Role of Mn and N and Fissuring Behaviour of Ferrite Free 18-8-Mo Stainless Steel Weld Metals

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Introduction

18-8-Mo type of stainless steels have found a wide range of applications in the industry due to their excellent corrosion resistance compatible with techno-economic considerations. They have found particularly wide usage in such important fields as fertilisers, paper, heavy chemicals, drugs and pharmaceuticals, food and beverage, and other industries where their corrosion resistance to acids and chemicals has led to longer service life, freedom from contamination in articles of human consumption, and trouble-free operation of plant and equipment.

It was however found out in later years, that welding fabrication and corrosion behaviour of these steels are beset with contradictory elements. The material was observed to give the best corrosion resistance when ferrite phase was absent, while, in the absence of ferrite phase, minute cracks, called fissures, started forming. Depending on Ni and Cr contents, varying degrees of ferrite were found to be necessary for elimination of cracking. Detailed studies were carried out by the Welding Research Council and their recommendation for the minimum amount of ferrite necessary for elimination of fissures is shown in Table 1.

However, as presence of ferrite led to increased corrosion which was not acceptable to many industries, investigations were undertaken by many researchers to delineate the nature and cause of the cracking in fully austenitic steels.

B. Hemsworth of CEGB, UK, in an excellent review, classified the fissuring of Ni—Cr austenitic steels into two categories :

1. Segregation cracking which is associated with micro-segregation leading to low melting point intergranular films.
2. Ductility dip cracking which occurs at newly migrated grain boundaries free from fissures.

Most of the researchers however agreed after detailed work, that the segregation mechanism of cracking is mostly responsible for fissuring in Ni—Cr type of stainless steels. Grain boundary wetting by segregates and the dihedral angle formed also constituted important conditions. Honeycombe and Gooch(1) determined by elaborate microstructural examinations that segregant mechanism associated with sulphide eutectics play the most significant role in micro—fissuring. Borland and Younger(2) had reached the same conclusion earlier. A mathematical expression was developed by Mores and Gunia(3) which correlates the effect of various elements based on circular groove test.

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Table—1

Minimum Ferrite content Required for Prevention of fissuring
(as per Welding Research Council)

Weld Metal Type	*Minm. Ferrite No. Required*	*Weld Metal Type*	*Minm. Ferrite No. Required*
16-8-2	0-2	308L	3
316L	1½	309	4
308	2	318	5
346	2½	347	6

The expression is given below :

$$\% \text{ cracking} = 133.6 + \frac{6.44}{C} \times \frac{43.1}{\% Mn} + 1.8 \times Si + 384 \times S + 2295 \times P + 998 \times Ni - 4.48 \times Cr - 28.8(Nb+Ta) - 487 \times N.$$

The equation is useful in pointing out the elements which must be controlled for reduction of the incidence of cracking. The overwhelming effect of S and P in increasing cracking susceptibility and the reverse effect exerted by Mn, N and Nb & Ta is noteworthy.

Effect of Mn, as an austenite stabiliser was well known. F C Hull(4) evaluated the effect by a number of chill cast pin tests and developed a correlation between the %Ni required vis-a-vis other elements for 0% ferrite. The equation is as follows :

$$\% Ni \text{ for } 0\% \text{ delta ferrite} = 4.71 + 0.92\ Cr - 0.088\ Mn + 0.0070\ Mn^2 + 1.30\ Mo + 0.51\ Si + 2.22V + 0.69W + 2.12\ Ti + 0.17\ Cb + 0.32\ Ta - 14.6\ N - 16.7\ C - 0.47Cc - 0.42Cu + 2.30\ Al.$$

It is obvious from the above that Mn and N are two among the elements which can stabilise austenite while reducing fissuring.

Introduction of Mn and N, therefore, in the weld metal as a means of reducing the fissuring tendency alongwith stabilisation of austenite has been resorted to since approximately the beginning of this decade. Vigorous work carried out by research laboratories of Sandvik, Avesta, Bohlers and others on Mn and N alloyed stainless steels could establish that fissuring tendency of the weld metal could be significantly brought down or completely eliminated with such additions.

