CHAPTER 9
WELDING OF SOME TYPICAL METALS AND ALLOYS

9.1 HIGH CARBON STEELS :

High Carbon Steels contained 0.5% C or more. They are generally used for tool bits, dies, springs etc. Because of their high carbon content, steels in this class are more difficult to weld than other steels. They are welded mainly for repairing cracked or worne out portions. High carbon steels are often heat treated. The welding heat will affect this heat treatment. A joint is produced with properties different from those of the original metal.

High Carbon Steels are gas welded using a carburizing flame to get stronger welds. High carbon welding rods are used. Mild steel rods will produce a satisfactory joint with only moderate strength but better ductility. Heat- treatment after welding is necessary to improve the properties of the welded joints.

High carbon steels do not possess good mechanical properties after arc welding. Hardness and brittleness results in the welded zone. They must be preheated to about 200°C before welding. Special type of covered steel electrodes are used which deposit a dense metal having although surface and moderate hardness. They must be heat-treated at 785°C after welding to improve the properties. Mild steel electrodes may also be used as in gas welding. Often, austenitic stainless steel electrodes are recommended. The resultant welds have good physical properties, although the fusion zone may still be hard and brittle.

High Carbon Steels are readily welded by thermit welding, flash welding and pressure gas welding.

9.2 TOOL STEELS

The Carbon content is from 0.8 to 1.5 % . Compared to other steels, tool steels are quite difficult to weld satisfactorily.

Tools steels are welded best by gas welding. Welding rods must contain enough carbon to deposit a weld deposit having carbon content at least equal to that of the base metal, and nearly same mechanical properties when hardened and tempered after welding. Usually pre-heating before welding and reheating and slow annealing after welding are used. A carburizing flame is advantageous.

Because of the heat effects of arc welding, it is practically not possible to weld tool steels satisfactorily by arc welding . However, if they must be arc welded, these procedures are recommended :

(1) The parts are annealed, preheated and welded with a suitable covered electrode. This is followed by heat- treatment to restore desired properties.

(2) Preheat and weld with austenitic steel electrode. Preheating prevents the formation of a hard fusion zone and austenitic steel weld is relatively ductile.

Tool steels are frequently joined to less expensive steels in the production of long drills and other machining tools. Pressure gas welding is used for this purpose, as this process is performed at lower temperature without adversely affecting the structure and properties of the tool. Heat treatment is usually necessary to produce the desired properties in the welded joint.

9.3 LOW ALLOY HIGH TENSILE STEELS

The total alloy content of these steels does not exceed 5%. The carbon content is usually below 0.15%. These steels may usually contain two or more alloying element out of Cr, Ni, Mn, Me and W. Despite the low carbon content, the steels are susceptible to hardening due to welding heat, and hence brittleness of the joint may result. The weldability of these steels depends upon the equivalent carbon content calculated as described in chapter 6. For Ce < 0.45 %, weldability is relatively good. For Ce > 0.45 % preheating is essential. The usual preheating temperatures are as follows.

Ce 0.45 - 0.5 - 100°C
Ce 0.5 - 0.55 - 150°C
Ce 0.55 - 0.6 - 200°C

A popular alloying element is Me, but it is not usually used alone in alloy steels. Its presence reduces the brittleness through out the entire range of cooling, thus retaining the ductility of the weld. As such, the risk of developing cracks, usually associated with low alloy steels is reduced. To ensure the presence of molybdenum, it is usually included in the filler metal or electrode.

With preheating the low alloy steels can readily be welded by gas, metal-arc, TIG, MIG and Sub-arc processes. Gas welding is normally confined to lower gauges because of the slow speed of welding. TIG welding produces high quality welds economically in thin sheets. MIG and CO_2 shielded arc welding may be used on thicker section. A suitable filler material, not necessarily of the same composition as the base metal, may be used. Excellent results are obtained using manual metal arc welding, and hence it is most widely used. Submerged arc process is economical while welding thick sections. Welds of radiographic quality are produced.

9.4 STAINLESS AND HEAT RESISTING STEELS

MARTENSITICS STAINLESS STEEL :

The composition of this group of steels varies from 11.5 - 14% Cr and 0.2 to 0.4 C contents. These steels are air hardening. When welding is done, the difficulties that arises are high hardness, accompanied by brittleness, which may results in cracking. This can be overcome by preheating to 200-350°C , which minimize the distortion also. The low carbon varieties have better weldability than high carbon types. A post-weld-heat treatment is often given which is followed by air cooling. Light sheets can be welded without preheating. High carbon varieties are preheated to 350°C before welding.

The deposited weld metal should preferably of a ductile character. A covered electrode of 25/20 Cr-Ni stainless steel meets this requirement. The AWS/ASTM classification of this electrode is E 310. It is important to realize that after welding, the heat affected zone will be the weakest area. Therefore post-heating is recommended immediately after welding.

FERRITIC STAINLESS STEEL :

Ferritic stainless steels contain 16 to 30 % Cr and C upto 0.1% maximum. They are non-hardenable and hence due to the welding heat, very little austenite is formed, depending upon the exact composition. During welding, heat affected zone on each side of the weld would undergo considerable grain growth and the small amount of austenite formed might entrapped in between the ferrite grains. Unless the rate of cooling is correctly controlled, the intergranular austenite, on cooling, will revert to martensite, with little change in the hardness of the alloy but with marked embrittlement of the weld. Distortion is minimum during welding. They are successfully welded with a pre-heating of about 200^{0}C, for welding thickness above 3.15 mm. A 25/20 Cr- Ni steel electrode of E 310 type is recommended, which ensures a ductile deposit. They may be given a past weld heating to about 730°C to control the embrittlement.

AUSTENITIC STAINLESS STEEL :

(1) BASE METAL COMPOSITIONS AND ELECTRODES :

The most popular austenitic stainless steel is 18/8 type. It has been established that 18/8 stainless steels with less than 0.02% C are not susceptible to serve sensitization even when they are kept at the critical temperature range. If the time at this temperature range is fairly brief, as in welding, this limit of 0.02% C could be raised to perhaps 0.05%. By recent investigations, a relationship has been established between carbon and chromium contents in austenitic stainless steels to prevent grain boundary corrosion with a probability factor of about 99.8 % . For a fully austenitic stainless steel having about 1.0% Ni, the relationship between the maximum Cr and C contents can be written in the form of Cr>= 80C 16.8. From this it can be deduced that as the chromium content increases , it should be possible to tolerate more carbon without incurring the risk of weld decay. For example, at 22% Cr, the Carbon content can be raised to 0.065% .

