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Effect of initial ferrite content on phase transformations in niobium stabilized austenitic clad metals

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Austenitic stainless steel welds which normally contain some ferrite may be exposed to high temperatures either during stress relief or service exposure. Ferrite being an unstable phase is transformed to various secondary phases during high temperature exposure. Data on the affect of temperature and time at temperature on the transformation products of austenitic stainless steel welds are meagre, also few reports are available on the affect of initial ferrite content on phase transformations.

The present study included cladding on low carbon steel with two niobium-stabilized austenitic stainless strips using submerged arc welding to obtain clads with two ferrite contents, low (4 FN) and high (12 FN). Clads were PWHT at 600, 800, 1000 °C for 1, 10 and 100 h. Ferrite was measured using a ferritescope. Electrochemical dissolution in 10%HCl–CH_3OH solution was done to separate out secondary phases which were analysed using the X-ray diffraction powder technique.

The results of the study indicated that the as-weld samples contained both M23C6 and NbC. The PWHT samples were found to contain M23C6, NbC and sigma phases. NbC was found in all the PWHT samples. Both 4 FN and 12 FN samples showed M23C6 after PWHT at 600 °C. After 800 °C PWHT 4 FN samples did not show M23C6, while 12 FN samples showed weak M23C6 lines. After 1000 °C PWHT, was absent in both cases.

Sigma was absent in the 4 FN sample PWHT at 600 °C, while it was present in the 800 °C PWHT samples. In contrast, samples containing 12 FN samples showed sigma both after 600 and 800 °C PWHT. Sigma was absent in samples PWHT at 1000 °C.

The interesting observation of the study was the effect of initial ferrite content on sigma phase formation. It was observed that ferrite transformed to sigma at 600 °C itself when ferrite content is relatively high (12 FN) and not when it is less (4 FN). This behaviour suggests that sigma formation is not only a function of temperature but also initial ferrite content and readily forms even at lower temperatures like 600 °C when initial ferrite content is high. This in contrast to the earlier studies where it was noticed that short time exposures at temperatures up to 700 °C did not show sigma formation.

The observations based on percentage ferrite transformed indicated that the kinetics of sigma at 600 and 800 °C are very fast. Also, ferrite dissolution is faster at 1000 °C when the ferrite content is lower.

1. Introduction

Austenitic stainless steel welds contain about 3 to 10 FN to control hot cracking in welds. Welds get exposed to high temperatures either during stress relief or service exposures. Ferrite being an unstable phase is transformed to various secondary phases during high temperature exposure. Data on the effect temperature and time at temperature on the transformation products and rate of austenitic stainless steel clad are meagre.

Austenitic welded structures may be exposed to post weld heating in the range of 500 to 1000 °C either for stress relief or due to service temperature exposure [1]. In heavily restrained joints the presence of residual stresses cannot guarantee the expected plant life. A 1050 °C post weld heat treatment (PWHT) in thick section complex geometry components can lead to distortion, thus there is considerable incentive, apart from the cost point of view, to use a lower temperature treatment between 600 and 800 °C. Van bemst [2] has discussed various PWHT for stainless steel. A PWHT in the 500 to 800 °C range leads to metallurgical transformation like carbide–sigma formation.

TABLE I Welding parameters used

Process	Current (A)	Voltage (V)	Speed ($mm\,min^{-1}$)	Polarity
SAW	600	32	100	DCEP
TIG	200	25	100	DCEN

Whilst there are reports available on the phase transformation aspects of austenitic weld metals, most of the data pertain to molybdenum-containing metals. Most workers found sigma to precipitate above 600 °C (700 to 800 °C). Few reports are available on the affect of initial ferrite content on phase transformation. The present work deals with niobium stabilized austenitic clad metals and the effect of initial ferrite content on phase transformation.

Low carbon steel was clad with two niobium stabilized strips austenitic stainless strips using the submerged arc welding (SAW) process to obtain clads with two ferrite contents, 4 and 12 FN. Clads were PWHT at 600, 800, 1000 °C for 1, 10 and 100 h. The ferrite content was measured using a ferritescope. Electrochemical dissolution in 10%HCl–CH_3OH solution was done to separate out secondary phases which were analysed using X-ray diffraction.

Table I shows the welding parameters used in this study. Table II shows the chemical composition of SAW samples and resultant ferrite content.

