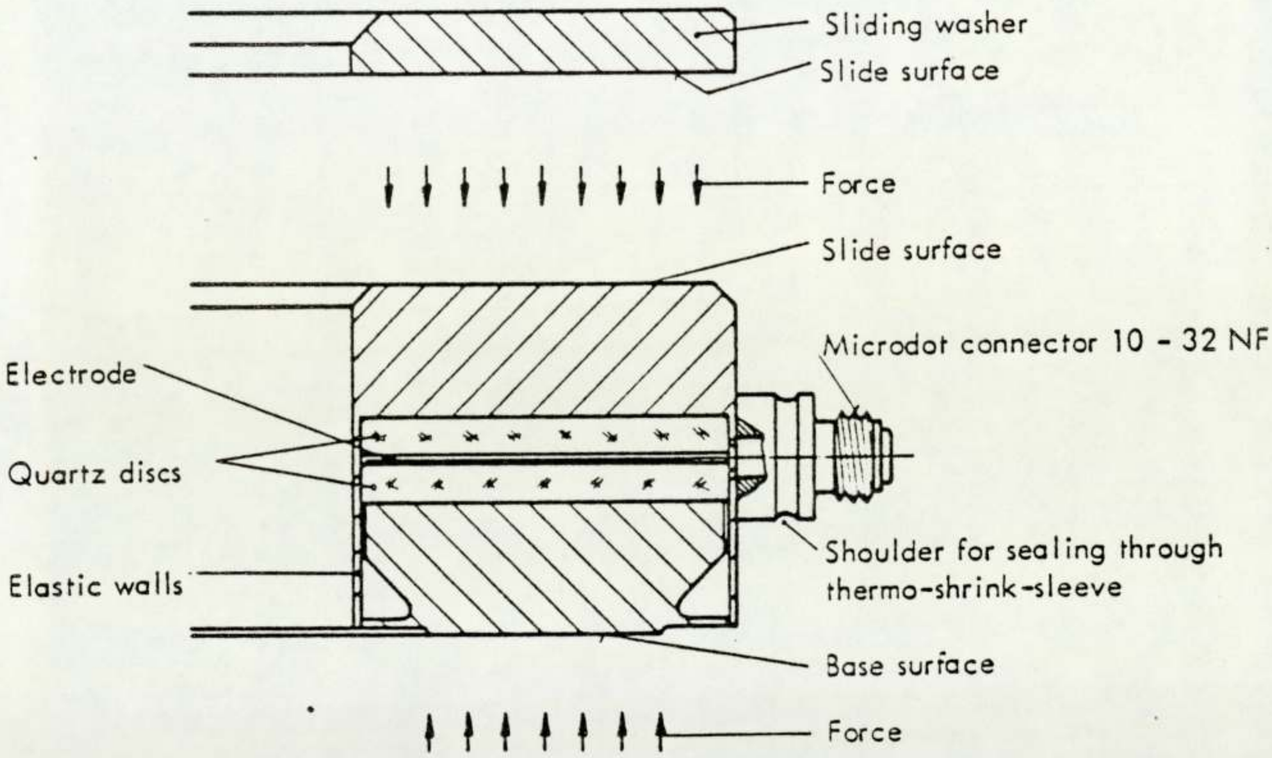


FIGURE G-1 DIAGRAMMATIC SECTION OF A QUARTZ LOAD WASHER force, and is not dependent on the size of the quartz disc (longitudinal piezo-effect). The resulting charge is taken off the electrode and transmitted to the electric connector. Through compression of the load washer, a negative charge is generated. By releasing a pre-loaded washer, whose negative charge resulting from the pre-load, was nullified through grounding, a positive charge is produced (negative charges result in positive voltages at the amplifier output).

TYPICAL APPLICATIONS

a) Measuring punch forces on presses, stamping presses, spot welds etc..

b) Measuring bolt stresses.

c) Measuring compressive and tractive forces between mechanical parts with a reciprocating motion.

d) Measuring compressive and tractive forces between mechanical parts with no reciprocating motion.

It is to these wide applications that the load cell is deemed suitable for measurements of the force generated in the pusher device used in the helical forming unit.

