PRODUCTION AND FABRICATION OF CLAD STEEL FOR PRESSURE VESSELS IN CHEMICAL PROCESS INDUSTRY IN INDIA

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INTRODUCTION

In the quest of achieving self sufficiency, various new and advanced process technologies are being employed by Indian Chemical Process Industry.

With the advancement of process technology, newer equipments to withstand much arduous service environments like more corrosive environments, higher temperatures and higher pressures had to be employed. This necessiated the use of nobler but costlier materials to be in contact with the intended service medium. With increasing emphasis on economics and easy fabricability, it became a natural choice to employ a low cost material carbon steel or low alloy steel, to provide the structural strength for the process equipment, which had been caldded with the layer of the costlier material that would be in contact with the service medium. In the fabrication of these materials for pressure vessels various new factors hitherto not considered in the fabrication of solid materials need to be considered.

A brief description of the various clad material combination used in Indian Chemical Process Industry and various methods of manufacture of clad plates employed as also the various general aspects associated with the welding fabrication of clad plates is discussed here.

Welding procedures of individual clad systems and detailed metallurgical discussions have not been covered in this brief discussions.

Clad Steel

A clad metal is a composite of two or more metallic materials joined in an essentially continuous manner at the mating surface by a metallurgical bond. Generally, a thick supporting, low cost base metal is bonded to a thinner layer of another metal that possesses special properties like corrosion resistance, thermal or electrical conductivity, abrasion, resistance, decorative qualities, hyginic properties etc. The thick low cost backing plate usually supplies the required structural strength as well as it affords appreciable economy over solid plates of the special metarial.

Methods of Clad plate production

In order to create a good bond between two metals, continuity should be established at the atomic level. If this bond is to have sufficient engineering properties for practical application, it must be established over the complete area of the interface. The main difficulty in producing a consistent bond between two metals is the need to produce intimate contact over the entire surface. This is prevented by the absorbed gas and oxide films on any surface. There are several ways in which atomic contact can be made.

The main processes used to produce cladding on a carbon or low alloy steel backing material are fusion welding, forge welding, casting, brazing, diffusion bonding friction welding, power compaction etc.

Of these processes forge welding process has been most widely used for the manufacture of clad plates. The following two methods failling under the classification of forge welding are the ones most economically exploited for the production of clad plates.

1. Pressure Cladding
2. Explosion Cladding

Pressure Cladding : Broadly speaking pressure cladding refers to those processes that utilise pressure, usually by rolling, to deform plastically the interfaces of the two components of the composite, creating a metallurgical bond. Heat is employed in order to decrease the pressure required to effect this plastic deformation. This process is popularly known as roll bonding or roll cladding.

In roll bonding process, normally two cladding plates are sandwiched between two plates of the backing material. The two cladding are separated from one another by a layer of a refractory parting compound which prevents any bonding between them. In order to promote the bonding between the backing plate and cladding plate, the oxide layer on the backing material surface should be removed by shot-peening. The stainless steel surface should be electroplated with nickel for preventing the formation of tenacious chromium oxide layer. This sandwich assembly would be secured together by tack welding all around in a vacum environment to avoid absorbed gases and this assembly would be heated in a furnace. The heated sandwich pack would then be hot rolled between two rollers in order to effect sufficient plastic deformation and pressure to bring about the required atomic contact between the surfaces to be bonded. The rolled assembly may be subjected to the heat treatment specified for the backing plate. After the heat treatment the assembly would be sheared all around to separate the two clad plates along the parting compound.

Explosion cladding is a high energy forming process which is suitably modified to become an effective welding technique. In this technique, the energy of detonating explosives is controlled and directed in such a way that similar and dissimilar metals can be metallurgically bonded without the uses of any filler metals.

The backing plate and the clad plate, in their final dimensions would be cleaned throughly before bonding. The backing plate would be kept on a firm ground and the clad plate kept on it, with a little gap called stand-off, so that a predetermined 'angle' would be suspended between the joining sufarces. A predetermined quantum of explosive charge and detonator would be laid over the clad material plate, The explosive charge would be detonated so that the controlled detonation would start from one end of the plate and advance towards the other end at an uniform rate.

The high energy developed due to the explosion would deform the clad material plate and propell it at a great velocity towards the backing plate kept below. The high velocity and pressure developed at the point of contact would also generate a high temperature that would melt a thin film containing the surface oxides and foreign materials. This thin film would be jetted out leaving fresh virgin surfaces of the materials to be forced into intimate contact under the high pressure, resulting in a good metallurgical bond. The metallic jet would be formed continuously ahead of the impact region and a part of it trapped between the colliding prime-metal and the backing plate and subsequently would solidify in a regularly spaced pool resulting in the appearance of a wavy bond.