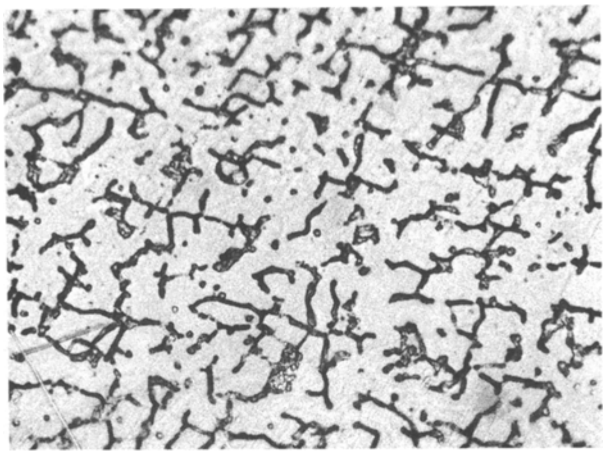

Figure 1 Discontinuous ferrite in low ferrite (4 FN) sample. × 500.

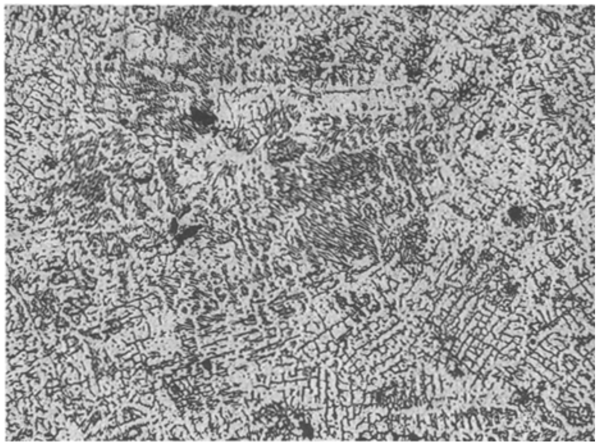

Figure 2 Continuous ferrite morphology in high ferrite (12 FN) sample. × 100.

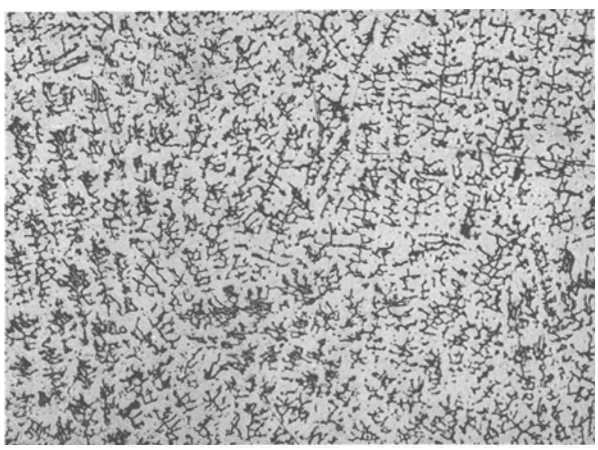

Figure 3 Microstructure of TIG sample showing finer ferrite, 8 FN. × 200.

2. Microstructures

Figs 1 and 2 show the as-weld microstructures. It can be noted that ferrite morphology changed from discontinuous vermicular type to a mixture of continuous network and lathy type when the content increased. The morphology was relatively finer for TIG samples (Fig. 3).

The microstructures of PWHT 4 FN samples are shown in Figs 4 and 5. The network was not affected much when heat treated at 600 °C even after 100 h. The case after 800 °C for 1 h, was the same, however, it tended to globularize after 100 h at 800 °C. There was a tendency for globularization after 1000 °C PWHT for 1 h and complete globularization was noticed after 100 h exposure.

For the PWHT 12 FN samples the network was intact after 600 °C PWHT. 800 °C PWHT also did not affect the network significantly even after 100 h exposure, however, 1000 °C PWHT, did not affect the network at the initial stages (1 h) but caused it to become globularized after prolonged exposure (10 and 100 h) (Fig. 6).

