# Comparative Study of Hot Cracking Susceptibility of AISI 347 Austenitic Stainless Steel (ASS) using Acidic and Basic Coated Filler Material

**Vishvesh J. Badheka[1], Prof S.K.Agrawal[2] & Umang Parikh[3]**
[1] Lecturer, Metallurgical Engineering Department The M.S.University of Baroda, India
[2] Formerly Professor of Metallurgical Engineering Department,
Presently - Director, Fusion Resources, 925/2/8, GIDC Makapura, Vadodara, India
[3] Welding Engineer, Anup Engineering, Ahmedabad

**ABSTRACT**

Hot cracking refers to cracking that occurs during welding, casti ng or hot worki ng at temperatures close to the melting point of the materials. Hot cracking susceptibility of austenitic stainless steel is a problem arising during welding of austenitic stainless steels, particularly in fully austenitic and stabilized compositions. Hot cracking in stainless steel welds is caused by low-melting eutectics containing impurities such as S, P and alloy elements such as Ti, Nb. In stabilized stainless steels, Ti and Nb react with S, N and C to form low melting eutectics. In austenitic stainless steels, segregation plays an overwhelming role in determining cracking susceptibility. Total crack length (TCL), has been used extensively as hot cracking parameter. [1,2]

In the present investigation, an attempt has been made to study hot cracking susceptibility of stabilized ASS on transvarestraint test unit, with acidic and basic coated electrodes.

Experiment, shows that acidic and basic coated electrodes both are more or less equally susceptible to hot

**Keywords:**

Austenitic Stainless Steel, Solidification Cracking, Transvarestraint testing, Delta Ferrite, Hot Cracking.

**INTRODUCTION**

Hot cracks occur mainly in the weld bead but sometimes they may develop in the HAZ. When located in the weld metal they are referred to as solidification cracks while in HAZ they are called as Liquation Cracks. Solidification cracks occur in the weld metal when the metal is very hot; just below the solidus temperature of the metal. Such cracks are often interdendritic and follow the random path of grain boundaries along segregated concentration of impurities deposited there by the solidifying weld metal. A hot crack will show temper colours in its inner surfaces. This is due to the oxide films formed there after the initiation of the hot crack.

Some of the important factors which promote solidification cracking in weldment include the following

1) Material composition; high carbon and Nickel contents, Crack sensitivity of the electrode Solidification Structure, Segregation,
2 High stress in weld metal, Material thickness, Joint restraint, Weld bead shape,
3) High current, Preheating increases liability to cracking, Weld procedure

Solidification cracking occurs predominantly by the segregation of solutes to form low melting phases, which under the action of shrinkage stresses accompanying solidification cause cracking. Several theories have been advanced to explain the phenomenon.

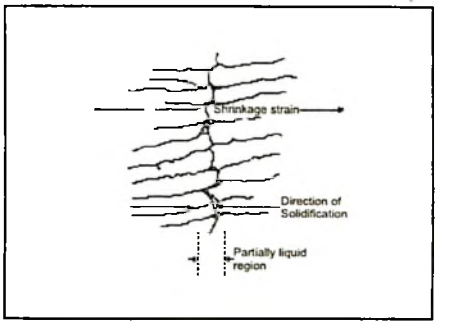


**Figure 1 :** Mechanism of Solidification Cracking

The initial theories took into account the fact that cracking is associated with segregation; the wider the liquidsolid range of the alloy, the greater the susceptibility.

However, this theory was not entirely satisfactory, as several exceptions could be found and the freezing range appeared to be only one of many factors influencing cracking. The 'Generalized Theory' of cracking was proposed by Borland (1960).

**ROLE OF FERRITE**

It was recognized that the presence of ferrite in room temperature, causes the micro structure to indicate a reduced fissuring tendency for ASS weld metals. It was shown that the weld metal

containing three to ten percent ferrite was more resistant to hot cracking than fully austenitic. [1]

In 1967 Hull summarized five theories that had been previously presented to explain the beneficial effect of ferrite in reducing hot cracking tendency.

1) The most common theory for the effect of delta ferrite in reducing cracking is based on the assumption that ferrite has a greater solubility than austenite for certain harmful elements and impurities.

   Ferrite can thereby reduce the amount of liquid film and the temperature range over which they persists by decreasing impurity segregation during solidification.