This process would enable the production of almost any dissimilar metal combination used in engineering applications at a very fast rate, viz, within a fraction of a second. Due to very little melting associated with this process, many widely different materials that could not be joined by any other fusion welding processes, could be explosion cladded.

Fusion Weld Cladding : Fusion welding processes employed for effecting a cladding are usually automated. The first recorded method using several rod electrodes required atleast two passes to produce both satisfactory bond and acceptable surface properties, because of dilution. The next development was to use strip electrodes which allowed sufficient control of electrode composition and polarity to keep dilution within acceptable limits and to complete production in one pass Subsequent development of dual strip welding, where a second strip, possibly produced by power metallurgy, is added to the weld as it progresses. However, this method is more sophisticated as it required careful control of welding parameters. Electrical resistance welding is also another method employed for clad production but as this process produces a discontinuous bond it cannot, in the real sense, be termed as a cladding operation. Another method employed for heavier pressure vessels, is that in which the clad material layer is welded on to the surface by electroslag welding which entails the solidification on the base plate of a molten pool of stainless steel produced by the resistance heating. In recent times, pulsed gas metal arc welding process is being developed to deposite clad layers with very low dilution rates.

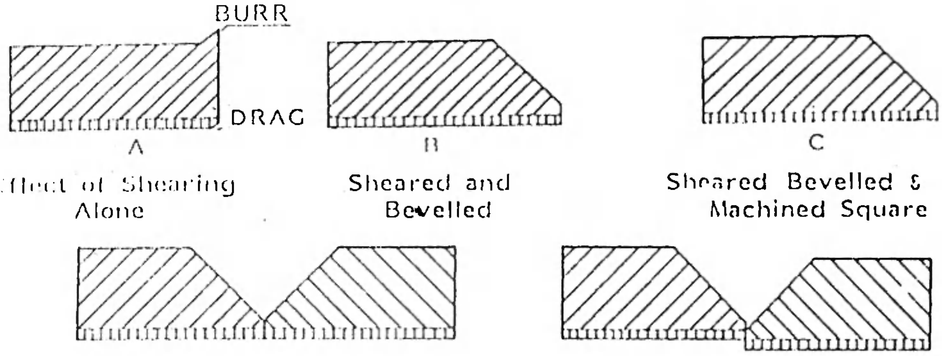
Friction Welding : The recent developments in friction welding has opened up another possiblity of cladding on base materials at a rapid rate. The clad material in the form of rods are rotated on the surface of backing material so that the friction generated heat would weld a small portion at the tip of the rod on to the backing substrate. The rotation is continued till sufficient material has transferred and the bond between the rod and deposit is broken leaving the deposit in its place. The process is repeated at the location immediately adjacent to the previous deposit so as to cover the entire area. This process also involves little surface fusion and hence joints between various combination of materials of wide metallurgical difference could be produced.

Casting : The production of bimetallic ingots by casting is less widespread but deserves considerable attention due to its decreased cost of operation. In this process, a specially prepared stainless plate is suspended asymmetrically in an ingot mould which is then filled by bottom pouring. The plate preparation requires complete removal of the oxide film since the surface energy of metal oxides is such as to make impossible the wetting of this surface by the molten metal. The teeming technique also requires careful control to ensure a good and uniform bond. In practical terms there exist a number of factors contributing to poorer quality, for example large amount of scaling, a poor and discontinuous bond and a large amount of scrap, all of which must be set against the decreased cost of production, in comparision to the sandwich pack rolling.

Availability of Clad Plates

Clad plates are available from international sources in large sizes ranging from 15 ft to 40 ft in length and 48" to 178" in width, with circles of 84" to 174" in diameter. Claddings of Nickel, Monel, Cupronickle, Ferritic Stainless Steels, Austenitic stainless steel, inconels, Duplex stainless steels, Titanium, Aluminium etc.

Effect of shearing & poor alignment



A — Effect of Shearing Alone; B — Sheared and Bevelled; C — Sheared Bevelled & Machined Square

D — Correct Alignment of Clad Plates; E — Incorrect Alignment

Clad plates of stainless steels (especially austenitic), nickel and 5% Ni alloys are available from indigenous sources to a limited extent in the size ranges upto 2M in length and 1.25M in width. The indigenous manufacturers are planning to make clad plates available in larger sizes also.

Typical thickness of the cladding layer could be 10%, 15% and 20% of the total plate thickness, except in a few exceptional cases where the cladding may be upto 50% of the thickness. The practical minimum and maximum, thickness of the clad layer are believed to be 0.030" and 0.25" respectively.

Fabrication of Clad Plates

The clad plate can be treated as if it is an integral unit for the purposes of mechanical operations. The clad plates can be cut by mechanical shearing or by a thermal cutting processes.