In important property of low carbon variety of austenitic stainless steel is its better impact strength as compared to the stabilized 18/8 austenitic stainless steels, which are brittle at very low temperatures. The E.L.C. stainless steels are though enough right up to liquid nitrogen temperatures (-192°C).

18/8 steel is stabilized with either titanium or columbium. They must be welded with columbium bearing stainless steel electrodes of type E 347. Titanium volatilizes rapidly at are temperature[and very little of it gets transferred from the electrode to the weld deposit. To offset this tendency, increasing the alloying content in the electrode core wire or coating is not satisfactory because the resultant welds are generally found to be porous. Titanium is consequently not added to the electrode. In chemical industry, we come across many corrosive conditions where the standard 18/8 type of stainless steels are not suitable because they either suffer from severe general corrosion or get pitted. Addition of molybdenum to about 2-4% (generally 3%) improves corrosion resistance and makes them more widely suitable> It is believed that the presence of stabilizing elements like Ti and Nb also is necessary. These steels may contain some ferrite, which, when heated to a temperature range of 650-850°C for some time gets transformed into sigma phase which is hard and brittle. Such conditions exist during welding. The amount of sigma phase formed in the heat affected zone during welding is very small as the time at the temperature is very short . 18/8 Mo steels are generally welded with AWS/ASTM E 316 electrodes giving filler metal of similar composition. The stabilized steels are welded with E 318 electrodes (austenitic stainless steel core with Nb as stabilizer). The low carbon variety of stainless steels containing 0.03% C and are welded with the low carbon variety stainless steel electrodes of the same class i.e. E 316 L or E 317 L or E 304 L (L stands for low carbon type).

There is yet another type of austenite stainless steel, the heat resisting variety, containing 25% Cr, and 20% Ni, which represents the limit of austenitic corrosion resistant steels. This steel exhibits a fully austenitic structure due to virtual absence of ferrite. For welding this type of steel ASTM/AWS E 310 electrodes (25/20 Cr Ni) are used. However the weld deposits obtained with these electrodes are prone to microfissuring because of their fully austenitic structure.

(2) WELDING :

Austenitic stainless steel are readily weldable by most welding processes. The preferred welding processes are metal inert gas, tungsten inert gas, and manual metal arc welding. Regardless of the process used, no grain-refinement occurs in multipass welds, as it does occur in mild steel. This is because there is no phase change taking place on heating austenitic stainless steel right upto its melting point. Hence coarse columnar grains persist in the weld deposit. Hot or cold working (peening) between each run of weld results in grain refinement. If the base metal is being used in the sufficiently cold worked condition, some refinement of the grain structure due to recrystallization occurs in the heat affect zone during welding.

Successful welding of stainless steel by any process requires a serious consideration of the following factors during welding :

(a) OXIDATION :

This is prevented by a flux shield in manual metal arc welding or argon in TIG welding. Quite often a backing gas argon is passed along the underside of the joint during welding . This results in a smooth undersurface on completion.

(b) CARBON PICK UP :

This increases the risk of forming undesirable carbides during welding. Care should be taken to ensure that there is no oil or grease or anything that will give off carbon at welding temperature. CO_2 should never be used as a shielding gas when welding with either of the gas shielded welding processes.

(c) DISTORTION :

The thermal conductivity of austenitic stainless steels is much lower than that of mild steel. Because of this, stainless steels are more susceptible to local overheating and distortion during welding. Further, the thermal expansion of stainless steel is approximately 1.5 times greater than that of mild steel. In welding, this results in excessive shrinkage stresses and distortion. The higher the chromium contents, the more pronounced is distortion. To avoid or minimize distortion, correct tacking or jigging must be carried out. Tacking must be much closer than that used in mild steel. The length of the tacks should also be longer. Step backing or staggering of welding must be used.

Oxyacetylene gas welding may be used for sheets of thicknesses upto 3.5 mm. The refractory chromium oxide formed during welding poses a serious problem and for its removal an active flux has to be used on both sides of the seam. Tacks at frequent intervals are essential. The filler metal used should be generally of the same composition as the base material. It is preferable to use stabilized filler metal because of the slight carburizing action of the flame.

Metal arc welding with coated electrodes can be done without any limitations of thickness. TIG welding is ideal for thin sections, or where a controlled amount of penetration is required. MIG welding is advantageous on thicker sections, such as above 1/8 inch. Metal transfer occurs through spraying . There is little loss of alloying elements. The advantage gain by this is that either titanium or niobium may be used for stabilizing the weld depositor. In an argon atmosphere both Ti and Nb are transferred across the arc.

Submerged arc welding is generally used on heavy section where the volume of the work justifies the initial heavy capital investments for installing the equipment.

The electrical conductivity of austenitic stainless steels is low, and hence excellent resistance welds can be produced.

To obtained satisfactory welds in the austenitic stainless steels, the following hints must be remembered :

1. Ensure that the surface of the material in weld area is clean and free from foreign matter.
2. Use proper edge preparation.
3. Tack at regular intervals at almost half the pitch used in mild steel welding.
4. Maintain a short arc during welding to avoid loss of alloying elements during transfer across the arc.
5. Use one size smaller electrode for equivalent thickness of mild steel.
6. Follow step back or adequate staggering sequence of welding for minimizing distortion.
7. Remove slag thoroughly from welds between passes, use a wire brush with stainless steel bristles rather than one with carbon steel bristles.

9.5 METALLURGICAL ASPECTS OF STAINLESS STEEL WELDING :

The metallurgical problems involved in the welding of stainless steels are in principle, the same irrespective of the welding method being used. Where filler materials are used the bulk of weld metal will consist of fused filler metal. Thus the filler metal must be chosen on the basis of what is required from the weld metal.

In the first instance the composition of the base metal will normally determine the choice of the weld metal. Over and above this, it must be acknowledged that the weld metal will assume certain basic characteristics that will significantly differ from those of the weld metal. These characteristics, namely, the structure, the corrosion resistance and the crack-susceptibility must fully be understood for the best choice of the filler rod.

STRUCTURE :

The properties of austenitic weld metal differ in several important respects from those of base metals of corresponding composition. These difference in the properties are chiefly due to the difference in their structure. During its manufacture, the base metal undergoes several hot and cold working operations and annealing so that in the as delivered condition, it has a regular, relatively fine grained structure. The weld metal by contrast has an irregular structure (cast structure - dendritic), which is quite difficult to be modified. It is well known that cast structure is brittle while the hot worked or annealed one is tough and ductile.