Secondary phases identified in the as-weld and PWHT sample of SAW are given in Table III. They

TABLE II Chemical composition of weld metals

Sample	Electrode used	Welding speed ($mm\,min^{-1}$)	Cr	Ni	C	Nb	Mn	Si	Ferrite content (FN)
1	309Cb	100	20.67	10.80	0.050	0.45	0.88	1.02	12
3	308Cb	100	18.67	9.6	0.052	0.44	0.90	0.98	4

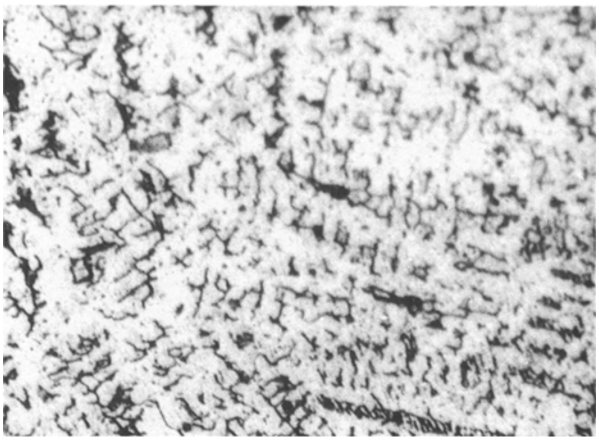

Figure 4 Microstructure of low ferrite sample, 4 FN, PWHT 600 °C, 100 h. × 200.

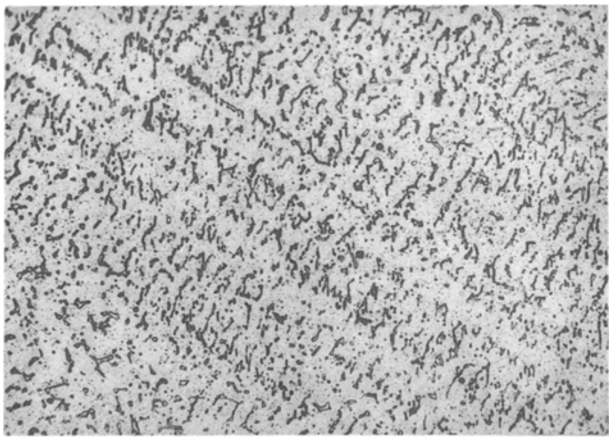

Figure 5 Microstructure of low ferrite sample, 4 FN, PWHT 800 °C, 1 h. × 200.

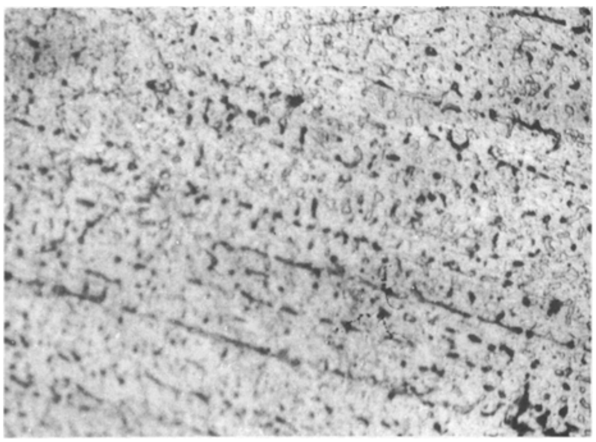

Figure 6 Globularization of ferrite in high ferrite sample, 12 FN, PWHT 1000 °C, 100 h. × 200.

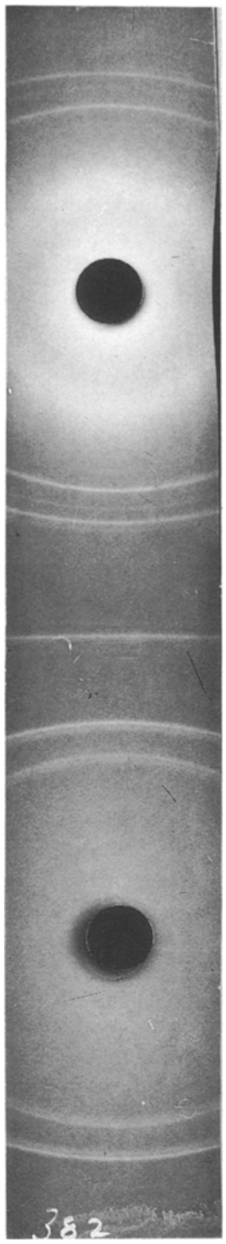

Figure 7 Typical X-ray diffraction picture of high ferrite sample, 12 FN, PWHT, 800 °C, 10 h.

are based on the lines both in the forward and backward reflections of Debye–Scherrer photographs of which a typical one is shown in Fig. 7.