The quartz load washer can be fitted at no great outlay in the plunger unit (i.e., pusher device), in which case an expansion bolt as elastic as possible is used for the pre-load. This will allow any of the following operations at will : registering the applications of the force, starting at its peak value, or releasing an alarm signal in the event of a pre-set stress being exceeded.

APPLICATION OF THE FORCE

When rigid surfaces are in contact with each other, even small uneven spots will result in high local overloads. To preclude such overloads, not only are the faces of the load washers ground and lapped, but also, the contact surfaces of the object to be measured should also be perfectly flat and smooth. If the surface is not perfectly flat, a stress distributing ring should be usde in addition to the washer.

Should it not be possible to provide exactly parallel surfaces, various washers of differing geometric shape should be used to compensate this condition.

Quartz force transducers are used for measuring dynamic and quasistatic forces from a few Newtons up to one mega-Newton, with very high resolution down to 0.01 N under any pre-load. Very high rigidity ensures high resonant frequency in the measuring rig.

APPENDIX H

LOAD CELL - OPERATION

OPERATING INSTRUCTIONS

For the basic circuit for a piezo-electric measuring installation see fig H-1.

The electrostatic charge given out by a quartz force measuring transducer (pC or pico-Coulombs) is converted in a charge amplifier into a proportional voltage, which may be read, recorded or put to another use.

The connecting cable between the force measuring transducer and the positive charge amplifier should not only have a very high degree of insulation (approx 10 to the power 14 ohms) but should also be practically free of friction electricity. None but special cables, therefore should be used in this instance. On the other hand, ordinary cables may be used between the charge amplifier and the indicating or recording device.