Mechanical shearing of clad plates should be done with the clad side up in order to throw the burrs in to the backing steel side and avoid separation of the cladding. Even with this method, some drag of the cladding material into the base plate is inevitable and this should be allowed for in edge preparation, especially of thicker plates. A correct scheme of joint preparation by shearing and machining is given in fig. 1.

Thermal cutting of clad steels from the steel side can be done by using oxy-acytelene flame cutting method by employing a cutting nozzle of one size larger than the usual for an equivalent steel thickness. The cutting should be done with the clad side at the bottom so as to take advantage of the steel melt that will aid the cutting of stainless steel and other higher alloys. Preheating at the start of the cut is advisable for stainless steel clad plates. While cutting monel and inconel clad plates, preheating throughout the cut is necessary in advance of the cutting flame. Plasma arc cutting can be an effective method of cutting clad plates to close tolerances. Bevelling of the steel side can be done in the usual manner. The final preparation of the edge, however, should be always done by machining.

It can be generally assumed that integrally clad plates produced by the mills behave like a solid plate when subjected to fabrication operations such as bending, rolling, pressing and spining. Although clad materials are less expensive than solid corrosion resistant alloy materials, they are by no means cheap enough to be treated like mild steel. In general, the guiding principle should be to handle them as if they were composed entirely of the material that form the cladding. During the fabrication operations the cladding should be protected against mechanical damage and impregnation by foreign particles such as steel chips and sand either of which would seriously effect the corrosion resistance. During hot forming, the temperature and furnace atmospheres must be carefully selected to suit the nature of the cladding material.

Choice of Welding Processes

It is a normal practice to treat the steel base plate and the cladding separately for welding even though in some of the cases the entire joint could be welded by a weldmetal of clad metal composition.

For welding the steel backing materials the following processes could be used :-

(i) Shielded Metal Arc Welding (SMAW)

(ii) Submerged Arc Welding (SAW)

(iii) Flux Cored Arc Welding Process (FCAW)

(iv) Gas Metal Arc Welding with pulsed current (PGMAW)

For welding the cladding side, the following processes are usually employed :-

(i) Shielded Metal Arc Welding (SMAW)

(ii) Gas Tungsten Arc Welding (GTAW)

(iii) Pulsed Gas metal Arc Welding (PGMAW)

(iv) Submerged Arc Welding (SAW) for strip clad plate SMAW is universally applied for all thicknesses. GTAW is not applied for barrier layer welding beacuse of high dilution and consequent cracking. However, this process is suitable for filling passes.

Selection of Welding Material

Welding electrode and electrode wires chosen for the welding of the backing material shall be capable of depositing a weld metal matching the mechanical properties and chemical composition of the parent metal. The selection criteria shall be that applicable to the non clad metals.

The choice of welding consumables on the clad side shall depend on such considerations like dilution, chemical composition of the cladding and corrosion reistance. Table 1 gives some examples of choices of welding consumables for welding the clad sides.

When the barrier of the first pass is welded on the backing metal deposit from the clad side, a richer alloyed weld metal has to be selected to allow for dilution of the weld metals by the backing metals, in order to prevent the occurance of hard and brittle weld metal highly susceptible to cracking.

Salient Features associated with the welding of clad steels.

In the fabrication of any clad steel the vital requirement is the maintenance of continuity of the cladding. This requirement controls the design and location of the joint, its preparation and welding technique. This requirement of continuity must be associated with the strength requirements demanded by the code specifications of pressure vessels and the like. Whenever possible, the aim should be to employ a butt weld as this facilitates easy welding and provides optimum strength. Other forms of joints should be used only as a second choice.

In the clad steels, two different types of materials are involved and it could be necessary to make two welds each requiring different filler material.

The welding of the steel side, in general, follows the conventional lines and hence need to be discussed only in so far as it affects the problem of interfusion with the cladding metal itself or with the weld on the clad side.

Similar problem of interfusion also exist while welding the clad side but there are additional factors to be considered such as porosity, undercutting, heat affected sense and surface finish.

In order to avoid interfusion in some circumstances, the entire weld may have to be made with the electrode or filler rod used for the clad side giving the joint which combines the required corrosion resistance with adequate strength under service conditions. Even in this method, the nature of the fusion zone between the weld metal and steel base metal must still be considered in relation to the dilution of weld deposit and any effect upon the corrosion resistance of the ductility of the joint.

In the more popularly known procedure of making two separate welds, there are two alternatives :-

a) The steel side can be welded first and the joint can be completed by welding the clad side later.

b) The clad side can be welded first and the steel side joint completed later.

Whenever the steel weld metal is laid on a material of the clad composition under consideration, the weld metal will be contaminated by the cladding material and the resultant deposit is likely to be martensitic and therefore hard and brittle, Careful control of penetration and welding technique may minimize this contamination to some extent, but the danger always persists. Associated with this is the risk of cracking or, atleast a ductility too poor to develop satisfactory mechanical propereties in the joint. This can be avoided by depositing weld material akin to the cladding on to the steel.