Apart from this difference in grain structure, there is another structural difference the type and amount of phases present in the two structures. The base metal is completely austenitic in structure. However, the weld metal, which has a composition aimed at austenitic structure, undergoes a complete cycle of fusion and solidification. During this solidification microserggregation invariably occurs. This local variation in the chemical composition leads to the formation of ferrite grains in the austenitic structure. The quantity of the precipitated ferrite phases will depend upon the proportion of ferrite forming elements e.g. Cr, Si, Mo etc.; with respect to the proportion of austenitic stabilizing elements, e.g. Ni, Mn, N etc. The ferrite content is affected by the cooling rate also after welding.

The presence or absence of ferrite has a very important influence on the properties of austenitic weld metal. For this reason, it should be possible to determine the ferrite content of the weld metal. A number of test methods, both destructive and nondestructive have been evolved. The best know aid is the Schacffler diagram which is based on the empirically derived relationships between ferrite contents and the chemical composition of the filler metal. The influence of the various alloying elements on the ferrite content is expressed by conversion to a chromium equivalent and a nickel equivalent. By applying these value to the diagram, shown in fig 9.1, it impossible to read of the approximate ferrite content of the weld metal. One limitation of the Shaeffler's diagram is that it makes on allowance for the cooling conditions. Hence the values of ferrite content obtained are not too certain.

Most of the other methods e.g. magnetometric method, also give uncertain values as in these cases, the values are generally affected by the form and size of the ferrite as well. The metallographic method, unfortunately destructive, gives the most reliable results. In modern TV microscope, the analysis can be carried out automatically and with good precision.

CRACK SUSCEPTIBILITY :

When we speak of crack susceptibility in austenitic stainless steel weld, we are almost always referring to what are known as hot cracks which appears at higher temperature during the solidification of the weld metal. The crack may be of different types and may vary from very small "micro cracks" in the grain boundaries to large cracks, fully visible to the naked eye. Upon closer examination, it is found that the latter follow an interdendritic course. This type of cracking is almost entirely confined to fully austenitic weld metal. The presence of ferrite has been found to prevent the initiation or, at all events, the propagation of such cracks.

The cause of such cracks is believed to be the final stage of solidification of the weld metal. In this period, there may be some residual molten metal which forms a kind of film in the grain boundaries, and substantially reduces the ability of the weld metal to withstand stresses during cooling. This appears to be favored by the presence of elements like phosphorous, niobium and silicon. Normally, this risk is avoided by choosing a filler metal that gives some ferrite content in the weld metal. The problem intrigues and makes itself felt when we are compelled for one reason or the other, to hold the ferrite content down to very low levels.

As will be seen shortly, it is necessary in certain corrosive environments to have an almost ferrite free weld metal. Another reason may be that the weld may be subjected to high temperatures, making it desirable to have no ferrite present, as this ferrite forms sigma phase which makes the weld extremely brittle. In such cases, the risk of hot cracks is countered by keeping the presence of elements like phosphorous and sulfur to the minimum, as these are the principal elements which form low melting point constituents responsible for the film formation at grain boundaries during final stages of solidification. These elements must be less than 0.03% max.

The risk of cracking can not be completely eliminated by the mere choice of a suitable filler material. Precautions must be taken to reduce the shrinkage stresses. The joint must be properly designed and the heat input must be kept to the minimum. It is this point in which TIG welding excels all other processes. Low currents and smallest possible gauge of filler wire must be used. A suitable multipass welding sequence should be adopted.

CORROSION RESISTANCE :

Normally, the austenitic stainless steel weld metal may be assumed to have corrosion resistance as good as that of the base metal of corresponding composition. In certain cases, however, the ferrite content may exert a grate influence on the corrosion resistance of the austenitic weld metal. This is because ferrite has a slightly different composition from the surrounding austenitic as has been revealed by electron micro-probe analysis of austenite and ferrite in an austenitic weld metal. The compositions are as given below :

	% Cr	% Ni	% Mo
Ferrite	20.6	8.3	3.3
Austenite	17.9	12.2	2.1
Weld metal	18.1	10.3	2.5

In reducing environments, ferrite in weld metals is not objectionable . The service life of the base metal and the weld metal containing ferrite is nearly same. However in certain cases where solution of HCl are to be handled, or in the urea producing plant , or tar distillation units, it has been found that ferrite bearing welds are attacked a good deal more heavily than ferrite free weld metal. The same of course, applies to the base metal also, which normally is free from ferrite. Hence it can be seen that there are cases in which the requirement of ferrite free weld metal is technically justified. But it is necessary to be quite certain as to whether a limitation of the ferrite content is really needed or not, since the use of a ferrite free weld increases the crack susceptibility of the joint. Apart from these cases, in those weld which are to be used at high temperatures, ferrite may transform into sigma phase and thus indirectly affect the corrosion resistance of the weld metal. Presence of Mo reduces risk of sigma formation.

In most of such cases, where there is a likelihood of selective attack on ferrite/sigma phase, serious corrosion damage can be avoided by keeping the ferrite content down to a maximum of 10-15 %. Above these levels, the ferrite forms network along which the corrosion attacks may penetrate deep in the material. But if ferrite is present as isolated islands in the austenitic structure, the corrosion attack can be kept down to harmless levels. About 6% ferrite is generally supposed to be harmless for corrosion, which at the same time there is full assurance against hot cracking. For special cases of corrosion e.g. in HCl solutions, or in the urea process, it has been established by experience that the ferrite content in such cases must be less than 2% or even as low as 0.6%.

It is paradox that, however, the presence of ferrite appears to improve the resistance of the weld metal to stress corrosion.

9.6 CAST IRON :

Out of the three varieties of industrially important cast irons, white cast iron should be regarded as having the poorest weldability. Success-full welds are very difficult and are possible by gas welding alone. Normally white cast iron is not welded because of the same. Gray cast iron and malleable cast iron can be successfully welded by both gas and arc welding methods although they require much more care than normal steels.

GREY CAST IRON :

A successful weld of this cast iron will be one which would produce grey cast iron structure in both the weld metal as well as the heat affected zone, both of which experience a fast cooling rate. This means that the weld and the surrounding area should be amenable to machining or filling, and should possess the other desirable properties also, associated with grey cast iron.

The difficulties which may be experience during the welding of grey cast iron are cracking, oxidation and loss of alloying elements.

(a) Cracking :

Cast iron is inherently brittle. Therefore it is particularly sensitive to effects of expansion and contraction, especially when the source of heat is localized as in gas or arc welding. By expanding the whole or part of the casting before welding the expansion or contraction stresses may be considerably balanced which prevents cracking. This may be done by preheating to a suitable temperature, depending upon the welding process used. Complicated castings are preheated to about 700°C. Post-heating after welding is essential, for it will remove internal stresses which may be present as a result of welding. The slow cooling rate would also ensure the formation of a correctly formed grey structure.

