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Effects Of Parameters On Flash Welding Using A Magnetically Controlled Arc

M. Sc. Degree Thesis

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February, 1992
Bornova - İZMİR

ABSTRACT

Flash welding is used more than upset welding because of greater weld strength; no need for special preparation of weld surface; lower power demand with less power consumption; faster speed and smaller upset; and less heat in the work since most heat appears at the interface. It is possible to weld dissimilar metals of widely differing melting points since flashing may be continued until both metals have reached their individual fusing temperatures.

In this process the parts are brought together lightly with current flowing, and then separated slightly; a flashing action is created at the interface. This heats them to their fusion temperature and permits the pressure which is then applied to force the fused areas together and form the weld.

In this study, the arc, which is initiated at the heating phase was rotated along the surfaces of the tubes to be welded by means of an external magnetic field to supply a uniform heating. The joints produced by the application of different welding heats and upset forces were mechanically tested and also examined under light-microscope. As a result, optimum parameters for flash welding of thin walled tubes were obtained.

ÖZET

Yakma alın kaynağı;yüksek kaynak mukavemeti,özel olarak yüzey hazırlığı gerektirmemesi,yüksek üretim hızı, farklı metallerin kaynaklanabilirliği,..gibi çeşitli özellikleri sayesinde pek çok uygulamada direnç alın kaynağının yerini almaktadır.

İşlem kaynak edilecek parçaların makinaya bağlanması ve bir biriyle hafif temasa getirilmesiyle başlar. Daha sonra parçalardan geçirilen akım temas halindeki yüzeyler arasında bir ark oluşturur . Böylece, ergime sıcaklığına ulaşan parçalara bir baskı kuvvetinin uygulanmasıyla ergimiş metal dışari atılıp hemen ardındaki plastik bölgede birleşme sağlanır.

Yapılan calışmada işlemin ısıtma safhasında oluşturulan ark dıştan uygulanan bir magnetik alanın etkisiyle döndürülerek boru şeklindeki iş parcalarının kaynak edilecek yüzeylerinde uniform bir ısıtma elde edilmesi amaçlanmıştır. Farkli enerji girdilerinin ve baskı kuvvetlerinin kullanılmasıyla elde edilen bağlantılar mekanik ve metalografik olarak test edilmiştir.Sonuç olarak sözkonusu malzemelerin kaynağı için optimum parametreler bulunmuştur.

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INTRODUCTION

The importance of resistance welding processes has been increasing especially in industries with high production schedules. The advantages of resistance welding over other forms are the speed,the accurate regulation of time and heat, the uniformity of the weld and the mechanical properties which result, the elimination of filler rods or fluxes, and the fact that the process is easy to automate.

Flash welding , which is one of the resistance welding processes is the subject of this study.The aim of this investigation is to obtain the relationship between the process variables and weld quality. The method used in this thesis differs from the conventional flash welding processes by the usage of external magnetic coils to control the arc.

The thesis consists of six chapters. Chapter 1 provides an introduction to the subject by giving some basic information about welding and welding processes. The principle of resistance welding and an outline of resistance welding processes are given in chapter 2.Chapter 3 gives a detailed information about the main subject of this study, flash welding. A small glassory for the definition of process variables is also included in this chapter.

Chapter 4 deals with the structure and the features of an electric arc and also covers the magnetic control of the arc in flash welding to obtain a uniform heating . Chapter 5 presents the test procedure with detailed information about welding machine, test material,standard destructive tests for welded specimens...etc. A simple test for determination of actual magnetic field distribution in the welding gap is also included in this chapter.Chapter 6 is concerned with the test results and their evaluation.

CHAPTER 1

PROPERTIES AND CLASSIFICATION OF WELDING PROCESSES

1.1 - Definition And Basic Requirements

A weld is defined by the American Welding Society as a"localized coalesence of metals wherein coalesence is produced by heating to suitable temperatures,with or without the application of pressure and with or without the use of filler metal. The filler metal either has a melting point approximately the same as the base metals or has a melting point below that of the base metals but above 800 °F (426 °C) " [1].

The ideal weld is one in which there is complete continuity between the parts joined and every part of the joint is indistinguishable from the metal in which the joint is made. Although this ideal is never achieved in practice,welds which give satisfactory service can be made in many ways. Not every welding process is equally suitable for each metal , type of joint or application, and much of the skill of the welding engineer consist in the recognition of the essential requirements which a particular weld must satisfy and the choice of the appropriate welding process.

For a permanent joint to be made , it is not enough just to bring one member with its surface thoroughly cleaned into contact with another member with a similarly prepared surface.

Each welding process must fulfill a number of conditions.Most important energy in some form, usually heat, must be supplied to the joint so that the parts can be united by being fused together.The heat may be generated by a flame,an arc,the resistance to an electric current,radiant energy or by mechanical means. In a limited number of processes such as pressure welding the union of the parts is accomplished without melting, but energy is expended in forcing together the parts to be joined and heat may be used to bring the weld region to a plastic condition. Fusion is generally considered as synonimous with melting, but in the context of welding it is desirable to distinguish at once between these words . By common usage the word fusion implies melting with subsequent union, and it is possible for the parts of a joint to be melted but not fused together.

Two surfaces can only be unified satisfactorily if they are free from oxide or other contaminants. Cleaning the surfaces before welding, though helpful,is not usually adequate and it is a feature of every welding process that the contaminated surface film is dissolved and dispersed. This may be done by the chemical action of a flux or the sputtering of an electric arc or even by mechanical means such as rupturing and rubbing. The contaminants which must be removed from the surface are of three types - organic films,adsorbed gases and chemical compounds of the base metal , generally oxides. Heat effectively removes thin organic films and adsorbed gases so that with the majority of welding processes where heat is employed it is the remaining oxide film which is of greatest importance.

Once removed, surface films and particularly nitrides,must be prevented from forming during the process of welding. In almost every welding process,therefore,there must be some way of excluding the atmosphere while the process is carried out. If a flux is used for cleaning the fusion faces of the joint, this also performs the function of shielding.If a flux is not used shielding can be provided by a blanket of an inert gas, or a gas which does not form refractory compounds with the base metal. The atmosphere may also be excluded mechanically by welding with the faces to be joined in close contact and the ultimate in protection from the atmosphere is obtained by removing it entirely by welding in a vacuum.Where the welding operation is carried out at high speed and with such limited heating that there is no time for appreciable oxidation, shielding may be unnecessary. It is possible with a few processes , however , for any contaminated molten metal to be expelled before the joint is completed or for the properties of the weld metal to be corrected by making alloying additions to the weld pool.

One further important requirement is that the joint produced by the welding process should have satisfactory metallurgical properties. In methods which involve melting of some part of the joint it is often necessary to add deoxidants or alloying additions, just as is done in the foundry. Frequently the material to be welded must have a controlled composition. Some alloys-happily few-are unweldable by almost any process, but a great many are only suitable for welding if their composition is controlled within close limits. These considerations are the basis of welding metallurgy.

To summarize: every welding process must fulfil four requirements [3]:

(1) A supply of energy to create union by fusion or pressure.
(2) A mechanism for removing superficial contamination from the joint faces.
(3) Avoidance of atmospheric contamination or its effects.
(4) Control of weld metallurgy.

1.2 - Types Of Welding Processes

The simplest welding process would be one in which the two parts to be joined have their surfaces prepared to contours matching with atomic precision. Such surfaces brought together in vacuum, so as to enable electrons to be shared between atoms across the interface could result in an ideal weld. The preparation of surfaces with this degree of precision and cleanliness is not feasible at present, although it is approached in space technology when metals may be in contact in the ultra-high vacuum of outer space. Slight rubbing of surfaces under these conditions can induce welding by satisfying the first two conditions above at limited points of contact, the third being supplied already by the vacuum. While such conditions of cleanliness and vacuum might be visualized for special micro-welding applications,alternative solutions must be found for practical welding.

The problem of achieving atomic contact between the parts to be joined is solved in one of two ways. Pressure may be applied so that abutting surfaces are plastically deformed giving the required intimacy of contact at least at asperities as indicated in fig 1.a.The deformation also helps to satisfy the cleaning requirement by rupturing films. With ductile metals the plastic deformation can be accomplished cold but less malleable metals may be first softened by heat. Alternatively, the surfaces to be joined may be bridged with liquid metal . The required adjustments in contour and structure are then affected as the melted metal solidifies (fig. 1.b). The majority of welding processes employ the latter method, and their variety is an indication of the many ways by which it is possible to generate locally the heat required for melting.

The two types of welding process described are fundamentally different , and the division between them forms the first breakdown in the classification of welding processes. Those welding methods employing pressure to plastically deform the faying surfaces are frequently called 'solid phase' methods. There is no accepted term for the methods in which union is made through liquid metal but they may be called 'liquid-phase' methods.

For some years it has been customary to divide welding processes into 'pressure' and 'fusion' welding methods. The pressure-welding processes were those in which pressure is

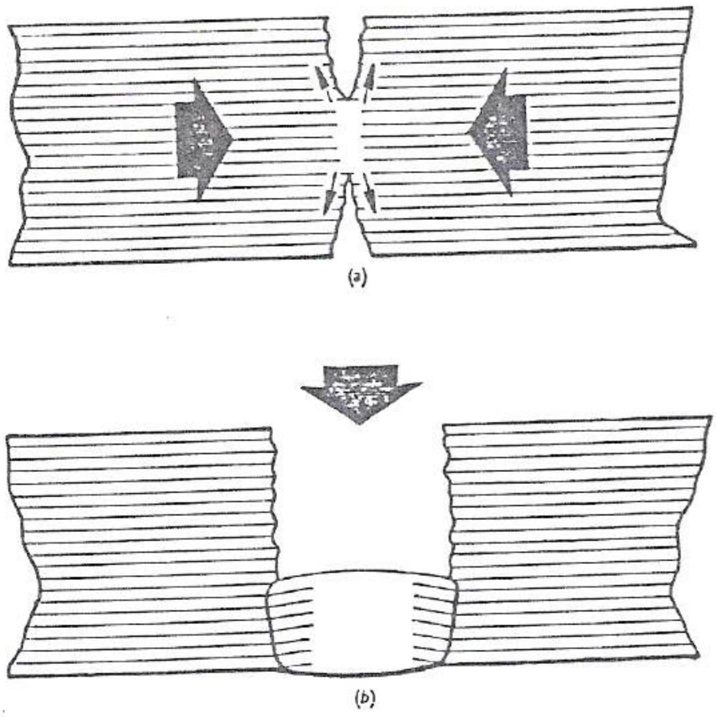


Fig 1.1 Basic mechanisms of welding (a) Union by flow,
(b) Union by molten metal bridging

used at some stage in welding , and while this classification included all the methods which could be truly classed as solid-phase methods it also included several methods in which fusion takes place. This is a second reason for using the word 'fusion' with care in the welding context.

1.3 - Classification Of Processes

Welding processes may be classified according to the way in which the four basic requirements - particularly the first three - are satisfied. The energy for welding is almost always supplied as heat so that divisions can be made according to the methods by which the heat is generated locally. These methods may be defined and grouped as follows [3] :

(a) Mechanical. Heat generated by impact or friction or liberated by the elastic or plastic deformation of the metal.
(b) Thermo-chemical. Exothermic reactions , flames and arc plasmas. It is necessary to explain why plasmas should be put in the same class as oxyfuel gas flames. Although chemical

reactions may not take place in a plasma the method of heat transfer to the work is the same as for processes employing an envelope of burning gas. This holds for all process in which the work does not form part of the arc circuit. The so-called non-transferred arc produces a plasma flame , whereas the transferred arc is a constricted arc and falls in the arc process category.

(c) **Electric resistance.** Heat generated by either the passage of a current introduced directly to the metal to be joined or by a current induced within the parent metal.
(d) **Electric arc.** Both a.c and d.c arcs with electrodes which melt and those which do not.
(e) **Radiation.** This category is suggested to cover the new processes such as laser and electron-beam weding and others which may yet be developed . The essential feature of a radiation process is that energy is focused on the workpiece and heat is generated only where the focused beam is intercepted .

It is not possible to define all welding processes completely by the source of thermal energy. This applies particularly to the many variations of arc welding and it is customary to complete the definition by reference to the way the process satisfies the condition of atmosphere control. All welding processes can be examined in the same way by placing the names of the processes within a grid formed by listing the sources of heat along one axis and methods of avoiding atmospheric contamination along the other axis as is done in fig1.2.The diagram can now be divided up into areas enclosing processes with a basic similarity.Seven such areas are readily identified corresponding the processes as follows : (1) solid phase, (2) thermochemical, (3) electric resistance, (4) unshielded arc, (5) flux-shielded arc, (6) gas-shielded arc , (7) radiaton.
Certain areas in the diagram can be marked out as regions

Welding process classification							
Source of heat		Shielding method					
		Vacuum	Inert gas	Gas	Flux	No shielding	Mechanical exclusion
No heat or heat by conduction		Cold pressure	Thermo compression bonding				Hot pressure Cold pressure
Mechanical		Explosive		1		Explosive	Friction Ultrasonic
Thermo chemical	Flames, plasma		Plasma	Atomic hydrogen	Gas	Forge	Pressure butt
Thermo chemical	Exothermic reactions			2	Thermit		
Electric resistance	Induction				3	H.f. induction	Induction butt
Electric resistance	Direct				Electro -slag	Flash butt H.f. resistance Projection	Spot seam Resist -ance butt
Electric arc	Consumable electrode		Inert gas metal arc	CO_2 metal arc Gas flux metal arc	Covered electrode Submerged arc	Bare wire Stud Spark — discharge Percussion	
Electric arc	Non-consumable		Inert gas tungsten arc	6	5	4 Carbon arc	
Radiation	Electro magnetic	7				Laser	
Radiation	Particle	Electron beam					

Fig 1.2 Grouping of welding processes according to heat source and shielding method [3].

where welding processes could not exist - for example flames cannot be used in vacuum.

This way of classifying welding processes is less rigid than the family tree method and makes it possible to account for certain anomalies. The resistance butt welding process, for example,while truly a solid-phase welding process,is normally included in the resistance welding category. In fig1.2 the position of this process is clarified by drawing the boundary of the group (1) solid-phase processes to include resistance butt and to exclude the remaining resistance processes . Similarly, electro-slag welding and its derivatives can be placed correctly in the resistance heat source grid , but may be linked with the flux-shielded arc processes with which they have a great deal in common.

There is no uniform method of naming welding processes. Many processes are named according to the heat source or shielding method, but certain specialized processes are named after the type of joint produced. Examples are stud,spot and butt welding. An overall classification cannot take account of this because the same type of joint may be produced by a variety of processes. Stud welding may be done by arc or projection welding and spot welding by electric resistance , arc , or elctron beam processes. Butt welding may be done by resistance, flash or any of a number of other methods. Although in common usage many processes have abbreviated names, the full names often follow the pattern : first , a statement of the type of shielding (where mentioned) ; secondly, the type of heat or energy source ; thirdly, the type of joint (where this is of specific and not general importance), e.g.

(Unshielded)	Arc	Stud
-	(Resistance)	Projection
(Vacuum)	Electron beam	-
-	Flash	(Butt)

(Brackets enclose terms implied but not mentioned)

CHAPTER 2
RESISTANCE WELDING
2.1 - The Resistance Welding Principle

Two ways exist of utilizing an electric current to produce heat directly in a metal. The current may be used to maintain an arc to the surface of the workpiece, as in arc welding, or heat may be liberated by the passage of the current through the work . In this latter method heat is generated by the resistance to the passage of the current according to Joule's law.

$$H = I^2RT \qquad (1)$$

where H = heat induced,
I = current (in amperes),
R = resistance (in ohms), and
T = time (in seconds).

To realize the greatest heating effect , it is evident that 'I' should be large, since 'H' varies as 'I^2'.For this reason resistance welders utilize low voltages and high amperages.

Heat in arc welding is generated at the surface and is distributed through the workpiece by conduction . In the resistance method heat can be liberated throughout the entire cross - section of the joint . The electric current which generates the heat may be introduced to the work through electrodes with which the work makes contact , or it may be induced within the metal by a fluctuating magnetic field which surrounds the work . Although both methods depend on resistance heating the term resistance welding is often used for the former.The latter process is known as induction welding.

