Deformation Behavior at High Temperature of Feeder Pipe Material in CANDU

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1. Introduction

The mild steel is a kind of a structural material in nuclear reactor being used as a feeder pipe in CANDU reactor and as a secondary side in PWR. The specification of these nuclear materials is called as a SA106 in pipe shape. The chemical composition of SA106 is same as mild steel.

The deformation behavior at high temperature in mild steel is rarely understood yet [1], although mild steel is a major structural material in commercial nuclear reactors. Thus, the high temperature tensile tests were carried out up to 500℃. The results are properly interpreted in the aspects of the short range order reaction.

2. Experimental

The rod with 10mm diameter was used. The carbon content is equivalent with SA 106 class B. The chemical composition of mild steel is shown in Table 1.

The specific heat (Cp) of mild steel is determined using a water quenched (WQ) from 960℃, a furnace cooled (FC).

The WQ specimens are scanned in different rate of 10-40k/min by DSC in order to determine the activation energy for the exothermic reaction. The activation energy for the ordering reaction is calculated as follows [2, 3];

$$\ln((\alpha_2 T_1^2/\alpha_1 T_2^2) = Q/R(1/T_1 - 1/T_2) \qquad (1)$$

where T_1 and T_2 are peak temperatures at scan rate α_1 and α_2 and R is gas constant.

The microstructure variation before and after deformation is examined by electron back scattered diffraction (EBSD). The specimens are prepared by grinding and electro-polishing in 10% perchloric acid + 90% methanol solution.

Table 1. Chemical composition of SS316L (wt. %).

elements	Fe	Mn	Si	N	C	P	S
Compositio n [%]	Bal.	0.81	0.29	0.004	0.23	0.02	0.006

3. Results and Discussions

The microstructure and grain orientation of FC mild steel is shown in Fig. 1. The microstructure of FC mild steel is consisted of ferrite and pearlite. The dark region is pearlite and the clear grains are ferrite in Fig. 1.

The (211) direct pole figure determined by EBSD shows a almost random texture (Fig. 2). The darker region appeared in Fig. 2 is due to a larger grains.

The Cp variations in mild steel are shown in Fig. 3. The exothermic reaction appears at 50-330^{o}C in WQ. This shows that the ordering reaction occur in mild steel. The nature of the ordering reaction seems to be the short range ordering (SRO) between Fe and C. The amount of released energy (FC-WQ) is calculated as 26 J/g

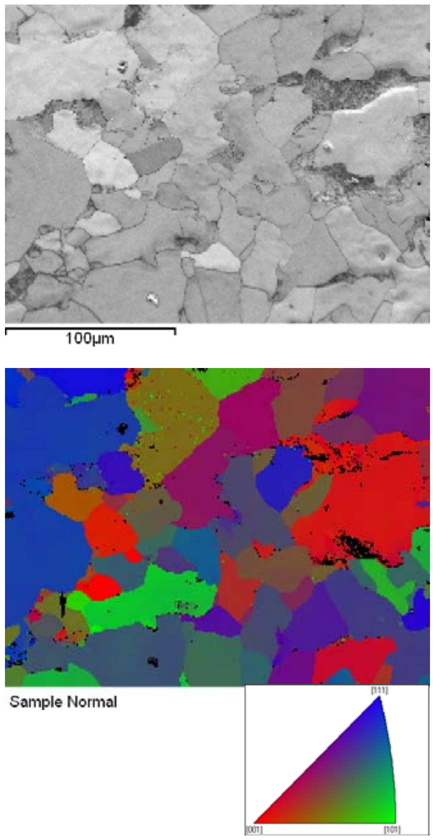

Fig. 1. Microstructure and Orientation map in furnace cooled (FC) mild steel.

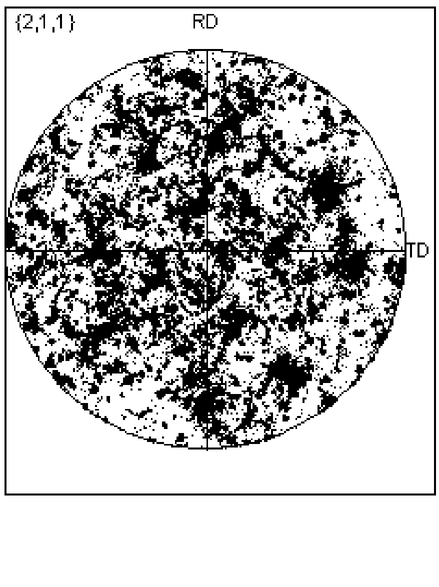

Fig. 2. (211) pole figure in FC mild steel.