2) A second effect of ferrite is the generation of substantial area of interphase boundary between ferrite and austenite in addition to the austenite austenite boundary. This extra interfacial area supposedly acts as sink to decrease the concentration of impurities at the austenite boundaries and reduce hot cracking.

3) In two phase alloy the austenite grain size would be refined. A smaller grain size would reduce hot cracking for the same reason mentioned above.

4) Composition resulting in primary ferrite reduce the solidification range of the weld metal, and thus there is a r~J:Juction in segregation of fissure forming elements to the grain boundaries. The fallacy of this theory is that the phase diagram shows only a gradual change in solidification range as a function of composition, whereas there is an abrupt change in hot cracking with only small amount offerrite

5) The effect of ferrite is that fissuring is reduced because the BCC ferrite has a smaller coefficient of thermal expansion than FCC austenite and thus shrinkage stress are decreased.

Hull indicated that this theory lacks substance only a minor effect on the total thermal expansion coefficient.

Hull proposed another theory to explain the role of ferrite in preventing fissuring. He postulates that the beneficial effect of ferrite results from the fact that the austenite -ferrite boundaries have a lower interfacial energy than the austen ite-austenite boundaries. The austeniteaustenite boundaries getwet by the last traces of liquid whereas the austenite-ferrite boundaries are not getting wet.

Thus austenite-ferrite boundaries can sustain the small but increasing stresses imposed by the contraction of the alloy as it freezes under restraint until all the liquid has solidified and the austenite-austenite boundaries can bear their share of the load.

## HOT CRACKING EVALUATION CRITERIA

Hot cracking is believed to occur o~ing the inability of the solidifying weld metal to support strain in a critical temperature range during freezing (Borland 1960). The cracking is a function of composition as well as strain. In actual welds, the amount of strain experienced by the weld metal is difficult to estimate in view of complex geometric and thermal conditions. Hence controlled strain applied on a geometrically simple specimen is preferred for evaluation of cracking tendency. Several tests exist that satisfy the above condition, such as the varestraint test, the sigma jig test.

The varestraint test uses a controlled, rapidly applied bending strain to produce cracking, and crack lengths are used for evaluation. The longitudinal varestraint test and the related Transvarestraint test are more widely used for assessment of hot cracking during welding than the other two tests (Goodwin 1990). In the longitudinal varestraint test (LVT) strain is applied in the direction of welding, whereas in the transvarestraint test (TVT), it is applied transverse to the welding direction. In the LVT, the total crack length (TCL) and cracking threshold strain are considered the most important assessment criteria (Lundin et al 1982), while in the TVT the maximum crack length (MCL) is used for assessment. In addition, in the TVT, the MCL is used for estimating the temperature range of cracking during solidification called the brittleness temperature range or BTR. Many studies have focused on determination of BTR, which is possible using the varestraint type of test. [4]

## THE TRANS-VARESTRAINT

It is a modified form of the varestraint test. While in the varestraint test, the axis of the bend is perpendicular to the direction of the weld and cracks occur vertically to the weld, in the trans-varestraint test this axis runs parallel to the weld, thus keeping cracks inside the weld metal resulting in centerline cracks. The schematic representation of the set-up for Trans-varestraint test with a bilateral bend is shown in figure 2.

Material susceptible to hot cracking: Austenitic stainless steel, Aluminium

## EXPERIMENT WORK

Experiment procedure consist of following four steps

### 1. Welding Specimen preparation

Size of the specimen : 150 mm X 40 mm X 6 mm

Edge preparation : Single V groove with degree included angle.

Root Gap : 1 to 2

Welding Process : SMAE

Welding : 3

Sample are welded with Rutox A and 3 from Batox -A

### 2. Ferrite measurement

Ferrite measurement was carried out with the help of ferritector model No 1581. It works on the principle of "electromagnetic induction. It represents the ferrite in terms of Ferrite Number (FN).

### 3.Transvarestraint testing

After ferrite measurements the samples were loaded in Transvarestraint testing unit. Various amount of strain was controlled by Sensor-4. Amount of strain (deflection) was fixed before loading and was set in unit by adjusting the position of limiting switch. Figure 4 is working set up of Transvarestraint testing unit and figure5 shows welded sample under deflection.

Sensor 1: Arcing start on the run on plate.

Sensor 2: With further movement of pug machine, it reaches at sensor 2, which at mid point of sample, sliding block moved downward to apply strain and bending starts.

Sensor 3: Pug machine reaches sensor 3, the arcing stops.

