Effects of Si and Mn on Mechanical Properties of 9Cr-1Mo Steel

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ABSTRACT

Effects of Si and Mn on mechanical properties, especially toughness after ageing, were investigated in this report. Four steels were vacuum melted and were normalized for 1h at 1050C, tempered for 1h at 740C. These materials respectively contains 0.4wt% Si and Mn, 0.02wt% Si and 0.4wt% Mn, 0.4wt% Si and 0.02wt% Mn, 0.02wt% Si and Mn. Results of charpy test after ageing at 550C indicated that the lowering of Si improved the decrease of toughness, but the lowering of only Mn unaffected. On the while, in the case of low cooling rate after normalization, the tendency of toughness decreasing was almost the same result as above. This tendency corresponded approximately to coagulation of precipitates, especially that of Laves phase. In the low cooling rate, Laves phase precipitated and coagulated more quickly than in the air cooling after normalization.

1 INTRODUCTION

In recent years 9Cr-1Mo steels have become taking an important part of steels in the power generation plants. These materials have good creep properties and corrosion resistance, so the application of these materials to FBR power plant are investigated. In 9Cr-2Mo dual phase steels, it is known that Si accelerated the decrease of toughness after ageing and it was dependent on precipitation of Laves phase or on the increase of precipitates (1). In 9Cr-1Mo steels, for example modified 9Cr-1Mo steel(2) which was developed at ORNL in the USA, effects of Si or Mn on mechanical properties and microstructure is less reported. So in this study, effects of Si and Mn on the decrease of toughness of 9Cr-1Mo steels after ageing at 500-600C were investigated for the application to the heavy forging which would be used to tube sheet in steam generator of FBR power plant.

2 EXPERIMENT

2.1 Tested materials

The chemical composition of tested materials are given in Table 1. Experiments were carried out on four steels with different Si and Mn contents, which were denoted HH, LH, HL and LL. These materials (ingot:5kg) were vacuum melted. All materials were normalized for 1h at 1050C and air-cooled, tempered for 1h at 740C and furnace-cooled. According to the results of above materials, two steels were melted in order to investigate cooling rate after normalization, of which chemical composition are given in Table 2. As the cooling rate, 400C/h was adopted. Initial heat treatment are the same as that of above materials. These were denoted H and L.

Table 1 Chemical composition of tested materials (wt%)

	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb
HH	0.10	0.37	0.39	0.006	0.007	0.17	8.40	0.97	0.20	0.07
LH	0.10	0.02	0.40	0.002	0.008	0.17	8.53	0.95	0.20	0.07
HL	0.10	0.33	0.03	0.001	0.008	0.17	8.39	0.95	0.21	0.07
LL	0.10	0.03	0.03	0.001	0.008	0.17	8.35	0.95	0.19	0.07

Table 2 Chemical composition of tested materials (wt%)

	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb
H	0.10	0.33	0.28	0.004	0.007	0.16	8.08	0.89	0.20	0.08
L	0.09	0.06	0.34	0.003	0.009	0.17	8.35	0.95	0.20	0.07

(cooling rate : 400C/h)

2.2 Experimental methods

The first series of materials (four materials) were aged at 550C and charpy test was carried out at -110C to 0C. The second series of materials (two materials) were aged at 500, 550 and 600C, and charpy test was carried out at 0C. Several materials were submitted to creep rupture test at 550C, too. Microstructure observation and composition analysis of precipitates were carried out under a transmission electron microscope (TEM) equipped with an energy dispersive X-ray spectrometer (EDX).

3 EXPERIMENTAL RESULTS

Fig.1 shows the relation between ageing time at 550C and impact value at 0C. The impact value of HH steel(0.37wt% Si and 0.39wt%Mn) and HL steel(0.33wt% Si and 0.03wt% Mn) decreased with ageing time, showing the same tendency. But the impact value of LH steel(0.02wt% Si and 0.4wt% Mn) and LL steel(0.03wt% Si and Mn) scarcely changed with ageing time, which indicated that the lowering of Si content contributed to improve toughness after ageing at 550C. However, the lowering of only Mn content did not improve toughness after ageing.