From Table III it can be noted that the as-weld samples contained both $M_{23}C_6$ and NbC. NbC was found to precipitate at the austenite–ferrite interface in niobium-stabilized austenitic clad metals [3]. $M_{23}C_6$ precipitation is generally not expected in the as-weld microstructure, however, studies by Thomas *et al.* [1] indicated that $M_{23}C_6$ can precipitate during welding at the austenite–ferrite interface. This interface is favoured because it is a high-energy nucleation site and ferrite is rich in chromium.

The PWHT samples were found to contain $M_{23}C_6$, NbC and sigma phases. NbC was found in all the PWHT samples. Both 4 FN and 12 FN samples showed $M_{23}C_6$ after PWHT at 600 °C. After 800 °C PWHT 4 FN samples did not show $M_{23}C_6$, while 12 FN samples showed weak $M_{23}C_6$ lines but after 1000 °C PWHT, it was absent in both the cases.

Sigma was absent in the 4 FN samples PWHT at 600 °C, while it was present in the 800 °C PWHT samples. In contrast, samples containing 12 FN samples showed sigma both after 600 and 800 °C PWHT. Sigma was absent in samples PWHT at 1000 °C.

TABLE III Secondary phases in SAW samples identified by diffraction technique (A Absent, P Present)

Sample	Sample identification NO.[†]	Sigma	M23C6	NbC
1	AW-4 FN	A	P	P
2	AW-12 FN	A	P	P
3	261	A	P	P
4	262	A	P	P
5	263	A	P	P
6	281	P	P[a]	P
7	282	P	A	P
8	283	P	A	P
9	201	A	A	P
10	202	A	A	P
11	203	A	A	P
12	361	P	P[b]	P
13	362	P	P	P
14	363	P	P[b]	P
15	381	P	P[c]	P
16	382	P	P[d]	P
17	383	P	P[e]	P
18	301	A	A	P
19	302	A	A	P
20	303	A	A	P

[a] Absent in forward reflection and weak in backward reflection.
[b] Absent in forward reflection and overlapped with NbC in backward reflection.
[c] Absent in forward reflection and weak in backward reflection.
[d] Overlapped with sigma in forward reflection and weak in backward reflection.
[e] Weak in forward and backward reflections.
[†] See Table III′ for specimen identification.

TABLE III′ Specimen identification numbers. As-weld samples will be referred as AW-4 FN or AW-12 FN

PWHT samples have numbers XYZ where				
X	– 2	4 FN	or	3 FN-T samples
	– 3	12 FN	or	8 FN-T samples
Y	– 6	600C	PWHT	
	– 8	800C	PWHT	
	– 0	1000C	PWHT	
Z	– 1	1 Hr	PWHT	
	– 2	10 Hr	PWHT	
	– 3	100 Hr	PWHT	

It is also interesting to note the effect of initial ferrite content on sigma phase formation. It is observed that ferrite transformed to sigma at 600 °C itself when ferrite content is relatively high (12 FN) and not when it is less (4 FN). This behaviour suggests that sigma formation is not only a function of temperature but also initial ferrite content and readily forms even at lower temperatures like 600 °C when initial ferrite content is high. This is in contrast to the earlier studies [1] where it was noticed that short time exposures at temperatures up to 700 °C did not show sigma formation. Hortan *et al.* [4] observed that prolonged exposure of several thousand hours at temperatures up to 600 °C resulted in only carbides and no sigma was noticed. The present study shows that one has to be careful in considering PWHT at 600 °C when the initial ferrite content is relatively high as it leads to sigma formation.

From the intensities of lines it was found that when sigma was present, $M_{23}C_6$ carbide lines were either absent or weak in one of the reflections (forward or backward). This shows that when sigma formation takes place, $M_{23}C_6$ formation is suppressed or slowed down.

The transformation of δ-ferrite to the sigma phase is related to the diffusion of chromium from the austenite matrix during ageing thus rendering the chromium-enriched ferrite susceptible to sigma formation

