TRANSVARESTRAINT TESTING OF LOW FERRITE CONSUMABLES FOR AUSTENITIC STAINLESS STEEL WELDING

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ABSTRACT

Two low ferrite filler wires and one autogenous weld were tried on 316L Stainless Steel sample plates, for assessing the hot cracking susceptibility. The deposited welds were tested for ferrite number and the autogenously melted using TIG process on Transvarestraint testing unit. These samples were strained at two different levels. The hot cracking susceptibility was measured in terms of number of cracks, total length of cracks and maximum crack length at two different strains to the weld metal. It was found that the total crack length or number of cracks are indicative of cracking susceptibility. Interestingly, order of increasing susceptibility in the welded samples matched with the decreasing level of delta ferrite.

INTRODUCTION

The problem of hot cracking during welding of stainless steels is normally overcome by the use of such welding consumables which assure 4-8% delta ferrite in the weld metal. Schaeffler and DeLong diagrams have been found useful in estimating the delta ferrite in the weld metal according to the chemistry of the consumables. Later on more refined versions of these diagrams such as Espy [1] and WRC-92 constitutional diagram for stainless steels [2] have been suggested. Improved correlation between ferrite number and chemical composition have also been proposed by several research workers [3]. However, presence of delta ferrite is not acceptable in certain welds to be used for cryogenic service (3) or in carbamate condenser during urea production where extremely corrosive condition/ environment exist. Low ferrite welding consumable are designed for such applications. With the use of such consumables, risk of hot cracking of the weld metal is to be eliminated. Therefore welds with low ferrite consumables are to be tested for hot cracking susceptibility.

Mechanism of Solidification Cracking

A hot crack is defined as "a crack that develops during solidification". Dixon [5] has presented a review of the theory of solidification cracking. In general hot cracking occurs whenever sufficient stresses get imposed over the susceptible microstructure [6]. Dixon [4] has considered three important factors which influence the crack sensitivity.

These are

Composition : This determines the freezing temperature range and the morphology of the grain boundary segregates. For cracking to occur, liquid needs to be present over a relatively wide temperature range and should wet the grain boundaries [7].

Strain : The factors affecting magnitude of the strain are discussed in several references [9].

Strain Rate : Within the solidifying weld pool, most strains are accommodated by the localized shearing of ductile intergranular phases. If the strain rate is too rapid, the grain boundary film can rupture with creation of cracks.

Thermal expansion and contraction, elastic and plastic deformation, and phase transformation involving volumetric change all contribute to the stress state [6]. However, most mechanisms proposed deal with the metallurgical factors that can lead to hot cracking. In austenitic stainless steels, the mode of solidification strongly influences the sensitivity to hot cracking.

A number of test methods have been developed for studying weld metal solidification cracking. A majority of these test procedures are specialized in their application and designed to determine the crack sensitivity under particular conditions. Many of the test procedures are 'go' and 'no go' type and no numeric value can be obtained for the comparison of data with other research workers.

Development of the Transvarestraint Test

Two most popular test procedures are the Varestraint and Transvarestraint tests. The machines for these two tests were developed almost simultaneously. They are both designed to apply a rapid, measured strain across a solidifying weld pool in a manner intended to simulate the thermally imposed strains experienced in actual welding. It is usually considered that by making the strain rate sufficiently rapid, fluctuations in strain rate have a negligible influence on cracking [4].

In the Transvarestraint test the strain is applied by deflecting a test plate by three-point bending over a roof top former. In this test the bending is transverse to the weld, while in the Varestraint test the bending is applied along the weld. In the Transvarestraint test. the angle of applied deflection or the deflection itself, as given by the distance of ram travel, may be measured. By varying the amount of strain applied to the weld, it is possible to obtain a plot of crack sensitivity against strain. On a transverse metallographic section, three types of hot cracks can be identified **Fig. 1** [4] shows the location of centre line, flare and radial cracks.