After heat run the sample is allowed to solidify under applied load. When solidification over, the bending force released by moving the sliding block upward.

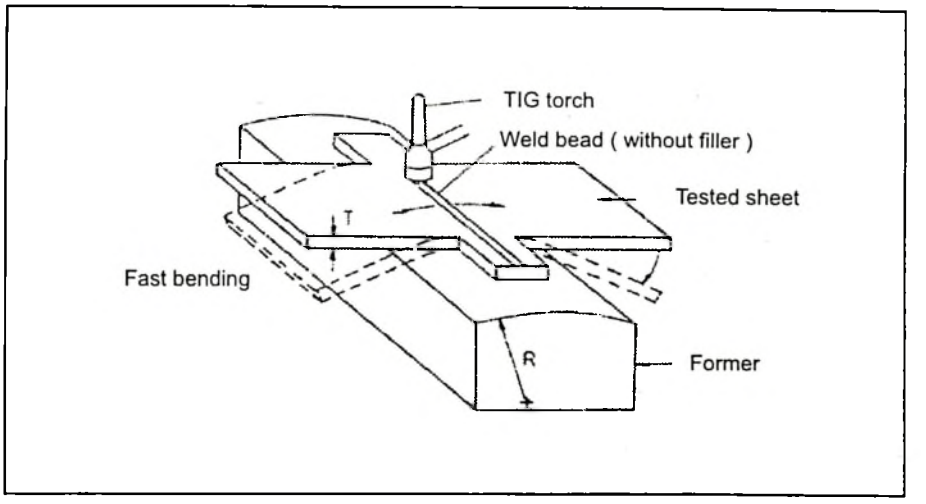


**Figure 2** : Schematic representation of the set-up for Trans-varestraint test unit

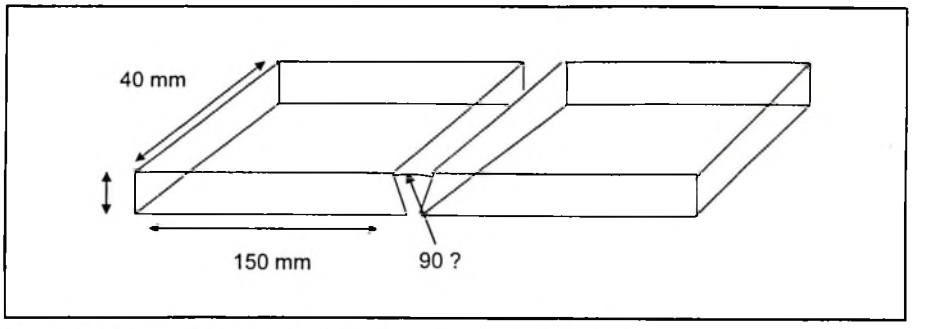


**Figure 3** : Shows dimensions and edge preparation of specimen

### 4. Specimen preparation and crack length measurement

The strained samples were cut into a required size from the middle of the sample.

Sample prepared for metallographic examination

Etching was carried out through electrolytic process.

Etchant : 10 % oxalic acid Microscope: Neophot II

Microscope was used for measurement of crack length using micrometer having list count of 0.01 mm. During observation the microphotograph were taken (Figure 6). The number of cracks, and crack length were measured.

**MATERIALS**

Base metal : 316L

| % C | % Cr | % Ni | % Mo | % Mn | % Si |
|---|---|---|---|---|---|
| 0.03 Max | 16 - 18 % | 10 - 14 % | 2 - 3 % | 2.0 % | 1.0 % |