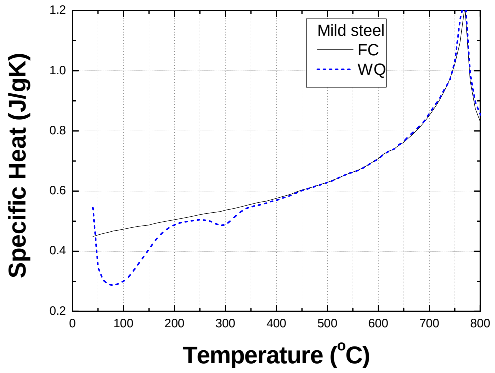

Fig. 3. The specific heat (Cp) variation in WQ and Mild steel.

Table 2. Peak temperature variation with heating rate in water quenched mild steel.

Material condition	Heating Rate (α, ℃/min)	Peak Temperature (Tp, ℃)	1/T $[K^{-1}]$	α/Tp2
water quenched mild steel	**10**	295.6	0.001758	3.09141E-05
	20	319.2	0.001688	5.69998E-05
	30	333.9	0.001647	8.1409E-05
	40	344.4	0.001619	0.000104886

The DSC results are shown in table. 2. The calculated result of the activation energy for the ordering reaction in WQ mild steel, Q ordering = 73 kJ/mol. This seems to be a reasonable value since the ordering reaction in mild steel occurs between Fe and C

The strain-stress curves in FC mils steel are compared in Fig. 4. The FC steel shows a yield point and serration at below 400℃. The yield point is formed at the beginning of deformation during tensile test, whereas the serration is formed during in the middle region of deformation. The reason of yield point and serration seems to be different, since the state of deformation is not same.

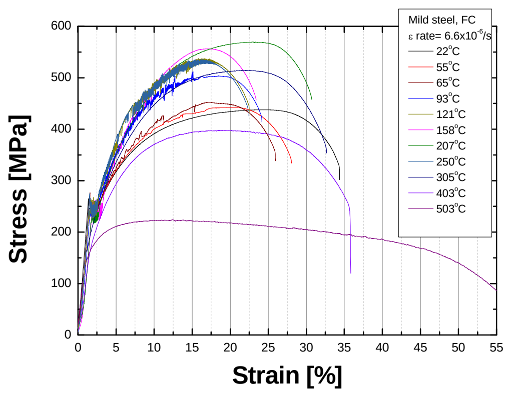

Fig. 4. Strain-stress curves with temperature in FC mild steel.

The strain-stress curves in WQ mils steel are compared in Fig. 5. The WQ material does not show yield point. However, the serration occurs 50-160℃. In addition, the yield and tensile strength increases with temperature at below 100℃. It is possible to understand that the deformation behavior at high temperature is influenced by cooling rate significantly in mild steel. It is reasonable to understand that the state of SRO affects the deformation behavior at high temperature in mild steel

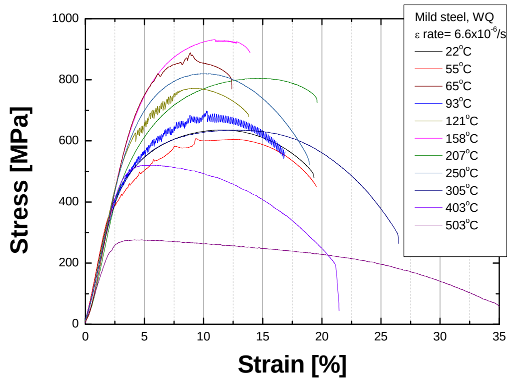

Fig. 5. Strain-stress curves with temperature in WQ mild steel.

4. Conclusions

1. The FC mild steel shows a yield point. at below 400℃, whereas the WQ does not show the yield point. The reason why the yield point appears is due to the destruction of SRO formed during furnace cooling process
2. The serration appears at 50-150℃, at which the exothermic reaction takes place. The origin of the exothermic reaction is a formation of SRO between Fe and C.
3. The shape of serration changes significantly at above 121℃ and becomes downward generally, this is mainly due to both destruction of SRO by the disordering and by the shearing.
4. The reason why the serration at 93℃ is the most clear is due to the strain induced ordering, although this temperature is above the critical temperature for the ordering.

Acknowledgements

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