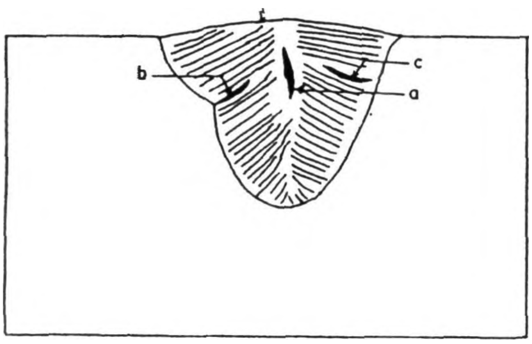

Fig. 1 : Solidification cracks in weld metal
(a) Centre-line Crack; (b) Flare Crack; (c) Radial Crack

Transvarestraint Test

It has been found that solidification cracking occurs most readily along the centre line of the weld. The Transvarestraint test has shown greater sensitivity over the Varestraint test since it produces centre line crack in the test sample. Transvarestraint test is found more suitable for studying the influence of composition upon crack severity. This test is used for studying the effect of various welding consumables and welding parameters on solidification cracking.

Experimental Work

The Transvarestraint test unit used in this investigation is hydraulically operated as shown in **Fig. 2**. It uses a roof top former for three point bending of plates under investigation. The strain is applied in transverse direction of the weld. The test specimens were 316L stainless steel of 150x40x5 mm dimensions. Two such samples were prepared for V-groove and joined by the consumables under investigation along 40 mm width, so as to create a specimen of 300x40x5 mm dimensions with filler metal deposited along the middle. Weld metal chemistry of the two filler materials tested is given in **Table I**. Two samples of 300x40x5 mm were autogenously welded. In all cases, tungsten inert gas welding process was used. Welding parameters are given in **Table II**. After joining the samples by depositing filler metal along the V-groove, the plates were checked for discontinuities by dye penetrant testing and radiography. The ferrite measurement on welds was carried out using Ferritector Model 1581 Data in ferrite number (FN) is reported in **Table III**.

On 300x40x5 mm samples, run-on and run-off pieces were tack welded. The test specimens (a in Fig. 2) were loaded on the Transvarestraint test unit in such a manner that the welded portion exactly coincided with the sharp edge of the roof top former (b). The two ends of the test specimen were located beneath the guide rollers (c) held in position by the sliding blocks (d). Each slide block is guided by a column and is connected to the ram by a firm joining plate (e). After loading the specimen, autogenous melting of the deposited metal was started from the run-on side of the weld at a predecided speed and arc current as per **Table IV**. When the torch reached exactly the middle of the weld run, ram of the Transvarestraint unit was moved downward through hydraulic system. Downward deflection of specimen was controlled to a predecided level with the help of a limit switch mounted on one of the columns. The melt run was maintained uninterrupted up to the run-off piece.

The deformed specimen was unloaded from the Transvarestraint test unit by upward movement of the loading ram as shown in **Fig. 3** and a transverse section was cut at a point where the torch was present during the straining. Transverse sections were electrolytically etched for 40-60 sec. with 10% oxalic acid solution at current density of 1 A/cm^2

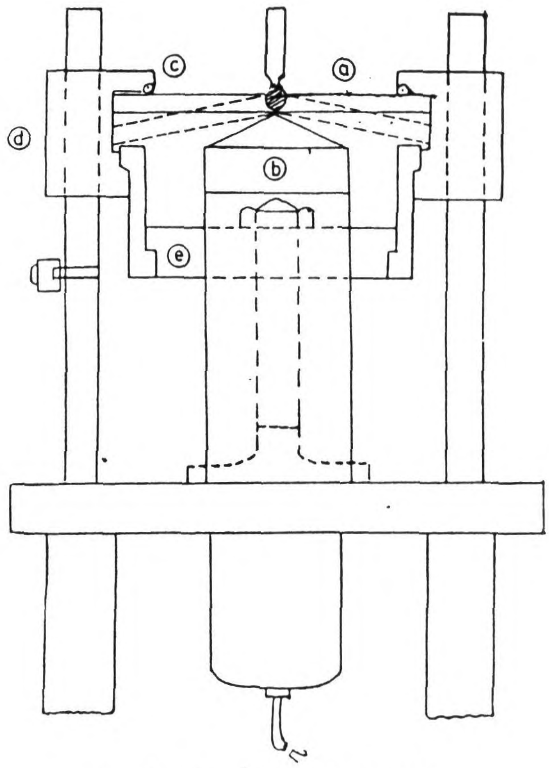

Fig. 2 : Transvarestraint test unit

the etched samples were observed under microscope at magnifications ranging from 90x to 225x. The number of cracks, total crack length, average crack length and maximum crack length data were recorded.