Resistance welding embraces a group of welding processes wherein coalesence is produced by the heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part, and by the application of pressure. There is no external heat source ; heat is developed in the metals to be welded and pressure is applied by the welding machine through the electrodes . No fluxes or filler metals are used.

The resistance of the welding circuit is a maximum at the interface of the parts to be joined, and the heat generated there must reach a value high enough to cause a localized fusion under pressure. There is an exception to this principle in flash welding, where a portion of the heat is derived from the flashing and the combustion of the metal at the interface. Even in this instance a part of the heat is generated in the work. The duration of the application of the current must be short so as to limit the zone of melting ; otherwise an inferior weld is produced.

A variety of resistance welding methods exist depending on the different ways of creating a locally high resistance so that heating may be concentrated at this point. Actual resistance depends on both resistivity and the geometry of the conductor. Since the resistivity is fixed by the workpiece materials it is usual to create the local high resistance by providing a restricted current path between the parts to be joined, a procedure known as current concentration. All resistance welding methods require a physical contact between the current carrying electrodes and the parts to be joined. Pressure is also required to place the parts in contact and consolidate the joint and these are features which distinguish the processes from most arc welding methods.

The advantages of resistance welding over other forms are the speed, the accurate regulation of time and heat, the uniformity of the weld and the mechanical properties which result, the elimination of the filler metals or fluxes , and the fact that the process is easy to automate.

2.2 - Types Of Resistance Welding

Spot welding, seam welding, projection welding, upset welding and flash welding are known as the most important resistance welding processes.

Spot Welding

This process, which came into use in the period 1900 to 1905, is now the most widely used resistance welding process. A diagrammatic arrangement of the process is given in fig.2.1.

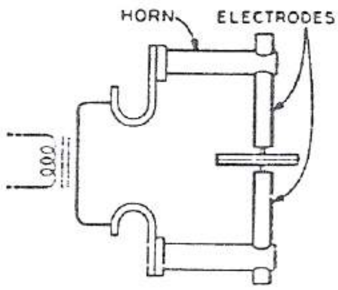


Fig 2.1 Sketch of spot welding circuit

The material to be joined is clamped between the electrodes by pressure applied through levers or pneumatically operated pistons. Springs may be used for this purpose on small welding machines. Then a quick shot of electricity is sent from one electrode through the work to the other electrode. This currents generally supplied by a step-down transformer, the work , electrodes , and arms of the machine being part of a secondary circuit consisting of only one or two turns.

The electrodes which conduct the current and which subsequently apply pressure to a spot are of low resistance,hard copper alloy. The shape of the work parts and the location of weld usually determine the size and general shapes of electrodes which must be of proper shape and correct material and should be water cooled. Contact resistances, electrode to workpiece, are wholly undesirable and kept to a minimum by using high conductivity electrodes and ensuring that there is adequate cleanliness and clamping force. Unfortunately, the high electrical and thermal conductivity requirements are not compatible with good mechanical strength and wear resistance at elevated temperatures.

A variety of copper alloys, for example chromium - copper cadmium copper or bryllium-cobalt-copper, are employed which provide a range of properties suitable for different applicat ions. The ill effects of resistance at the work surface, surface pick-up,splashing and electrode wear can be mitigated by water cooling the electrodes internally so that heat is conducted away rapidly.Efficient electrode cooling is essential with high production rate.

The effects of current and time can be considered together but, while they both affect the quantity of heat developed, it is the current alone which determines the rate of heat development. While the current is passing some of the heat generated is lost, mainly to the water-cooled electrodes. The size to which a nugget will grow,and indeed whether a nugget will form at all, depends on the heat being generated faster than it is removed by conduction. Current, therefore, is a most critical variable.

Accurate timing of current flow is the essence of satisfactory spot welding. In addition to producing strong,well-formed spots at a high rate of speed,it is metallurgically important in most cases, that the heating cycles be restricted to minimum periods of time.Furthermore,short time periods afford less opportunity for heat dissipation into the parent metal with consequent possibility of distortion.Modern spot welding machines are controlled by electronic devices.

In making a satisfactory weld one factor not always given due consideration because of the difficulty in accurately predicting the exact effect is correct **heat balance** which may be defined as a condition in which the fusion zones in the pieces of material to be joined undergo approximately the same degree of heating. In order to make the weld section or nugget be symmetrical about the weld interface, the two workpieces in contact must be of equal thickness and of the same type of material ; the welding electrodes must also be of the same design and similar material . There are frequently occasions when metal of two thicknesses or compositions must be joined. Such differences result in greater heat generation on one side than the other and the nugget may grow with its centre-line away from the interface resulting in a weak weld. In joints with sheets of equal thicknesses but unequal resistivity and conductivity the nugget will grow towards the high resistivity side. Where similar materials are welded,but the thicknesses are unequal the nugget grows toward the thicker side. A correct heat balance can be obtained by the following techniques [4]:

1. By using an electrode having a smaller contact area on the high conductivity or thin metal will cause equal fusion of the material. A higher current density (concentrated) is produced in the metal which has a contact with the electrode having smaller diameter.This technique not only increases the heat generated , but also minimizes the heat losses to the electrode from the contact area.
2. By using an electrode material of low conductivity on the higher conductivity or thin material, which will lessen the heat losses in the electrode.
3. By use of a combination of items 1 and 2.

Resistance spot welding machines vary from small, manually operated units to large , elaborately instrumented units designed to produce high-quality welds, as on aircraft parts.

Portable gun-type machines are avilable for use where assemblies are too large to be transported to a fixed machine. Spot welds may be made singly or in multiple, the latter being generally by special-purpose machines. Spacing of electrodes is important to avoid excessive shunting of welding current.

The process has extensive application in the joining of sheet metal not only in mild steel but also in stainless steel, heat resisting alloys, aluminium and copper alloys and reactive metals. Dissimilar metal combinations are also welded. The process is generally limited to thin materials, and although carbon steel up to about 25mm thick has been spot welded, this is exceptional.

Seam Welding

The AWS defines seam welding as a resistance welding process wherein coalesence is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by wheel-like or roller electrodes. The resulting weld is a series of overlapping spot welds made progressively along the joint by rolling the electrodes [2].

Seam welding may be accomplished in several ways depending on travel speed and timing of welding current. In continious-motion welding, the electrodes (or work) are driven at a constant speed and welding current is either interrupted or flows continiously (fig 2.2.a). In either case a continious air-tight seam is obtained. Adjustment of timing can be made to produce not a continious seam but a series of individual welds. When this is done the process is called roller-spot welding (fig 2.2.b). Spot and seam welding are very similar and the terminology refers to the resultant weld. The real distinction is between the use of spot electrodes and roller electrodes.

In most applications the two pieces to be seam welded overlap each other more than the width of the welding wheel face and form a lap-seam welded joint (fig.2.3.a). The overlap can be

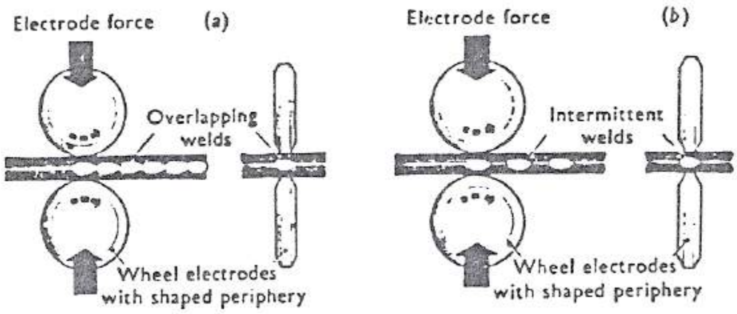


Fig 2.2 Seam welding principles (a) Overlapping spots
(b) Roller spot

made so small that the pieces forge together during welding and attain a thickness through the weld area slightly greater than a one-sheet thickness, producing a so-called "mash-seam" weld (fig2.3.b).

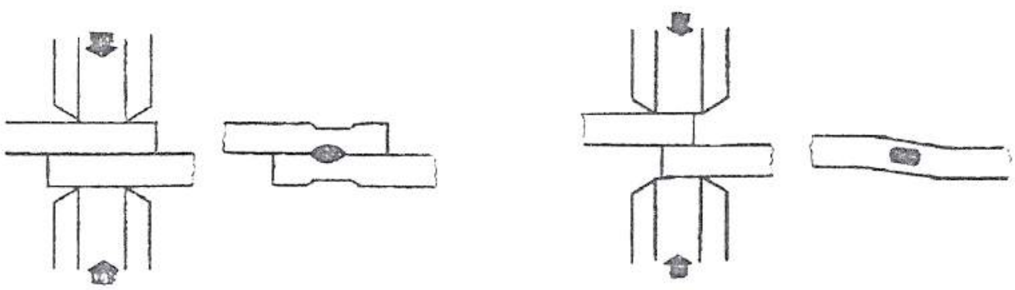


Fig 2.3 (a) Lap seam welding (b) Mash seam welding

Warpage of work is a factor to be considered in seam welding, and several methods are used to minimize distortion. On long seams skip welding is used ; on the second pass all skipped portions are welded. Another method employs flooding, usually through water jets immediately before and after the wheels.

Seam welding electrodes must be of proper material and shape and should be water cooled. The size and general shape of the electrode will usually be determined by the shape of the parts to be welded, by the location of the welds, and by the need of a driving mechanism to keep the electrodes rotating. The contour of the electrode changes in welding , and the contacting electrode face becomes wider. It will eventually reach a point where the reduced unit welding current and unit force will not permit fusion, and the wheels should then be turned to their original width and contour before reaching this point. The maximum width can be determined by test.

Where high quality in seam welding is desired, steel whether low carbon or stainless should be free from rust, paint,heavy grease, or oil and from any other coating such as bonderizing or parkerizing finish, although steels with zinc-, tin-, or lead-coated surfaces, etc, are, weldable. A light film of oil to prevent rusting usually has no bad effect on the weld, provided rust has not accumulated on the sheet surface during storage. Dust or dirt should be wiped off before welding,as a clean work surface is important in welding applications.

The use of seam welders is generally restricted to sheet-metal fabrication, a circumstance due largely to cost of the equipment and electric supply difficulty involved in the larger units , although in certain cases where the cost is justified, heavy units have been satisfactorily used [5].

Projection Welding

Current concentration is achieved in this process by shaping the workpiece so that when the two halves are brought together in the welding machine current flows through limited points of contact. With lap joints in sheet a projection is raised in one sheet through which the current flows to cause local heat and collapse of the projection. Both the projection and the metal on the other side of the joint with which it makes contact are fused so that a localized weld is formed. The process is illustrated in fig.2.4 . Because current concentration is carried out by the workpiece the shaped

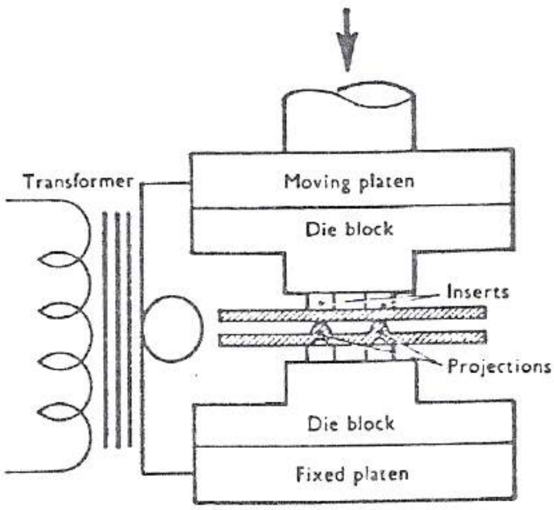


Fig 2.4 Projection welding

electrodes used in spot welding can be replaced by flat-surfaced platens. These not only conduct the current to the workpiece they also give support so that there is no deflection except at the projection.

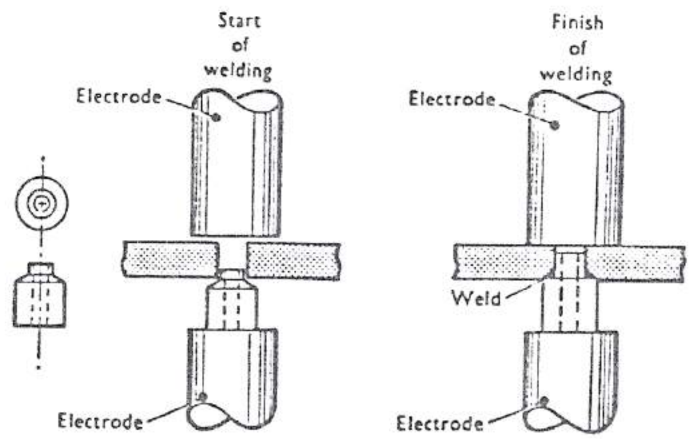


Fig 2.5 Annular projection of hollow stud to plate

Projection welding is not limited to sheet-sheet joints and any two mild steel surfaces which can be brought together to give line or point contact can be projection welded. Projections can be artificial produced deliberately by pressing and machining (see fig. 2.4) or they can be formed by the natural contours of the parts to be joined (fig. 2.5) . Excellent examples of the latter are the welds between crossed wires in wire mesh or between sheet and rod as in the welding of the wards of a key to its shaft. Unlike spot welding there is the possibility of making not only lap welds, but many other types of joint as well. The welds do not have to be individual spots but may be alongated or even annular.

Similar equipment is used to that for spot welding except that the cylindrical electrodes are replaced by flat copper platens or dies. These may have inserts of wear-resistant high-conductivity copper alloys to increase the working life of the die surfaces. It is common for three projection welds to be made at one time and even groups of four or five have been attempted. With more than three simultaneous welds, however, there is a tendency for lack of consistency as, unless special pressure - equalizing dies are used, it cannot be guaranteed that all the projections will behave identically. Because several welds can be made simultaneously there is no shunting problem, as in spot welding. The method is therefore satisfactory for designs where several welds must be made close together.

With spot welding the important process variables controlling weld size are electrode tip diameter, current, time, force, electrical resistivity and thermal conductivity of metal and surface resistance. The electrode diameter does not apply in projection welding and surface resistance is of reduced importance, but we may add to the list of variables, projection diameter, height and shape and the strength / temperature properties of the metal being welded.

When the initial load is applied the projection should not suffer excessive 'cold collapse' as this will reduce the current concentration and hence the heat generated during welding. Low electrode forces are, therefore, preferred and additionally the velocity of approach of the welding dies should be controlled to avoid damaging projections by impact.

On passing the current the projection heats up , the metal softens and collapse takes place often in less than one cycle of current and the rate of follow up of the welding head must be such that during this stage the hot metal bridge does not become molten and splash. On the other hand,excessively rapid collapse of a projection will limit the heat generated. Projection height, diameter, and shape must therefore vary systematically with metal thickness. The process does not end with the collapse of the projection, however,this stage is of critical importance because the hot slug of metal formed during collapse acts as a marker for the nugget.

Because heat is generated during projection collapse there is a tendency for the part of the workpiece containing the projection to become hotter than the other. Where unequal thicknesses are to be joined, therefore, the projection is placed in the thicker material . Similarly , if different composition materials are being welded together heat balance is improved by placing the projection in the metal with the higher thermal conductivity. As with spot welding , if one electrode has a low thermal conductivity the nugget will move toward the electrode.These are the main methods by which heat balance is controlled.

The process is used extensively for making attachments to sheet and pressings and these attachments may be either sheet metal or solid parts. Joints of the latter type could not be made by normal spot welding. Other important applications are the joining of small solid components to forgings or machined parts. Crossed-wire projection welding is widely used.A great variety of joints is possible, the limitations being chiefly those of material and the ingenuity of the designer to devise projections to satisfy the conditions for heat generation. Because there is no possibility of using post-weld current pulses for heat treatment weld assemblies in hardenable materials must be heat treated in a furnace. Apart from mild steels projection welds may be made readily in alloy steels and titanium alloys.