However, as one of the primary concerns in use of 18—8—Mo type of steels, specially in sophisticated services such as urea reactors, digesters in paper mills, and many other acid and chemical services, is the corrosion resistance of the material, detailed investigations needed to be carried out on the effect of Mn and N on this property. The present work was taken up as a comprehensive investigation of 316L(Mod.) type of weldments for their corrosion behaviour and fissuring tendency, and design and economics in use of such materials.

Experimental :

Welding alloys of 316L modified types containing varying amount of Mn and N were developed in the form of coated electrodes by introduction of required amount of alloys through coating and use of 316L type core wire. The electrodes so developed were used in two sets of experiments one for determining the cracking tendency and the other for evaluation of corrosion resistance.

(a) The cracking tendency was investigated by a simulated Restraint Test, an apparatus for which was fabricated. Sketch I shows the basic details of the set up. MS plates of 20mm thick were bevelled 30°. The bevelled edges were weld deposited with three layers of the weldmetal under investigation and re-bevelled to $30^\circ\ {}^{+5^\circ}_{-0^\circ}$ with root face of 2mm. Root gaps varying

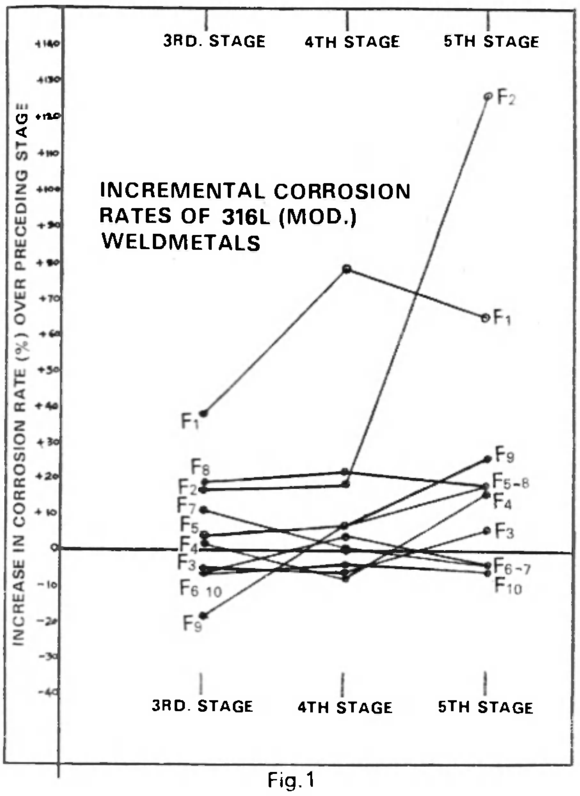

Fig. 1

from 0.5 to 5mm at steps of 0.5, 1, 1.5, 2, 3, 4 and 5mm were used to weld the root bead ; welding conditions for 4mm electrode were as below :

Polarity	— Electrode + Ve.
Voltage	— 25 V
Current	— 130 Amp.
Size of electrode	— 4 mm
Travel speed	— 6.5 ipm.

Duplicate samples of the electrodes were tested as per Stamicarbon crack tests, where weldmetal was deposited on a 50mm thick plate to a deposit of 200 × 50 × 10mm thick and surface grinding the deposit to 0,1,2, and 3mm below top layer. The cracks were examined at 50X under a binocular microscope after etching with glycergia.

(b) Corrosion behaviour was investigated by two sets of tests, the first set by Huey Test as per ASTM A262 Practice E, whereby general as well as intergranular attack could be evaluated. The second set was tested by Strauss test so as to reveal intergranular attack if any. A set of samples were also sensitised for different durations so as to evaluate the effect of Mn and N on the sensitisation characteristics of the metal. Sensitisation was done by subjecting the metal to 670°C for varying durations and then carrying out Strauss test.