RESULTS AND DISCUSSIONS

In Table I compositions of the two filler metals selected for investigation are given. The Cr/Ni equivalent ratio of ER 316L is 1.41 while for WW 1122 (NF) is 1.12. These ratios have been calculated on the basis of DeLong equation. Average ferrite number in the three welds are shown in Table III, the ferrite number was checked by the use of WRC-92 constitutional diagram (2) and found correct within +1 FN i.e. the WRC-92 diagram indicated values lower by 1 FN. Radiographs of welded samples did not indicate any discontinuity in the weld.

Crack sensitivity measurements on transverse sections are given in **Table V** in terms of number of

TABLE I
Chemical composition of consumavbles

Consumable	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Mo	%N	Cr/Ni
ER 316L	0.3	1.53	0.47	0.021	0.01	17.51	13.82	2.33	-	1.408
WW112(NF)	0.018	1.76	0.31	0.013	0.007	18.25	38.85	2.56	0.13	1.12

TABLE II
Operating Parameters for Welding of Plates

Consumable	No. of Passes	Voltage (V)	Current (I)	Time (S)	Avg. Speed (mm/s)	Heat Input (kJ/mm)	Avg./Heat Input (KJ/mm)
Autogenous	1	13.90	110	80	1	1.07	1.1
	2	13.90	90	100	0.8	1.09	
	3	13.90	90	110	0.7	1.2	
ER316L	1	13.95	115	38	1.0	1.09	1.0
	2	13.90	100	40	1.0	1.07	
	3	14.70	100	39	1.03	1.0	
WW 1122(NF)	1	13.20	90	40	1.0	0.83	0.8
	2	13.20	90	43	0.93	0.89	
	3	13.20	90	38	1.05	0.79	

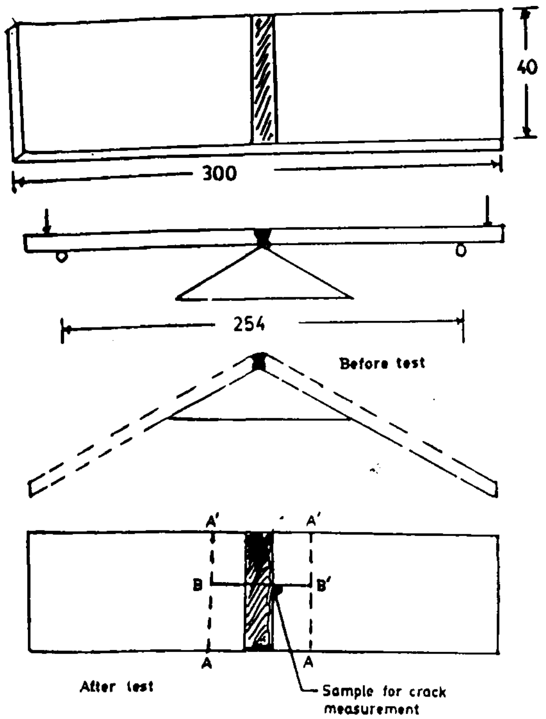

Fig. 3 : Scheme of generation of sample

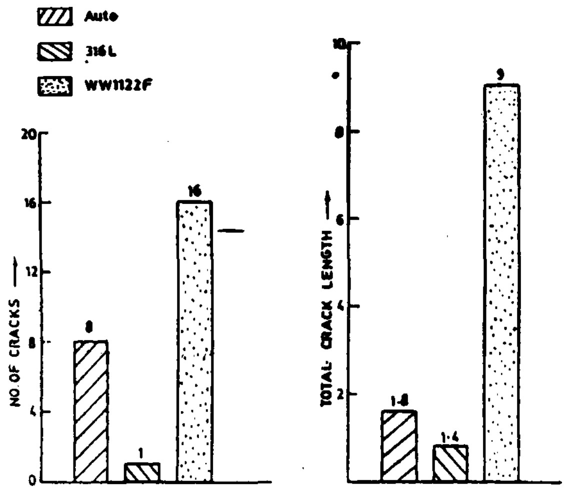

Fig. 4 : Bar Chart for Number of Cracks and Total Crak length for different consumables

TABLE III Ferrite Measurement Data

Specimen with Welded	Mean Ferrite Number (FN)	Std Deviation (FN)
Autogenous Weld	2.8	0.3
ER 316L	2.9	0.4
WW 1122 (NF)	1.8	0.4