OPERATING PRECAUTIONS

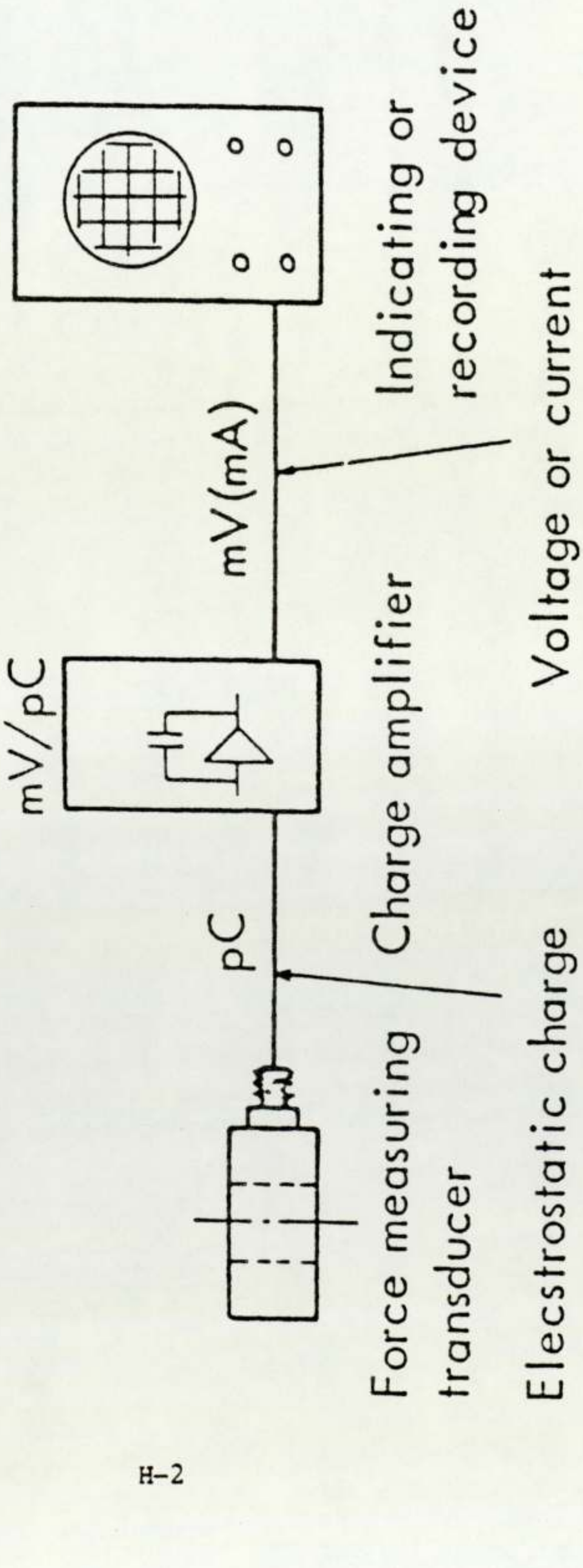


FIGURE H-1 BASIC CIRCUIT FOR A PIEZO-ELECTRIC MEASURING INSTALLATION

LOAD CELL - OPERATION

To ensure satisfactory results, a few precautions are to be observed; the load washer should be used within the indicated limits of temperature only. The micro-dot connector is to be kept perfectly clean and should be covered with a protecting cap as soon as the cable is removed. Cleaning can be done with fluids such as freon.

APPENDIX I

LOAD CELL - CHARGE AMPLIFIER

The charge amplifier type 5006, converts the charge yielded by the piezo-electric transducer into proportional electrical signals. Once it is adapted to a particular transducer connected, it allows working with fixed scales graded 1,2,5 -10 mechanical units per volt. In addition, it allows a galvanometer to be driven in a calibrated fashion. The charge applied is converted into a proportional voltage by a first stage with a capacitive feedback. In the amplifier following, the signal is finally scaled for the voltage output. This output signal is furthermore converted into a proportional current for deflecting a galvanometer by the galvo part of the amplifier. The adaptation to the connected galvanometer is done by the user fitting the galvo connector accordingly, as well as by the adjustments on the instrument.

The charge amplifier consists essentially of an operational amplifier with high input impedence and high open loop gain, and a highly insulating feedback capacitor. The input impedence of the feedback amplifier is thus virtually nil. However the high insulation resistance at the input is retained, because the input stage is equipped with a double MOSFET. Through the capacity feedback, the charge amplifier generates a charge which is equal with reverse sign to that delivered by the connected transducer. The charge yielded by the transducer thus appears to pass straight onto the feedback (range) capacitor. Consequently, the resulting output voltage is proportional to the charge and hence also to the measurand acting on the transducer. The voltage at the input remains so low that the cable capacitance has virtually no effect on the measured result.

By switching in a suitable resistor paralleling the feedback capacitor, the time constant is shortened, allowing dynamic measurements without drift.

For further information refer to the manual on amplifier type 5006, provided by Kistler Instruments A.G..

APPENDIX J

MEASUREMENT PROGRAM FOR MACSYM COMPUTER

```
10 REM ****PROGRAM TO MEASURE CONTROL PARAMETERS FOR****
20 REM ****------HELICAL FORMING UNIT---------------****
30 DIM I(1500),T1(1500,V1(1500),L1(1500),V2(1500),D1(1500),V3(1500)
40 DIM R(1500)
50 DIM A(5),B(5)
60 A(1)=4.83473E1 A(2)=1.10983E-1 A(3)=-2.43539E-6
70 A(4)=4.51645E-11 A(5)=1.81726E-16
80 B(1)=0 B(2)=1.5239E-1 B(3)=-1.37557E-5
90 B(4)=1.26109E-9 B(5)=-4.42813E-14
100 REM ****COMPENSATING VOLTAGE FOR ROOM TEMP****
110 V=0.105
120 ZERO TIMER
130 R(1)=TIMER
140 FOR I=1 TO 2000
150   V(1)=AIN(3,9,9)*1E3+V
160   V(2)=AIN(0,0,1)
170   V(3)=AIN(0,1,2)
180   GOSUB 260
```

MEASUREMENT PROGRAM FOR MACSYM COMPUTER

```
190   L1(I)=2*V2(I)
200   D1(I)=V3(I)*100
210   I(I)=I
220   GOSUB 310
230 NEXT I
240 CLOSE
250 END
260 IF V1(I)< 3.407 GOTO 290
270 T1(I)=POLY(V1(I)*1E3,A(1),5)
280 RETURN
290 T1(I)=POLY(V1(I)*1E3,B(1),5)
300 RETURN
310 R(I+1)=TIMER
320 IF R(I+1)-R(I)<1 GOTO 350
330 ZERO TIMER
340 R(I+1)=0
350 RETURN
360 INPUT "FILE NO?" M
370 SAVE ARRAY I(1) "MTO:"STR$(M)
380 SAVE ARRAY T1(1) "MTO:"STR$(M+1)
390 SAVE ARRAY L1(1) "MTO:"STR$(M+2)
400 SAVE ARRAY D1(1) "MTO:"STR$(M+3)
410 SAVE ARRAY R(I) "MTO:"STR$(M+4)
```