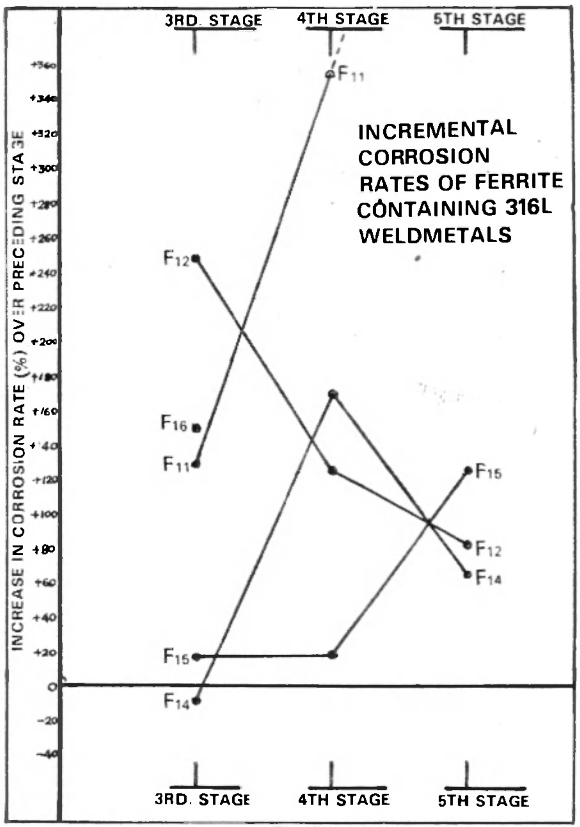

Fig. 2

Boiling nitric acid or Huey Test was selected as the principal corrosion test because of the fact that its behaviour follows closely some of the highly corrosive meida in industrial use such as ammonium carbamate (for the production of urea fertiliser), nitric acid, etc. and also can readily detect selective attack in presence of sigma phase and ferrite.

Corrosion Behaviour :

(a) Table II and III give the corrosion characteristics of 316L (Mod) and 316L weldmetals in Huey Test. Further analysis of the data in terms of incremental corrosion rates is presented in Tables VI and VII with figures I and II. Ferrite content and chemical composition of the deposits, as also their Ni and Cr equivalents are given in Table IV and V.

It would be observed from the data that with increase in Cr and Ni contents together with increase in Ni/Cr ratio, corrosion resistance of the metal improves.

In the absence of ferrite, the weld metals show a decidedly low corrosion rate which remains unchanged at higher manganese content. Weldmetals nos, 3,4,5, 6,7, & 10, all having Mn on the higher side show high

Table—II
Corrosion Behaviour of 316L (Mod) Weldmetals in Boiling Nitric Acid (Huey) Test.

Weld Metal No.	*Corrosion Rates in mils/year*					
	1st 48 hrs.	*2nd 48 hrs.*	*3rd 48 hrs.*	*4th 48 hrs.*	*5th 48 hrs.*	*Average*
1	6.43	6.35	8.79	15.64	25.80	12.59
2	12.61	8.39	9.85	11.63	26.23	13.75
3	5.80	4.54	4.32	4.07	4.30	4.60
4	7.92	6.55	6.68	6.17	7.13	6.89
5	8.81	6.90	7.20	7.74	9.12	8.11
6	7.71	5.12	4.81	4.99	4.74	5.48
7	6.66	4.49	4.98	5.02	4.80	5.19
8	7.34	7.86	9.35	11.45	13.37	9.87
9	7.89	6.11	5.04	5.39	6.79	6.24
10	7.80	7.20	6.80	6.50	6.90	7.00

Table—III
Corrosion Behaviour of 316L Weld Metals in Boiling Nitric Acid (Huey) Test.

