SELECTION OF ELECTRODES FOR WELDING OF ARMOUR PLATES AND PROCEDURE FOR APPROVAL

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1.0 Introduction

Armour plates used in the fabrication of fighting vehicles are low alloy high strength steel hardened and tempered to predetermined level of hardness, high tensile strength and optimum ductility. This unique combination of material properties imparts antibullet properties to armour plates. Such steels have high carbon equivalent conducive to formation of crack during welding unless suitable welding procedure utilising correct welding consumable is selected. A suitable ferritic or austenitic electrode is selected based on plate thickness, joint configuration, welding process (i.e. whether manual, semi-automatic, automatic) etc. However, any welding electrode before being approved for use is thoroughly tested for various characteristics of which the resistance to cracking is of maximum importance. Moreover, before final approval, the bullet resistance property in the welded area is also examined. As such a number of functional tests are carried out in addition to the conventional tests before an electrode is finally approved for fabrication of armoured vehicles.

2.0 Cracking Phenomena in Armour Steel Plate

Two principal considerations in the successful welding of low alloy high strength armour steel are:

(a) Avoidance of Hydrogen induced cracking.

(b) Avoidance of solidification cracking.

2.1 *Hydrogen Induced Cracking* :

Hydrogen induced cold cracking in arc welded steel is a most harmful defect and affects the safety and performance of a welded structure. The cause of cold cracking in steel welds is the interaction among the loss of ductility, stress concerntration and hydrogen embrittlement of the area where a crack initiates and propagates. Cracks may occur in weld metal, heat affected zone (HAZ) and or base metal. Cold cracking can occur as a result of the following factors:

(i) Hardened microstructure : Hardened microstructure arising out of high cooling rates associated with conventional arc welding processes. The corelation between the HAZ hardness with the chemical composition of steel giving each alloying element a coefficient relating its influence to that of the equivalent amount of carbon has been established by many research workers. One such formula is,

Carbon Equivalent (CE) =

$$C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu + Si)/15$$

Example of some types of armour plates along with their CE (calculated as per the above formula) are given in Table 1.

(ii) Sufficient concentration of free hydrogen : Hydrogen is introduced into the weld metal pool mainly from the decomposition of organic compounds, moisture in flux, moisture in the plates to be welded and moisture from ambient atmosphere if sufficient coverage of shielding gas during arc welding is absent.

TABLE 1

Carbon Equivalents of armour plates

Types	Carbon Equivalent(Average)
28 Cr 2 Mo	0.86
31 Cr 2Ni 1Mo	0.96
30 Cr 2Ni 2Mo	0.98
30 Cr 1Ni 1Mo	0.86
32 Cr 1Mo	0.75

(iii) Dilution : The degree of dilution depends on heat input during welding, plate thickness, the welding technique and other practical factors such as high interpass temperature etc. The dilution is more pronounced in the root of the joint. If plate thickness is more, the dilution may be more.

(iv) Residual tensile stresses and stress concentra tions : The degree depends on joint design, heating and cooling of plates of varying thickness, welding procedure etc.

2.2 Solidification Cracking:

Solidification or hot cracking is caused primarily by an insufficient degree of hot ductility within the weld metal. Liquation cracking in steel occurs because of the formation of low melting point phases along the grain boundries. Sulphur and Phosphorous in the weld metal can lead to low melting point liquids. Sulphur and Phosphorous are to be controlled with 0.03 max in each when these will be dispersed evenly in the weld metal. Higher content will lead to formation of massive Sulphur and Phosphorous compounds located in the grain boundries and hot cracking resistance decreases. Solidification cracking has been encountered in weldments made by the manual metal arc process where the larger thermal cycles permit more grain coarsening and allow hot cracking to take place more readily. In those welding processes and consumables which produce deep, narrow weld beads or where weld beads are deposited into narrow preparations, the hot cracking suceptibility increases. Important considerations in hot cracking suceptibility are :

(i) Composition of weld metal.

(ii) Plate misfit and weld pool profile. As plate misfit increases, the strain on the hot weld metal increases the likelihood of solidification cracking. The weld pool width to depth ratio also influences the hot cracking suceptibility.

(iii) High thermal stresses arising out of temperature difference between weld metal and parent metal and faster rate of heat transfer.

3.0 Selection of Welding Consumable

Proper selection of welding consumable and the process is broadly based on the considerations of strength of the weld deposit, avoidance of cracking and the characteristics of armour plate and the joint to be welded. However, the principal consideration in the successful welding of low alloy steel armour is the avoidance of HAZ cracking. Solidification and weldmetal hydrogen cracking can occur but may be minimised by careful selection of consumable and technique.

We have noted that the hydrogen concentration in the weld metal is the primary factor leading to cracking. The equillibrium relationship between hydrogen solubility and temperature for austenitic and ferrite phases is shown in Figure 1.