Upset Welding

This early form of resistance welding is limited to joining members of approximately equal cross section. The parts to be welded are brought together under pressure and current is passed through the contact area (fig.2.6). This results in

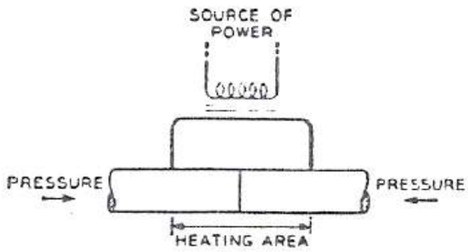


Fig 2.6 The basic upset welder

creating a forge weld of symmetrical shape. The heat generated at the juncture of the work pieces is purely that resulting from the inherent resistance of the materials to the flow of electricity. The heat induced is the I^2RT quantity as discussed in section 2.1. Pressure and current are maintained through out the welding cycle, although pressure is initiated at a low value (to raise the initial contact resistance) and subsequently raised to that necessary for forging. When the required upset is achieved, welding current is cut off.

In upset welding it is difficult to distribute heat uniformly throughout the cross - sectional area of the work. For this reason upset welding is limited to parts with a cross - sectional area of not over 200-250 mm^2. Bars with a cross-sectional area of 250-100 000 mm^2 are joined by flash welding [6].

Flash Welding

In this process the parts are brought together lightly, with current flowing, and then seperated slightly; a flashing action is created at the interface (fig.2.7). This heats them to

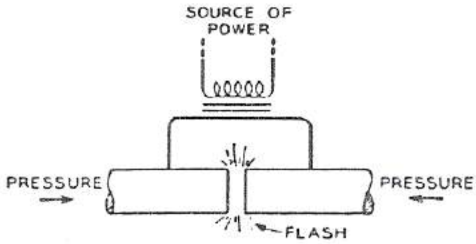


Fig 2.7 The basic flash welder

their fusion temperature and permits the pressure which is then applied to force the fused areas together and form the weld . **Flash welding** differs from the resistance welding processes in that greater masses can be joined. For example, two pieces of bar stock can be joined to each other. **Flash welding** is used more than upset welding because of greater weld strength ; no need for special preparetion of weld surface ; lower power demand with less power consumption; faster speed and smaller upset; and less heat in the work since most heat appears at the interface. It is possible to weld dissimilar metals of widely differing melting points since flashing may be continued until both metals have reached their individual fusing temperatures [7].

CHAPTER 3

FLASH WELDING

3.1 - Definition And General Description Of The Process

Flash welding is defined by the American Welding Society [2] as a resistance welding process wherein coalesence is produced,simultaneously over the entire area of abutting surfaces, by the heat obtained from resistance to the flow of electric current between the two surfaces and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint.

The flash welding process was developed from resistance butt welding probably by accident in attempts to increase the capacity of the butt welding machines by raising the voltage and applying pressure intermittently [3].Similar equipment is used for flash and for upset welding. This consists of one fixed and one movable clamp so that the workpieces may be gripped and forced together,a power source which is usually a heavy-duty single phase a.c. transformer with a single-turn secondary,and finally equipment for controlling current,movement force and time. In flash welding the parts to be welded are gripped by the clamps and brought into very light contact in an electric current (see fig.3.1).When the welding voltage

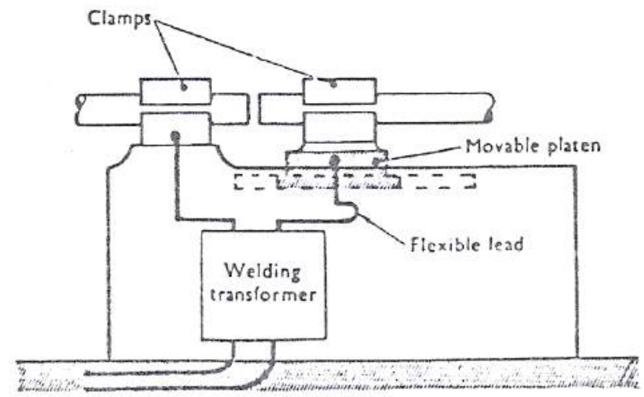


Fig 3.1 Basic arrangement for flash welding

is applied at the clamps a current flows through the initial points of contact. The current is of sufficient magnitude to produce a flashing action between the adjacent pieces of metal. The metal is thereby heated to the fusion point, and the weld is completed by the application of sufficient upset force. Fig. 3.2 illustrates the relationship of parts for this application.

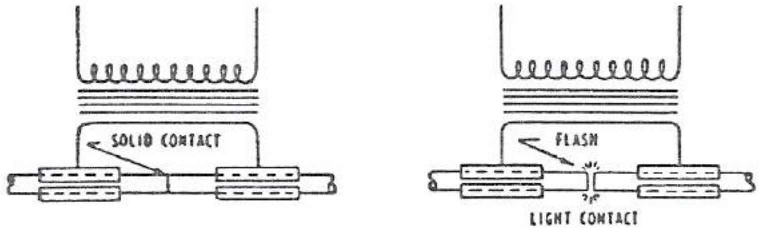


Fig 3.2 Relationship of parts for flash welding

3.2 - Principles Of Operation

Sequence

There are additional steps involved in the cycle in many applications. The sequence of operations which may be required is indicated in the following list:

1. Load machine
2. Clamp work
3. Apply preheating force
4. Preheat
5. Release preheat force to separate workpieces
6. Connect parts lightly for flashing
7. Apply welding voltage
8. Flash at high voltage
9. Flash at normal voltage
10. Upset
11. Cut off welding current
12. Reclamp and postheat
13. Pinch-off and shear die operation
14. Unclamp work

15. <u>Return platen and unload</u>

16. Trim flash

The basic or most generally used cycle is obtained by using only the underlined operations. One of the most complicated forms of a flash welding cycle is illustrated by the additional operations . All of the steps are necessary for certain applications.The additional operations are used only when the design of the parts or the nature of the material makes them necessary . The basic cycle is followed in all cases.The trimming of the flash may or may not be necessary, depending upon the requirements of the particular assembly.

When heavy or unequal sections or nonferrous metals are flash welded, it is often difficult to establish a flashing action, because rather large amount of cold metal may be present at the flashing surfaces. Preheating of the workpieces before flashing may help to improve this condition . Preheating reduces the required secondary voltage and,therefore, the power demand . Another method is to bevel the surfaces to be welded.

The flashing action may be established manually by shorting the pieces intermittently until the temperature has risen to a point where flashing may take place as a part of the automatic cycle of the machine . 'Flashing at high voltage' which is given as item 8 in the sequence of operations indicates another method of establishing a flashing action wherein a higher open circuit voltage is used at the start of flashing than is used later in the cycle. All of the foregoing methods have proved satisfactory in production and in many instances combinations of them are employed.

Flashing

A brief description has been given of the flashing which takes place between two parts prior to upset and is started by the passage of welding current through the initial points of contact. The current which has a high concentration at the first contacting points heats up these minute areas to incan-descence and causes the molten metal to be blown out in the form of small particles. The platen on which the movable clamp is mounted is moving forward while this takes place and fresh contacts are then made elsewhere so that cycle of events can be repeated. This intermittent process, during which much of the metal contained in the molten bridge is expelled violently in a spectacular manner is called **'flashing'** [3]. Flashing is allowed to continue until the surfaces to be joined are uniformly heated or molten. By this time the moving platen will have advanced at an increasing rate, to close the gap as metal is expelled, the total distance up to the point of upset being known as the flashing allowance or flash off.

In order to maintain a continious flashing action , it is necessary to accelerate the platen at the proper rate. This rate is determined by the size of the workpieces and by the amount of electrical current used. Both the instantaneous and the average rates of flashing must be considered.

The average rate of flashing is equal to the total distance the platen travels during the flashing period divided by the time required for this travel . If the rate is too high , the workpieces freeze together without welding, but if the rate is too low, flashing is obtained only intermittently , and it is difficult to obtain sufficient heat, in the parts to provide for an adequate upset.

The overall flashing time is the total time during which the flashing action takes place . The time taken over the process directly affects the loss of metal and, therefore, the total flash off. The effect of flashing time on surface temperature and temperature gradient has greater importance in relation to weld quality.

If the time is too short , insufficient heat is generated in the parts and it is impossible to obtain a proper upset . In contrast , if the time is too long , the welding surfaces are overheated and again it is impossible to obtain a proper upset . This is due to the fact that there is a rather large amount of molten or plastic material to be forced out of the weld area , making it difficult to utilize the correct force during the upset cycle.

The flashing rate and the flashing time on automatic machines may usually be considered as a single variable , because any change in driven mechanism of the movable platen affects both variables.

Flashing current and voltage are usually determined by the transformer setting and, therefore, cannot be changed individually . Since current control is by the turns ratio on the transformer through a primary tap switch , high voltages are associated with high currents . Setting the current too high, therefore , results in greater ease of maintaining the microarcs formed in the flashing period , but deep craters can be caused in the flashing face. Deep empty craters formed in the latter stages of flashing may not be filled with molten metal or closed during forging so that dangerous regions of lack of fusion , called 'flat spots' may be left in the plane of the weld. The effect of having too low an energy input is similar to that of having too high a rate of flashing.It is difficult to obtain sufficient heat , and there is a possibility of freezing the pieces together as the platen is accelerated. Fig.3.3 indicates the effect of flashing with too high a rate of energy input.

As soon as sufficient heat to obtain a fusing temperature has been generated , an upset force is applied suddenly and the welding current is cut off.To obtain plasticity for upsetting some large pieces , it is necessary to prolong the flashing

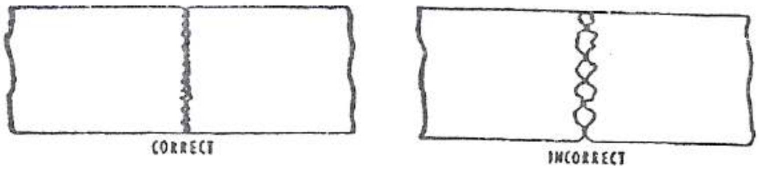


Fig 3.3 Effect of correct rate of energy input (left) compared with too high rate of input (right)

cycle after the surfaces have reached a fusing temperature. Some authorities have maintained that the flashing action assists in providing a protective atmosphere by combustion of the particles expelled. It is also believed that combustion of these particles furnishes heat in addition to that obtained from the electrical energy. Investigations, however, indicate that the importance of these effects is negligible.

It is sometimes necessary to use shielding gases to improve the quality of the weld joint by reducing the possibility of oxidation of the flashing edges. Flash welding of mild and low alloy steels does not call for a shielding atmosphere, because imperfections in the seam and oxides can be eliminated from the weld junction by the upsetting process if the parameters are correctly chosen. However, practice has shown that reliable ignition and start up of the arc is more readily guaranteed if a suitable shielding gas is used . On the other hand , a perfect gas shielding should be supplied if aluminium and high alloy steels are to be welded . In such cases , the gas shield must be complete since the oxides which form under the influence of the atmosphere are of very low mobility and can no longer be removed from the vicinity of the seam during the upsetting process, thus leading to imperfections in the seam.

Upsetting

The upset force is applied suddenly to complete the weld, after the flashing action has progressed for a sufficient time to establish a plastic zone of metal. Application of this force not only provides a forging action of sufficient intensity to unite the plastic weld metal, but also squeezes out slag or oxidized materials which may be on the abbuting surfaces just prior to upset.

The current flowing through the pieces during upset must be sufficient to prevent the material from chilling too rapidly. If the upset current is too low, it is impossible to squeeze out the oxides and slag inclusions, causing an improper upset similar to one made with insufficient heat in the material prior to upset. On the other hand, too high an upset current may blow out molten material adjacent to the weld, causing a defect. It is necessary, therefore, to have sufficient current to provide a proper upsetting action with no blowing-out or loss of pressure due to plastic material in back of the weld region. Excessive upset current may also result in overheating to the extent of burning the weld apart. Overheating can be prevented by reducing the amount of current flowing during this period.

The upset force should extrude the molten metal so that the the weld is made in the plastic metal immediately adjacent. This force is greatest at the center of the section and decreases toward the outer edges. Since slag trapped in the center of the section must travel the farthest, it is reasonable to expect that the center section must be freed first of any unwanted slag particles during the upset. If these foreign particles become trapped on their way out, they will produce defects in the completed weld.

The upset force should be sufficient to extrude the molten metal completely at the weld line beyond the original cross section of the workpiece, in order to ensure that slag and inclusions will be removed when the upset material is removed. There should be no external evidence of the weld after the flash and upset have been removed by machining. If the weld is sectioned and etched, there should be no evidence of porosity or slag. Porosity or defects indicate incomplete upset, due or slag. Porosity or defects indicate incomplete upset, due either to insufficient upset force or insufficient plasticity of the metal in weld region.

The upset velocity is closely related to the upset force and must be sufficiently rapid to avoid oxidation or cooling of the material . The upset force required on any material depends primarily on the physical properties of the materials being welded.

Values of upset force normally used with various materials are indicated in the section of this chapter discussing classification of steels for flash welding.

3.3 - Effect Of The Process On Material Welded

As previously described , flash welding heats the abutting surfaces to a plastic temperature. The surfaces should be reasonably uniformly heated and if not actually molten all over then at least the metal shold be highly plastic and close to the melting point.The welding procedure employed has considerable effect upon the temperature gradients from the weld line to the cool material. The temperature gradient should be such that when the upset force is applied the molten metal can be expelled and flow can take place at the interface. It is generally felt that knowledge of the temperature gradients at the time of upset will assist in determining optimum welding conditions , and thus the machine settings may be predetermined without the necessity of making a considerable number of samples.

As the material is heated to a plastic condition, alloy or high carbon steel will tend to harden unless the cooling rate is retarted. Carbon steels containing more than 0.4 %C, or alloy steels with equivalent hardenability require post weld heat treatment to prevent excessive formation of the hard be achieved by delaying the cooling as a result of passing the postheating current after upset has taken place. After removal from the clamps the parts may be transferred to a bath of powdered insulating material to delay cooling still further. In some cases it is necessary to heat the complete assembly after welding in order to obtain a uniform structure.

Because of flashing and upsetting, a certain amount of material is lost when this process is used. Since it is desired that the upset pressure be maintained consistently, it is usually necessary to have the parts made to close tolerances, especially on machines with automatic feed. The tolerances of the parts should be closer than those of the assembly after welding.

Because of the slow cooling and symmetrical shapes usually flash welded,residual stresses at the conclusion of the welding operation are not a major problem. Residual stresses may be developed, however, when tubular sections are welded to heavy forgings, and it may be necessary to stress relieve or heat treat completely after welding.

Weld Quality

Welds made on manually operated machined may show large variations in quality, depending upon the skill of the operator. The quality of the flash welds can be determined easily by a simple bend test. Other mechanical tests, such as a tensile test, can also be made to determine the weld quality. Another method of determining whether any defects are present is the use of a cut and etched cross section.

The outward appearance of a weld which has been made properly is illustated in fig3.4a. Fig.3.4b shows a weld which cracked longitudinally because of insufficient heat in the material at the time of upset, and fig.3.4c illustrates a weld upset with insufficient heat and/or force. It should be noted that the slope of the upset material on the weld properly made.

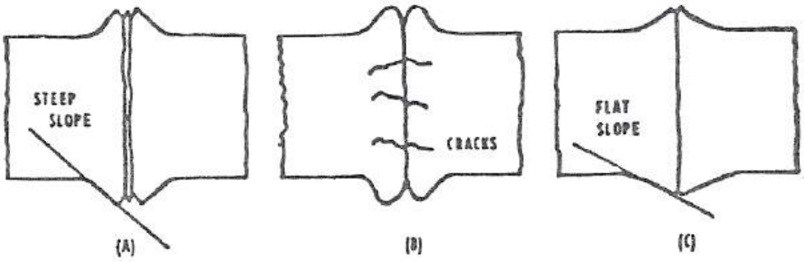


Fig 3.4 Influence of process variables on the condition of the upset metal in flash welding (a) satisfactory heat and upset,(b) cracks due to insufficient heat (c) insufficient heat and insufficient upset force

In order to maintain consistant quality, it is necessary that both the parts to be welded and the dies used in the welding machines be designed properly.The pieces should be clamped to prevent them from slipping during the upset cycle. These clamps and dies must be designed so that they will carry sufficient current to the parts and distribute this current properly.