(b) Oxidation :

Grey cast iron rapidly oxidizes at elevated temperatures. The formation of oxide prevents the combination of the --- weld metal with the parent metal. It also burns out carbon, thereby endangering the formation of white cast iron. The heat of oxy-acetylene flame results in the volatilization of silicon, which again results in promoting the white structure.

(c) Loss of alloying elements :

This loss of silicon must be made good by using filler rods with an excess of silicon. Silicon loss is also due to its action as a deoxidizer, although this prevents below holes.

When welding grey cast iron, the best results are obtained by using oxy-acetylene gas welding. This is only process which is capable of providing a grey iron structure in the weld metal and the H.A. Zone. Correct type of filler rod, preheating, a neutral flame and flux of suitable composition must be used. To obtain good results, welding should be done at the fastest possible speed to avoid the loss of silicon. Manual metal arcing may also produce good welds. The preheating is either totally dispensed with or done to a very low temperature. The points to be noted are :

(a) Use of low input
(b) Choice of electrode
(c) Electrical conditions
(d) Buttering layer
(e) Skip welding and peening

In the manual arc welding heating is very much localized and hence preheating may not be necessary. Hence this method is useful in those cases when preheating is impracticable due to design and larger dimensions.

Because of this localized heating, cooling after welding is extremely fast. As such, it is impossible to produce a grey iron weld metal, even by using a grey cast iron type of electrode. The situation is still more aggravated by the loss of silicon, the principal graphitizer due to the intense heat of the arc. As a consequence of these conditions, the weld becomes porous and extremely brittle. As such the electrodes used for cast iron are normally 55% Ni-Fe alloy, phosphor-bronze or soft-iron electrodes. Nickel-alloy electrodes produce a soft and ductile deposit. With soft iron electrodes, the carbon pick up by the weld metal may produce a medium carbon steel weld. Cracking and hardness can be prevented by preheat and post-heat. Smaller gauges of electrodes must be used to keep the heat input minimum. This is further achieved by using DCRP technique. Nickel alloy electrodes are advantageous as the current density required for these is lower than for soft iron electrode.

A buttering layer on the fusion edges prepares them for welding. This buttering layer is given by using the same Nickel-alloy electrode. This layer completely blanks off the casting from the weld metal which is to be subsequently deposited. The buttering layer ensure soft and ductile fusion zone. For economic reasons, the subsequent filling-in-runs of the weld may be made by using soft iron electrodes. The soft iron deposit is not affected by the carbon in the casting, because this has been blanked off by the previously deposited buttering layers. It is obvious that better welds with economy are made by this technique.

To reduced the contraction stresses, without any preheat, skip welding process is normally used. This reduces the concentration of contraction stresses. The casting is welded intermittently, each run of weld bead not exceeding 1.5 in. in length. Immediately after each bead is deposited, it should be lightly peened (cool worked), which expands the shrinking weld deposit, thereby reducing the contraction stresses. The short runs of weld bead have the effect of reducing the heat input and thus prevent the formation of hard zones. In casting practice, the casting should be kept cool enough to allow the welder to place his hand upon the casting, about there inches away from any welded area; if this is not possible the casting should be considered to be too hot.

It would sometimes be found that some castings may defy any attempt to be welded. These cast irons may be considered as burnt cast iron which might have undergone internal oxidation due to frequent heating to high temperatures. The material simply refuses to melt hence no welding is possible. Such unweldable cast irons are rarely met with, but it is well to know of their existence.

Thermit welding is done in case of heavy structures. However, it cannot be used on all castings because of the weld metal when it cools, Contraction of thermit steel is approximately twice that of cast iron. Therefore, if the length of the weld is more than eight times the thickness, the difference in shrinkage results in small hair-line cracks. Because of the slow cooling, a soft, ductile, merchantable weld is produced.

MALLEABLE CAST IRON :

Malleable cast iron may lose its properties due to the heating and subsequent fast cooling during welding. A hard and brittle heat affected zone as well as the weld may result. As such fusion welding of malleable cast iron is not considered to be satisfactory. This particularly applies to axy-acetylene gas welding. Use of Nickel alloy electrode may produce a ductile weld metal but the hard and brittle heat affected zone can be avoided even by preheating.

Bronze welding or "branze welding" of malleable cast iron is readily done. The filler alloy is 50:50 brass or a brass containing a small amount of nickel. The parts to be joined are bevelled to an included angle of 90°C and the edges are thoroughly cleaned. A suitable flux should be used to remove any oxides which may form during welding. Oxy-acetylene flame is used to heat locally the edges, and the area around it. The temperature should be in between 800-900°C, so that the edges do not melt. At this point, the filler is applied along the joint. This flows evenly over the prepared surface. At the edges, where the bounding occurs, zinc diffuses into the casting and forms a solid solution with iron atoms. This is responsible for the bond. The temperature is not very high and hence the properties of the base metal are not seriously affected. Consequently strong and effective joints may be produced. Branze welding may be done by arc method also.

S-G CAST IRON :

Spheroidal graphite iron can be welded easily to itself and to mild steel also. Manual arc welding process with Nickel alloy electrodes is used. Soft and ductile deposits are obtained. However, adjacent to the weld a narrow hardened zone may be produced which is insignificant for many applications. If necessary, it can be eliminated by full annealing after welding, or by tempering at 550-700 °C. Ferritic S-G iron does not require any preheating. Pearlitic varieties are preheated to about 200 °C. Oxyacetylene gas welding of S-G irons is similar to that of grey-cast iron. A cerium bearing S-G iron filler rod is used to provide weld deposits having a S-G iron structure. Braze welding also is used but the strength of such a joint is considerably less than that of the S-G iron weld metal.

9.7 ALLUMINIUM AND ITS ALLOYS :

Depending upon the way in which the aluminium and its alloys derive their strength, they can be broadly classified into two categories - non-heat treatable and heat treatable. Strength of commercial aluminium and non-heat treatable alloys is developed by strain hardening and alloying elements which solution harden the matrix to a limited extent. In the annealed state, the composition of the degree of strain hardening controls the strength. In heat-treatable alloy, strengthening is primarily due to age-hardening. It may further be strengthened by strain hardening also. In wrought products, some degree of strain-hardening is always present.