Fig.2 shows relation between brittle fracture appearance(ratio of brittle fracture area) and test temperature of the four materials which were aged for 0, 1000, 3000 and 6000h at 550C. Although the transition temperature was improved by lowering Mn content comparing HL with HH steel, an increase of the transition temperature of HL steel was larger than that of HH steel. The transition temperatures of LH and LL steels were less than that of HH steel, of which tendency was almost the same as decrease of impact value at 0C.

Fig.3 shows creep rupture properties at 550C. HH, LH and HL steels had almost the same strength, but the strength of LL steel was less than that of the others. Creep rupture ductilities(elongation and reduction of area) were not affected by Si and Mn contents.

According to above results the lowering of only Si content was effective for improving toughness after ageing at 550C, without decreasing creep rupture strength. So, microstructure analysis was carried out mainly on HH and LH steels.

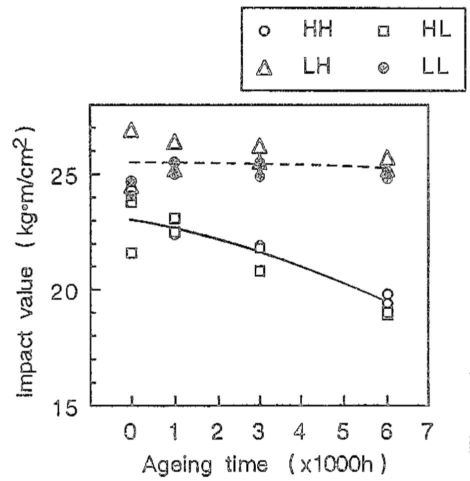