3.4 - Design

General

Flash welding is a satisfactory welding process,provided that the parts are properly designed for its use. The following fundamental product design principles are recommended in flash welding [4].

1. Parts must be shaped so that both pieces will obtain the same degree of plasticity and the same depth of plastic zone during the flashing action and hence weld properly during the forging action.This characteristic is generally designated as obtaining an even or good heat balance. For this reason it is necessary to weld sections of nearly identical shape and size
2. The design must take into account the metallurgical changes that occur as the result of all welding processes.

Air hardenable steels are normally harder in the weld zone than in normalized parent metal. The copper dies that hold the parts during welding and the metal behind the welding surfaces of the parts serve as cooling agents. Any additional strength given to a part by cold work before welding will be altered and often destroyed in welding.

3. Parts must be designed so that the forging force exerted by the welder is resisted in the workpieces by forces that are parallel to the axis of the workpieces that are in the direction of the welding force.

4. Sections to be welded must be of such shape that they can be held in alignment by the clamping dies during the forging action. This implies sufficient clamping area to allow application of the necessary clamping force , at parts of such shape that the reactive resistive forces do not tend to destroy alignment during the forging operation. Obtaining an adequate die contact is also important for current flowing into the workpieces.This involves provisions for a sufficient area of electrode contact. These areas must also be clean in order to conduct the high currents while preventing flashing or contact burns of the welding dies at the electrodes.

When close tolerances are required in the welded assembly, it is essential that the locating points which are used in the dies be held to the same, or closer tolerances than those desired on the completed assembly. Closer tolerances are obtainable with flash welding than are obtained consistently by any other welding process. The accuracy in production is influenced by the following factors : (1) tolerances of the parts before welding, (2) the rigidity and precision of the welding machine and fixtures,(3) the dressing and maintenance given to welding electrodes to control normal electrode wear, and (4) the care used in loading the work in the welding machine.

Heat Balance

So that similar temperatures may be reached and plastic flow can take place on both sides of the joint there must be a heat balance. This may be difficult under certain conditions, because of either a difference in the cross-sectional area of the two parts or differences in their heat conductivity and melting temperature. If a part with a small cross-section must be joined to one considerably larger, the larger part must be prepared so that the weld is made between similar areas. In the case of joining of dissimilar metals by flash welding proper allowance must be made for differences in thermal conductivity. If two such parts are disposed symmetrically between the clamps the weld would tend to finish up closer to the clamp holding the low thermal conductivity metal.

Several techniques may be used to obtain proper heat balance. One method is to extend the part which has the higher thermal conductivity farther from the clamping electrode so that the length of its resistance path is increased (fig.3.5). The

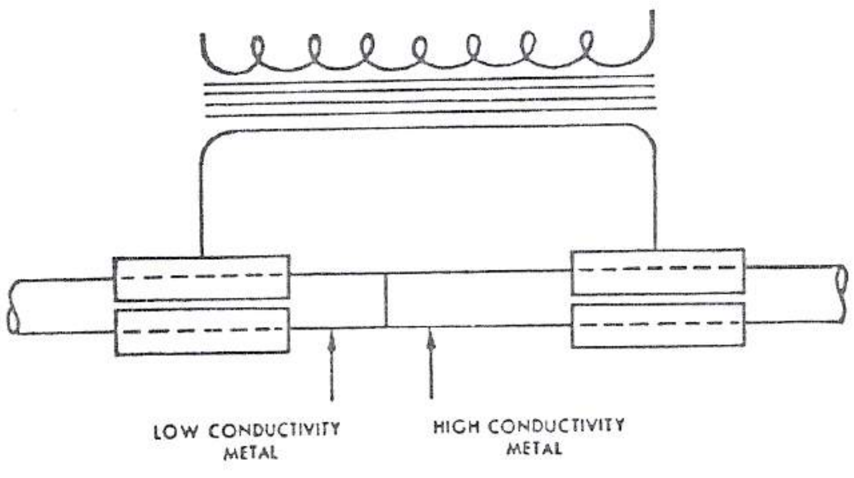


Fig 3.5 Method of heat balance by unequal extension of workpieces from dies

electrode, being nearer to the weld on the lower-conductivity side, removes more heat from that part. Differences in melting points between the two alloys being welded will also affect the amount of extension.

Other methods involve the unequal beveling of the two parts, as in fig.3.6, and the use of appropriate electrode design. In

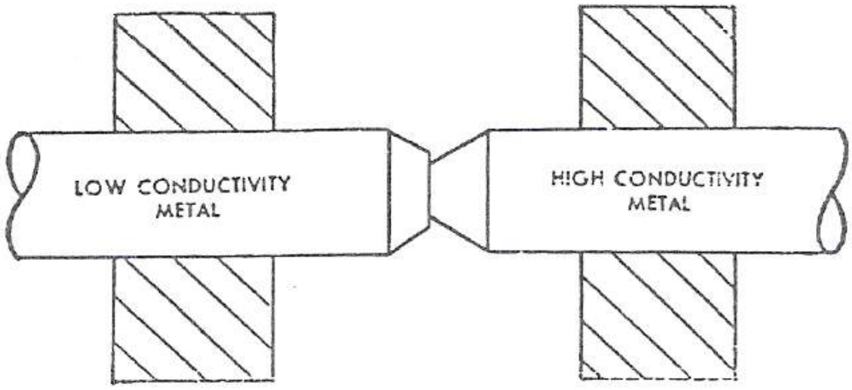


Fig 3.6 Method of heat balance by unequal beveling of workpieces

extreme cases it is possible to preheat one piece, either before it is put into the welding machine or while it is already in the machine, by the use of a bridge (Fig.3.7).Such a bridge is usually made of copper and is designed to short

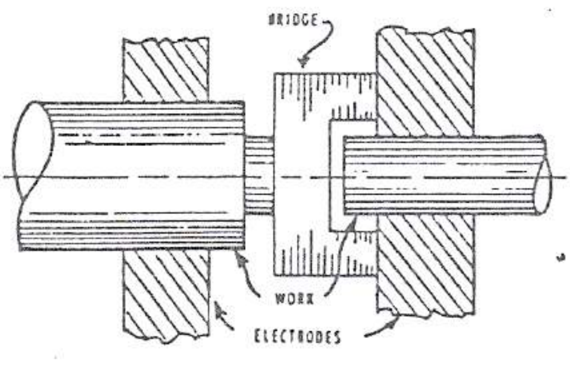


Fig 3.7 Method of heat balance by use of copper bridge.

circuit one workpiece in the machine in order to preheat the other piece. After the preheating is accomplished, the bridge is removed and the pieces are welded in the usual manner.

In the design of flash welded assemblies the heat balance should be designed into the parts rather than obtained by special procedures during the welding operation.

When heavy sections are welded,it is often advisable to bevel the end of at least one part in order to facilitate the starting of flashing. By means of such beveling, it may be possible to eliminate the necessity for preheating or flashing at a voltage higher than normal for the first part of the flashing period. This type of beveling, with suggested dimensions, is shown in fig. 3. 8.

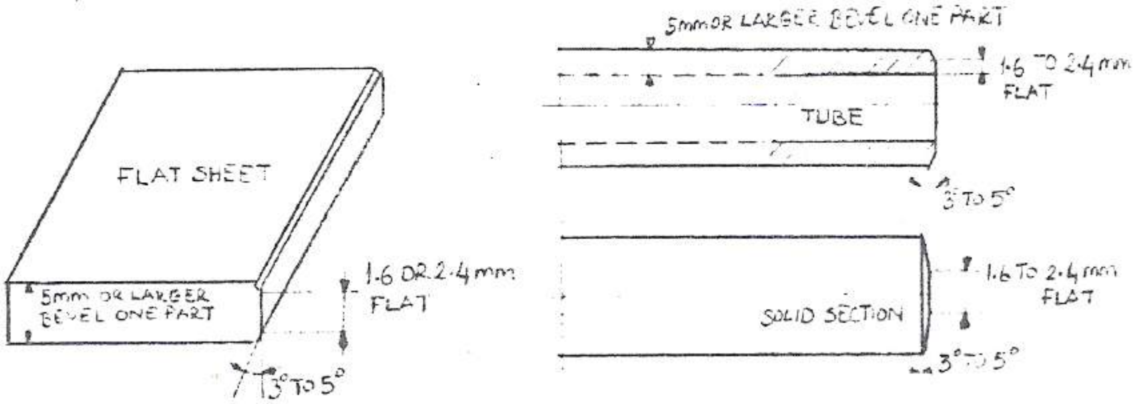


Fig3. 8 End preparation for heavy pieces to facilitate flashing.

It is of prime importance that the surfaces to be welded should line up properly in the welding machine so that the heat generated by flashing is the same over the entire contact area.Should the parts be out of alignment flashing will occur only in the sections where contact is obtained, and at the time of upset the parts will tend to slip past each other on the cold metal as illustrated in fig3.9.This factor should

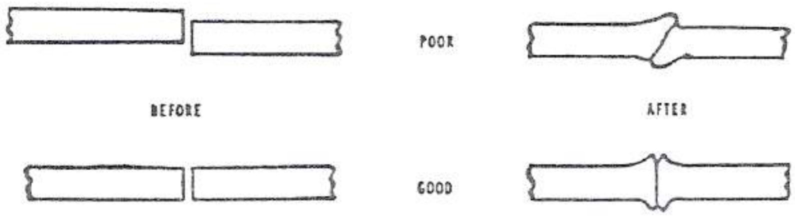


Fig 3.9 Effect of alignment.

be given careful consideration in the design of the machine, the parts to be welded and the tooling for welding them, especially when the ratio of the length to the width of the sections is high.

In the design of a flash-welded assembly it is necessary to allow extra stock for flashing,and in most cases the sections to be joined should be approximately the same. It is also essential that the provisions made for clamping the pieces enable the welding dies to hold the parts in proper alignment.

Clamping

Whenever practical, the workpieces should be backed up by using fixed stops on the platens, and the upset force should be transmitted through these stops. Under this condition the clamping pressure on the electrodes has only to be sufficient to provide a low - resistance contact to the welding current and to maintain alignment of the weld. The usual range of clamping pressure is from 200 to 300 kp/cm^2 of the weld area. Where it is not practical to back up the work such as in circular rings or long pieces, the clamps have to grip the work with sufficient force to prevent slippage when the upset pressure is applied. It is necessary to consider the upset force in relation to the coefficient of friction between the workpiece and the electrode or jaws. It has been common practice of welding machine designers to assume a ratio of 2.5 to 3 times the upset pressure for determining clamping pressures. When one of the clamping jaws is made of steel,and slight markings on the work are not objectionable, serrations on teeth may be placed on the face of the clamping jaws. The necessary clamping force is thus reduced. Stainless steels which require high upset forces need still higher clamping forces because of their smooth surfaces.

When rings of any design, such as wheels and ring gears, are welded, the application must be analyzed carefully to determine whether or not it can be flash welded satisfactorily. Consideration must be given to the fact that welding current will shunt around the solid section of the ring, thus cutting down the effective welding current. The amount of this shunting action,of course,depends upon the ratio of the length of the ring to the area being welded and the electrical conductivity of the material. It is also necessary to recognize the fact that the ring must be deformed to a smaller diameter during the welding operation. This naturally requires additional force. It is particularly difficult to use adequate clamping jaws on small rings because of space limitations.

Flash Removal

As indicated before,a ragged fin or flash is formed round the joint by the expelled metal after the application of upset force. Ideally, all the molten contaminated metal produced during flashing should be removed in this way to produce a high quality joint.This increased size which is caused by the flash and the upset material,left at the point of weld is the only serious problem encountered in flash welding.

If the finish area of the weld is important, then it becomes necessary to remove both the flash and the upset material. In some cases, this necessary only for the sake of appearance.

The tensile strength of the joint is somewhat greater before the flash is removed because of the added rigidity of the upset material. However, the notch effect at the weld line may cause a reduction of fatigue strength. A portion of the upset material may be retained when the design of parts indicates that reinforcement is beneficial.

This material may be removed by the following means: (1) air chisels, (2) machine tools and cutting tools, (3) grinding wheels, (4) high-speed burning wheels, (5) die trimming, (6) oxygen machining or oxyacetylene cutting, (7) high-speed sander, and (8) flash trimmer.

The use of any of the above methods of flash removal is dependent upon the type of operation. When alloy steels are welded, the removal of flash by means of cutting tools is often difficult because of the hardness of the flash. Either grinding or oxyacetylene cutting is usually employed. It is generally easier to remove the flash immediately after welding while the material is still hot.

Tooling

The welding electrode used in the flash welding usually carry current to the workpieces and clamp them. It is necessary, therefore, to use an electrode material of the right physical and electrical properties to accomplish the clamping properly and to carry current to the workpieces. Many materials have been developed for this use. In the design of these welding electrodes it is important that adequate water cooling be provided to avoid changes in electrical and mechanical properties caused by elevated temperatures.

3.5 - Inspection And Testing

Visual inspection is the most widely used method of inspecting flash welds. It is usually necessary to inspect the appearance prior to removing the flash and upset material, because this material often tends to hide defects. There are several other nondestructive inspection methods which have been used with varying degrees of success. None of them, however, actually locates all types of defects.Magnetic particle inspection will indicate cracks and small inclusions and discontinuities, provided that they are of sufficient size and in such a location that an indication may be obtained. Naturally, magnetic inspection is not applicable on nonmagnetic materials , and its use has been rather limited for the inspection of flash welds. Other methods of inspection suitable for certain applications are those using eddy currents as well as ultrasonic and dye penetrant methods.

Radiographic inspection of flash welds has not been wholly satisfactory , because small defects which are known to be detrimental may not be brought out on the radiograph.

In some cases good inspection is automatically obtained by stressing the material well above the yield point in sizing operations. Where uniform high strength is imperative, the assembly may be proof loaded to design specification. Destruction testing of a percentage of the assemblies welded has also been employed with good results.

Macrographic examination is satisfactory for determining whether or not the machine is properly set up to weld a particular assembly. It is not, however, usually employed as a regular inspection procedure.

When automatic welding machines are used,it is most important to make sure that the setup remains constant after production starts, because there is little that the operator can do to influence welding conditions or weld quality.

Flash welds may be tested by most of the means available for testing the base properties of the metal. The following properties of a flash weld may be investigated, in addition to those previously mentioned : (1) hardness, (2) strength, (3) tension impact, (4) fatigue, (5) bending, (6) cupping, (7) corrosion resistance, and (8) metallographic structure.

With the proper application of the flash welding process it is possible to obtain high joint efficiency,provided that the joint has been designed properly and that the proper steps have been taken to obtain a metallurgically sound weld area.

The reliability and speed of the operation, as well as the fact that the training of operators is not difficult (when the automatic types of machines are used), have done much toward making flash welding practical on high - production applications.

3.6 - Equipment Used

Machines

Flash welding machines may be either manual, semiautomatic or fully automatic in their operation. Most of the equipment being manufactured today is either semiautomatic or fully automatic. Many of the small-capacity flash welding machines are provided with platen motion by means of a variable-speed cam driven by an electric motor through a speed reducer. Usually the large-capacity machines are hydraulically operated and are equipped so that the speed of the platen motion may be changed.

In fully manual operation the operator controls the speed of the platen from the time that flashing is initiated until the upset is completed. In semiautomatic operation the operator usually initiates flashing manually, after which the rest of the cycle is completed automatically. In fully automatic operation the workpieces are loaded into the machine, after which the cycle is completed automatically.

Controls And Auxilary Equipment

Electrical controls on flash welding machines are primarily designed to start and stop the current supply to the welding transformer and to sequence the motion of the movable platen. The contactor for making and breaking the power supply may be either magnetic or electronic in operation. The controls for automatic flash welding machines in some instances are capable of sequencing all of the steps listed earlier in this chapter.Most of the control equipment in service, however, is designed to use the basic cycle without preheat, postheat or any other special operations.