The heat of welding decreases the strength of both non-heat treatable and heat-treatable alloys except when the N-H alloys are in the annealed condition. In some cases, it lowers their corrosion resistance also.

The factors which must be given consideration before welding are -

(1) Oxide films at the surface.
(2) Fluxes used for welding.
(3) Distortion

Regardless of the composition, oxide film is always present and presents great difficulties during welding as this is a refractory oxide with a melting point of 2050 °C. Removal of this oxide film and protection against the reforming of oxide during welding are essential . Removal of oxides is mostly done mechanically by wire brushing and filling. In oxy-acetylene welding, the flux used a melts prior to the metal and dissolves the oxide film, leaving a clean surface. In TIG and MIG welding, use of DGRP technique gives excellent cathodic cleaning action.

In the welding and manual metal arc process, a flux is essential for removal of oxide films. All aluminium welding fluxes contain alkali chlorides and fluorides. As such residual fluxes on joints after welding, corrode the base metal in presence of moisture. Hence through flux removal after welding is essential. Mechanical cleaning by scrubbing with a fibre brush and boiling water is used for accessible surfaces. Non-accessible deposits are cleaned by pickling in a 10 % H_2SO_4 solution for 30 minutes, followed by rinsing in hot or cold water. The expansion rate of aluminium is considerably higher than mild steel. As such, precautions are essential to avoid distortion and buckling. This is still more aggravated by the high thermal conductivity of the aluminium. Therefore, preheating of thicker sections is usually carried out before welding. The preheat temperature should be about 350° C.

WELDING OF PURE ALUMINIUM AND NON-HEAT TRLTABLE ALLOYS :

These materials are used mainly in the cold-rolled state or as castings. When cold-rolled material is used, the structure shows elongated grains. During welding, the adjacent portions of the work pieces are heated to various temperatures depending upon the distances from the fusion zone.

After welding, three ---- distinct zones are seen in the microstructure of the welded joint, as shown in fig. 9.2.

ZONE 1 : Fusion zone. The weld metal shows the characteristics as cast structure of coarse columnar grains. The properties are comparable to that of a cast alloy.

ZONE 2 : The heat affected zone where the temperature is high enough to cause recrystallization of the cold-worked material. Equiaxed grains are seen in this zone.

ZONE 3 : The temperature is not high enough to cause recrystallization. Hence the original structure - elongated grains of the base metal is retained.

The coarse grained weld metal structure can be refined by heating to the annealing temperature and hammering.

Casting show a uniformly cast structure on welding, as the welding heat do not produce any phase change because of the absence of cold-working. The weld metal of castings is never refined by hammering.

Fusion welding non-heat treatable alloys may be carried out by TIG, MIG or oxy-acetylene welding processes. TIG and MIG processes produce welds of the finest appearance and quality. No flux is used. In both the cases, DCRP technique gives excellent results due to the cathodic cleaning. Because no flux is required, there is no danger of flux entrapment. The faster welding speeds and localized heating of these methods, produces a smaller heat affected zone with less distortion as compared to oxy-acetylene gas welding.

Welds may of course be made with the oxyacetylene gas welding, with the use of a flux and a neutral flame, but the type of joints made this way are confined to butt and corner joints. Resistance spot welding is also used on these alloys but welds are confined to lap joints.

THE HEAT TREATABLE ALUMINIUM ALLOYS :

Al-Cu, Al-Mg-Si, Al-Zn and Al-Cu-Si alloys, both rolled or cast products, come into this category. Normally, it might be required to make the weld in the age-hardened condition. The welding heat cycle is very unfavorable and the strength and hardness of the alloy is lowered in the vicinity of the weld. A large portion around the weld may be affected since the thermal conductivity of aluminium is high. The thermal cycle during welding produces five distinct zones in the welded joint as shown in Fig. 9.3.

ZONE 1 : The weld metal. The deposited weld metal shown as coarse as cast structure and consists of filler metal and some base metal fused together.

ZONE 2 : Fusion zone in base metal. In this region, partial melting of the base metal fuses with some liquid filler metal. After solidification of the weld metal are directly pulling on these fusion for faces.

ZONE 3 : During welding, the temperature of this region is raised sufficiently to enable the previously precipitated phases to get dissolved back in the aluminium matrix. The rate of cooling is sufficiently rapid to quench this solid solution effectively, thus forming a supersaturated solid solution. After period of upto six days, aging of this region takes place.

ZONE 4 : Temperature in this region does not rise to such high levels as in Zone 3, but it is sufficiently high to overage the alloy. Visible precipitation may occurs in this region. This overaged condition is undesirable as it lowers the strength and hardness of the alloy.

ZONE 5 : Unaffected region as the heating takes place to so low temperature that no change in the structure occurs.

Regardless of the fusion welding process used, these five regions are indicated. If a correction of the structure in heat affected zone is required, the entire job must be resolutionized and aged. Normally the weld deposit is made of a non-hardenable filler metal and hence remains unaffected during this re-aging. The strength of the weld is increased by making larger reinforcement or build up.

TIG and MIG welding processes are used to great advantage as in the nonhardenable alloys. Oxy-acetylene welding is less suitable. Resistance spot welding offers the best possibilities. The speed of heating and cooling is so quick and localized that there is little alteration in the microstructure or properties of the work pieces.

CHOICE OF THE FILLER METAL :

In welding wrought aluminium alloys of any type, a welding rod containing 5% Si and aluminium is generally used. This rod has a lower melting point than pure aluminium, and many other alloys of aluminium. As such , it permits the dissipation of some of the contraction stresses, as it remains molten for a longer time. Cracks in the weld and transition zone are minimized by using this type of rod. The same rod is used for gas welding of castings, as well as for TIG and MIG welding except in some special cases where high corrosion resistance is of prime importance. In such cases, a core wire of the same composition as the base metal, is used.

9.8 MAGNESIUM ALLOYS :

Far too many welders have grave doubts about the possibility of welding magnesium and its alloys Rumours about fire risks tend to be exaggerated. Except in thinnest sheets, any chances of magnesium firing during the course of welding is a direct result of carelessness.

Magnesium is rarely used as a pure metal. A number of alloys are extensively used in aircraft industry, as rolled products or as casting. Important alloys are Mg-Al, Mg-Zn-Zr, Mg-Zn-Th, Mg-Zn-Zr-Rare earth combinations.

The welding problems encountered with magnesium alloys are ------ quite similar to those of aluminium. These are oxidation, high thermal conductivity and expansion, low melting point, cracking and flux removal.

