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Microalloying effects on microstructure and mechanical properties of 18Cr–2Mo ferritic stainless steel heavy plates

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ABSTRACT

The microstructure, including grain size and precipitation, tensile strength and Charpy impact toughness of (Nb + V) 18Cr–2Mo ferritic stainless steel heavy plates with/without Ti were investigated by means of optical microscopy, scanning electron microscopy, transmission electron microscopy, X-ray diffraction and standard tensile strength and Charpy impact toughness testing. It was found that for 18Cr–2Mo heavy plate, a good combination of Nb–V stabilized method without Ti induces refinement of grain sizes due to the precipitation of amounts of fine Nb carbonitrides and V nitrides. Meanwhile, the mechanical testing results indicate that optimal transformation of grain size, precipitation that Nb–V composition system brings to 18Cr–2Mo heavy plate is beneficial to improvement of strength and impact toughness.

1. Introduction

Ferritic stainless steel (FSS), which is body centered cubic (BCC) structure, is essentially Fe–Cr or Fe–Cr–Mo alloy [1]. FSS has various advantages in comparison with austenitic stainless steel (ASS): lower cost, higher thermal conductivity, smaller linear expansion and better resistance to chloride stress-corrosion cracking, atmospheric corrosion and oxidation. Because of these merits, FSS is very attractive in numbers of application fields [2–4]. The Cr and Mo balance in 18Cr–2Mo FSS, together with stabilizing additions, such as Nb, V, Ti, provides higher corrosion resistance than other ferritic grades [5] and is even comparable to austenitic AISI 316 [6].

However, one limitation of 18Cr–2Mo FSS is its relatively high ductile to brittle transition temperature (DBTT) [7], which is always above room temperature and particularly as thickness is beyond 5 mm [8]. In addition, it is impossible to reduce the thickness of FSS products due to its comparatively low strength. For instance, for 18Cr–2Mo FSS, which is named S44400 according to ASTM: A240/A240M-13c, the bottomline of its yield strength is only 275 MPa. At present, 18Cr–2Mo FSS heavy plates (above 4 mm) have been applied in limited industrial fields, such as water treatment and brewing. Therefore, the challenge of 18Cr–2Mo FSS heavy plate is how to improve toughness and utilize the other attributes of this steel group.

Some factors affecting the toughness properties have already been identified for FSS. Wright [9] proposed that the BCC crystallography limits the number of available slip systems, lowers the deformation compatibility and increases the probability of initiation and propagation of brittle fracture. Xiao [10] explained the brittleness of FSS from the point of crack cores that form at the boundaries of deformation bands, which influences DBTT of high Cr FSS [8]. Van Zwieten and Bulloch [11] suggested that for Fe–Cr stainless steel, C and N dramatically reduce the impact toughness properties due to carbides and nitrides form at the grain boundaries, while O has only a small detrimental effect since O in BCC metals promotes the occurrence of intergranular fracture. The presence of second phases, viz. carbides, nitrides and oxides, can negatively influence the toughness properties of FSS. In high C and/or N alloys, the toughness is decreased after a high temperature annealing treatment, which increases the lattice friction stress and the flow stress as a result of the precipitation of carbides and nitrides on dislocations. Ohashi et al. [9] believed that coarse grains tend to promote crack initiation, and thus the grain size contributes mainly to resistance to initiation of brittle fracture and only slightly to crack propagation.

The detrimental effect of interstitials may be controlled by the addition of stabilizing elements, such as Nb, V, Ti and Zr. These elements form strong carbides and nitrides [7,12,13], which are more stable than Cr carbides and nitrides. Semchyshen et al. [7] found Nb and Ti are both effective in retarding the increment in transition temperature. V has a strong tendency to form carbides and ni-

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Table 1
Chemical compositions (wt.%) of the studied 18Cr–2Mo steels.

Steel no.	C	Si	Mn	Cr	Mo	Nb	V	Ti	N	Fe
FSS-1#	0.0047	0.093	0.090	17.83	1.81	0.15	0.14	–	0.0105	Bal.
FSS-2#	0.0046	0.080	0.081	17.95	1.78	0.15	0.11	0.05	0.0101	Bal.