3.7 - Classification Of Steels For Flash Welding

The values of the upsettting forces required for various sections of various steels are related to the temperature gradient of the workpieces in the plastic zone and to the compressive strengths of the steel at these elevated temperatures. The classification of steels and typical steels of various classes are given below [2] :

Low Forging Strength Steels - This class is typified by SAE 1020, SAE 1112 etc.

Medium Forging Strength Steels - This class is typified by SAE 1045, SAE 1065, SAE 3135, SAE 4130, SAE 4140, etc.

High Forging Strength Steels - This class is typified by SAE 4640,stainless steel(chromium type),stainless steel(chromium-nickel type),stainless steel (cutlery type),high-speed steel, special tool, die and austenitic valve - stem steels, etc.

Extra High Forging Strength Steels - This class is typified by all steels exhibiting extra high compressive strength at elevated temperatures.

The selection of flash welding equipment depends, to a great extent, upon the forging strength of the steel to be flash welded.

Steels with low forging strength require a relatively low pressure, but high forging strength steels require equipment capable of exerting extremely high pressures.

Experience indicates that the selection of equipment should be based on the following values of recommended platen force. Such values are based on the welding heat attained solely by flashing, i.e, no preheating :

Low Forging Strength Steels - 700 daN/cm^2 of weld sectional area

Medium Forging Strength Steels - 1000 daN/cm^2 of weld sectional area

High Forging Strength Steels - 1750 daN/cm^2 of weld sectional area

Extra High Forging Strength Steels - 2500 daN/cm^2 of weld sectional area.

3.8 - Definitions Of Process Variables

Flash welding process has a number of variables which are defined in this section. When the definitions presented here are considered, it should be realized that neither all flash welding equipment nor all flash welding schedules make use of all the listed variables. See flash welding definitions chart, fig.3.10 [2].

(1) **Weld Line** is the plane of fusion of the welded workpiece

(2) **Flash** is the extraneous material which is thrown and extruded from weld line during the flashig and upsettting action.

(3) **Initial Electrode Opening (A,mm)** is the distance between the electrodes when the workpieces first contact.

(4) **Material Lost (B,mm)** is the total length of material used in making the weld.

(5) **Final Electrode Opening(C,mm)** is the distance between the electrodes at the completion of the weld.

(6) **Total Flash-Off (D,mm)** is the total length of material lost in flashing.

(7) **Manual Flash-Off (E,mm)** is the length of material lost in flashing while the flashing is controlled manually.

(8) **Automatic Flash-Off(F,mm)** is the length of material lost in flashing while the flashing is controlled automatically.

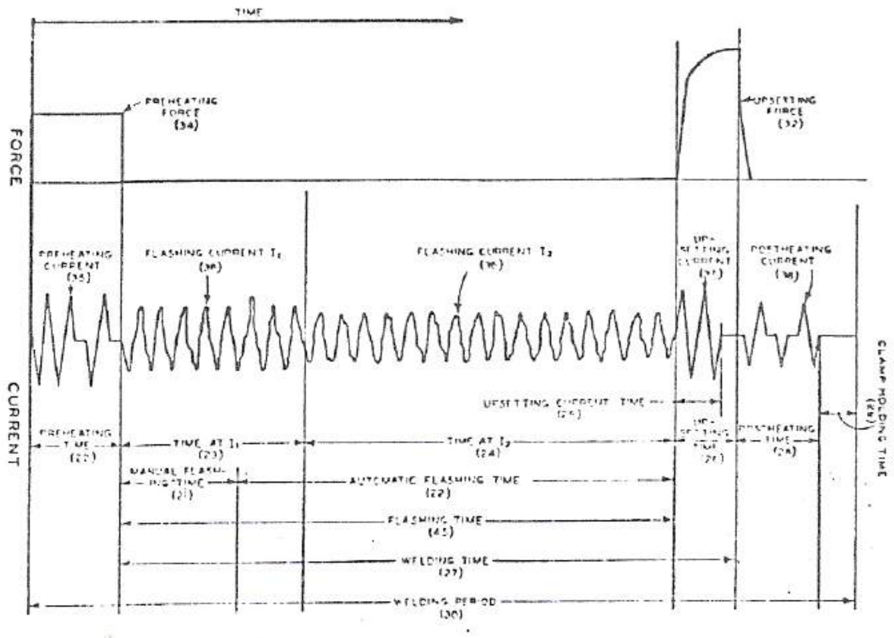
(9) **Preheating Lost(G,mm)** is the length of the material lost as a result of the preheating action.

(10) **Total Upset (H,mm)** is the length of material lost as a result of the forging action.

(11) **Material X Lost (J,mm)** is the length of material x used in making the weld.

(12) **Material Y Lost (K,mm)** is the length of material y used in making the weld.

(13) **Initial Extension, Material X(L,mm)** is the dimension from



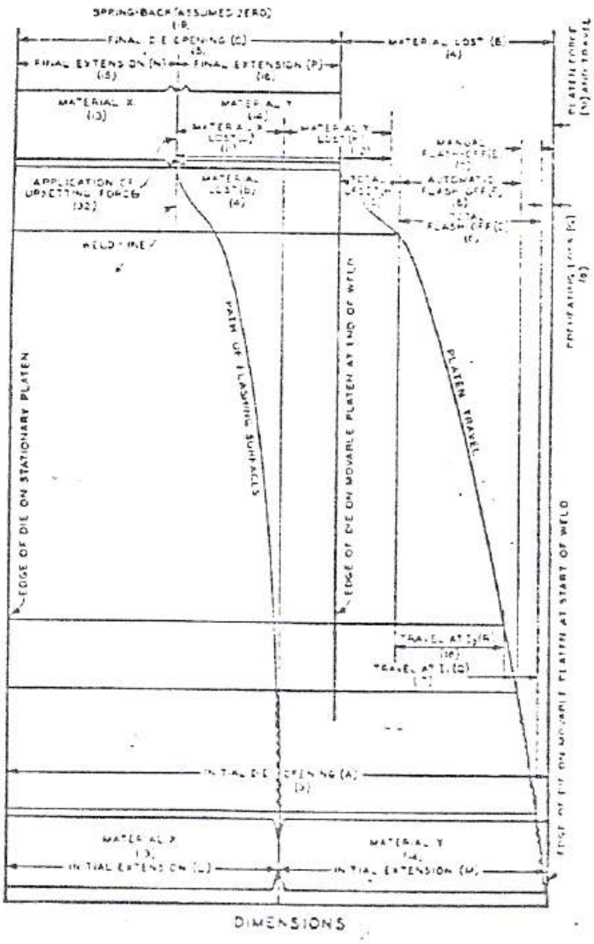


Fig 3.10 Chart of flash welding definitions.

the electrode which clamps material X to that point on material X which first contacts material Y.

(14) **Initial Extension,Material Y(M,mm)** is the dimension from the electrode which clamps material Y to that point on material Y which first contacts material X.

(15) **Final Extension Material X (N,mm)** is the dimension from the electrode which clamps material X to the weld line at the completion of the weld.

(16) **Final Extension Material Y (P,mm)** is the dimension from the electrode which clamps material Y to the weld line at the completion of the weld.

(17) **Travel At I (Q,mm)** is the dimension the movable platen (material Y)travels during the time flashing current I flows.

(18) **Travel At I (R,mm)** is the dimension the movable platen (material Y)travels during the time flashing current I flows.

(19) **Spring Back(mm)** is the deflection of the welding machine when making the weld.

(20) **Preheating Time (sec.)** is the time during which preheating takes place.

(21) **Manual Flashing Time (sec.)** is the time during which flashing by manual control is taking place.
surfaces during upsetting.

(22) **Automatic Flashing Time (sec.)** is the time during which flashing by automatic control is taking place.

(23) **Time At Flashing Current I (sec.)** is the time during which flashing with current I is taking place.

(24) **Time At Flashing Current I (sec.)** is the time during which flashing with current I is taken place.

(25) **Flashing Time (sec.)** is the time during which the flashing action is taking place.

(26) **Upsetting Current Time (sec.)** is the time during which upsetting current flow is taking place.

(27) **Upsetting Time (sec.)** is the time during which upsetting is taking place.

(28) **Welding Time(sec.)** is the time during which flashing and upsetting are taking place.

is taking place.

(30) Clamp Holding Time (sec.) is the time measured from the end of the postheating time(or end of upsetting time when no preheat is used) to the time at which the clamping force is released from the workpieces.

(31) Welding Period (sec.) is the time that elapses from the start of the preheating time to the end of the clamp-holding time.

(32) Platen Force (daN) is the force available at the movable platen to cause upsetting. This force may be dynamic, theoratical or static.

(33) Upsetting Force(daN) is the force exerted at the welding surface during upsetting.

(34) Clamping Force (daN) is the force exerted on the jaws by the clamping system.

(35) Preheating Force (daN) is the force exerted on the welding surfaces during preheating.

(36) Preheating Current (amp.) is the current that flows through the workpieces during preheating.

(37) Flashing Current(amp.) is the current that flows through the workpieces during flashing.

(38) Upsetting Current(amp.)is the current that flows through the workpieces during upsetting.

(39) Postheating Current (amp.) is the current that flows through the workpieces during postheating.

(40) Secondary Voltage (E ,volts) is the open circuit voltage of the welding transformer measured on the secondary side.

(41) Load Voltage (E ,volts) is the voltage across the workpiece during welding and postheating.

(42) Instantaneous Rate Of Flash-Off (mm. per sec.) is the instantaneous velocity of one workpiece relative to the other during the flashing action and is the first derivative of such motion at a specified position.

(43) Average Rate Of Flash-Off (mm. per sec.) is the average velocity of one workpiece relative to the other during the entire flashing action.

(44) Instantaneous Velocity Of Upset (mm. per sec.) is the instantaneous of one workpiece relative to the other during upsettting action and is the first derivative of such motion at a specified position.

(45) Average Velocity Of Upset (mm. per sec.) is the average velocity of one workpiece relative to the other during the entire upsetting action.

3.9 - Common Applications

Flash welding is particularly suited to joining two pieces of metal end to end or welding one piece of material to a projecting part of another piece.Typical applications include (1) the welding together of two shafts, tubes or strip of steel, (2) the welding of a forging or casting either to another forging or to some standart section,and (3) the welding of strips or bars to form rings, such as wheel rims. Fig.3.11 illustrates various joints made by using flash welding.If any of these applications are to be practical, it is necessary that the cross-sections of the workpieces be nearly identical Where thin sections are joined high quality jigging is required to secure accurate alignment.

Mild, carbon and alloy steels are extensively welded by flash welding as well as aluminium alloys and other non-ferrous metals.In the following discussion,the weldability of various metals by the flash welding process is considered from the standpoint of the number of steps necessary to ensure good welds.Steels of low haredenability may be welded without preheat or postheat consistently good results. As the hardenability of the steel increases, it is necessary to resort to combinations of preheat or postheat or to other methods of immediate heat treatment to make the welded joint as good as that obtained in steels of lower hardenability . It is

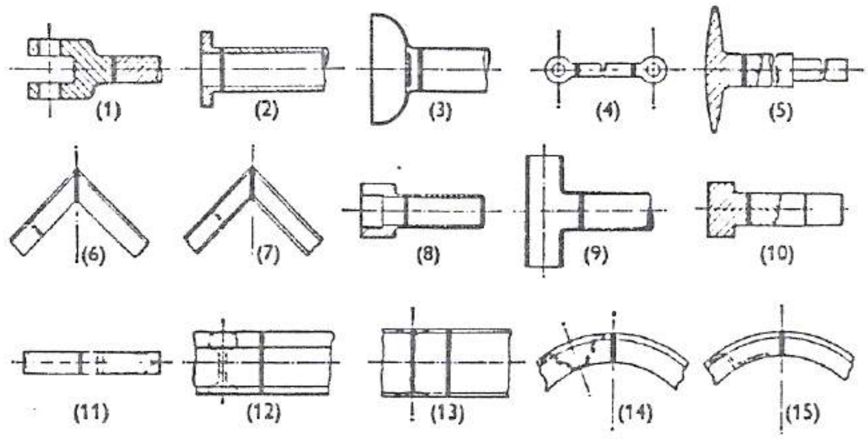


Fig 3.11 Applications for flash welding.

(1) Connecting rod	(6) Angle	(11) Drill blank
(2) Flange	(7) Metal casement	(12) Track rail
(3) Housing	(8) Adapter	(13) Beam
(4) Tie bar	(9) Tube T piece	(14) Auto wheel
(5) Buffer end	(11) Bolt	(15) Heavy rim

generally considered that flash welding is satisfactory on almost all types of steel,provided that the proper steps are taken to obtain a sound joint. Combinations of steel, such as high speed tool steel and low carbon steel, are welded satisfactorily,although it is usually necessary to employ special procedures to equilize the differences in hardness , fusion temperature, electrical and thermal conductivity,geometry and crack sensitivity. Most of the nonferrous metals are welded satisfactorily. The procedures and techniques required are varied, and each case must be considered individually.

The flash welding of cast iron has been successful only to a limited extent. Lead, tin, zinc, antimony, bismuth and alloys in which they are the principal constituents, as well as copper alloys in which any of the above metals are present in large percentages, are not generally recommended for flash welding application. These are the exceptions. The process usually can be considered applicable to almost any of the combination of metals , regardless of their dissimilarity, although the necessity for special procedures and techniques might make certain applications impractical.

The essentially automatic nature and high speed of flash welding make it a mess production process which is being used generally by almost all the fabricating industries. Its use in job shop fabrication or industries with low production is limited, because of the expense of tooling and establishing welding procedures.

Flash welding is used to a considerable extent in conjuction with the manufacture of automative and aircraft products. The process is also used widely in the manufacture of household appliances, refrigerators and farm implements.

CHAPTER 4

THE ELECTRIC ARC - ITS USE AND MAGNETIC CONTROL IN FLASH WELDING

4.1 - Introduction

The flashing action , which is started by the melting of initial contacting points by the passage of welding current through the workpieces and progresses by the formation of short-lived arcs after rupturing the molten bridges , is analagous to a consumable electrode arc system and has some features in common with the short-circuit arc processes. The arcing process which is accompanied by flashing greatly increases the temperature of abutting surfaces and allowed to continue until the surfaces to be joined are uniformly heated or molten.

This chapter deals with the structure and features of an electric arc and also covers the magnetic control of the arc in flash welding to obtain a uniform heating.

4.2 - Definition And Structure Of The Arc

The electric arc is the heat source for a variety of the most important welding processes, possibly because it is an easily produced high intensity source.

An arc is an electric discharge between two electrodes through an ionized column of gas called 'plasma'. The space between two electrodes or the space between the parts to be joined in flash welding can be divided into three areas of heat generation ; the cathode, the anode, and the arc plasma.

The welding arc is characterized as a high-current , low-voltage arc that requires a high concentration of the electrons to carry the current. As shown in fig.4.1 , negative electrons are emitted from the cathode and flow-along with

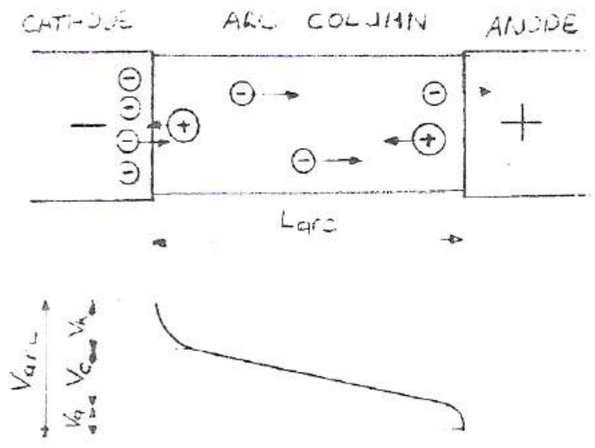


Fig 4.1 Electric arc mechanism and distribution of voltage drop. (V_k - Cathode voltage drop, V_c - arc column drop, V_a - Anode voltage drop, V_{arc} - arc voltage)

the negative ions of the plasma - to the positive anode. Positive ions flow in the reverse direction. A negative ion is an atom that has picked up one or more electrons beyond the number needed to balance the positive charge on its nucleus-thus the negative charge. A positive ion is an atom that has lost one or more electrons - thus the positive charge. However just as in a solid conductor, the principal flow of current in the arc is by electron travel.