OXIDATION :

Magnesium rapidly oxidizes on heating to its melting point - a condition always found during welding. As such the arc and gas welding requires a protective shield of inert gas or a flux during welding. Apart from this the base metal itself is normally covered with a layer of MgO. As such a cleaning treatment, similar to that given to aluminium alloys, is necessary before welding. Cathodic cleaning is also used during TIG welding.

HIGH THERMAL CONDUCTIVITY AND THERMAL EXPANSION :

During welding, because of the high thermal conductivity of magnesium, large amount of heat is lost to the nearby base metal heating it to high temperatures. The heat- flow may tend to be uneven. Coupled with this fact is a very high thermal expansion contraction rate. As a result, uneven expansion and contraction may occur, giving rise to buckling and distortion. Because of this high contraction, if allowance is not made, distortion may result in cracking. Preheating is necessary to balance these dimensional changes.

LOW MELTING POINT :

Magnesium alloys have quite lower melting points. A preheat may normally be used. As such, to avoid the danger of excessive melting of the base metal, welding speeds may have to be fast.

CRACKING :

Magnesium is more liable to crack during welding. Not only may cracking take place during welding, but also after a considerable lapse of time to prevent this, stress relieving is often carried out by heating the component to a temperature of 260 °C for one hour or so. Higher temperatures and longer times are detrimental and result in grain growth and overaging of the heat-treatable alloys.

After welding, straightening of some sections may be needed. The straightening should be done at a temperature of 200-300 °C .

FLUX REMOVAL :

Flux removal is essential in oxy-acetylene welding. Flux residue should be removed by brushing in hot running water. Then the component should be immersed in a solution of 5% dichromate and hot water.

SELECTION OF WELDING PROCESS :

A magnesium alloys are not welded by the manual metal arc welding. The preferred processes are TIG and MIG welding. Argon provides satisfactory protection to the work piece and excellent welds are produced. A filler rod, similar in composition to the base metal, is used.

Oxy-acetylene welding may produce satisfactory result with due care. However, it is limited to butt and corner joints. Flux removal after welding is essential. Resistance spot welding process finds many applications on lap joints required on relatively thin sections, especially those used in the air-craft industry.

Magnesium castings are welded in much the same way about 200-300°C. Cooling after weldings require a preheat to possible.

9.9 WELDING OF DISSIMILAR MATERIALS :

For many application it is necessary to weld dissimilar materials. Quite often, this is required in maintenance, the most frequent one being welding of cast iron to mild steel. The two materials may be entirely different to each other with respect to their physical properties, mechanical properties and metallurgical characteristics. This requires a careful choice of filler metal and the welding process. Before doing so, it is essential to understand the difficulties that may normally be encountered during welding of dissimilar materials. These difficulties are mainly due to the differences in thermal expansion, thermal and electrical conductivity, oxidation, and dilution of the weld deposit.

(1) Expansion :

The rates of thermal expansions of the two materials to be welded should be known. If the expansion rates are nearly equal, then no special difficulty is experienced in controling distortion and dimensional changes during welding. If there is considerable difference between the two expansion rates, then this may possibly be overcome by applying a higher preheat to the material with a lower expansion rate.

(2) Conduction :

In order to reduce the heat losses during welding, it may be necessary to apply a greater amount of heat to the material which has the best thermal conductivity. Preheating one plate more than the other is one way of doing this, whilst during actual welding, the source of heat may be applied so as to concentrate more on the material which is better conductor.

Difference in electric conductivity should be considered for resistances spot welding. With dissimilar materials, the difference in resistivities to current flow will result unequal heating of the parts to be welded. This difference must be balanced by way of proper designing and choosing electrodes of different areas.

(3) Oxidation :

An oxide layer always prevents the joining of any two materials together, similar or dissimilar. Similar precautions, as are observed in case of aluminium welding, are necessary.

(4) Dilution of the weld deposit :

When a root run of weld is deposited between two edges to be joined, dilution of weld material with the base material occurs, and may be as high as 45%. If two mild steel plates are welded, this dilution is not serious, because there is no detrimental effect on the properties of the material and weld metal. However, if dissimilar metals are joined, the defects of dilution may be disastrous. When fusion welding dissimilar materials, dilution can be controlled by buttering on one or both surfaces to be joined. When buttering, metal is deposited along the fusion face of the material. By doing this, dilution with the base metal is reduced to below 20%, which for many applications is acceptable. The object in cutting down on dilution is normally to prevent the formation of a hard, brittle constituent in the weld metal structure, there reducing the risk of cracking. The weld metal and H.A. Zone must be ductile enough. The most widely used industrial method of welding dissimilar materials are flash butt welding, upset butt welding, pressure gas welding, spot welding, manual metals arc welding, MIG welding, friction welding, bronze welding (braze welding) and soldering. The first three methods give excellent quality welds, but first two require high capital equipment. Arc welding processes give satisfactory welds and are used for economic reasons. Branze- welding produces joints of moderate strength. In the following paras, we shall deal with the examples of welding dissimilar metals.

MILD STEEL TO CAST IRON :

Mild steel contains less than 0.3% while grey cast iron contains about 3-3.5 % C and is inherently brittle while steel is ductile. Thermal expansion and contraction are almost equal, but because of brittleness, cast iron may crack during contraction after welding during cooling stage, to assist in controlling the stress due to contraction. In order to keep the carbon out of the weld area, the cast iron is butter with Nickel-alloy as shown in Fig, . 9.4., using manual metal arc process. After buttering, the remainder of the joint may be filled up with a soft iron deposit. This type of joint is ideal for many applications. Bronze welding may also be used. It should be remembered that, after welding, the joint should reheated (post-heating) and cooled slowly to prevent the cracking in cast iron through uneven contraction.

AUSTENITIC STAINLESS STEEL TO MILD STEEL :

This combination is often welded together. Dilution of the base material with the deposited metal is still a problem. In order to out down on dilution, buttering of the mild steel edges by the manual metal arc method is recommended, using a 25/20 Cr:Ni stainless steel electrode. This ensure that fusion zone is austenitic and hence, ductile. It should be noted that the buttering is done with an austenitic stainless steel electrode, containing a high Nickel content. If the normal austenitic stainless steel (18.8) buttering would have been done, then a hard martensitic deposit would have resulted because of dilution of the buttering layer. This would have been prone to cracking. The nickel content of the weld metal should not be less than 6% otherwise hard martensite forms. After buttering, the rest of the joint may be completed by using a more conventional stabilized 18.8 type electrode.