Here we find that the austenitic phase has got increased solubility of Hydrogen compared to the ferritic phase. However, what is more important is that Hydrogen has a much lower diffusivity in austenite. A case study has indicated that Hydrogen diffusion rate out of austenitic weld metal can be less than 2 ml H_2/100 gm per twenty five years. Due to the above reasons HAZ cracking is clearly a problem while welding with mild steel ferritic electrodes. During the process of cooling of the weld metal, undissolved Hydrogen from ferritic phase diffuse to HAZ and creates the problem. The use of austenitic consumable is preferred to ferritic and would greatly reduce the risk of hydrogen induced cracking. Although experimental datas are sparse, what are available suggest that to have any

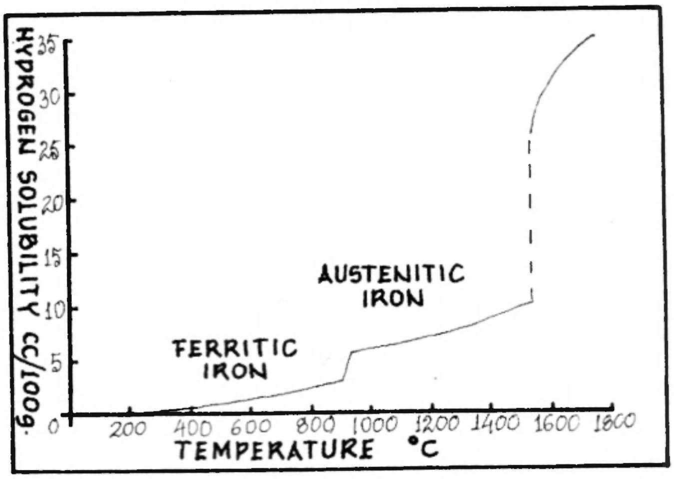

Fig. 1 Hydrogen Solibility in Iron

degree of confidence in avoiding HAZ cracking in armour steel, the hydrogen content of ferriitic weld metal should not exceed 2 ml/100 gm of weld metal whereas for austenitic weld deposit a higher level of Hydrogen of 5 ml/100 gm of weld metal may be tolerated.

With the advancement in welding technology, the ferritic electrodes are being used for fabrication utilising semi-automatic MIG/TIG processes, with proper control on preheating. In some European countries, certain amount of armour welding for thicknesses upto 14 mm is done with ferritic consumable by the MIG process using $C0_2$ gas. This process if properly controlled has the potential for generating very low weld metal Hydrogen content. Moreover it offers one more advantage that alloyed ferrite imparts high strength and hardness in the weld deposit rendering high antibullet properties in the welded area.

However, for the thicker armour plates and restrained joints the most reliable welds are made using austenitic stainless steel electrodes. For MMAW using flux cored electrodes, the austenitic electrodes are preferred. Actually pure austenitic weld metal deposit is never recommended for armour plate joining. Austenitic-ferrite duplex structure has been found suitable. The composition of the austenitic electrode will depend on the desired values of weld metal strength & hardness, the amount of dilution and the desired volume of delta ferrite. It is desirable to have around 5 to 20% delta ferrite in the austenite matrix of weld metal to avoid solidification cracking. With its higher solubility for impurity elements like S, P, Sb and Sn, the ferrite eliminates the danger of formation of low melting films along the grain boundaries, thus solidification cracking. Ferrite is known to be very beneficial in reducing the tendency for cracking or fissuring in some stainless steel weld metals. Generally, ferrite of help when the welds are restrained and the joints are large. Ferrite increases the weld strength level.However, it is generally regarded as detrimental to toughness in cryogenic service and the amount of ferrite is restricted for such applications.

Hence, while finally selecting an electrode the plate thickness,joint configuration, restraint, plate composition and above all welding technique become the primary considerations. For low thickness armour plates and where restraints are less, ferritic electrode utilising automatic and semi-automatic processes using CO_2 gas shield are being used in some countries. However, for thicker armour plates, highly restrained joints or where MMAW is used, austenitic electrodes are preferred.

4.0 Approval of Welding Electrodes

An elecrtrode before being introduced for fabrication of armour fighting vehicles is required to be assessed thoroughly. Two types of tests are involved for approval and utilisation of coated stainless steel electrode purported for armour welding.

(a) Acceptance tests for a particular batch of electrode, the type of which has already been approved for armour welding.

(b) Full approval tests of a particular type of electrode before introduction.

4.1 Acceptance tests

The acceptance tests, carried out for a particular batch of electrode are listed in Table 2.

TABLE 2

Acceptance Tests for a batch of electrodes

	Test Procedure	Brief Content
1.	Determination of chemical composition of deposited metal	8 layer deposition on the low carbon steel plate. Samples taken from 3 upper layers.
2.	Determination of mechanical properties of deposited metal	8 layer deposition on the low carbon steel plate. Tensile and Impact test pieces are taken
3.	Determination of Tensile and bend test properties of welded joint	Two armour plates are welded and test pieces are taken from the joint.
4.	Determination of resistance of welded joints to formation of cold cracks.	R.D. Rigid Butt joint test or Modified Reeve test depending upon dia. of electrode
5.	Determination of resistance of welded joints to formation of hot cracks.	Swinden Tied Tee test or standard Heavy Tee Test depending upon dia of electrode.