Heat is generated in the cathode area mostly by the positive ions striking the surface of the cathode. Heat at the anode is generated mostly by the electrons. These have been accelerated as they pass through the plasma by the arc voltage and they give up their energy as heat when striking the anode.

The plasma, or arc column, is a mixture of natural and excited gas atoms. In the central column of the plasma, electrons, atoms and ions are in accelerated motion and constantly colliding. The hottest part of the plasma is the central column where the motion is most intense. With a high current arc at atmospheric pressure extremely high temperatures, from 5000 to 50000°K, can exist in the axis of the arc column. The outer portion of the arc flame is somewhat cooler and consists of recombining gas molecules that were disassociated in the central column.

The distribution of heat or voltage drop in the three heat areas can be changed. Changing the arc length has the greatest effect on the arc plasma . Changing the shielding gas can change the heat balance between the anode and the cathode. The addition of potassium salts to the plasma reduces the arc voltage because of increased ionization [8].

4.3 - Initiation And Maintenance Of The Arc

An electric arc cannot be switched on merely by applying the potential required by the arc to the cold electrodes which are connected to the workpieces. The arc can only be ignited by providing a conducting or ionized channel between the parts to be welded. This can be done in two ways at atmospheric pressure; by applying a sufficiently high voltage between the workpieces to cause a discharge or by touching the workpieces together and drawing them apart. As discussed before in section 3.2 both solutions are adapted in flash welding process to establish a flashing action.

Spark discharges are sometimes used for igniting the arc in flash welding. Voltages in excess of 10^4 V are required to to break down the arc gaps used. Once breakdown has occured, however, the voltage drops rapidly and the current begins to rise until after about 1 ms the normal arc voltage and the steady-state conditions of a stable arc are approached. Voltage and current continue to change slowly for seconds later as thermal equilibrium is achieved in both workpieces. The use of voltages sufficient to breakdown arc gaps directly would be lethal in welding and it is therefore necessary to employ a high frequency discharge.

The most common method of striking an arc in flash welding is by touching one of the workpieces to the other, thus setting up a closed circuit , and allowing the initial contacting points to rise in temperature owing to the heat generated by the current flow through these high electrical resistive points, and then withdrawing the movable workpiece from the fixed one for a distance of 1 mm or a little more. Just as the movable workpiece is withdrawn from the other , thermionic emission of electrons begins from the hot points of contact. The stream of electrons ionizes the gases and metal vapour present in the gap between the workpieces which are the anode and the cathode in the process. Then both an electron and an ion current begin to flow in the arc. The arc discharge may be taken as a steady-state one within 1x10 to 10 s of its initiation. If the power circuit is suitable a stable welding arc will then be established.

Once an arc has been ignited and thermal equilibrium established it can often be re-ignited after a momentary extinction with relative ease. Thus, thousands of volts might be required to ignite an arc with cold workpieces, only tens or hundreds of volts are required to re-ignite a thermonic arc. Re-ignition is a particular problem with the a.c. arc which is extinguished at the point of current zero on each reversal twice in every cycle. For the arc to re-ignite the required voltage must be available at this time of current zero. This problem with a.c. arcs can be solved by the inclusion of a reactive impedance (an increased inductance) in the welding circuit. When an inductive reactance is included in the welding circuit, the arc is not extinguished periodically.

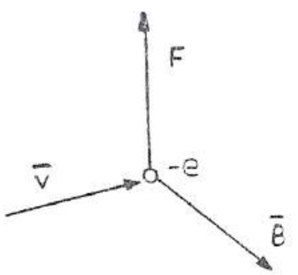
In d.c. welding it is only necessary to consider re-ignition after arc extinction due to accidental short circuiting or insufficient speed of movable part during flashing. This requires a suitable dynamic characteristic from the power source so that voltage and current can recover their normal values rapidly giving a smooth arc.

4.4 - Magnetic Control Of The Arc

One of the most important properties of plasma, which is a mixture of electrons, ions, neutral atoms, photons, excited atoms and molecules, is that it can be controlled by the electric and magnetic fields. The total force acting on a charged particle in the presence of both electric and magnetic fields is given by :

$$F = q\bar{E} + q(\bar{V} x \bar{B}) \qquad (2)$$

Here, $q\bar{E}$ is the force which is caused by the electric field and has no major effect on the arc. So, it can be neglected. The other term $q(\bar{V} x \bar{B})$ is known as Lorentz force, where B is a vector field referred to as the magnetic induction and V is the velocity of the charge q moving through the field. The Lorentz force is always perpendicular to the direction of the velocity of the charge. Thus, unlike electric field, magnetic field does not affect the energy of the charge , it only changes the direction of the charged particles. The Lorentz force acting on a negative charge (electron) is illustrated in fig 4.2 [9].



$$F = -e(\bar{V} x \bar{B})$$

Fig 4.2 Lorentz force exerted on an electron moving through the magnetic field

In flash welding, external magnetic coils are used to control the arc. A magnetic field which is created by these coils exerts a force (Lorentz force) on the arc, causing it to run along the surfaces to be flash welded. The surfaces are heated up and become uniformly surface melted. After adequate uniform heating the process is completed by an upsetting process as mentioned before.

Flash welding using a magnetically controlled arc is a mechanized process for joining hollow sections with a closed contour. It is predominantly used in mass production on components with a wall thickness of between 0.8 and 5 mm (mainly between 2 and 4 mm) and tube diameters of 5 to 300 mm (preferably between 20 and 80 mm) most cases of use involve mild or low alloy steels and combinations of the same [10].

4.5 - Theoretical Magnetic Field Distribution In The Welding Gap

In this section, the distribution of magnetic field created by flat-cored magnetic coils with pole plates is explained.

In a magnetic field, the magnetic lines of force indicates the direction of the force which are perpendicular to the surface of ferromagnetic materials. Fig 4.3 shows the lines of force for the welding gap according to this theoretical definition. The lines of force emerge at right angles from the surfaces to be welded in the welding gap and are immediately deflected to form a predominantly radial field. They are symmetrical about both halves of the workpiece. The inside of the tube is free of magnetic fields. However, the actual distribution of the field differs somewhat from this assumption. In the welding area, the location of iron masses which are the path of magnetic lines of force and varying resistances (air gap) which act against the magnetic field, have important effects on the actual distribution of the field. The distribution of

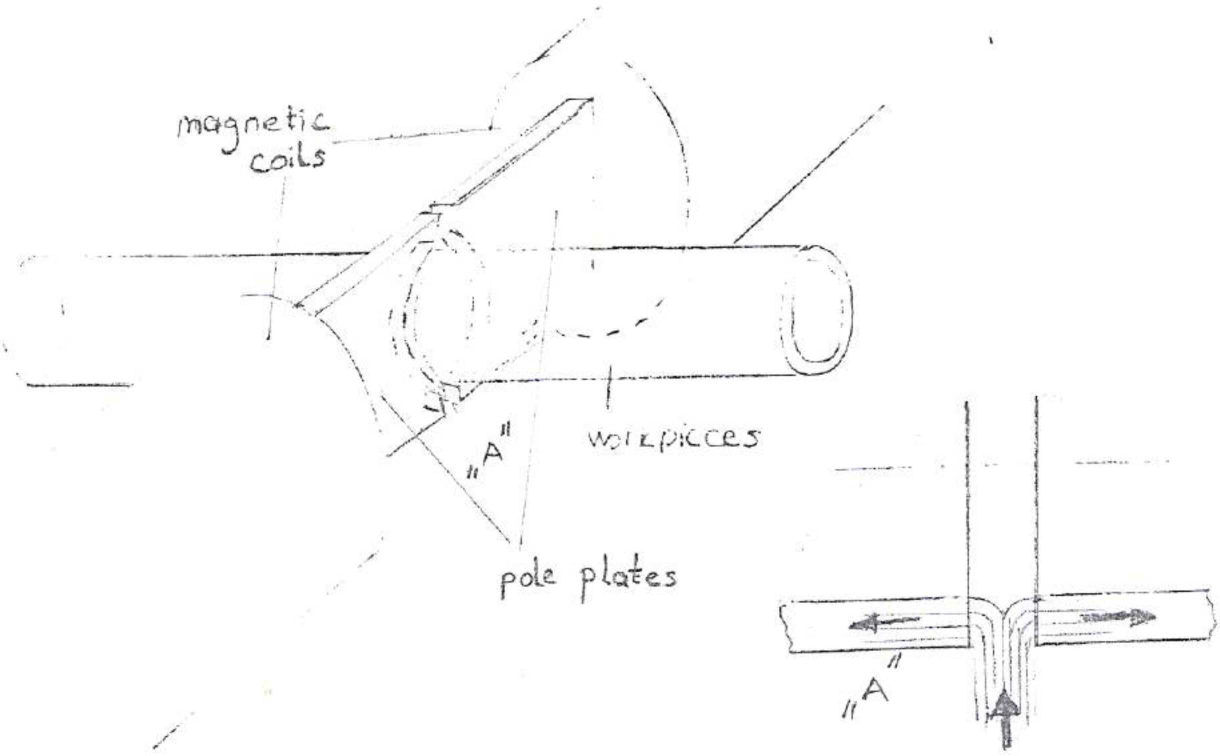


Fig 4.3 Theoretical magnetic field distribution in the welding gap.

the magnetic field is also changed by the relative motion of magnetic poles and welding gap during process. The more the distance between the welding gap and magnetic poles is, the more easily influenced the arc from disturbance and the slower the speed of rotation becomes [10].

CHAPTER 5

5.1 - Welding Machine

This section gives the characteristic fetures of the welding machine on which the tests were carried out (Fig.5.1).

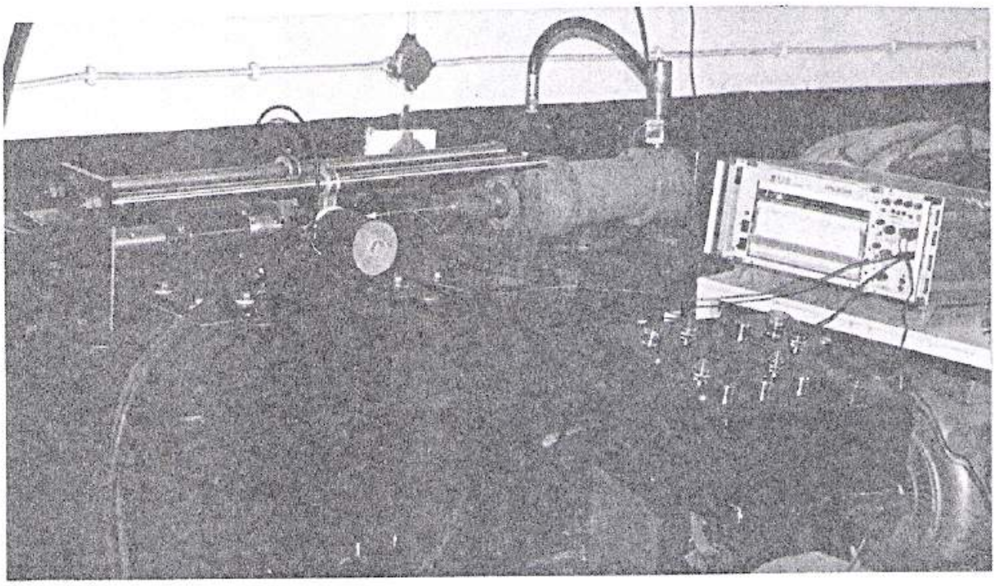


Fig 5.1 The flash welding machine

As shown in fig.5.2 wide ring-like copper electrodes are used to give the current to the workpieces which are clamped by means of two mechanically centred three-jaw chucks in this horizontally designed flash welding machine.

The values of the d.c. generator which was used throughout the tests are : welding current 40 to 315 A, no load voltage 45 to 94 V, welding voltage 22 to 36 V.

The magnetic coils were wound using long copper tube which had an outside diameter of 6.25 mm and a thickness of 1 mm. Usage of such a coil material limited the number of turns (60 for each coil), and made it necessary to use high amperages (up to 200 A) to obtain required magnetic field density. The magnetic coils have ferromagnetic cores and pole plates which are formed to suppply a homogenous distribution of magnetic field around the pieces (see fig.5.2). An investigation on the actual magnetic field distribution is given in section 5.3.

The movable part was drived by means of a hydraulic system (cylinder bore: 100 mm, stroke: 150 mm). The scale of hydrolic pressure gage was calibrated in terms of upset force by using a load cell. Due to the difficulty in precise control of the hydraulic system during flashing, this stage was controlled manually by a screw mechanism which is the section connecting the hydraulic system to the moving part of the flash welder.

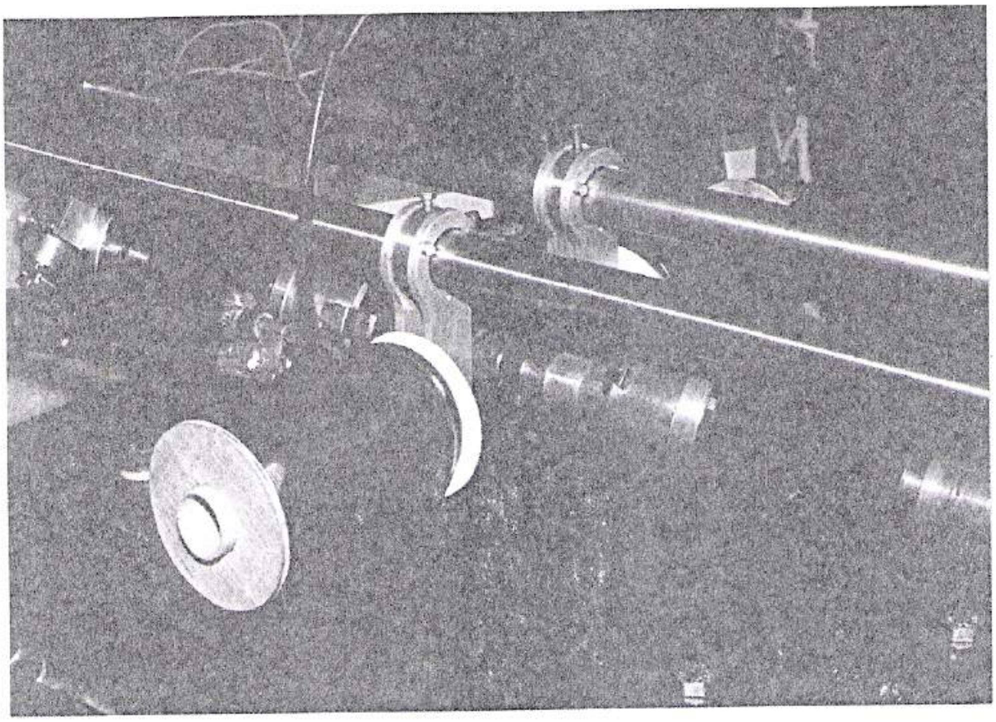


Fig 5.2 Clamps, coppper electrodes and magnetic coils of the flash welder

5.2 - Test Material

As mentioned before, flash welding using a magnetically controlled arc is especially suitable for joining hollow sections with a closed contour. For this reason, a tubular section was chosen to use in investigations. The outside diameter and wall thickness of the tubes were 27mm and 2.5mm respectively. The chemical composition and mechanical properties of the test material are given in table 1.

The values of mechanical properties were obtained by using the same test procedures and same type of specimens as used for welded materials (see section 5.5).

The specimens were produced by first cutting the tubes into pieces, then turning their faces and finally removing any burrs from the edges. The average length of the specimens were 70 mm. Some of them were also bored by using a drill having a diameter of 1 mm to prepare thermocouple slots.

Table 1. Chemical composition and mechanical properties of test material

Chemical Composition						
C %	Si %	Mn %	P %	S %	Cu %	Ni %
0.1060	0.0079	0.3907	0.0024	0.0081	0.0172	0.0126

Mechanical Properties			
yield strength N/mm^2	tensile strength N/mm^2	elongation %	hardness HV
382	445	25	143

5.3 - Determination Of Magnetic Field Distribution In The Gap

The theoretical magnetic field distribution in the welding gap was explained in chapter 4 and also showed in fig. 4.3. The magnetic field after reaching the workpieces completes its cycle through the parts to be welded and components of the welding machine which are made of ferromagnetic materials.