APPENDIX K

OUTPUT OF RESULTS FOR MACSYM COMPUTER

```
10 REM **** PROGRAM TO LOAD AND PRINT RESULTS OF ****
20 REM **** MEASUREMENT PROGRAM *********************
30 DIM 1(1500),T1(1500),L1(1500),D1(1500),R(1500)
40 DIM A$(45),B$(45)
50 A$="    NO.    T(SECS)    T('C)    L(KG)    D(MM)"
60 B$=" -****.   -****.**   -****:   -**.***  -***.*"
70 INPUT "TAPE NO ? "N
80 INPUT "FILE NO ? "M
90 OPENW :2 "$QTO:1"
100 PRINT :2 "RESULTS ARE SAVED AT FOLLOWING LOCATIONS"
110 PRINT :2 "    TAPE NO. ";N
120 PRINT :2 "   ARRAY I = FILE ";M
130 PRINT :2 "   ARRAY T1 = FILE ";M+1
140 PRINT :2 "   ARRAY L1 = FILE ";M+2
150 PRINT :2 "   ARRAY D1 = FILE ";M+3
160 PRINT :2 "   ARRAY R(TIME) = FILE ";M+4
170 LOAD ARRAY I(1)"MTO:"SIR$(M)
180 LOAD ARRAY T1(1)"MTO:"STR$(M+1)
```

OUTPUT OF RESULTS FOR MACSYM COMPUTER

```
190 LOAD ARRAY L1(1)"MTO:"STR$(M+2)

200 LOAD ARRAY D1(1)"MTO:"STR$(M+3)

210 LOAD ARRAY R(1)"MTO:"STR$(M+4)

220 PRINT :2

230 PRINT A$

240 PRINT :2 A$

250 FOR I=1 TO 1500

260    IF R(1)=0 PRINT :2

270    PRINT USING B$,I(I),R(I),T1(I),L1(I),D1(I)

280    PRINT USING :2 B$,I(I),R(I),T1(I),L1(I),D1(I)

290 NEXT I

300 CLOSE

310 END
```