When separate welds are made from the backing metal side with the clad metal being welded first, it becomes necessary to interpose a transition or buffer layer between the steel side and the clad side weld, in order to prevent the formation of a brittle layer at the interfusion zone. One popular method is to use high purity iron (ARMCO iron or equivalent) deposited on the already present alloy steel weld, in one or two layers before continuing the welding on the steel side using the electrodes recommended for the steel side. In general, the material for the buffer layer shall be chosen based upon the metallurgical considerations.

When the weld is made by depositing alloy weld metal on the steel, hard deposits can be avoided even though dilution of the corrosion resistant deposits is inevitable in the first layer of the weld. Significance of this factor depends on the cladding thickness, the number of subsequent runs, the welding technique and the intended service conditions of the fabricated equipment. With cladding of austenitic stainless steels and inconel, the dilution may be offset by the use of filler metals with alloy contents greater than that would be necessary if there were no Iron pick up. With Nickel and Monel caldding, it is not possible to compensate for dilution by electrode or filler metal. For these materials use of specially developed electrodes having very low carbon and iron content must be employed alongwith an appropriate welding technique that would minimise dilution.

Thinner the cladding, greater would be the risk of dilution of any weld metal made from clad side. Therefore the fabricator must bear in mind, constantly, the minimum thickness of cladding which can be welded without endangering continuity or corrosion reistant surface. We should employ only highly skilled welders who are especially trained for clad welding in order to achieve good results.

Preheating for Welding Clad Steels

Preheating is employed to lower the temperature gradient between the weld metal and the backing material. This would help in preventing cracks in the weld and the backing material. Besides, preheat decreases the shrinkage stresses in the weldment and helps reduce distortion. Preheating is normally recommended if the backing material is of high tensile strength, the clad plates are thick or if the weldment is of a rigid design. A preheat of upto 150°C to 220°C is generally sufficient.

Preheating becomes mandatory in case of all straight chromium stainless steel cladding except for the type 405 Straight Chromium steels are martensitic and possesses a pronounced air hardening nature, whereas 405 is a ferrite stainless steel.

Butt Welding in Clad Steels

Joint Preparation : Butt joint is the most preferred joint design for clad materials. While designing the edge form, the following points must be kept in mind :

a) Accurate joint alignment would be necessary

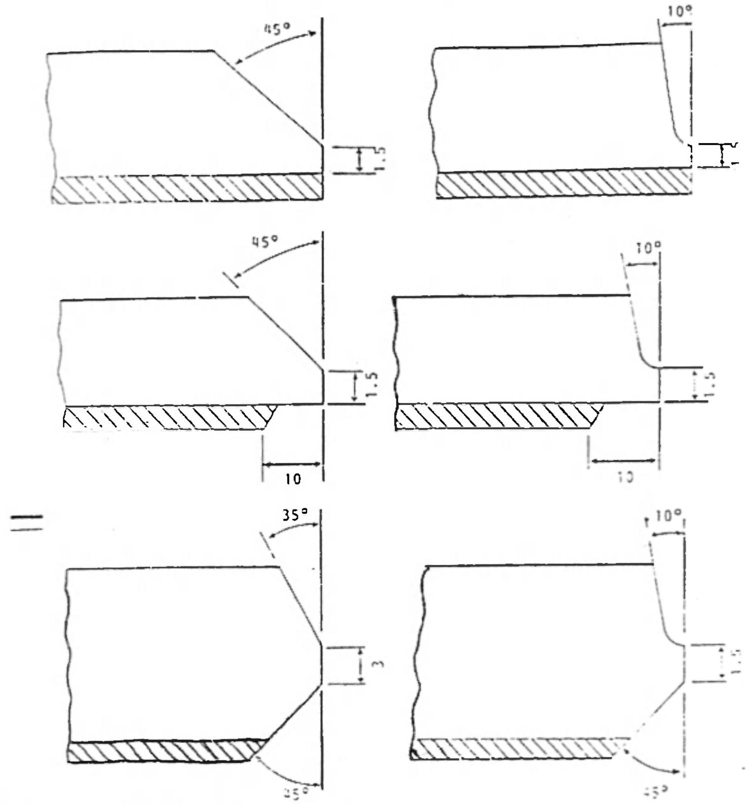
b) A small lip of the steel material should be left behind the cladding in order to prevent the melting of the cladding during the welding of the backing steel side.

Popular designs of butt welds in clad steels are shown in fig. 3.

Welding sequence : There are different edge forms and sequences of welding for butt joints. As mentioned earlier two work situations could emerge while welding the clad joints. In one case, both sides of the joint would be accessible for welding. In the other case the access could be restricted to steel side only.