The distribution of lines of force can be demonstrated by introducing the iron filings into the welding gap. A three dimensional representation which was obtained by blowing the iron filing directly into the welding gap is shown in fig. 5.3

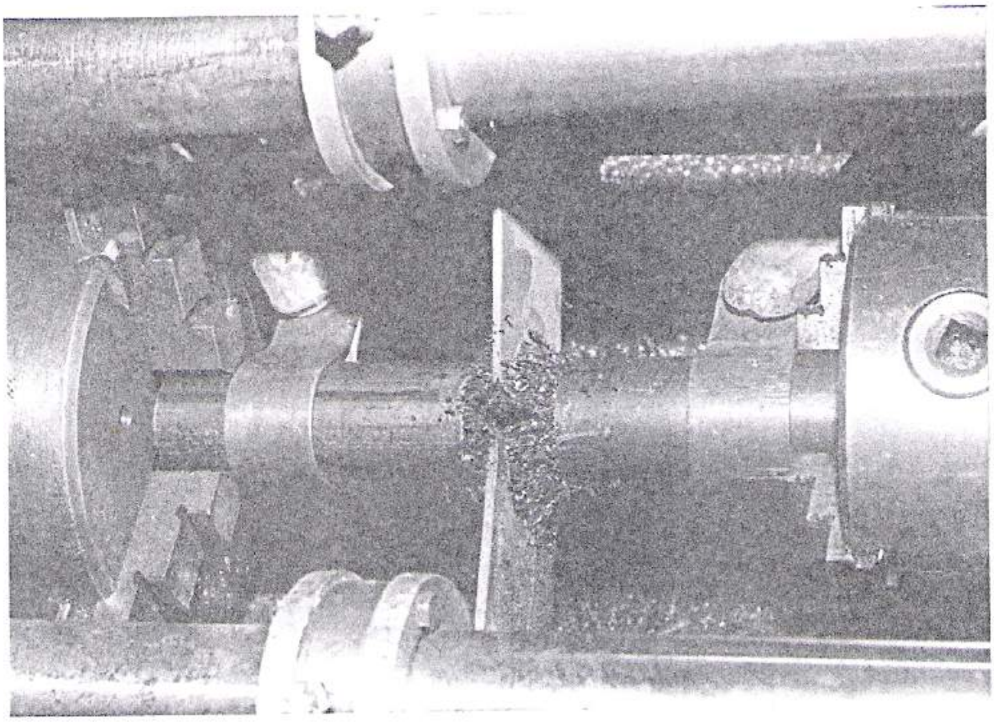


Fig 5.3 Representation of magnetic lines of force through direct application of iron filings.

When magnetic current is switched on and the iron fillings are blown on, they congregate at points where the magnetic field is most concentrated. The lines of force run between the pole plate and the tube, and the inferior of the tube is free from the magnetic field. The field density is also low along the inside edge of the tube. At the outer edge of the tube the radial field is stronger than the axial field. At the inside edge of the tube the iron filings stand upright, so the axial field is much stronger there than the radial field. The transition from radial to axial field always preceeds from the outside inwards.

5.4 - Carrying Out The Tests

The process was started by driving the movable part of the welding machine,after switching on the magnetic coil and welding currents. The flashing was initiated by touch-withdraw method (see chapter 4).The movable workpiece which was driven manually by screw mechanism was slightly touched to the other workpiece. This caused a very high short-circuit current to flow through them, which heated the contact area and made it possible to ignite flashing after withdrawing the movable part from the other for a distance of 1 mm or a little more. The arc was rotated along the faces of the tubes by the Lorentz force exerted by the magnetic field which was created by the external magnetic coils. The process was completed by the application of an upset force after a predetermined flashing time.

A number of tests were carried out for various upset force, flashing current and flashing time. One of the three upset values,which were 610, 1360, and 2060 daN,was applied to each joint. The rates of the movable part at these upset force levels were : 11.74, 12.56, and 12,60 mm/sn respectively.

A strip-chart recorder with four channels was used to obtain the variations of welding current and voltage and temperature of specimens at certain points.

The welding current was measured by using a shunt resistance (60 mV/300A), while the welding voltage was measured directly at the clamping jaws.NiCr-Ni thermocouples of 0.5 mm diameter were used for measuring the temperature at a point 4 mm away from the face. In this way temperatures of up to 1200 C could be recorded.Fig5.4 gives a record of these measured variables

By using the obtained data,important parameters,such as welding power and welding heat were calculated, and the variation

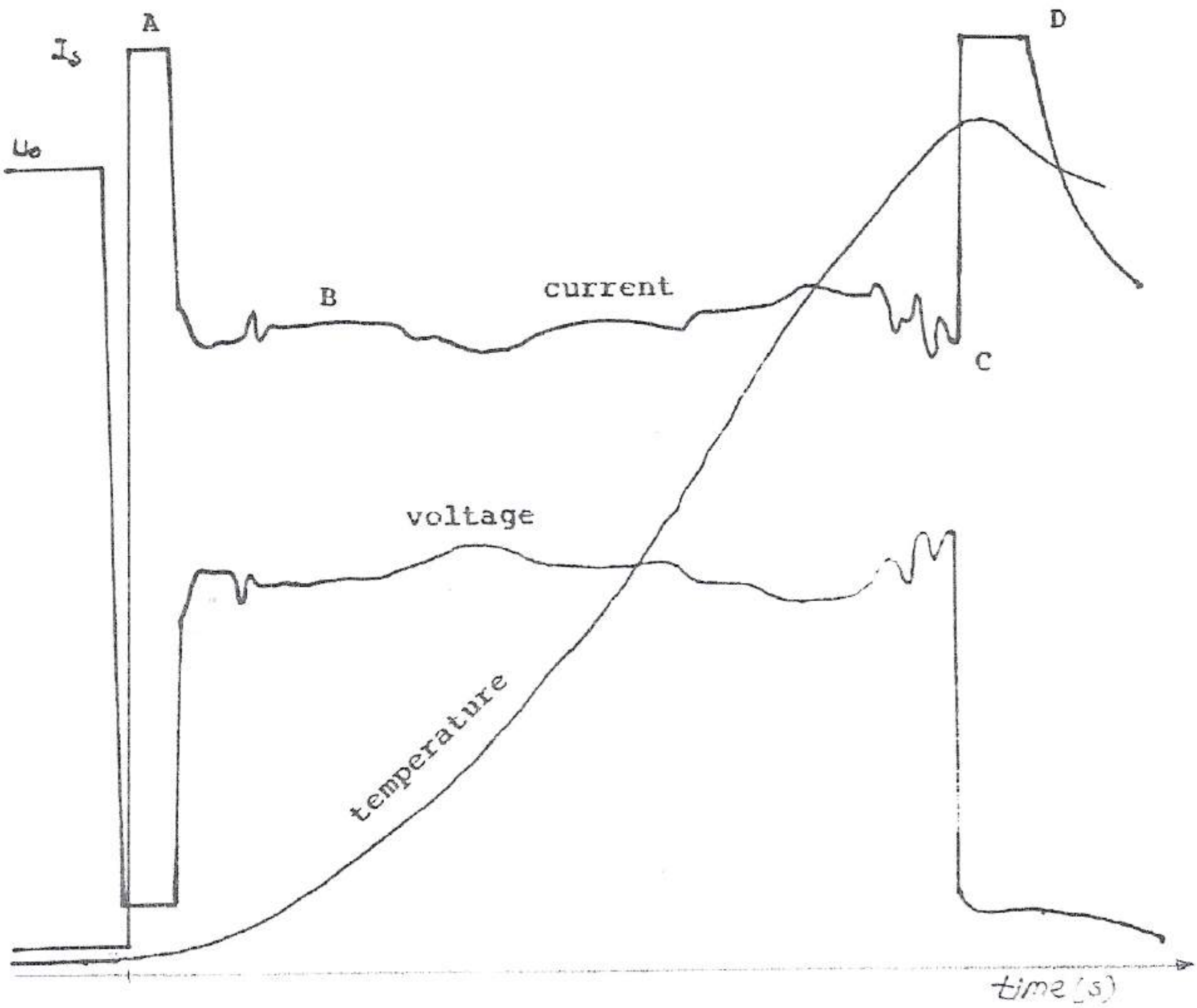


Fig. 5.4 Records of current, voltage, and temperature (4 mm away from the butting surface of the workpiece) in making a flash weld. I_s: short circuit current, U_o: open circuit voltage. A: arc initiation, B : flashing, C : upsettting, D : switching off the current, chart speed = 1cm/sn).

of the temperature was investigated. Welding power and welding heat was calculated by using the following simple equations :

$$P = U.I \qquad (3)$$

where P = welding power (W),
U = voltage across the electrodes (V),
I = welding current (A).

Welding heat, the energy given to the workpieces, is directly related to the welding power :

$$H = P.t = U.I.t \qquad (4)$$

where t is the time during which the current passes through the workpieces.

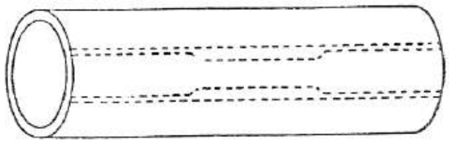
As no preheating and postheating were used in our tests, the total energy was taken as the energy given to the parts during flashing. The energy given to the workpieces during initiation of arc and upsetting was neglected. Because, the total duration of these phases is very short, and the short circuit voltage being only a few volts, greatly decreases the power at the stages in question (see fig.5.4).

Records of current, voltage and temperature (4mm away from the butting surface of the workpiece) in making a flash weld. I : short circuit current, U: open circu it voltage. A: arc initiation, B: flashing, C: upsetting, D: switching off the current, chart speed = 1 cm/sn.

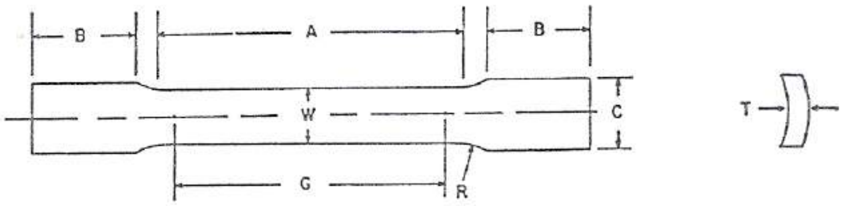
All of the obtained and calculated data were classified according to main welding parameters. The effects of main parameters were investigated taking into consideration the certain weld groups.

Mechanical And Metallurgical Tests : The produced joints were tested to obtain the optimum welding conditions. Tensile, bending and metalographic tests were made (and also hardness of some joints was measured).

Flash welded tubes were cut to produce longitudinal test specimens for tensile testing (fig.5.5.a). The specimens, the dimensions of which is given in fig.5.5.b, were prepared in



(a)



W-Width	8.00
G-Gage length	25.00
T-Thickness	2.50
R-Radius of fillet,min	12.50
A-Length of reduced section,min	30.00
B-Length of grip sectton,min	25.00
C-Width of grip section,approximate	13,50

(b)

Fig.5.5 (a) The location of a longitudinal tensile test specimen on the tube.(b) Dimensions of the specimen.

accordance with ASTM E8 standards [11].The tensile tests were made at a speed of 0.5 cm/dk.

Three specimens were produced from each joint, to investigate the homogenity of the tensile properties, which is related to the weld quality.

In tensile testing some specimens fractured from the weld zone while the other fractured from the heat affected zone (HAZ). In this way, useful information to compare the quality of welds were obtained.

A semi-guided bend test, in accordance with ASTM E290, was made to investigate the ductility of the welds. The tubes were machined to produce flat strip specimens. After removing the flash and upset from both inside and out of the strips, the longitudinal edges of the specimens were rounded to a radius not exceeding 1.5 mm. The arrangement of bend test, which is preferred especially for thin materials, is shown in fig.5.6.

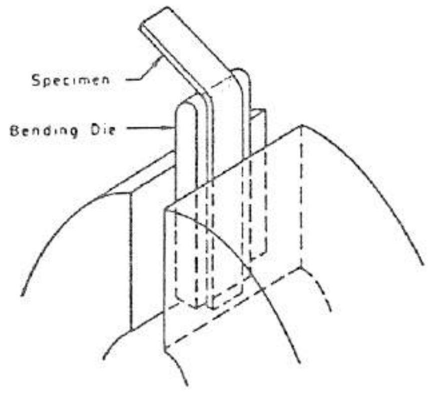


Fig.5.6 Schematic fixture for semi-guided bend test of thin specimens - one end held.

Diameter of bending die is 15 mm, while the thickness of specimen is 2.5 mm. The tests were finished through a 180-deg bend.

In order to investigate the hardness profiles of the welds vickers hardness tests were made at a test load of 10 kgf applied for 15 s.

Metallographic tests were carried out to observe the structural changes due to welding. After polishing and etching with nital (95 % ethyl alcohol, 5 % nitric acid) joints made by various welding parameters were examined using a conventional light-microscope.

5.5 - Effects Of Changes In Welding Power

In order to evaluate the effect of welding power on the joint quality, all welded joints were grouped into three levels. The average values of these levels are given in table 2 for comparative purposes.

Table 2 Comparison of main parameters for three levels of power.

Groups	Parameter	Average value	Standard deviation	%	Minimum	Maximum
	Power (kw)	2.88	0.19	6.6	2.5	3.3
1	Current(A)	113.82	13.29	11.6	95.0	137.0
	Heat (kj)	24.4	8.66	35.5	11.3	36.5
	Power (kw)	3.88	0.228	5.9	3.5	4.2
2	Current(A)	152.2	13.14	8.6	135.0	175.0
	Heat (kj)	24.78	9.0	36.3	14.5	35.0
	Power (kw)	6.51	0.416	6.4	5.62	7.0
3	Current(A)	198.0	13.14	6.6	180.0	230.0
	Heat (kj)	28.15	8.43	29.9	20.0	50.0

(Number of welds for each group : 23,9 and 17 respectively.)

The welding power is directly related to welding current. If the current is too low, as in group 1, the arc becomes weak. This level of current or power is uncapable of making the workpieces surface melted in a reasonable period. The joints made at this current level after a flashing period of 5 - 6s. could reach a temperature of 500-550 °C. A temperature about 1000 °C could be reached in 15s. of flashing(the temperatures were recorded at a distance of 4 mm away from the butting surfaces as mentioned before).

At the medium level of current or power(group 2) sufficiently strong arc could be obtained. The temperature can be reached to 1000 °C if the flashing period is continued about 8.5 s.

The most powerful arcs were obtained by adjusting the D.C. generator about a level of 200A(group 3).The material lost in the form of small particles during flashing prevent us from increasing the current any more. Fig.5.7 gives the flashing period at this current level. The time for reaching 1000 °C decreased to 5.5 s. in this high speed level.