**Table 1** : Chemical composition of 316 L

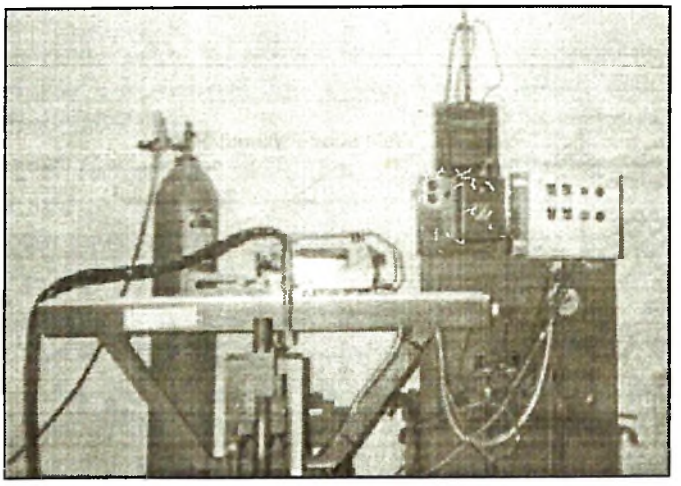

**Figure 4** : Working set up of Transvarestraint testing unit

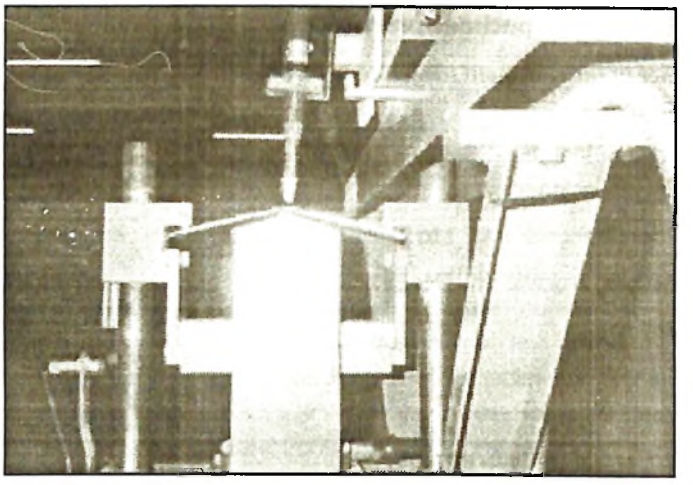

**Figure 5 :** Shows welded sample under deflection

| Y.S (Mpa) | UTS, (Mpa) | Elongation (%) | Hardness (HB) |
|---|---|---|---|
| 170 | 485 | 40.0 | 217 |

**Table 2** : Mechanical composition of 316 L

| Brand name | C | Mn | Si | S | P | Cr | Ni | Cb | Mo | UTS $Kg/mm^2$ | Elongation (%) | Ferrite Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rutox A | 0.04 | 1.17 | 0.45 | 0.012 | 0.018 | 17.90 | 9.80 | 0.43 | Trace | 65.4 | 65.4 | 3-8 |
| Batox A | 0.035 | 1.50 | 0.48 | 0.012 | 0.022 | 20.30 | 10.40 | 0.45 | Trace | 60.2 | 60.2 | 5-7.4 |

**Table 3** : Chemical composition of Consumable (Rutox A & Batox A)

Acid and Basic coated consumable used which give sufficient amount of ferrite to prevent susceptibility of hot cracking. Rutox A is acid coated and Batox A is basic coated

**Observation Table**

| Specimen Number | Ferrite Number (F, N) | Avg. Ferrite Number |
|---|---|---|
| B5 | 6.4, 7, 6 | 6.47 |
| B10 | 6.8, 6, 8.5 | 6.20 |
| B15 | 6, 8, 6.7 | 6.60 |
| B20 | 6.4, 6.2, 5.8 | 6.13 |
| A5 | 7.4, 7.4, 6.4 | 7.07 |
| A10 | 7.8, 7.6, 8 | 7.80 |
| A15 | 6.8, 7.4, 7.6 | 7.27 |
| A20 | 7.2, 8.7, 7.8 | 7.40 |

**Table 4** : Ferrite Number measurement data

A : Rutox A, & 5, 10, 15, 20 are values of deflection in mms

B : Batox A & 5, 10, 15, 20 are values of deflection in mms

**Welding Valuables**

Welding Voltage : 25 Volts
Welding Current : 110 A
Welding speed : 4 mm / sec
Heat Input : : 0.6875 KJ/mm

| Specimen Number | Deflection (mm) | Crack No. | Crack Length (mm) | Total Crack Length (mm) | Avg. Crack length (mm) | Maximum crack length (mm) |
|---|---|---|---|---|---|---|
| B5 | 5 | 1 | 4 | 4 | 4 | 4 |
| B10 | 10 | NO CRACK OBSERVED | | | | |
| B15 | 15 | 1 | 6 | 10 | 5 | 6 |
| | | 2 | 4 | | | |
| B20 | 20 | 1 | 4 | 22 | 7.33 | 13 |
| | | 2 | 13 | | | |
| | | 3 | 5 | | | |
| A5 | 5 | NO CRACK OBSERVED | | | | |
| A10 | 10 | NO CRACK OBSERVED | | | | |
| A15 | 15 | 1 | 5 | 19 | 9.5 | 14 |
| | | 2 | 14 | | | |
| A20 | 20 | 1 | 4 | 24 | 4 | 9 |
| | | 2 | 3 | | | |
| | | 3 | 2 | | | |
| | | 4 | 2 | | | |
| | | 5 | 9 | | | |
| | | 6 | 4 | | | |