APPENDIX L

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
.B
10 REM **** GRAPH PLOTTING ****
20 DIM T1(2000),L1(2000),D1(2000),R(2000)
30 DIM N$(10),Q$(1),L$(1),D$(1),F$(1)
40 DIM C$(3)
50 PNT 5 PNT 10
60 INPUT "RESULTS FROM TAPE OR KEYBOARD (T OR K) ? "Q$
70 IF Q$="K" GOTO 170
80 INPUT "TEMP FILE NO ?"M
90 INPUT "LOAD FILE NO ?"M1
100 INPUT "DISP FILE NO ?"M2
110 INPUT "TIME FILE NO ?"M4
120 LOAD ARRAY T1(1)"MTO:"STR$(M)
130 LOAD ARRAY L1(1)"MTO:"STR$(M1)
140 LOAD ARRAY D1(1)"MTO:"STR$(M2)
150 LOAD ARRAY R(1)"MTO:"STR$(M4)
160 GOTO 290
170 PRINT PRINT PRINT "INPUT DATA FOR EACH TEST AS BELOW "
180 PRINT
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
190 PRINT "IF NO RESULT IS AVAILABLE , ENTER '-1'"
200 PRINT "WHEN RESULTS ARE COMPLETED , ENTER 'O,-1,-1,-1'"
210 PRINT
220 PRINT
230 K=0
240 K=K+1
250 INPUT "TEMP, LOAD, DISP, TIME ? "T1(K),L1(K),D1(K),R(K)
260 IF T1(K)=0 GOTO 290
270 IF T1(K)=1 GOTO 1070
280 GOTO 240
290 OPENW :4 "$QTO:0"
300 OPENW :2 "$QTO:1"
310 PRINT "DO YOU WISH TO PLOT TEMP/FORCE/DISP V TIME"
320 INPUT "(Y/N) ?"F$
330 IF F$="N" GOTO 1710
340 PRINT :4 "IN"
350 PRINT :4 "DT",CHR$(5);
360 PRINT :4 "SP1"
370 PRINT :4 "IP2000,700,10500,7100";
380 FOR I=1 TO 2
390  PRINT :4 "PU9000,6100PD10500,6100,7100,9000,7100,9000,6100PU"
400 NEXT I
410 PRINT :4 "DI;PA",9000,6100,"CP1,4;LBTEMP "
420 PRINT :4 "DI;PA",9000,6100,"CP1,3;LBFORCE "
430 PRINT :4 "DI;PA",9000,6100,"CP1,2;LBDISP "
440 INPUT "TEST- "N$
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
450 PRINT :4 "DI;PA",9000,6100,"CP2,1;LBTEST-";N$""
460 PRINT :4 "DI;PA",5500,220,"CP0,;LBTIME(SECS) "
470 WAIT 2
480 PRINT :4 "LT;PU9600,6920PD10200,6920 "
490 WAIT 2
500 PRINT :4 "LTA;PU9600,6720PD10200,6720 "
510 WAIT 2
520 PRINT :4 "LT6;PU9600,6520PD10200,6520 "
530 PRINT :4 "PU"
540 WAIT 2
550 PRINT :4 "LT"
560 PRINT "INPUT X1 AND X2 (TIME AXIS) "
570 INPUT X1,X2
580 Y1=1000 Y2=1500
590 PRINT :4 "SP1"
600 PRINT :4 "SC",X1,X2,Y1,Y2
610 PRINT :4 "PU";
620 PRINT :4 "VS";
630 PRINT :4 "PA",X1,Y1
640 FOR I=1 TO 3
650  PRINT :4 "PD;PA",X2,Y1,X2,Y2,X1,Y2,X1,Y1
660 NEXT I
670 PRINT :4 "PU";
680 PRINT :4 "SI.18.23;TL1.5,0"
690 WAIT 8
700 FOR X=X1 TO X2 STEP 0.25
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
710  PRINT :4 "PA",X,Y1,"XT";
720  PRINT :4 "CP-.33,-1;LB";X;
730  PNT :4 5
740  WAIT .5
750 NEXT X
760 WAIT 3
770 FOR Y=Y1 TO STEP 100
780  PRINT :4 "PA2,X1,Y,"YT";
790  PRINT :4 "CP-4.5,-.25;LB;Y;
800  PNT :4 5
810  WAIT 1
820 NEXT Y
830 WAIT 3
840 PRINT :4 "DI0,1;PA",X1,Y2*.8,"CP0,3.25;LBTEMPERATURE('C) "
850 PRINT :2 "TEST-"N$
860 PRINT :2
870 WAIT 5
880 INPUT "RANGE OF POINTS TO BE PLOTTED ? "N,P
890 DIM A$(37),B$(37)
900 A$="  T(SECS)    T('C)  FORCE(N)    D(MM)"
910 B$=" -####.##   -####.   -###.##   -###.#"
920 PRINT :2 A$
930 FOR K=N TO P
940  PRINT USING :2 B$,R(K),T1(K),L1(K),D1(K)
950 NEXT K
960 PRINT :2
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
970  FOR J=N TO P
980   IF T1(J)=0 THEN RESET FOR GOTO 1060
990   IF T1(J)>Y2 THEN T1(J)=Y2
1000  IF T1(J)<Y1 THEN T1(J)=Y1
1010  PRINT :4 "PA",R(J),T1(J),;"PD";
1020  PRINT T1(J),R(J)
1030  WAIT 1
1040 NEXT J
1050 WAIT 3
1060 PRINT :4 "PU"
1070 PRINT "PLOTTING OF TEMPERATURE FINISHED"
1080 INPUT "DO YOU WISH TO PLOT AGAINST FORCE ? "L$
1090 IF L$="N" GOTO 1390
1100 Y1=0 Y2=100
1110 PRINT :4 "SP1"
1120 PRINT :4 "SC",X1,X2,Y1,Y2
1130 PRINT :4 "PU";
1140 PRINT :4 "VS";
1150 PRINT :4 "PA",X1,Y1
1160 PRINT :4 "PU";
1170 PRINT :4 "SI.18,.23;TL1.5,0"
1180 WAIT 8
1190 FOR Y=Y1 TO Y2 STEP 20
1200   PRINT :4 "PA",X1,Y,"YT";
1210   PRINT :4 "DI;CP-9,-.25;LB";Y;
1220   PNT :4 5
```