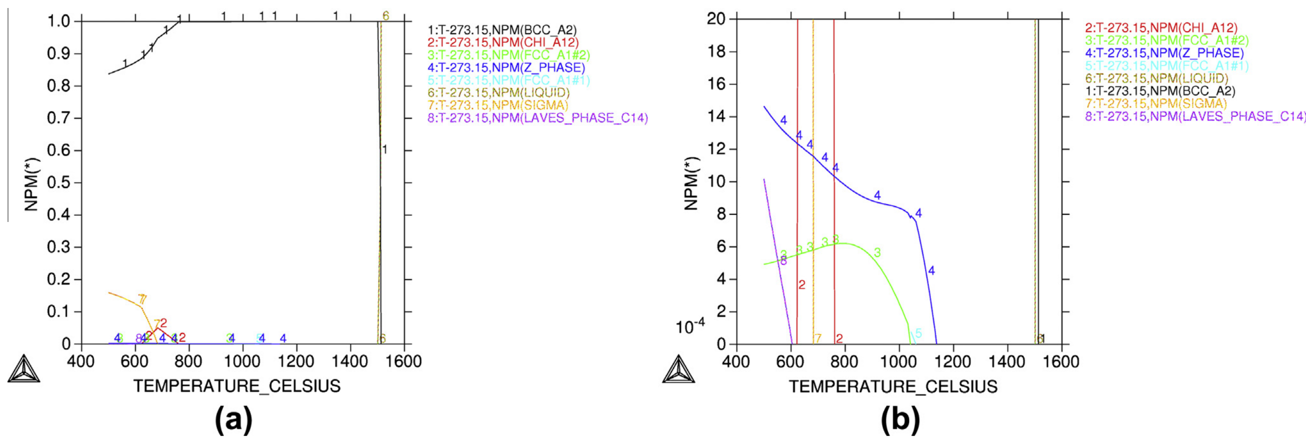

Fig. 1. Calculated equilibrium molar fractions of precipitates of FSS-1#: (a) *Y* axis from 0–1 mol; (b) *Y* axis from 0–2 × 10^{-3} mole.

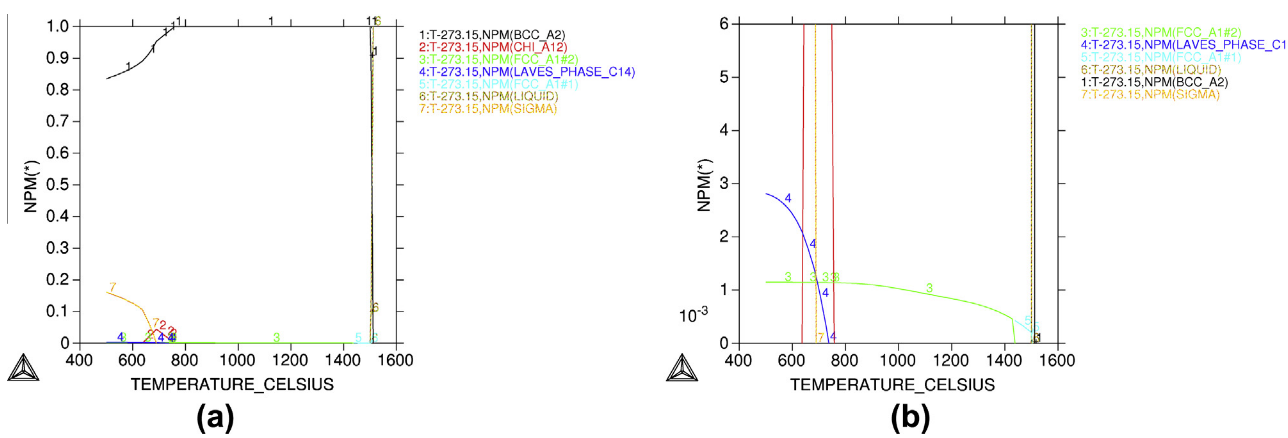

Fig. 2. Calculated equilibrium molar fractions of precipitates of FSS-2#: (a) *Y* axis from 0–1 mol; (b) *Y* axis from 0–6 × 10^{-3} mole.

Table 2
Tensile properties of the studied 18Cr–2Mo steels.

Steel no.	YS (MPa)	UTS (MPa)	Elongation (%)
FSS-1#	337.5	470.0	32.0
FSS-2#	302.5	442.5	33.0

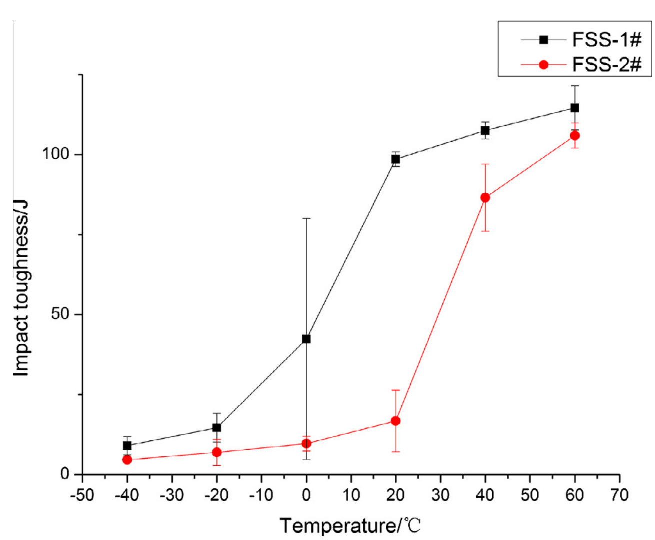

Fig. 3. Charpy impact values of FSS-1# and FSS-2# from −40 to 60 °C.

trides, and meanwhile, the solid solubility of its carbides and nitrides are very small in ferrite, which will disperse V precipitates at specific temperature [14]. Paton [15] pointed that some benefit is obtained in impact toughness by the addition of V.

In this study, Ti was added to traditional (Nb + V)-stabilized 18Cr–2Mo FSS heavy plates to investigate the role of microalloy additions on microstructure and mechanical properties. V is added to the studied steels instead of part Nb in consideration of its effect of solution and dispersion strengthening, which is beneficial for the development of FSS heavy plate.