**Table 5** : Number of cracks, crack length and total crack length

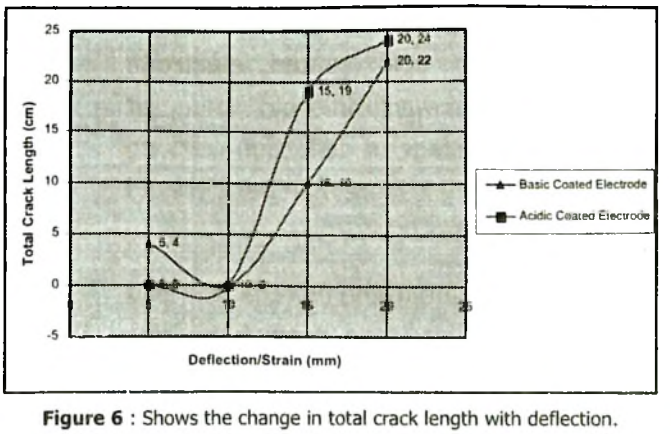


**Figure 6** : Shows the change in total crack length with deflection.

## DISCUSSION

The procedure adopted in experimental work is to assess the relative Hot Cracking Susceptibility of welding consumable under investigation. The electrode was deposited in a groove made into the plate of 316L material. Upon deposition there may be some melting of base metal, intermixing with the deposited metal. There is a danger; weld metal may not reflect the composition and physical properties of welding electrode. However, it is presumed that the weld metal still broadly reflect the properties of electrode. Groove geometry was selected in such a way that dilution will be minimum. During transvarestraint test, cracking will be confined to weld metal and therefore it will reflect Hot Cracking Susceptibility behavior of welding consumable rather than parent metal.

Basic coated electrode shows ferrite number between 6.13-6.60 and for acid coated electrode it was between 7.07-7.80. The supplier of electrode has also given the ferrite number of weld metal of basic and acid coated between 5-7.4 and 6-8 (Table 3) respectively, which is in agreement with our observation (Table 4 ). It was also observed that basic coated electrode has slightly less ferrite number than the acid coated electrode.

From observation table 5 as well as from graph (Fig 6), it is clear that with increases in the amount of deflection i.e. strain, that total crack length is increased for both acid and basic coated electrode.

Fig6 also shows that for given deflection, acidic coated electrodes are more susceptible to hot cracks. The composition can be considered to be crack resistant irrespective of two type of coating because ferrite number is in the range of 6-8 which is sufficient to ensure crack resistant behavior.

The minimum deflection which is required to initiate cracking in the weld metal (threshold value ) from the graph (Fig6), the crack starts at approximately 10 mm of deflection for basic coated electrode and acid coated electrode i.e. all weld metal composition is such that crack resistance is good for the basic coated and acid coated electrode. However, during comparison of B5 &A5 the result does not match. The difference is relatively small.

## CONCLUSION

Though acid coated electrode shows lower threshold value, at higher stage of deflection cracking tendency is more than basic coated electrode.

This is due to the fact that the acid coated electrode deposit contains high oxygen which results in high loss of Mn, Si and C etc. Due to high Mn loss they are more crack susceptible.

It is also observed that in basic coated electrodes, slag effectively removes the Sulfur hence the chance of cracking for basic coated electrode is less.

The threshold value of acid and basic coated electrode, from the graph is around 10 mm deflection.

## REFERENCE


1) Hot Cracking Susceptibility of Austenitic Stainless Steel Weld Metals by C.D.Ludin and C.P.D.Chou, WRC bulletin 289.

2) Solidification cracking in austenitic stainless steel welds by V. Shankar, T.P.S.Gill, S.L.Mannan and S.Sundaresan, Sadhana Vol. 28, Parts 3 & 4, June/August 2003, pp 359-382.

3) Criteria for hot cracking evaluation in austenitic stainless steel welds using longitudinal varestraint and transvarestraint test V. Shankar, T.P.S.Gill, S.L.Mannan and S.Sundaresan

Science and Technology of Welding & Joining, 2000, Vol 5, No 2.