Effect of Bainite Morphology on the Mechanical Properties of a Ferrite-Bainite-Martensite Triple-Phase Steel

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1- Introduction

Dual and triple phase steels have unique properties such as continuous yielding behavior, low ratio of YS/UTS, high work hardening rate and high homogenous elongation percentage; thus, they are used widely for automotive applications. The aim of this study is to develop a triple-phase microstructure of ferrite-bainite-martensite with desirable mechanical properties.

2- Experimental

The 4140 steel used in the present research is in the form of a rod with diameter of 10 mm and microstructure of ferrite-pearlite. The chemical composition of this steel is given in Table 1. The samples were austenitized at 850 °C for 1 h. Then, kept at 720 °C (the ferrite-austenite region) for 3 min, and transferred to a salt bath at different temperatures of 380, 400, 420 and 450 °C for 4 min to obtain various morphologies of bainite, finally quenched in water to form martensite. Microstructure, hardness, tensile properties (yield strength, ultimate tensile strength, elongation, work hardening exponent) and fracture surface of the austempered samples after tensile test were investigated.

3- Results and Discussion

Fig. 1 and Fig. 2 show the SEM images of the samples austempered at different temperatures. As can be seen, with increasing the austempering temperature from 380 to 450 °C, the bainite morphology has been changed from lower bainite to upper bainite.

Table 1 Chemical composition of the investigated steel (in wt.%)

Fe	C	Cr	Mo	Mn	Si
Bal.	0.416	1.13	0.221	0.741	0.342
P	S	Ni	AL	Co	Cu
0.015	0.0214	0.0273	0.0311	0.0041	0.0119
Nb	Ti	V	W	Pb	Sn
0.00067	0.0018	0.0034	0.0016	0.0024	0.00075

Investigations revealed that increasing austempering temperature resulted in a decrease in the values of hardness, yield strength, ultimate tensile strength, strength difference (UTS-YS), strength ratio (YS/UTS) and elongation. For instance, the changes of YS and UTS with austempering temperature are shown in Fig. 3.

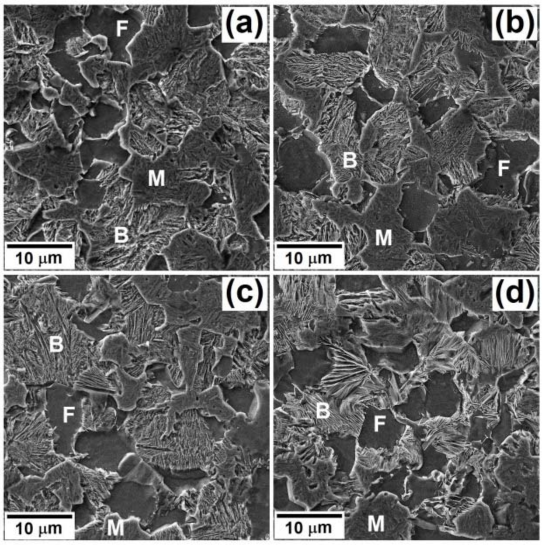

Fig. 1 SEM images of the samples austempered at (a) 380, (b) 400, (c) 420, (d) 450 °C

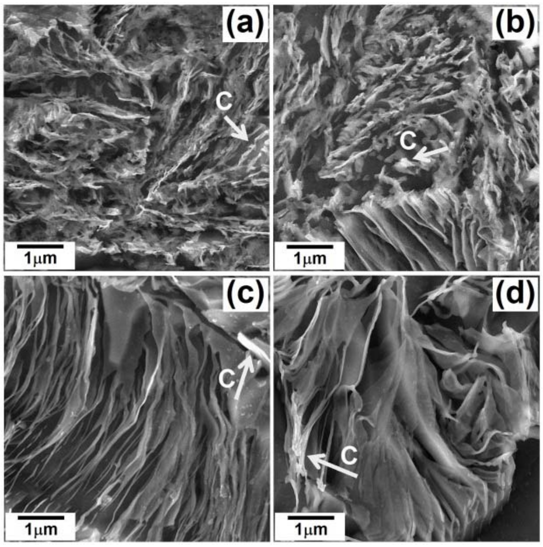

Fig. 2 Morphology of bainite in the samples austempered at (a) 380, (b) 400, (c) 420, (d) 450 °C

Fig. 4 shows the stereo-microscopy images of fracture surfaces of tensile tested samples. As can be seen, with increasing the austempering temperature, the rough-dark surfaces are changed to the smooth-bright surfaces, which is indicative of increase in brittle fracture behavior.