When the weld joint is accessible for welding from both sides, the recommended welding sequence would be

Fig. 3 : Design of butt Joints in Clad Steel



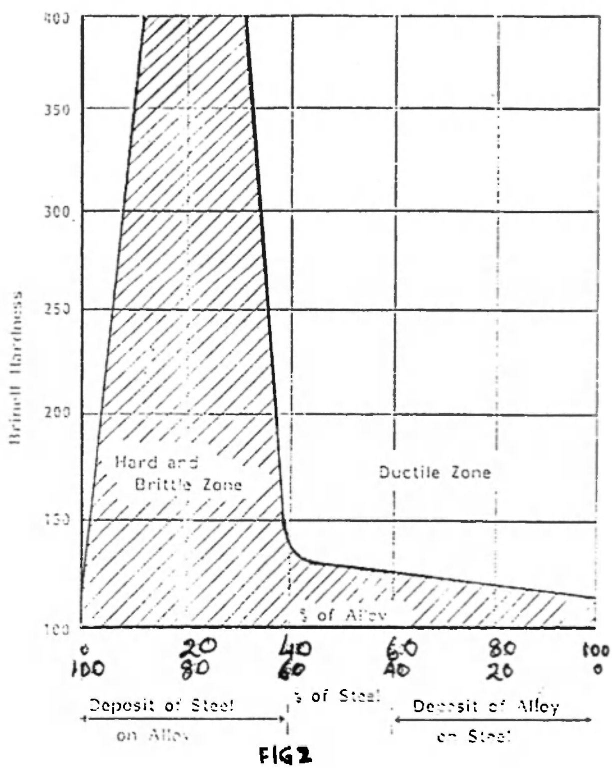


FIG 2

as illustrated in fig. 4 where two schemes have been indicated .

In the scheme 1, the welding is first completed from the backing metal side using electrodes matching the parent metal. While laying the root pass, it should be ensured that it does not fuse with the caldding so as to avoid formation of brittle zone. In order to avoid such accidental fusion with clad metal, enough root face in the backing metal (dimension 'X' in fig.4) should be provided. After welding from the backing metal side, the root should be cleaned by gouging before laying the corrosion resistant layers on the clad side. This scheme is quite economical as far as material and labour costs are concerned. However, it calls for an uniform fit-up and close control of welding parameters during the first pass from backing metal side. In the case of larger thicknesses and diameters of vessels it is extremely difficult to get consistant results by this scheme because of the variation of root gap and occurance of local offset.

Scheme No. 2 has the clad metal stripped back for a distance of about 10 mm from the plate edge. The backing metal is first welded from the 'V' side. The root is cleaned by gouging before welding flush with the backing metal using the electrodes suitable for the backing metal. Sebsequently, the clad thickness is built up using the corrosion resistant weld metal.

When the joint is accessible from the steel side only as in the case of small diameter piping, the entire welding should be completed from the steel side. The recommended welding sequences are illustrated in fig. 5.