The chemical composition and mechanical properties of deposited metal are routine tests. However, special tests like (i) Tensile and Bend tests of welded joint of two armour plates, (ii) Cold cracking test and (iii) Hot cracking test are conducted since these are pertinent to the intended application. The tensile and bend test of welded joint are done with the samples as indicated in Figure 2.

Rigid Butt joint test is a restrained plate weld test to establish the suceptibility of the electrode to induce 'cold cracking" in the Heat Affected Zone. The two plates butted closely together at each end on a specially prepared Vee. The Vee shall be filled by welding runs. The welded joint is cross sectioned at 3 places. The faces of cross sections are microscopically examined for presence of crack.

Swinden Tied Tee test is carried out in order to assess the susceptibility of the weld metal to hot cracking.

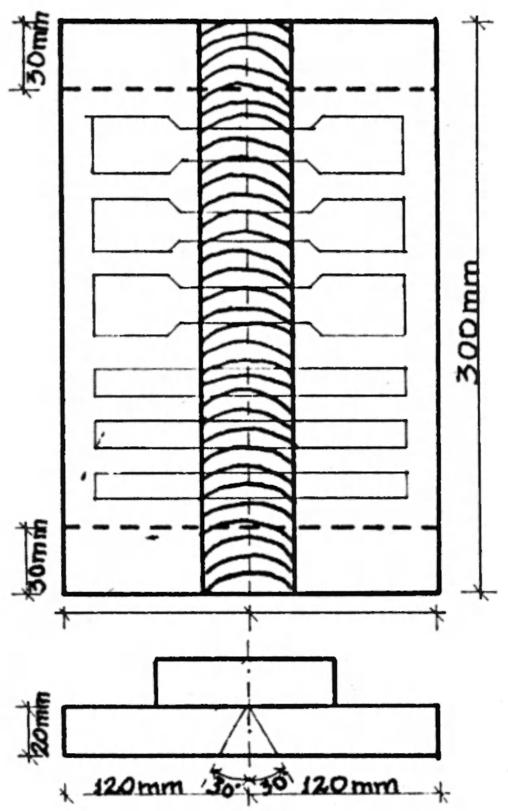

Fig. 2 Tensile and Bend Test Specimens in welded test plate

These are restrained fillet weld tests to establish whether deposited metal is susceptible to hot cracking. In this also cross sections of the welded joints are microscopically examined for the presence of any crack.

4.2 Type Approval Tests

For type approval of new welding materials and technological process of arc welding for production of armoured antishell designs for military tracked vehicles, certain additional tests are carried out since these are pertinent to the actual applications. These tests vary from country to country and are adopted mainly simulating the actual welding condition. Highest thickness of armour plate to be used in the vehicle is used for checking crack sensitivity. Some of these tests often carried out in many countries are given in brief in Table 3.

TABLE 3

Type Approval tests for New Welding Materials and Technological Processes
(Some of the typical tests conducted in addition to the routine all welded tests are only indicated)

Test Procedure	Brief Content
1. Determination of resistance of welded joints to formation of cold cracks	Utilising thickest armour plates X-shaped seames are welded. Before welding of seams, the armour plates are anchored by welding with other steel plates. Cold cracks are checked in test weld sections.
2. Determination of resistance of welded joints to formation of hot cracks.	Weld bead is deposited in V-shaped groove on a test piece prepared with the thickest armour plate. Sec tions are microscopically examined for cracks.
3. Determination of Tensile and bend test properties of welded joint.	Two armour plates of medium hardness are welded and test pieces are taken from the joint.
4. Determination of micro-structure in the weld metal.	From the test piece at Sl. No. 1, microsections are taken and checked for weld structure and hareness of welded joint sections.
5. Determination of chemical composition of the weld metal.	Chemical composition is determined in the weld metal of the sample from test piece at Sl. No. 1.
6. Determination of the mechanical properties of the weld metal.	Tensils and Impact test pieces are cut out from the weld deposit and HAZ area of test pieces taken from Sl. No. 1.
7. Antibullet test	Welded area is fired from a specified distance with the specified armaments.

5.0 Conclusions

The welding of low alloy high strength armour plates is quite a tricky problem due to the associated phenomena of hot and cold cracking. The welding process is selected with due consideration to plate composition, plate thickness, joint configuration, restraint etc. Whereas both ferritic and austenitic consumables may be used for higher thickness and restrained joints austenitic consumables are preferred. The type approval of covered austenitic electrode is done after rigorous tests including antibullet tests, whereas for acceptance of a particular batch of electrode, control routine and special tests are carried out.

6.0 References

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