Fig. 1 Impact value after ageing at 550C

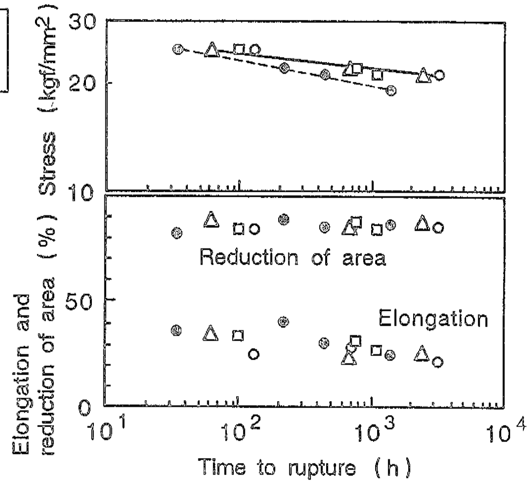

Fig.3 Creep rupture properties

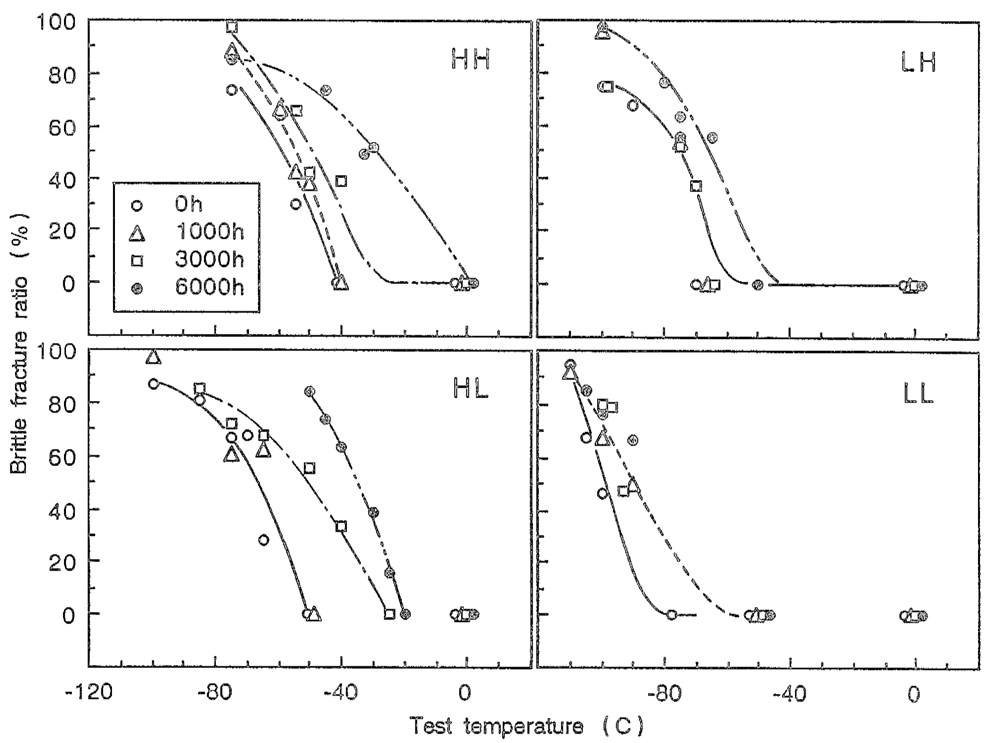

Fig. 2 Brittle fracture ratio after ageing at 550C

Fig.4 shows change of precipitation morphologies of HH and LH steels during 550C ageing, using carbon extracted replicas. In LH steel with low Si content, remarkable change was scarcely recognized. However, in HH steel, growth or coagulation of precipitates was recognized for longer ageing time. Fig.5 shows precipitation characteristics of HH and LH steels after 6000h ageing at 550C by electron diffraction and EDX analysis. Most of coagulated precipitates which were observed in HH steel were identified as the Laves phase of which composition was $(Fe_{1.4}Cr_{0.3}Si_{0.3})Mo$. This type of phase started precipitating from about 4000h ageing at 550C and saturated after about 10000h. On the while, in LH steel no Laves phase was not identified and $M_{23}C_6$ type carbide scarcely coagulated after 6000h ageing and its composition was stable.