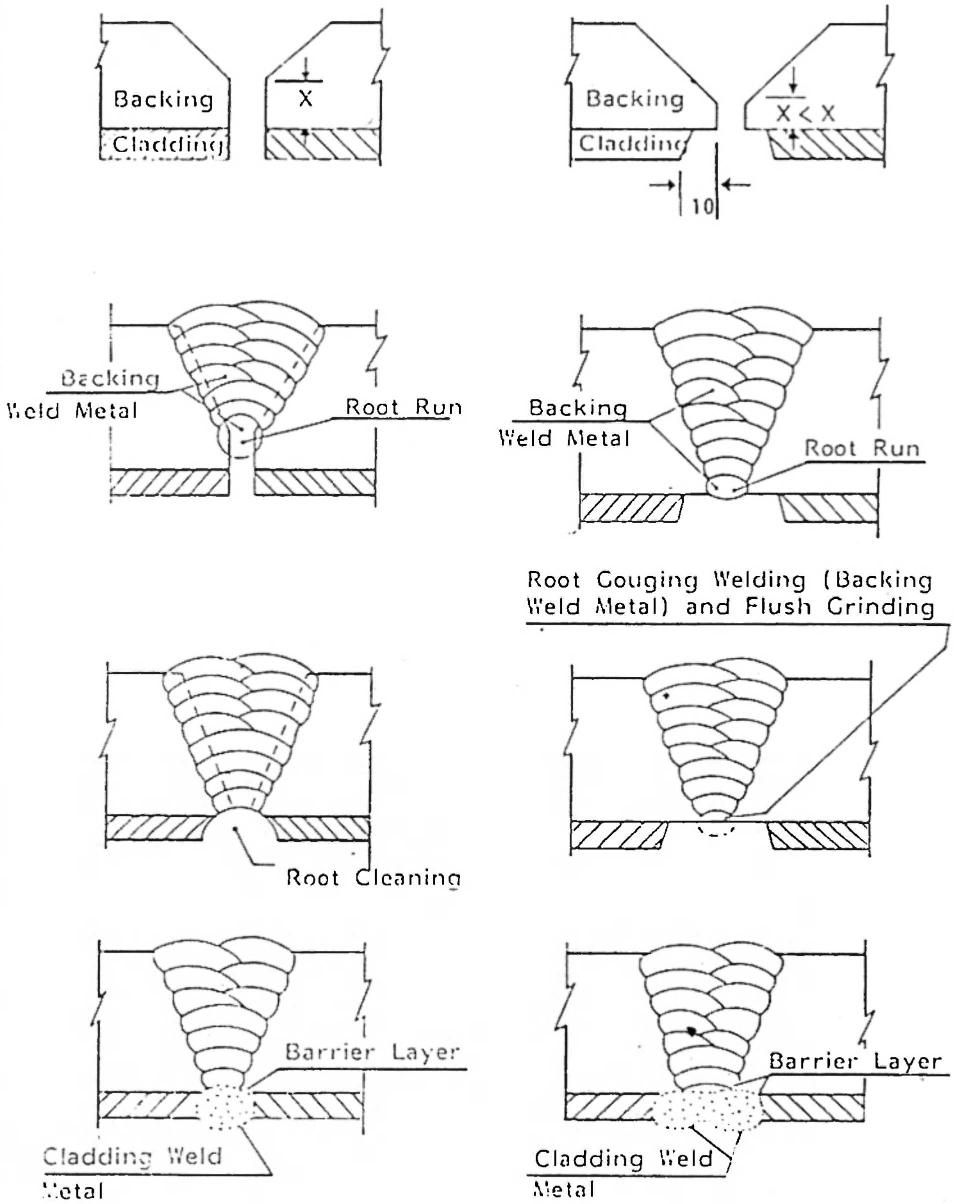
Here also two scheme viz, 1 & 2 have been indicated

In Scheme 1, complete welding should be done using welding consumables appropriate to the cladding. Such a sequence may not be acceptable for certain applications where the steel side has to be welded using a filler material appropriate to the steel grade.

Fig. 4 : Welding Sequence forButt Joints

Scheme 1 — Both Sides Accessible

Scheme 2 — Both Sides Accessible



In scheme 2, the cladding is welded using the appropriate filler. Next, two layers of high purity iron (ARMCO Iron) before switching over to the use of filler metal appropriate to the steel side, using stringer bead technique.

High purity iron deposit gets sandwiched between the alloy and steel deposits and provides a buffer.

The edge forms described earlier hold good for downhand, vertical, overhead and other positions of butt weld joints. However, in case of horizontal and overhead butt welds, more runs and a guage or two smaller than the usual size of electrodes should be used compared to downhand and vertical butt welds.

Tee, Lap and Corner welds in clad steels

Even though one always aims at employing butt welding on clad plates, there are occasions when it is necessary to imply other types of joints as indicated in Fig. 6. Corner joints can, to an extent, be obviated by employing radiused section using two butt welds as shown in figure 6 but, it should be kept in mind that such radiused joints increase the cost of fabrication.

Fig. 6 also illustrates the welding sequence for fillet and corner joints. But the essential requirements remain as always that is continuity of cladding, avoidance of brittle layers and achieving optimum joints strength.