```
1230   WAIT 1
1240 NEXT Y
1250 WAIT 3
1260 PRINT :4 "DIO,1;PA",X1,Y2*.4,"CPO,6;LBFORCE(NEWTONS) "
1270 WAIT 2
1280 FOR J=N TO P
1290   IF L1(J)=-1 THEN RESET FOR GOTO 1370
1300   IF L1(J)>Y2 THEN L1(J)=Y2
1310   IF L1(J)<Y1 THEN L1(J)=Y1
1320   PRINT :4 "LTA"
1330   PRINT :4 "PA,R(J),L1(J);"PD";
1340   WAIT 2
1350 NEXT J
1360 WAIT 8
1370 PRINT :4 "PU"
1380 PRINT "PLOTTING OF LOAD FINISHED"
1390 INPUT "DO YOU WISH TO PLOT AGAINST DISPLACEMENT ? "D$
1400 IF D$="N" GOTO 1710
1410 Y1=O Y2=50
1420 PRINT :4 "SP1"
1430 PRINT :4 "SC",X1,X2,Y1,Y2
1440 PRINT :4 "PU";
1450 PRINT :4 "VS";
1460 PRINT :4 "PA",X1,Y1
1470 PRINT :4 "PU";
1480 PRINT :4 "SI.18,.23;TL1.5,0"
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
1490 WAIT 8
1500 FOR Y=Y1 TO Y2 STEP 10
1510   PRINT :4 "PA",X1,Y,"YT";
1520   PRINT :4 "DI;CP-13.5,-.25;LB";Y;
1530   PNT :4 5
1540   WAIT 1
1550 NEXT Y
1560 WAIT 3
1570 PRINT :4 "DIO,1;PA",X1,Y2*.4,"CPO,9;LBDISPLACEMENT(MM) "
1580 WAIT 2
1590 FOR J=N TO P
1600   IF D1(J)=-1 THEN RESET FOR GOTO 1680
1610   IF D1(J)=Y2 THEN D1(J)=Y2
1620   IF D1(J)<Y1 THEN D1(J)=Y1
1630   PRINT :4 "LT6"
1640   PRINT :4 "PA",R(J),D1(J);"PD";
1650   WAIT 2
1660 NEXT J
1670 WAIT 5
1680 PRINT :4 "PU"
1690 PRINT :4 "LT"
1700 PRINT "PLOTTING OF DISP. FINISHED"
1710 PRINT "DO YOU WISH TO PLOT FORCE V/S DISPLACMENT?"
1720 INPUT "(Y/N) ?"F$
1730 IF F$="N" GOTO 2240
1740 PRINT "NOTE ; CHANGE PAPER IF REQUIRED "
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
1750 INPUT "TYPE CON TO CONTINUE "C$
1760 PRINT :4 "IN"
1770 PRINT :4 "DT",CHR$(5);
1780 PRINT :4 "SP1"
1790 PRINT :4 "IP1500,1000,10000,7400";
1800 PRINT :4 "DI;PA",5300,520,"CPO,0;LBDISPLACEMENT(MM) "
1810 PRINT :4 "DI;PA",5000,220,"CPO,0;LBFORCE-V-DISPLACEMENT "
1820 PRINT "INPUT X1 AND X2 (DISP AXIS)"
1830 INPUT X1,X2
1840 Y1=0 Y2=50
1850 PRINT :4 "SP1"
1860 PRINT :4 "SC",X1,X2,Y1,Y2
1870 PRINT :4 "PU";
1880 PRINT :4 "VS";
1890 PRINT :4 "PA",X1,Y1
1900 FOR I=1 TO 3
1910   PRINT :4 "PD;PA",X2,Y1,X2,Y2,X1,Y2,X1,Y1
1920 NEXT I
1930 PRINT :4 "PU"
1940 PRINT :4 "SI.18.23;TL1.5,0"
1950 WAIT 6
1960 FOR X=X1 TO X2 STEP 2
1970   PRINT :4 "PA",X,Y1,"XT";
1980   PRINT :4 "DI;CP-.33.-1;LB";X;
1990   PNT :4 5
2000   WAIT 1
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
2010 NEXT X
2020 WAIT 3
2030 FOR Y=Y1 TO Y2 STEP 10
2040   PRINT :4 "PA",X1,Y,YT;"
2050   PRINT :4 "CP-4.5,-.25;LB";Y;
2060   PNT :4 5
2070   WAIT 1
2080 NEXT Y
2090 WAIT 3
2100 PRINT :4 "DIO,1;PA",X1,Y2*.4,"CPO,LBFORCE(NEWTONS) "
2110 INPUT "TEST " N$
2120 PRINT :4 "DI;PA",X2*.85,Y2*.955;"LBTEST-";N$;""
2130 WAIT 5
2140 INPUT "RANGE OF POINTS TO BE PLOTTED ? "N,P
2150 K=N
2160 PRINT :4 "PA,D1(K),L1(K);"PD";
2170 FOR J=N+1 TO P
2180   IF D1(J)<D1(K) THEN GOTO 2210
2190   PRINT :4 "PA,D1(J),L1(J);"PD";
2200   K=J
2210 NEXT J
2220 PRINT :4 "PU"
2230 PRINT "PLOTTING OF LOAD V/S DISPLACEMENT FINISHED"
2240 PRINT "DO YOU WISH TO PLOT FURTHER RESULTS FROM SAME FILES?"
2250 INPUT "(Y/N) ?"F$
2260 IF F$="N" GOTO 2300
```

PROGRAM FOR PLOTTING RESULTS USING THE MACSYM COMPUTER