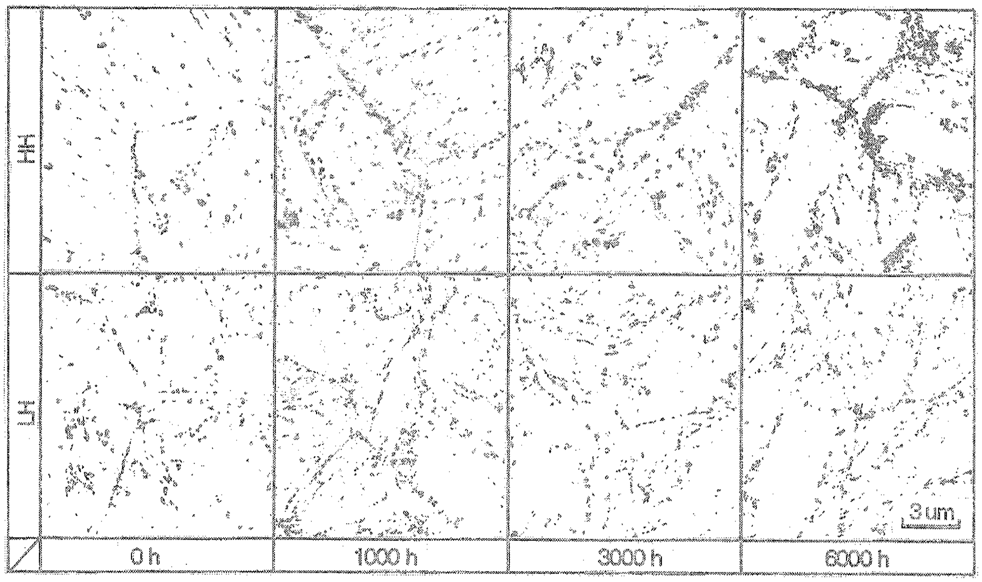

Fig. 4 Precipitation morphologies of HH and LH steels after ageing at 550C

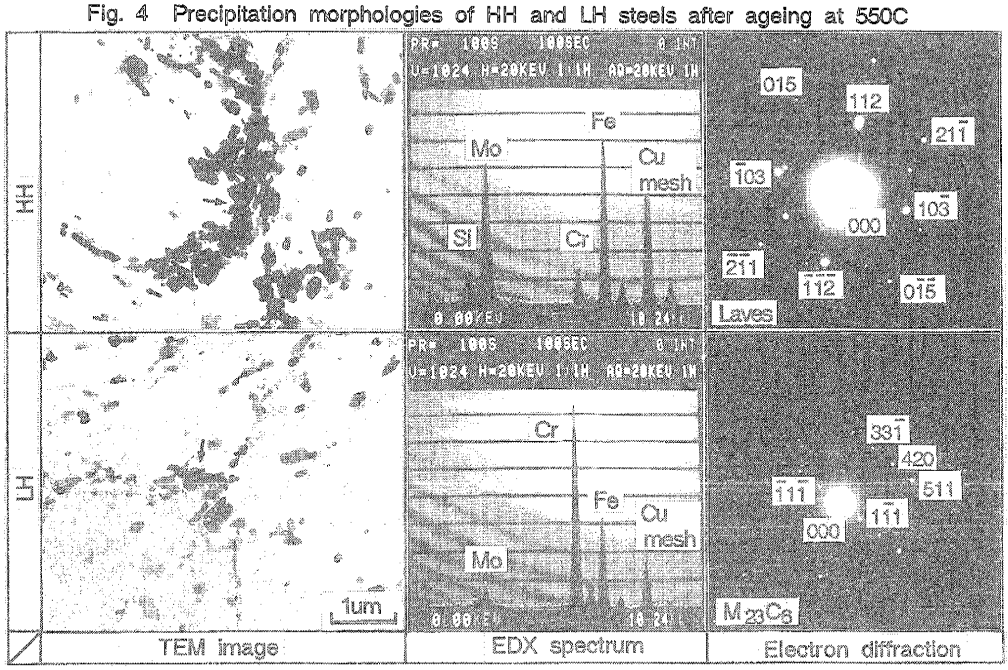

Fig. 5 Characteristics of precipitates in HH and LH steels after ageing for 6000h at 550C

Fig.6 shows the change of impact value at 0C of two materials which was normalized and cooled by the ratio of 400C/h. Ageing temperatures were 500, 550 and 600C. At 550C, change of impact value show the same tendency as the above results in Fig.1. However, decrease of impact value was recognized at both of 500 and 600C. Fig.7 shows microstructure of H and L steels after ageing at 550C by carbon extracted replicas. In H steel, Laves phase started precipitating more quickly than that of air-cooled material. Fig.8 shows the relation between ageing time at 550C and I/I_{as}(I:impact value after ageing, I_{as}:impact value as heat treated) of H steel. The tendency of decrease of toughness corresponded approximately to Laves phase coagulation(3-5). At 500C remarkable change of precipitation morphology was not recognized and at 600C the amount of Laves phase was much less than at 550C in H steel, which were supposed to affect above results.