Precautions during Heat Treatment of Clad Steels

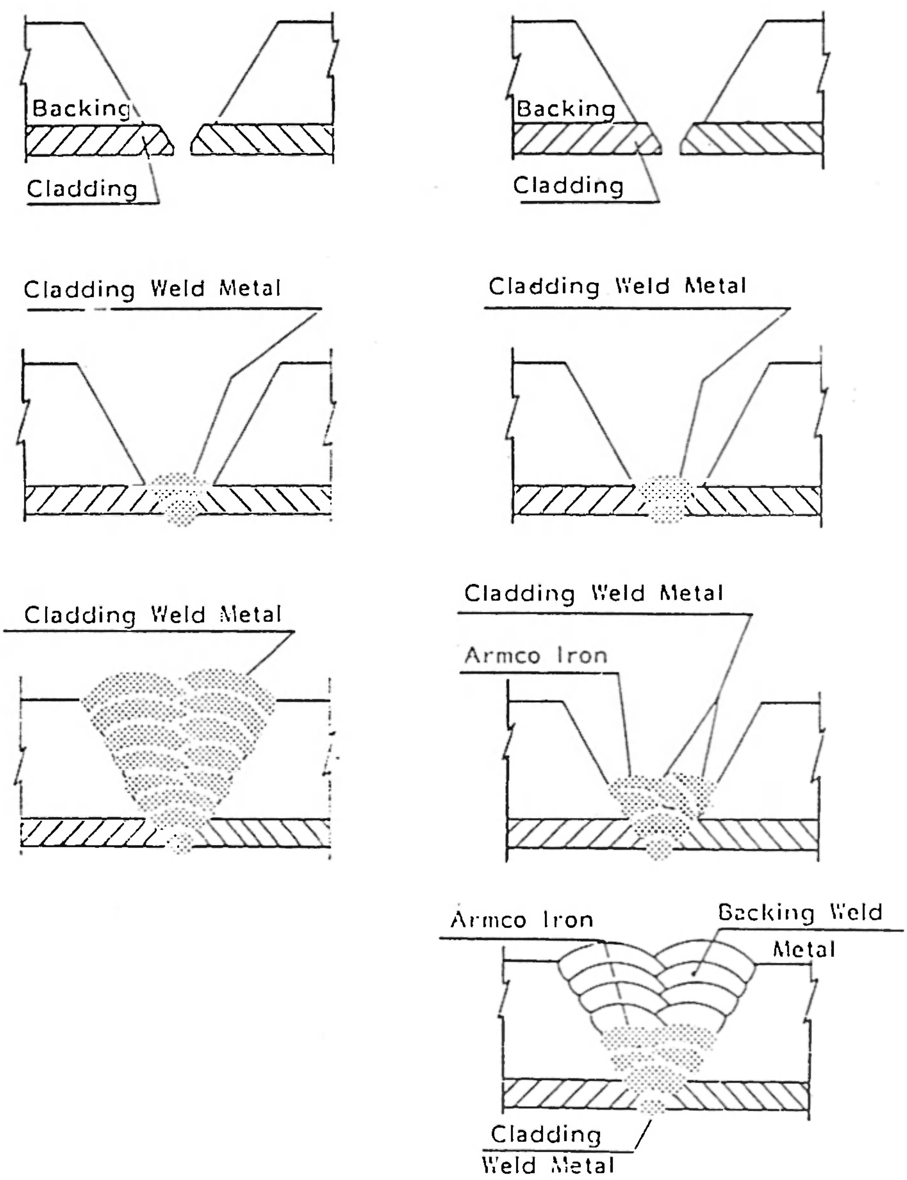
When post weld stress relief is found necessary for the backing steel side, care should be taken to avoid prolonged soaking in order to avoid complications due to grain growth, embrittlement, oxidation etc. The time and temperature are to be precisely controlled. Wherever possible, muffle type furnaces should be employed to avoid flame impingement.

Sulphur contamination in Nickel, Monel and inconel must be avoided.

Fig. 5 : Welding Sequence for Butt Joints

Scheme 1 — Backing side Accessible

Scheme 2 — Backing side Accessible



The furnace atmosphere must be very low in sulphur content. Any contact with brick work or furnace supports that may be impregnated with sulphur must be avoided. Steel scale too may be sulphur rich and hence should not be left with the cladding during the heat treatment. The furnace atmosphere should be slightly oxidising in order to reduce sulphur attack above 260°C.

For the austenitic stainless steels also a slightly oxidising atmosphere is necessary to avoid any carburization that would impair the corrosion resistance of the cladding. There are several features associated with the heat treatment of austenitic stainless steels which are equally applicable to steels clad with these materials. If an unstablized stainless steel has been made for cladding the service conditions must be such that the stainless steel cladding which got sencitized due to the stress relief treatment which otherwise, is imperative that a low carbon grade is chosen at the stage of material selection itself. The