TABLE IV
Operating Parameters for Transvarestraint Test

Consumables	Deflection (mm)	Welding (v) Speed	Voltage (I) (mm/s)	Current	Heat Input (kJ/mm)
Autogenous	10	0.9	13	90	0.7
	20	1.6	12	90	
ER316L	10	0.6	14	90	1.4
	20	0.6	14	90	
WW1122(NF)	10	0.6	14	90	1.4
	20	0.7	14	90	

TABLE V
Crack Length Measurement Data

Consumables	Deflection (mm)	No. of Crack Cracks	Total crack Length (mm)	Average Length (mm)	Maximum Crack Length (mm)
Autogenous	10	None observed			
	20	8	1.8	0.225	0.43
ER316L	10	None observed			
	20	1	1.4	1.4	1.4
WW1122(NF)	10	None observed			
	20	16	9.00	0.58	2.00

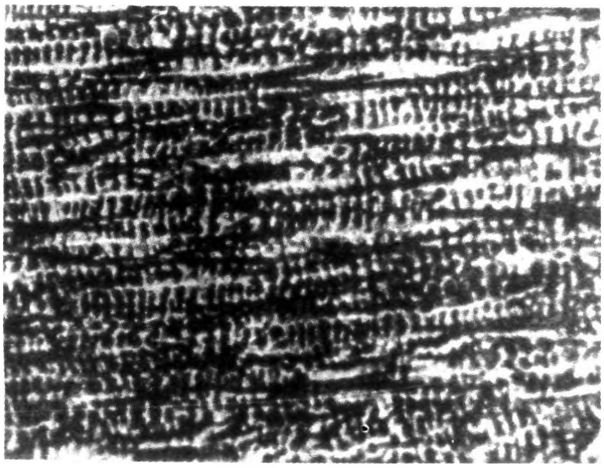

Fig. 5 : Micro photograph
ER 316 L Filler Wire Mag 225X

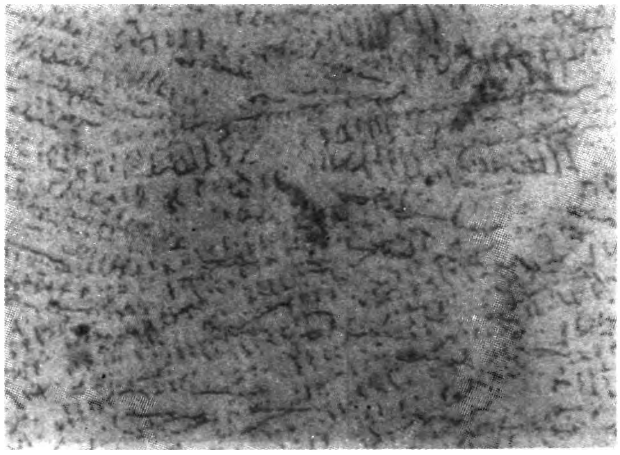

Fig. 6 : Micro photograph
WW 1122 (NF) Mag 90X

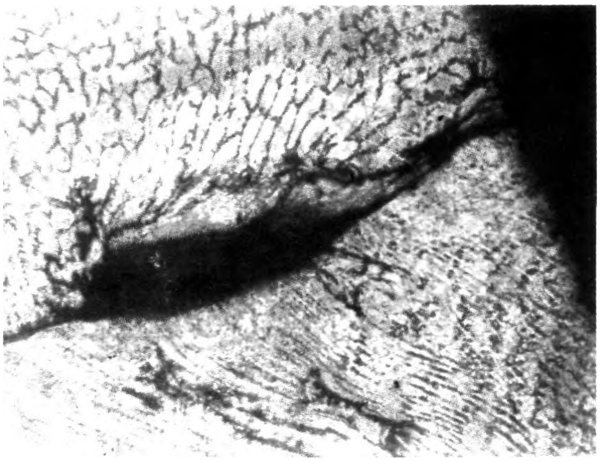

Fig. 7 : Micro photograph 90X

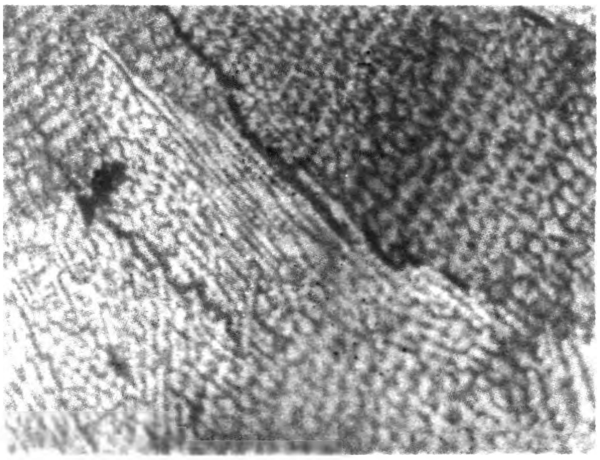

Fig. 8 : Micro photograph 90X

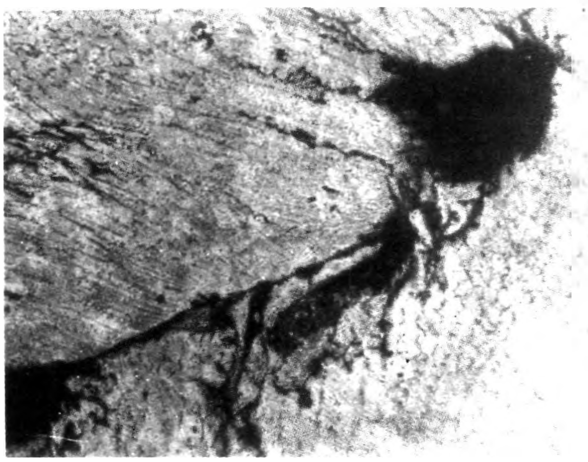

Fig. 9 : Micro photograph 90X

cracks, total crack length, average crack length and maximum crack length. Same information is also given in the form of bar diagram in **Fig. 4**.

Figs. 5 and 6 show the microstructures of weld metals produced using ER316L and WW1122 (NF) filler metals, while **Figs. 7, 8 and 9** show cracks in different samples at 20 mm deflection.

Results show no evidence of cracking in the samples when the transverse strain is 10 mm. However at 20 mm deflection, all the test specimens show tendency for hot cracking. These results indicate that all samples including WW 1122 (NF) are resistant to hot cracking at low strains. For comparing the relative cracking susceptibility between three test samples Dixon [8] suggests that in transvarestraint test using metallography for crack measurement, it is better to consider crack length than number of cracks. As per this criterion ER316L filler metal with a ferrite number of 2.9 shows crack length of 1.4 mm, while autogenous weld is intermediate in its tendency to cracking susceptibility (total crack length 1.8 mm and FN 2.8) and WW 1122 (NF) (having a FN of 1.8 and total crack length of 9.00 mm) shows highest susceptibility. Same order of ranking is obtained even if number of cracks are taken as criterion for crack sensitivity. Interestingly, ferrite number in three samples is found decreasing with increasing susceptibility to cracking.