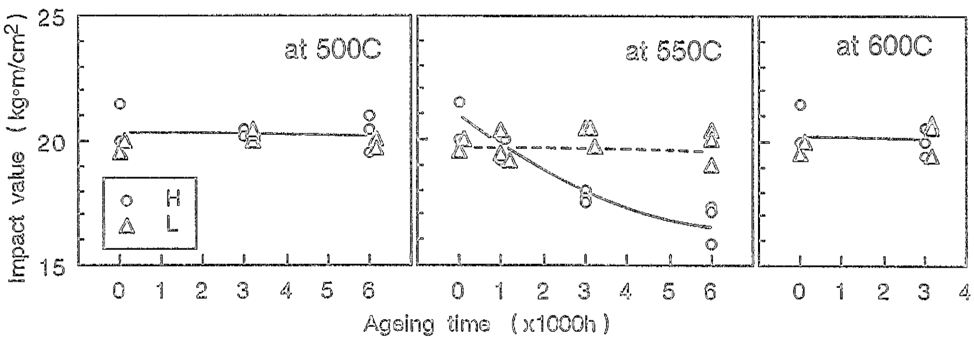

Fig. 6 Impact value after ageing at 500, 550 and 600C

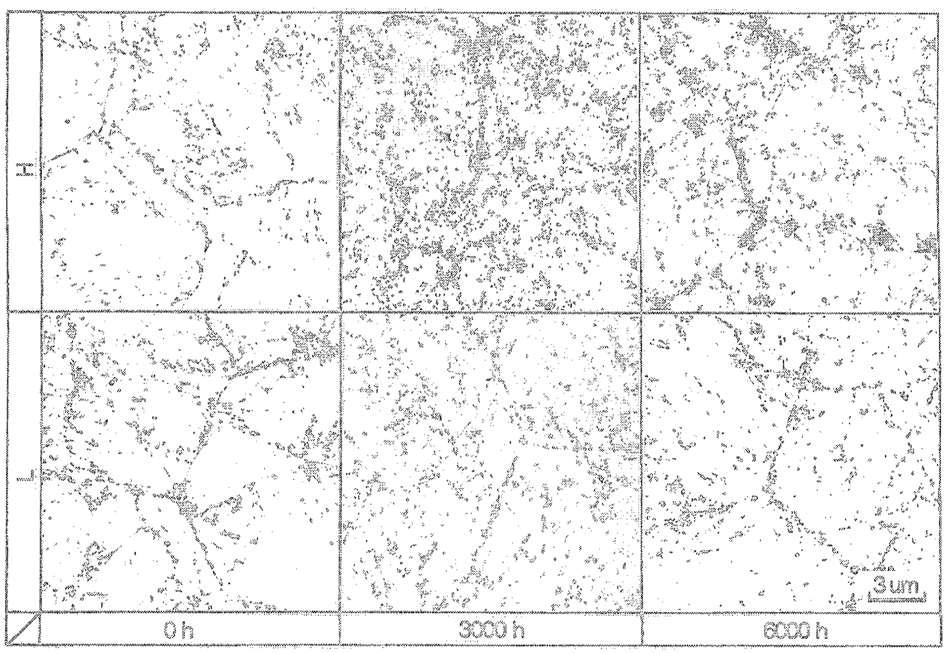

Fig. 7 Precipitation morphologies of H and L steels after ageing at 550C

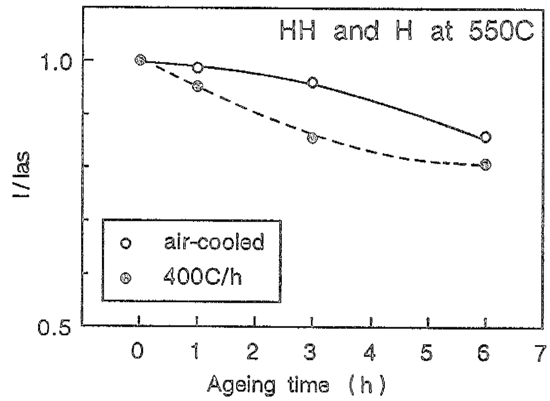

Fig. 8 Effect of cooling rate on decrease of toughness

4 CONCLUSIONS

In 9Cr-1Mo steels, the lowering of Si improved decrease of toughness after ageing at 550C, but the lowering of only Mn did not contribute to its improvement. The lowering of Si inhibited not only growth and coagulation of precipitates but also Laves phase formation. In the case of low cooling rate at normalization, Laves phase started precipitating more quickly and the tendency of decrease of toughness corresponded approximately to its behavior.

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