Fig. 6 : Tee, Lap and Corner welds on clad steels

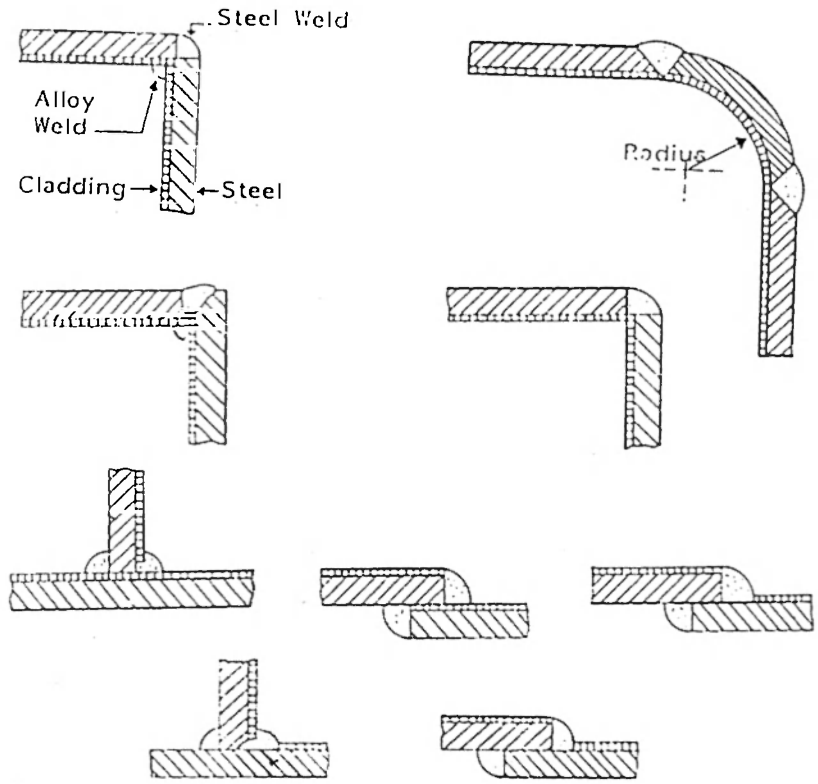


TABLE - 1
Choice of Welding consumables of the clad side

SR. NO.	CLADDING	FIRST PASS (BACKING EXPOSED)	FILLING PASSES	ALLOY TO STEEL WELDS (NOT EXPOSED TO CORROSION)
1.	450	25 Cr - 20 Ni	25 Cr - 20 Ni	25 Cr - 20 Ni
		25 Cr - 12 Ni	25 Cr - 12 Ni	25 Cr - 12 Ni
2.	4109	- do -	- do -	- do -
3.	410	- do -	- do -	- do -
4.	430	- do -	- do -	- do -
5.	304	- do -	19 Cr - 9 Ni	- do -
6.	304L	- do -	- do -	- do -
7.	309S	25 Cr - 20 Ni	25 Cr - 12 Ni	25 Cr - 20 Ni
				25 Cr - 12 Ni
8.	310S	- do -	25 Cr - 20 Ni	25 Cr - 20 Ni
9.	316	25 Cr - 20 Ni Mo	19 Cr - 19 Ni Mo	25 Cr - 20 Ni Mo
		25 Cr - 12 Ni Mo		25 Cr - 12 Ni Mo
10.	316L	- do -	- do -	- do -
11.	321	25 Cr - 20 Ni Cb	19 Cr - 9 Ni Cb	25 Cr - 20 Ni Cb
		25 Cr - 12 Ni Cb		25 Cr - 12 Ni Cb
12.	347	- do -	- do -	- do -
13.	NICKEL	NICKEL	NICKEL	NICKEL
14.	MONEL	NICKEL	MONEL	NICKEL
15.	INCONEL	80 Ni - 20 Cr	80 Ni - 20 Cr	80 Ni - 20 Cr

* Under certain corrosive conditions, 18 Cr filler is recommended for first pass and filling passes.
The filler metal shall also be of the extra low Carpon variety
Under certain corrosive conditions, 80 Ni - 20 Cr Filler is recommended for first pass and filling passes.

possibility of sigma phase. Formation in ferrite bearing stainless steels, when heat treated for prolonged period in the temperature range of 650°C to 900°C and the development of stresses due to differential thermal expansion of the austenitic and ferrite materials should be considered while stress relief heat treatment of clad plates are contemplated.

Requirement of the Pressure Vessel Codes

The essential requirements of the fabricated clad equipment include sound weld and continuity of the cladding. The welds on the steel side must provide the requisite strength.

The pressure vessels fabricated of clad steel should conform to the relevant design code and the related construction and material standards. Some of the codes of construction used by Indian industry are :

i. ASME Boiler and Pressure Vessels code sec VIII Dir I and II.

ii. British Standard Institution Code BS : 5500 - 'Fusion Welded Pressure Vessels'

iii. Bureau of Indian Standards BIS 2825 - Code for unfired Pressure Vessels.

These codes or specifications cover the supply of clad plates, certain design aspects of pressure vessels, quality control tests and acceptance levels of defects in welded joints. Approval tests on the welding procedure and on welders and operators are to be conducted as per the governing codes/standards. For example, if a pressure vessel is designed as per ASME code Section VIII, then the approval tests are to be carried out as per the requirements of ASME Sec IX using materials/welding consumables meeting the requirements ASME SEC II Part A, B & C and inspected as per the procedures laid down in ASME SEC V.

During the welding procedure approval for clad steels, radiographic examination and bend, testing are of major concern. Some inspection authorities ask for radiographic examination of the steel side before the welding of clad side. This requires cutting away of the cladding at the weld joint. The weld defects such as incomplete penetration revealed during radiographic examination must be repaired thoroughly before laying the clad deposit as otherwise such defects would cause failure during the bend test. Brittle martensite layer of the weld if formed because of excessive penetration of the steel weld into the cladding while welding from the steel side, would be revealed during the bend test.