Weld Metal No.	*Corrosion Rates in mils/year*					
	1st 48 hrs.	*2nd 48 hrs.*	*3rd 48 hrs.*	*4th 48 hrs.*	*5th 48 hrs.*	*Average 48 hrs.*
11	5.70	9.92	22.73	103.11	D	61.07
12	1.87	8.96	31.16	70.32	128.28	48.11
13	48.39	162.60	D	D	D	H
14	6.43	6.35	5.79	15.64	25.80	12.59
15	12.61	8.39	9.85	11.63	26.23	13.79
16	8.44	22.94	57.25	D	D	H

D = Discontinued.
H = High.

Table—IV
Chemical Composition of 316L (Mod) Weld Metals. (Refer Table II)

Filler Metal No.	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*N*	*Cr/Ni Ratio*	*Ni/Cr Ratio*	*Ferrite Content*
1	0.03	1.26	0.30	17.03	12.02	2.20	0.05 max.	1.42	0.70	0.2-04
2	0.03	1.62	0.34	17.85	14.09	2.54	—do—	1.23	0.81	0.2
3	0.02	3.74	0.35	19.53	15.95	2.68	—do—	1.22	0.82	Nil
4	0.035	5.45	0.34	18.59	15.67	2.80	0.11	1.19	0.84	Nil
5	0.025	2.50	0.30	18.50	15.40	2.80	0.12	1.20	0.83	Nil
6	0.03	3.76	0.38	20.45	15.28	2.65	0.12	1.34	0.75	Nil
7	0.03	2.45	0.33	18.01	15.60	2.25	0.11	1.15	0.87	Nil
8	0.02	1.92	0.43	18.16	14.75	3.28	0.09 0.10	1.23	0.81	Nil
9	0.025	2.10	0.31	17.74	14.30	2.50	—do—	1.24	0.81	Nil
10	0.04	6.05	0.44	19.50	15.58	2.65	0.12	1.25	0.80	Nil

Table—V
Chemical Composition of 316L Weld Metals. (Refer Table III)

Weld Metal No.	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*Cr/Ni Ratio*	*Ni/Cr Ratio*	*Ferrite Content*
11	0.04	1.80	0.42	19.0	11.60	3.0	1.64	0.61	9.2-9.8
12	0.04	1.12	0.36	18.21	12.76	2.48	1.43	0.70	4.8-5.2
13	0.04	1.70	0.32	20.18	12.52	2.64	1.61	0.62	6.0-6.8
14	0.03	1.26	0.30	17.03	12.02	2.20	1.42	0.71	0.2-0.4
15	0.03	1.62	0.34	17.85	14.09	2.54	1.27	0.79	0.2
16	0.03	2.04	0.36	20.51	15.92	2.80	1.29	0.78	1.8-2.2

Table—VI
Incremental Corrosion Rates of 316L (Modified) Weldmetals (expressed as Increase% over Preceding Stage)

Filler Metal No.	*Increase in Corrosion (%) in*		
	3rd Stage	*4th Stage*	*5th Stage*
1	38	78	65
2	17	18	126
3	-5	-6	6
4	2	-8	16
5	4	7	18
6	-6	4	-4
7	11	0.8	-4
8	19	22	18
9	-18	7	26
10	-6	-4	-6

(-) Sign indicates decrease in corrosion over previous stage.

corrosion resistance. In the presence of ferrite phase, the corrosion resistance deteriorates appreciably even at high Cr and Ni levels. This is presumed to be due to selective attack which is sometimes enhanced by formation of incipient sigma phase.

(b) Corrosion rates of stainless steels have been found to vary widely from stage to stage due to the transpassive behaviour exhibited by these steels. This characteristic may result in severe corrosion under certain conditions where highly oxidising or reducing environments can be met with for short intervals. Incremental corrosion rates specially in the 3rd, 4th and 5th stages in the Huey test would be an important indicator of this behavior. In fact, in certain industrial applications, an incremental rate exceeding 50% over the previous stage is considered harmful for the service. The incremental rate analysis was therefore carried out for the modified as well as the standard 316L materials and the results in Tables VI and VII and Fig. 1 and II show some interesting features.