AUSTENITIC STAINLESS STEEL TO LOW STEELS :

In the earlier joints, the heat affected zone is ignored as mild steel is quite ductile, and so is the heat affected zone. This is so because mild steel has low hardenability. However, when austenitic stainless steel is to be welded to hardenable low alloy steel, in addition to the problem of dilution, there is a risk of cracking, occurring in the heat affected zone as well. Manual metal arc process is favoured for this joint, but because of the localized heat input, rapid cooling takes place, forming martensite in the H.A.Zone. To overcome this, a preheat of 250°C is necessary on the hardenable side. To control dilution, a 25/20 Cr/Ni type electrode should be used to deposit a buttering layer on the hardenable steel edges. After the first run, subsequent welding may be done with the normal 18/8 type stabilized electrode. After welding, a post-heat should be applied. Small sections of round bars and similar shapes, may be joined by friction welding.

COPPER TO STEELS AND STAINLESS STEEL :

This may be done either by bronze welding, or metal arc welding. When metal arc process is used, the first important factor to be consider is the heat losses by thermal conduction through copper. This may be controlled by adequate pre-heating. A buttering layer of nickel is then applied to the face of copper as shown in Fig. 9.5 (a) , before welding. This acts as a barrier to heat losses into the copper when depositing subsequent layers of weld metal. A buttering layer of nickel-iron alloy should be deposited on the steel side of the joint, as shown in Fig. 9.5(b). The remainder of the joint may now be filled up by depositing layers of weld metal using a monel (Ni-Cu alloy) electrode as shown in Fig. 9.5 (c). It will be noted that the monel is not directly deposited on steel as this would form a brittle fusion zone material, resulting in possible cracking.

The other popular method is bronze welding.

When copper has to be joined to austenitic stainless steel, the surface of the copper is again buttered with nickel. It is not necessary to butter the surface of the austenitic stainless steel. The remainder of the joint may be completed with an austenitic stainless steel electrode. Preheating is essential due to the high thermal conductivity of copper.

WELDING OF AUSTENITIC STAINLESS STEEL CLAD STEEL :

Nickel, monel, inconel or stainless steel are often used for corrosion resisting conditions. However, they are expensive. To cut costs, a thin layer of any of these materials is applied to a thick steel section. By this, costs are effectively reduced and a suitable corrosion resisting surface is obtained. This is known as cladding. Austenitic stainless steel clad steels are most popular. The corrosion resisting surface on the clad steel is about 10-20% of the total thickness.

The metallurgical problems that can arise during welding are quite similar to those that occur when joining two dissimilar materials together. If during welding, dilution takes place between the clad material and the base, there is a possibility martensite formation, high hardness and probable cracking. Hence dilution should never be allowed. "Never, never penetrate the cladding " must be never forgotten and should be honored. For practical welding purposes, manual metal are process is preferred. The steel side of the weld must be filled first.

Consider the welding of steel side in the proposed joint. If penetration is excessive and even about 3% Cr is diluted with the weld metal, the high cooling rate after welding will produce martensite. This results in hardness, brittleness and possibility of cracking. Note that the design of the joint is such that the root face is on the clad side, as shown in Fig. 9.6 . After completely filling the steel side of the joint using a steel electrode, the joint is turned over. The weld groove is chipped out until clean faced steel is seen. This is to remove any unfused metal, slag etc. The slag may cause porosity while the clad side. The clad side of the joint is now welded. The first run on the weld on clad side of the joint is made with a 25/20 Cr/Ni electrode. During welding, the penetration of the steel deposit takes place. This is not harmful as the iron pick up is not sufficient to alter the soft ductile deposit of 25/20 Cr-Ni first run metal. The remainder of the joint may be composited with an electrode of the same composition as the austenitic stainless steel cladding itself. Niobium stabilized electrodes are used for welding. The finished weld is shown in Fig. 9.7 .

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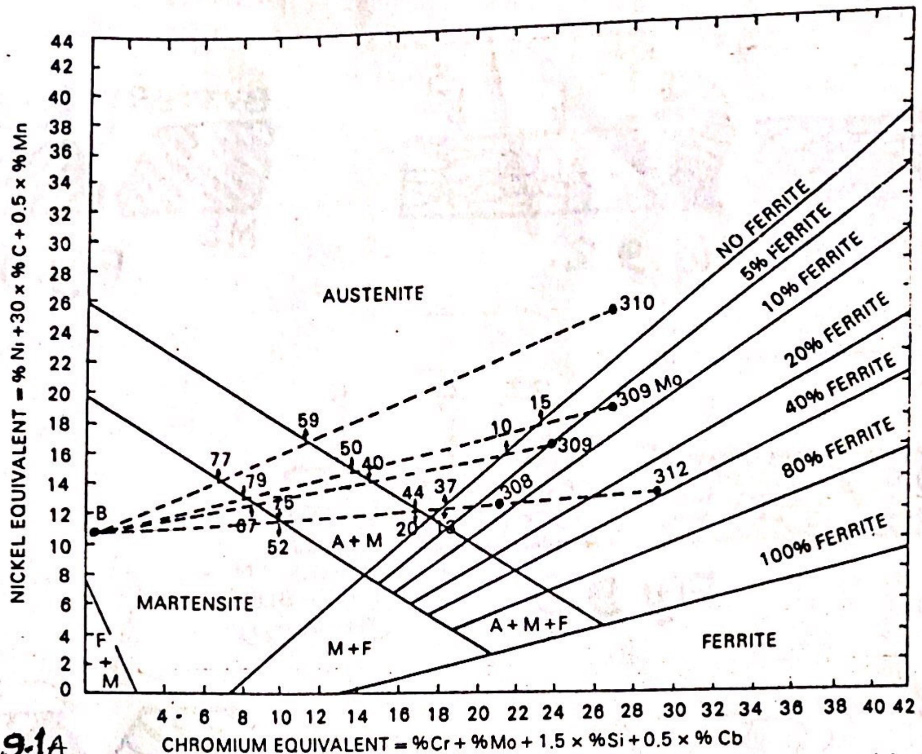
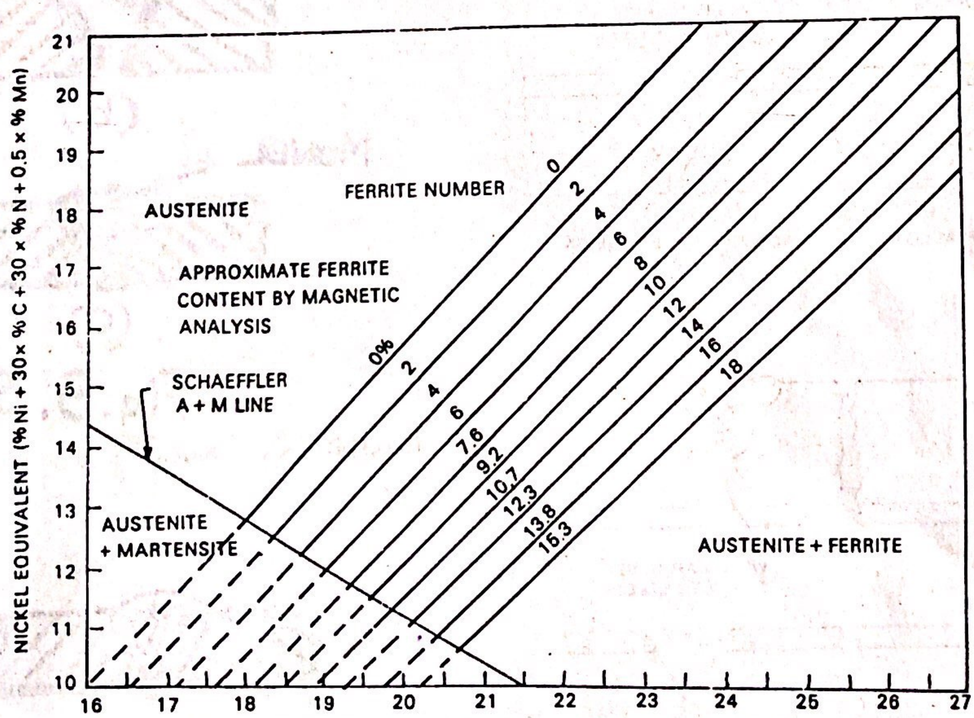