```
2270 PRINT "NOTE : CHANGE PAPER "
2280 INPUT "TYPE CON TO CONTINUE "C$
2290 IF C$="CON" GOTO 340
2300 CLOSE
2310 END
```

APPENDIX M

RAMET 1 TECHNICAL DATA

RAMET 1 a new cutting tool material, has unique properties never achieved before - the strength of high speed steel combined with the hardness and wear resistance of conventional carbides . Concomitant with this high hardness is a high degree of shock resistance.

Placed within a broad spectrum, Ramet finds effective application in those cutting tool areas where carbides chip because of slow surface speeds, and high speed steels fail due to lack of wear resistance or loose hardness because of heat generated by high machining speeds. It has the highest strength for its hardness, or conversely, the highest hardness for its strength, of any cutting tool material.

These properties, in combination permit profitable machining in problem areas where high speed steels and carbides have not been effective. Among them: machining high temperature high strength alloys - the "space age" metals - work hardening stainless steels, hard metals, cut-off operations, screw machine operations and milling applications.

RAMET 1 TECHNICAL DATA

In addition to its high strength hardness, Ramet 1 physical properties that result in a tool material which can operate far beyond the surface speeds of high speed steels and retain the hardness of carbides. Ramet 1 has a high compressive strength, a high modulus of elasticity, excellent temperature and wear resistance, low thermal conductivity and a low coefficient of friction.

With a hardness of 91.5 Rockwell A, Ramet 1 is within the range of C2 carbide grades, and is much harder than any high speed steel. As much, or more important, however, is the fact that hardness is retained at elevated temperatures that are generated by high speeds and high interface temperatures.

The transverse rupture strength value for Ramet 1 is 400,000 psi, which gives it the highest strength for its hardness of any cutting tool material. This is greater than any C2 carbide and approaching that of high speed steel. Because Ramet 1 has this high strength, or toughness, high positive rake angles can be used for work hardening metals, or wherever positive rakes are desired for free cutting action, low interface temperatures that reduce welding between the tool and the chip, and lower the tool power consumption.

Youngs modulus of elasticity is 80,000,000 psi. This value is about three times that of high speed steel. High resistance to bending readily lends itself to any application where heavy load conditions are present, such as in boring and grooving, or cut-off operations.

With a value of 525,000 psi, Ramet 1 has several times the compressive strength of high speed steels. This high compressive strength, combined with high transverse rupture strength gives high shock resistance and edge strength, making it an optimum tool for milling operations and interrupted cuts where speeds are too slow for carbides.

Hardness and temperature resistance interact in that when both have high values, the tool material has better wear resistance, and since it can run at higher speeds than high speed steel, it produces greater economies, accurate size control and good finishes.

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