Table—VII
Incremental Corrosion Rate of Ferrite containing 316L Weldmetals. (expressed as (%) increase over Previous Stage)

Metal No.	*Increase in Corrosion (%) in*		
	3rd Stage	*4th Stage*	*5th Stage*
11	129	354	Test Abandoned
12	248	2911	2
13	Very High and Hence Abandoned.		
14	-9	170	65
15	17	18	126
16	150	Abandoned	

It would be readily noticed that the weld metals differ widely as far as incremental rates are concerned. Weldmetals having even a trace of ferrite show much higher incremental rates in 3rd, 4th and 5th stages of test than weld metals containing no ferrite. In fully austenitic material with no second phase, the incremental rates show even a negative tendency as seen in case of alloy nos. 3,4,6,7, & 10. In these alloys, the Mn content is high so also is Ni. A further separation of the influence of these two elements has not, at this stage, been possible but it appears that an amount of Mn at the level of 6% such as in alloy No. 10, does not in any way deteriorate the corrosion so also incremental corrosion resistance, although it may or may not improve it. Further work, to separate out the effect of Ni and Mn contents is in progress. Ni content is considered important and it would be desirable to maintain it at a level of above 15.

(c) Mn adds to the austenite stability as can be found from the excellent correlation developed by, Schaeffler, Delong and other workers and the actual measurements by Elcometer and Magne-Gage, See Table IV—A. Correlation by these workers takes Mn as a contributing factor towards stabilisation of austenite.

Schzumachowski and Reid(5) modified the Delong diagram so as to indicate negative ferrite contents. Calculations by the authors based on Schzumachowski

Table—IV-A
Predicted Ferrite Content

Filler No.	Actual Ferrite Content	*as per Schaeffler* Cr eq	Ni eq	Ferrite Content	*as per Delong* Cr eq	Ni eq	Ferrite Content	*as per Szumachowski & Reid (Mod. Delong Diagram)* Cr eq	Ni eq	Ferrite content
1	0.2-0.4%	19.7	13.6	0%	19.7	14.5	0-2 FN	19.7	14.5	0-2 FN
2	0.2%	20.9	15.8	0%	20.9	16.7	0 FN	20.9	16.7	0 FN
3	0%	22.7	18.4	0%	22.7	19.3	0 FN	22.7	19.3	0 FN
4	0%	21.9	19.4	0%	21.9	22.7	0 FN	21.9	22.7	-10 FN
5	0%	21.8	17.4	0%	21.8	21.0	0 FN	21.8	21.0	-5/6-(-5.5) FN
6	0%	23.7	18.1	0%	23.7	21.7	0 FN	23.7	21.7	-2 FN
7	0%	20.8	17.7	0%	20.8	21.0	0 FN	20.8	21.0	-8/-10(-9) FN
8	0.2%	22.1	16.3	0%	22.1	19.6	0 FN	22.1	19.6	-2 FN
9	0%	20.7	16.1	0%	19.4	20.7	0 FN	20.7	19.4	-6/-8 (7) FN
10	0%	22.8	19.8	0%	22.8	23.4	0 FN	22.8	23.4	-6 FN

and Reid diagrams and comparison of corrosion rates showed that negative ferrite content does not have any significant effect on corrosion properties. It is thought that unless there is any change in the phase content of the alloy or there is a difference in the kinetics of the protection layer forming mechanism, addition of further amount of Mn or other elements so as to decrease the ferrite number may not have any effect on corrosion behaviour.

The contribution of Mn in reducing ferrite content and indirectly helping in achieving increased corrosion resistance by elimination of selective type of attack should however be noted. Some authors have postulated that above certain percentage, around 5—6%, Mn acts as ferrite stabiliser. As the present investigations cover a Mn range upto 6%, the effect of higher additions could not be examined.