9.1A

Fig. ~~10.33~~: Schaeffler diagram showing dilution direction lines for A105 Gr. II steel and various stainless steel electrodes



9.1B

Fig. ~~10.25~~: The Delong constitution diagram for austenitic stainless steel weld-metal

WELD ZONES IN NON HT. TREATABLE ALLOYS

Fig.9.2.

Fig.9.4.

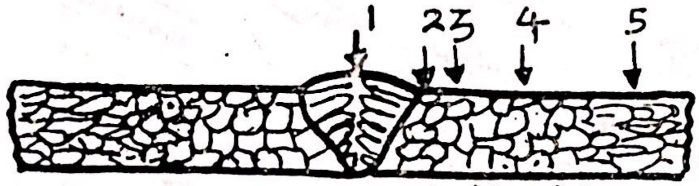


Fig. 9.3. WELD ZONES IN HT. TREATABLE ALLOYS (Al-alloys)

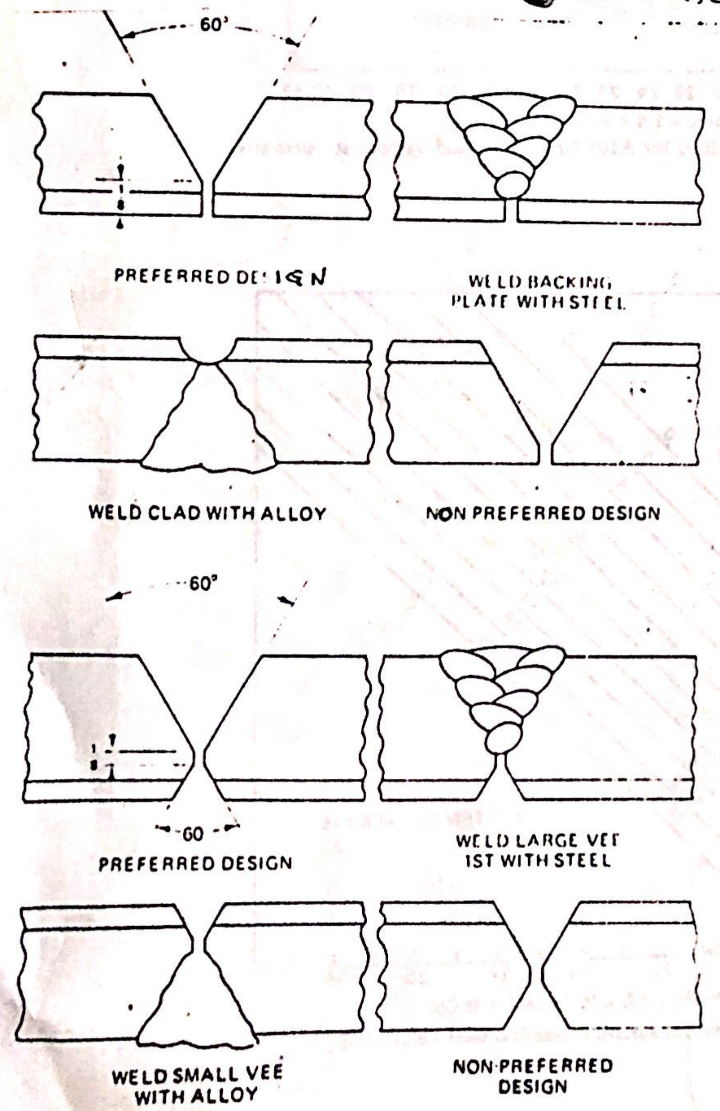


FIGURE 9.6 Weld joint design for clad plate.

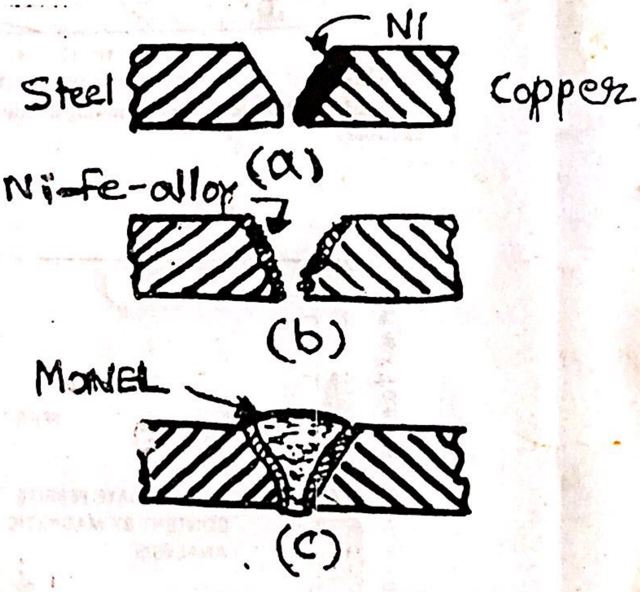


Fig.9.5.

Buttering layer of Ni on copper

Fig.9.7. Finished weld structure