Another approach based on type of crack can be considered while interpreting the data in Table V. It was found during transvarestraint testing that centerline cracks were first to develop. As the crack sensitivity increases, flare and radial cracks develop and increase the total number of cracks. Crack length measurement data indicate a single crack in ER 316L samples which is a centre line crack. While the samples of autogenous weld and WW 1122 (NF) filler metal show radial cracks in addition to centerline cracks which is indicative of their increased susceptibility to cracking. It can be inferred that the less crack sensitive material will show only centre line cracking while more susceptible will show centerline, radial and flare cracks also.

CONCLUSION

On the basis of the present investigation into hot cracking susceptibility, the following conclusions were drawn :

1. One autogenous weld of 316L and two low ferrite filler wires found resistant to hot cracking at low level of strain

2. It is possible to compare three weld metals for hot cracking susceptibility based on the total crack length, since other parameters such as deflection, and heat input to various samples are similar.

3. At higher level of strain, solidification cracks were observed in all the three samples. Er 316L filler metal indicated least cracking susceptibility, autogenous weld intermediate tendency, while filler wire WW 1122 (NF) showed the highest tendency when the susceptibility criterion was taken as total crack length. Same order of ranking was obtained when number of cracks was taken as the criterion.

4. Though the difference in ferrite number of autogenous weld and weld with ER 316L filler wire was minor and insignificant, the increasing susceptibility was shown decreasing ferrite number.

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