The alloys were checked for grain and cell sizes as this would have an influence on corrosion and cracking behaviour. It was found (See Table XI) that they were not practically affected by the Mn content of the alloy, although the cell size reduces to some extent on elimination of the ferrite phase. Nitrogen content was found to affect the grain size. With addition of nitrogen, the grain gets smaller. This is thought to be due to formation of nitrides which helps grain nucleation in larger numbers thereby increasing the grain counts and decreasing the grain size. The cell size which is more dependant on the growth phenomena remained more or less unaffected.

Fissure Resistance :

(a) Investigation of the fissuring of the alloys was carried out by a number of tests. An adjustable restraint apparatus (see Fig. 3) was developed in the R & D and was used to find the level at which cracking starts. 20mm thick plates with a bevel of $30^\circ\,{}^{+5}_{-0^\circ}$ and root face of 1.5—2.0mm were employed. The bevelled edges were overlaid with 3 layers of weldmetal under investigation and the overlay was machined out again to the bevel of $30^\circ\,{}^{+5}_{-0^\circ}$ and root face of 1.6—2.0mm. Varying degrees of restraint were introduced by variation in the

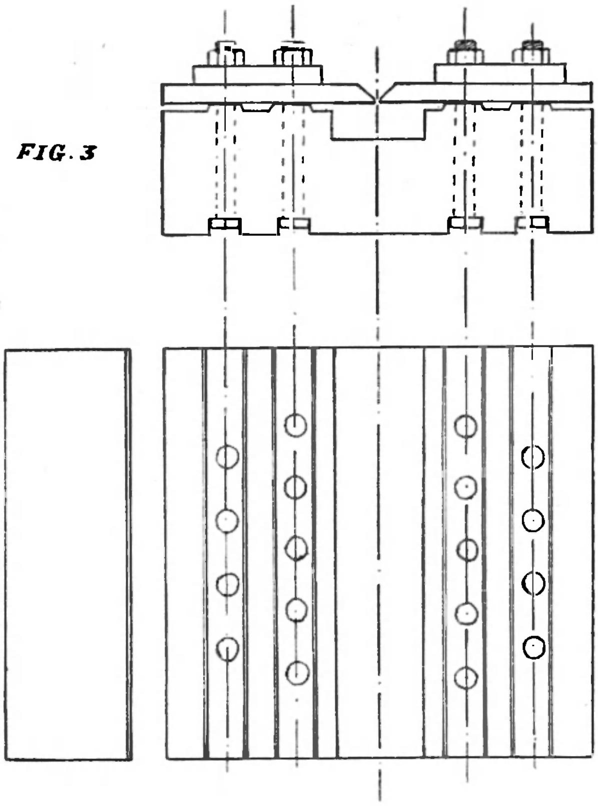

FIG. 3

root gap. Approximately 150mm long root bead was welded after adjustment of the root gap. Cracking susceptibility was determined by counting the number of fissures in the cross-section at start, middle and end of bead. Sections were cut and macro-etched for the purpose.

The results of the tests are given in Table VIII and the composition of the alloys investigated in Table IX. It is evident from the data that with increasing amount of Mn—content the weldmetal becomes gradually insensitive to cracking. Presence of around 2.5% Mn is essential to withstand a restraint represented by a root gap of 3 mm which is very common in commercial fabrications. Under more rigorous welding condition such as in welding of branches, nozzles. and other joints where root gap can not be controlled accurately due to mechanical fitting difficulties, higher Mn—contents around 4% would be desirable to eliminate fissuring propensity. The above observations are however based on the results with weldmetal having max 0.025% S & P contents. With higher S & P contents, the fissure resistance of the metal will vary.