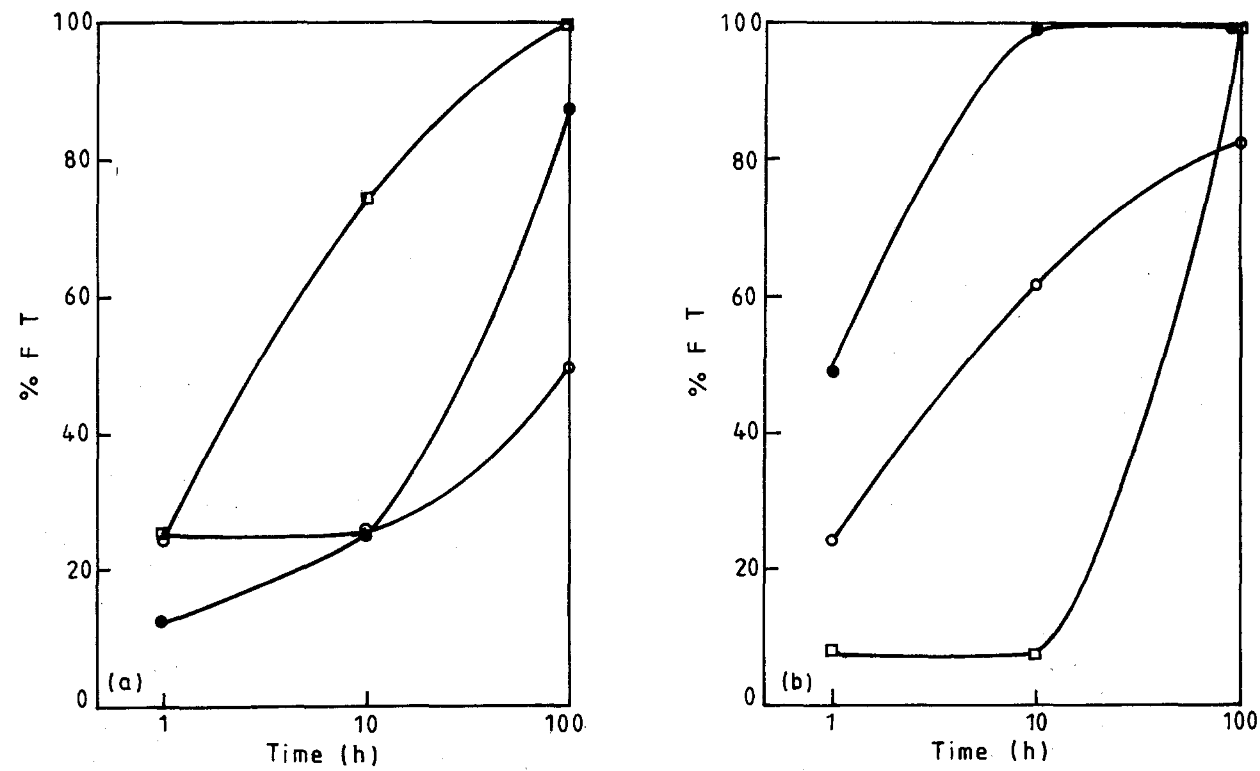

Figure 8 Percentage ferrite transformed for SAW PWHT samples. (○ 600 °C, ● 800 °C, □ 1000 °C)

[5]. The fact that higher ferrite contents are susceptible to sigma formation suggests that the chemical composition of ferrite may be different with different contents, for example the ferrite may be enriched with higher levels of ferrite forming elements such as chromium and niobium. When the ferrite content is relatively high, the enrichment of these elements may be responsible for the easy formation of the sigma phase.

The present results also have shown that at 1000 °C sigma does not form and it has been shown by earlier workers [6] that ferrite becomes austenite at this temperature.

3. Percentage ferrite transformed

Fig. 8 shows percentage ferrite transformed (FT). As can be seen from the figure ferrite content in general decreases after PWHT. Samples showed higher percentage FT at 800 °C than either at 600 or 1000 °C especially after 1 or 10 h exposures. Phase identification studies have indicated that at 800 °C, ferrite transforms to sigma whereas at 1000 °C, ferrite dissolves into austenite, therefore it, appears that sigma kinetics are faster than ferrite dissolution into austenite. The lower percentage FT for 600 °C the sample PWHT 12 FN indicates that sigma formation at 600 °C is slower than formation at 800 °C. It can also be noted that at 1000 °C the percentage of ferrite is low when initial ferrite content is high. It can also be noted that ferrite dissolution into austenite is slower if ferrite content is high.

Overall, the study showed that ferrite is transformed to sigma readily even at 600 °C exposure for shorter periods like 1 h when the ferrite content is higher and the kinetics of sigma are very fast compared to ferrite dissolution in austenite. Irrespective of the ferrite content, the sigma phase precipitated after 800 °C PWHT. Ferrite dissolution is faster at 1000 °C when the ferrite content is lower.

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