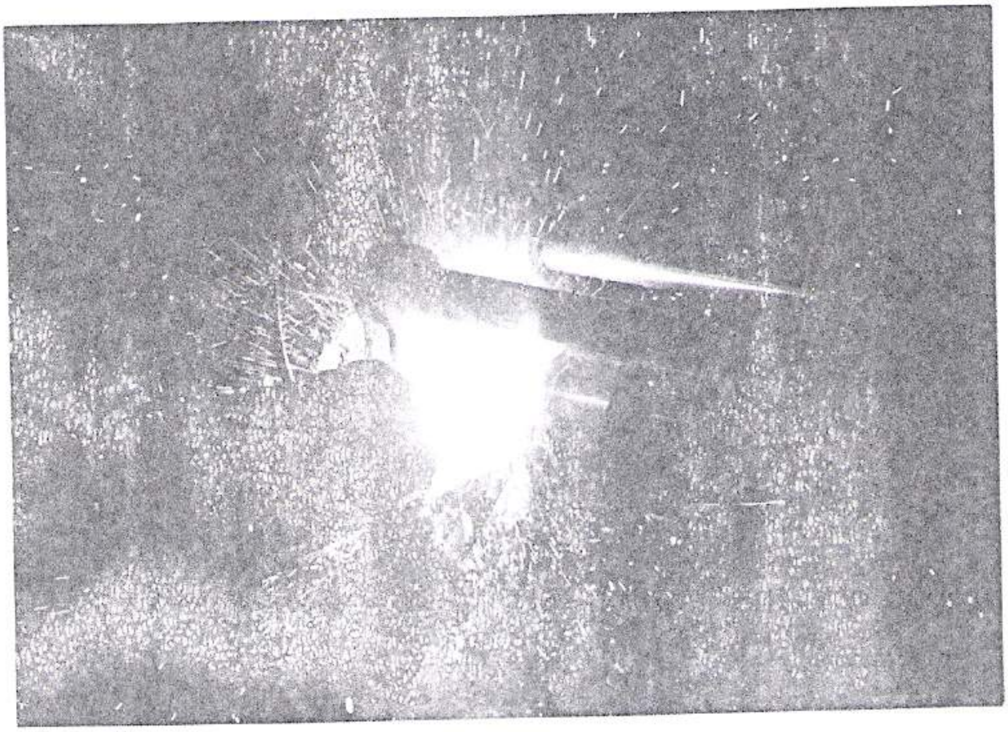
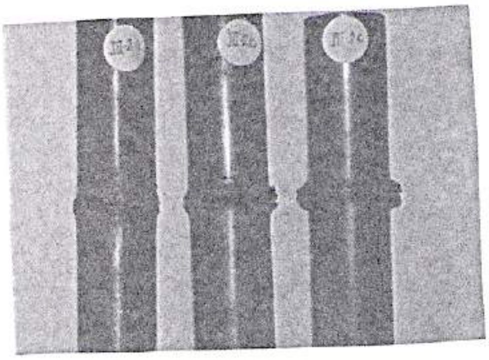


Fig 5.7 Flashing at high current.

To summarize: Short times and high flashing speeds gave steep temperature gradients and long times and low flashing speed allowed heat to spread. In the case of high welding speeds (high currents) the width of the plastic or molten material was narrow. On the other hand the low power arc created a wider plastic region (for the same energy input). This relation is given in fig5.8 for the three groups of welding power



	1	2	3
I (A)	110	145	187
t (s)	11	8.2	6.1

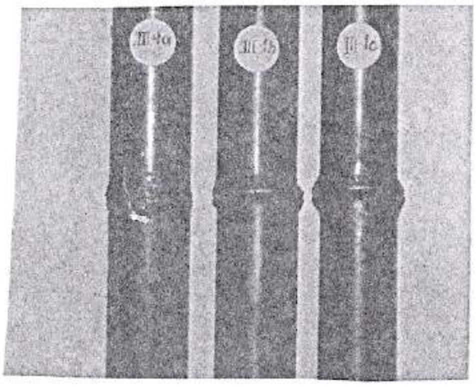
Fig. 5.8 Effect of welding power on the formation of upset band.

After flashing, a proper upset process is required to complete the weld. As indicated before three different upset forces were used in investigations. Upset force directly affected the upset loss as expected. Effect of upset force is given in fig. 5.9 for a given welding speed and heat.

5.6 - Effects Of Changes In Welding Heat

The effect of welding heat on the weld quality was investigated by the classification of the produced joints into three groups according to welding heat. Table 3 gives the average values and limits of these groups.

The most significant measured variable that differed from group to group was temperature. The maximum temperature



Upset Force (daN)	610	1360	2050
Upset Loss (mm)	1.4	2.7	4.3

Fig.5.9 Effect of upset force on the formation of upset.

Table 3 Comparison of main parameters for three levels of heat.

Groups	Parameter	Average value	Standard deviation	%	Minimum	Maximum
A	Heat (kj)	16.65	2.32	13.9	11.3	20.7
	Power (kw)	3.95	1.35	34.1	2.62	6.63
	Current (A)	142.6	33.16	23.2	97.0	200.0
B	Heat (kj)	25.56	2.99	11.7	21.0	30.0
	Power (kw)	4.3	1.62	377.0	2.8	7.0
	Current (A)	153.3	43.13	28.1	95.0	200.0
C	Heat (kj)	38.0	4.58	12.0	34.5	51.0
	Power (kw)	4.5	1.63	36.3	2.53	6.65
	Current (A)	155.5	43.21	27.7	107.0	200.0

(Number of welds for each group: 17,19, and 13 respectively.)

measured from a specimen that belonged to group A was 745 °C. In group B, 980 °C was measured as maximum temperature. In the case of application of 38 kj welding heat (group C), temperatures exceeded 1000 °C and sometimes thermocouples were destroyed due to excessive temperatures (+1200 °C).

The cross sections of flash welded tubes, belonging to the groups A, B and C (mentioned above) for different upset forces are given in fig 5.10.

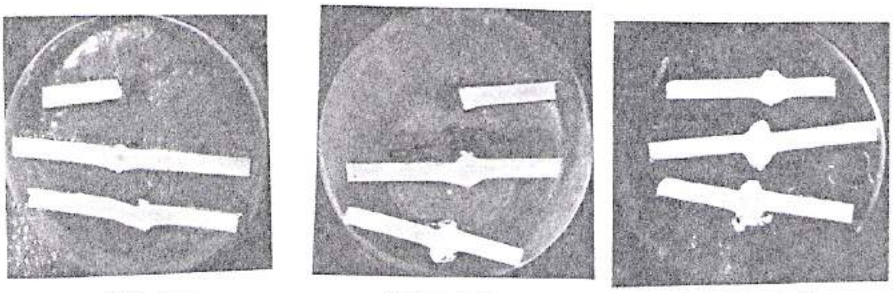
Heat

(kj)

16

25

36



610 daN 1360 daN 2060 daN

Fig. 5.10 Weld-seam cross sections with different level of heating and upset force (the axis of the tube is always below).

The strength of the joints was low, when 16 kj of welding heat is applied. They fractured immediately in the semi-guided bend test and tensile test, irrespective of the upsetting force. The fracture surfaces had the brightness from turning and only one half of the wall thickness on the inside were surface melted. There were slight fusions only at these points. Total flash off and total upset of the specimens were 0.5 to 1.2mm depending upon the upsett ing force. Where 25 kj of welding heat was applied, very evenly formed upset bands were obtained at medium and high upset forces. The total flash off and upset of the specimens amounted to between 1.6 to 3.8 mm depending on

The results of the bend test were in good agreement with the tensile tests. The results of the tests were not changed much by increasing the upset force to 1360 daN. Although tensile strengths up to 38 daN/cm^2 were reached, all of the specimens fractured at the weld line.

In the case of 25 kj heat and 2060 daN upset force, most of the specimens fractured at the HAZ,a few milimeters away from the weld line. Bend test specimens produced from the same joints proved the ductility of the weld zone by being bent through 180-deg. without cracking.

The application of maximum energy, 36 kj, was resulted in the abutting surfaces being heated to considerably high temperatures in excess of 1000 C . Increased plasticity of the materials due to high temperatures,caused the total upset and flash off to increase. The loss of metal at the highest upset force level was about 10mm.Under thses conditions satisfactory welds were made by the application of medium (1360 daN) and maximum (2060 daN) levels of upset forces.

5.7 - Metallographic Tests And Hardness Measurement

The structure in the vicinity of the seam undergoes certain changes as a result of the flash welding process. The microstructure of a flash weld, which is made by the application of 28 kj heat (welding power:7kw) and 2060 daN upset force, is given in fig.5.11 . The centre of the seam has a fine structure and adjacent to a coarse grain zone.

The reasons for the fracture of specimens of certain groups at lower upset forces was understood after the metallographic examination of such specimens.Fig.5.12 shows a weld zone that has some slag or oxidized materials. This welding was made by the application of 34 kj heat (welding power:4kw) and 610 daN upset force . The maximum temperature of the material at a

Fig.5.11 Microstructure of a flash welded joint (X160).

distance of 4 mm from the butting surface was 1010 C, so the heating process was proper. This formation was caused by the improper upset force and/or slow upset speed.

The factors determining the width of HAZ were also investigated by measuring this distance for various welds . The maximum measured length was 12.7 mm,and the weld was made by applying 39 kj heat (current = 107A,time = 15s.) and 610 daN upset force.

The width of the HAZ is affected by the welding heat,welding speed (welding power), and upset force.

A higher upset force gives narrower HAZ by increasing the extruded metal.The width of the HAZ is directly proportional to the amount of welding heat. On the other hand, for a certain level of heat, if the welding speed is increased by

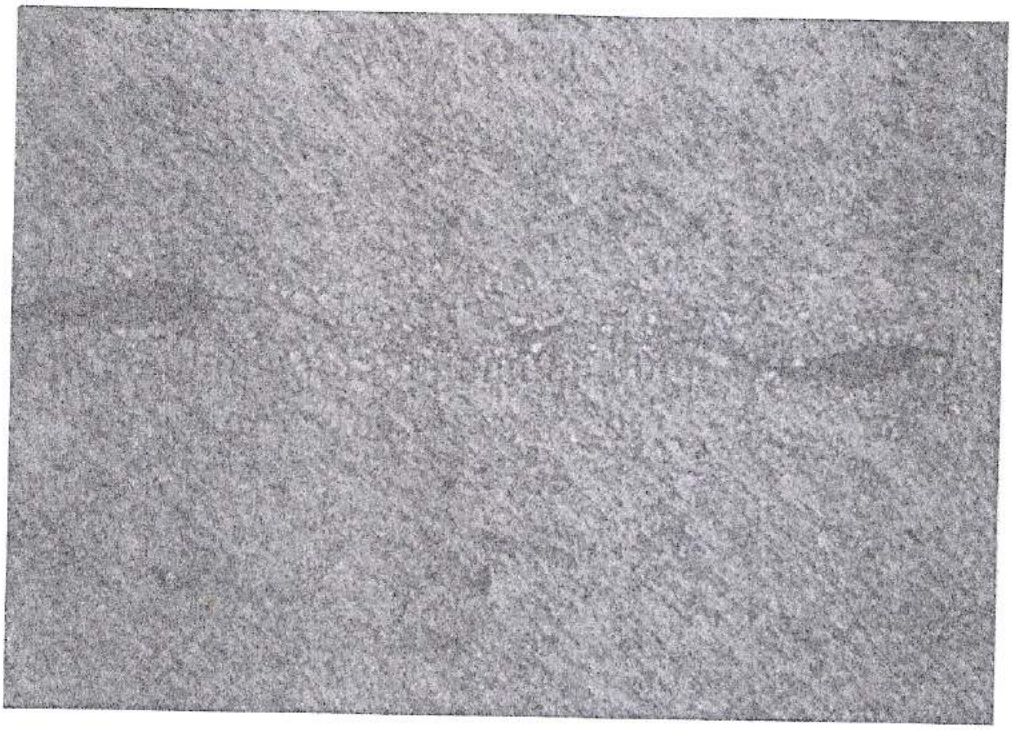


Fig. 5.12 Microstructure of a joint with slags and inclusions (X160).

raising the welding current, the welding time will be shortened and the HAZ will be narrow.

A number of hardness measurements were made to obtain the hardness profiles of certain specimens. The variations in the hardness of the material in the various portions of the weld were insignificant. Only small hardness peeks were obtained on the coarse grain zones.

CHAPTER 6
RESULTS AND DISCUSSION

In this study, effects of welding parameters on the quality of flash welded thin-walled tubes were investigated.

The joints which were produced at different levels of welding power, welding heat, and upset force, were tested to obtain optimum parameters.

Effects of welding power, welding heat and upset force on the quality of flash welds are given in fig. 6.1. Good welds can

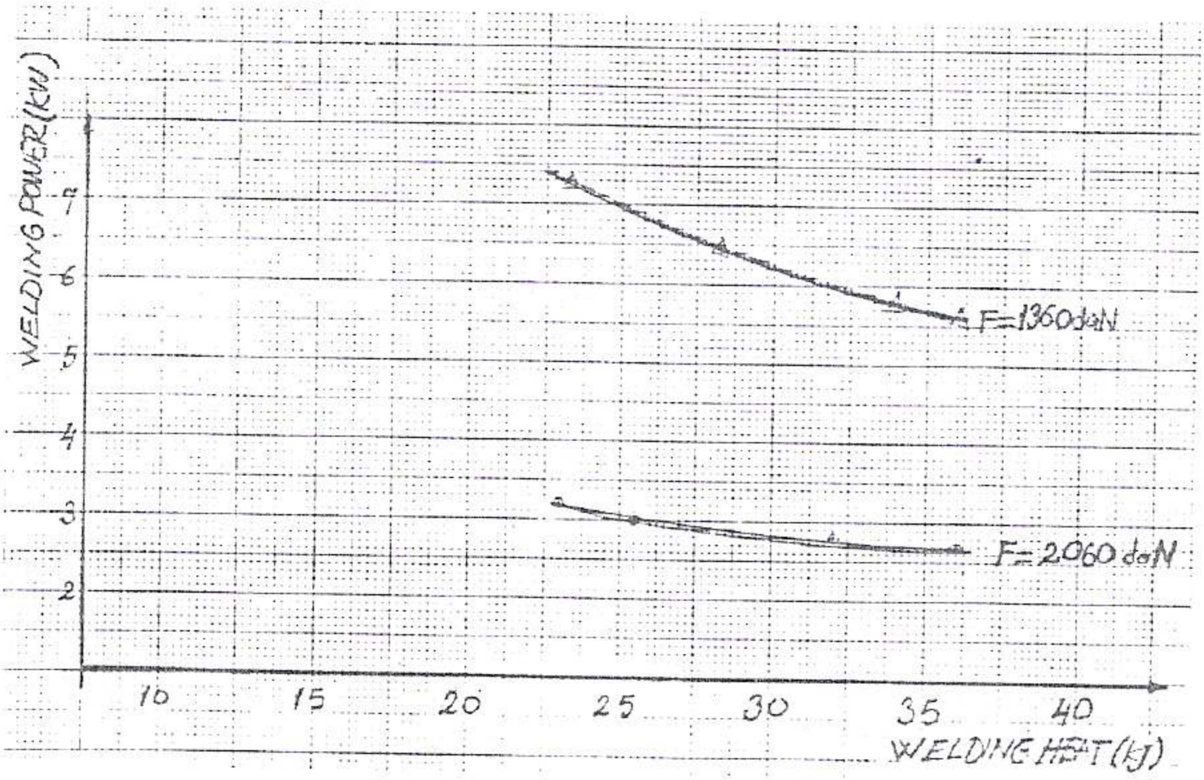


Fig. 6.1 Effects of main parameters on the weld quality.

be obtained by choosing the parameters above the given lines of force.

1-A low welding power, causes a weak arc to form and increases the welding time. The low welding speed reduces the rate of production and increases the heat loss. On the other hand it makes the HAZ wider and increases the width of upset band.

2-Settting the welding power too high (by increasing the current) results in greater ease of maintaining the micro - arcs formed in the flashing period and deep craters can be caused in the flashing face. Deep empty craters may not be filled with molten metal or closed during upset causing the dangerous regions of lack of fusion.

On the other hand the flash-off rate is increased in the case of flashinf at high power. This causes the material to be blown of into the air in the form of small particles. These molten droplets may cause important problems such as fire - and personnel hazards.

3-If the welding energy is not sufficient, materials cannot be plastic enough for proper upset and there is a tendency to freeze.

4-Applying the welding heat too high greatly increases the material lost which is wasted and should be compensated for in the original dimensions of the pieces being welded.

5-If the upset force is insufficient, the defects cannot be squeezed out of the weld and the weld will have oxides, inclusions and voids.

6-Too much an upset force causing a deflection of the flash welder, increases the tendency for improper alignment. Excessive upset force may also squeeze out too much plastic material and make poor welds.

7-The flash welding machine used throughout the tests has an hydraulic drive mechanism which is not fast enough. It also needs a precise control mechanism for travel. Although adequate heating was supplied at lower heat levels the process could not be completed properly due to the insufficient upset travel.

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