(b) Fissure resistance was also tested by Stamicarbon type of weld overlay test in which an overlay of

Table—VIII

Adjustable Restraint Test Results

Weld Metal No. 21		*Weld Metal No. 22*		*Weld Metal No. 23*	
Restraint Root Gap	*No. of fissures*	*Restraint Root Gap*	*No. of fissures*	*Restraint Root Gap*	*No. of fissures*
5 mm	11	5 mm	1	5 mm	Nil
3.5 mm	2	4 mm	Nil	4 mm	Nil
2 mm	Nil				

Table—IX

Weld Metal No.	*Chemical Composition*								
	C	*Mn*	*Si*	*P*	*S*	*Cr*	*Ni*	*Mo*	*N*
21	0.03	1.17	0.03	0.026	0.03	16.80	13.40	2.60	—
22	0.025	2.45	0.30	0.025	0.025	18.33	15.21	2.80	0.10
23	0.03	5.12	0.29	0.026	0.024	18.20	14.25	2.40	0.11

Table—X

Overlay Test Data as per Stamicarbon Procedures :

Alloy No.	*Cracks Observed (Total)*
21	32
22	2 to 3
23	Nil

Table—XI

Effect of Nitrogen on grain refinement

Weld Metal No.	*Type*	*Grain Size*
1	316L (Mod)	5-6
2	316L (Mod)	5-7
3	316L (Mod)+N	7-8
4	—do—	8-9
5	—do—	7-8
6	—do—	8-9

approximately 10mm thickness is deposited on MS base plate. From the top of the overlay 0,1,2, and 3mm layer is machined, surface ground and checked after etching macroscopically at a magnification of 50X. Cracks of length less than 0.6mm are tabulated for evaluation. Length of all cracks greater than 0.6 mm long is reported for further investigations.

A maximum number of 15 cracks (total of 3 layers) is allowed in MMA welding with coated electrodes and 20 cracks with strip electrodes, in a surface of 100mm × 500mm. Cracks longer than 0.6mm are not allowed and the material is considered unacceptable. A maximum depth of 1mm vertical to the overlay surface is permitted.

The results obtained with various weld metals when tested as per Stamicarbon procedures are produced in Table X. The results show that the weld metals are quite sensitive to this test. The tendency to cracking is decreased with increase in nitrogen content. As stated before, this may be due to decrease in the grain size as shown in Table XI. Improvement in grain size is presumed to be due to greater nucleation of grains made possible by presence of increased amount of nitride nucleii.

(c) Elimination of fissure sensitivity by Mn has been attributed to the formation of manganese sulphides which have poor wettability to grain boundaries both in austenitic and ferrite phases. Mn—sulphides, as a result, form in globular configurations compared to Fe and Ni sulphides which form in continuous films.

The sulphide being of low melting type can easily cause cracking under thermal stresses by liquation mechanism. Globular configurations prevent continuous films and hence reduce the fissuring tendency of the metal. It should however be noted that ductility dip mechanism of cracking is not prevented by introduction of higher Mn-content. A 25Cr—20Ni weldmetal having composition given below shows innumerable fissures in two layer bead tests even when a Mn content as high as 5 was introduced.

On microscopic examination, it was observed that fissures had formed not only in the regular boundaries but also in incipient grain boundaries which could be resolved only at high magnifications. The grain boundaries were not always containing inclusions. Cracks also appeared at grain boundaries containing Mn S dots arranged in a string. The observations point out that with higher alloying, there is possibility of cracking at grain boundaries even with higher Mn—content. Ductility dip mechanism may be favoured in such alloys.

Nitrogen improves the yield strength of the metal with very little or no detriment to the ductility properties. Investigations on a number of weld metals to find out the behaviour of the nitrogen added 316 metals, (see Table XII) show that, the nitrogen content increases the strength to the extent of 15—20% in the range of 0.1—0.15% Nitrogen. The increase in the strength properties can be advantageously used in the industry whereby lesser wall thickness can be employed. Coupled with reduced corrosion rates, use of such material becomes doubly economical. It has been estimated that

25 Cr/20 Ni	C	Mn	Si	S	P	Cr	Ni
Weldmetal	0.065	4.95	0.39	0.012	0.028	26.1	21.1

Table—XII
Effect of Nitrogen on Mechanical Properties

Weld Metal No.	*Chemical Composition*							
	C	*Ni*	*Cr*	*Mo*	*Mn*	*Nitrogen*	*UTS kg/mm^2*	*E%*
1	0.02	15.95	19.53	2.68	3.74	Not added	53.2	44
2	0.025	14.09	17.94	2.48	1.50	—do—	54.5	42
3	0.035	15.67	18.59	2.80	5.45	Up to 0.1%	61.2	48
4	0.025	16.00	19.63	2.70	5.20	Up to 0.1%	60.0	42
5	0.03	15.80	19.25	3.00	6.60	0.13%	64.8	38
6	0.03	16.26	19.14	2.80	4.55	0.12%	64.5	40
7	0.04	15.58	19.50	2.65	6.05	0.12%	64.0	36

about 15% cost saving can be realised using nitrogen added high strength stainless steels from strength aspects alone.

Resistance to Sensitisation

The effect of Mn and N on sensitisation characteristics was studied. Carbon content of the alloys was kept around 0.03% in all the weldments investigated. Strauss Test was carried out after sensitisation at 675°C for different periods. The results are shown in Table XIII. The data indicate that higher Mn—content affects the sensitisation characteristics to some extent. In applications involving long time stress relieving, the stress relieving cycles therefore, need to be engineered carefully so as to avoid intergranular attack. The time required for sensitisation is however long enough not to interfere in normal applications of the metal. A comparision of time to failure in Strauss Test after sensitisation is also given in the table.

Conclusions

1. Higher Mn-containing 18—8—Mo (Modified) stainless steel weldmetals were found to possess equal or superior corrosion resistance compared to normal Mn metals with 2.5% Mn maximum as per some of the current standards.

2. Mn improves austenitic stability and decreases ferrite content ; thereby it contributes to prevention of selective attack.

Table—XIII

Sensitisation Characteristics of SS Weld Metals.

Weld Metal	*C-content*	*Approx. Time required at Temp °C for failure in Strauss Test.*
SS 304	0.03% 0.04%	6 hrs at 680°C 1 hr at 680°C
SS 316	0.03% 0.04%	8 hrs at 680°C 2 hrs at 680°C
SS 316L (Mod)	C-0.04 Mn-6.05 N-0.12	2 hrs at 675°C-Cracked 1 hr 10 mins.-O K
SS 316L (Mod)	C-0.03 Mn-2. 0 N-0.12	2 hrs at 675°C.

3. Mn reduces fissuring tendency of fully austenitic 18-8 Mo steels presumably by change in morphology of sulphide type of impurities which form in discontinuous form and do not wet the grain boundaries. The effect may be limited to certain Cr/Ni ranges, however.

4. In combination with nitrogen, the fissuring tendency is further reduced presumably due to formation of finer grains and hence larger amount of grain boundaries and leaner distribution of the impurities at the grain boundaries.

5. Investigations into sensitisation characteristics show that high Mn steels may be slightly prone to sensitisation compared to lower Mn steels. High Mn containing 18—8—Mo steels therefore should be used cautiously where the metal is subjected to long duration at sensitisation temperatures before or during service.

6. Nitrogen increases the strength of the weld metal considerably. At a level of 0.12% N, the strength increased by 15—20%. Cost of the plant and equipment will get considerably reduced by use of the higher nitrogen stainless steels with improved corrosion resistance represented by 316L (Mod). This too is without detriment to either corrosion or ductility properties.

7. There is no possibility of nitrogen, unlike carbon, making the steel susceptible to sensitisation when subjected to high temperature. Tests carried out point to this and confirm findings of others. In combination with high Mn, the behaviour may be affected. When long time stress relief is involved such as in dissimilar metal joints or in overlays, necessary precautions should be taken while using high Mn—high N metals so as to engineer the heating cycle suitably.

8. Adjustable Restraint Test by virtue of its being able to simulate actual fabrication conditions of restraint, should prove a useful tool in rapid testing of weldmetals for sensitivity to cracking.

Reference

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