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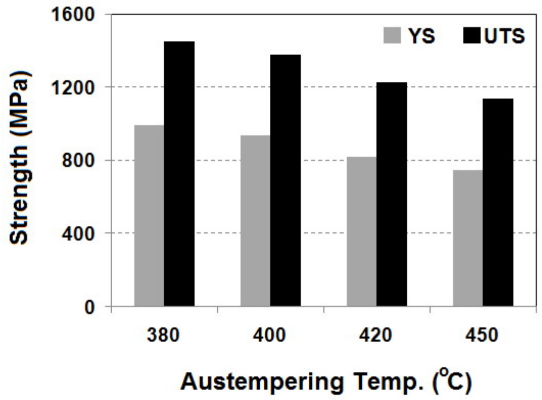

Fig. 3 The change of YS and UTS with austempering temperature

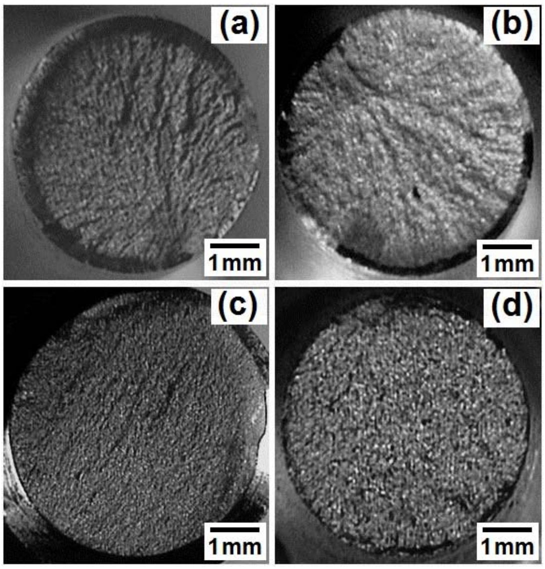

Fig. 4 Stereo-microscopy images of fracture surface after tensile test for the samples austempered at (a) 380, (b) 400, (c) 420, (d) 450 °C

Lnσ vs. Ln□ curves for the samples austempered at different temperatures are shown in Fig. 5. The curves are non-linear but can be considered as two linear curves, thus, the work hardening obeys the two-stage mechanism. The slope of the lines is equal to the work hardening exponent (n). The higher ‘n’ indicates the higher work hardening rate. According to Fig. 6, ‘n’ in the first stage is greater than the second stage. As the austempering temperature increases, the ‘n’ value decreases.

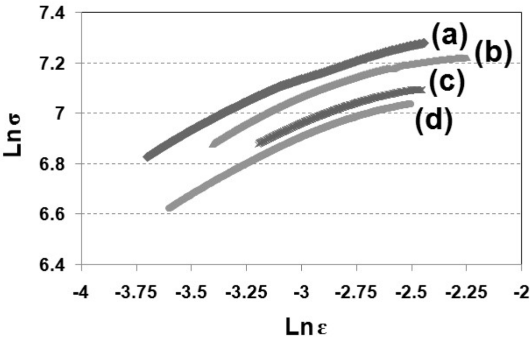

Fig. 5 Lnσ-Ln□ curve for samples austempered at (a) 380, (b) 400, (c) 420, (d) 450 °C

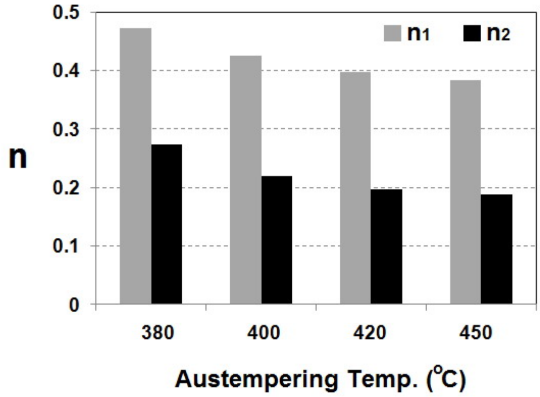

Fig. 6 Values of work hardening exponent in the first stage (n_1) and second stage (n_2) for the samples austempered at different temperatures

4- Conclusions

This research revealed that with increasing the austempering temperature from 380 to 450 °C:

1- Values of hardness, YS, UTS, UTS-YS, YS/UTS and elongation decrease.

2- The tendency for brittle fracture increases.

3- Work hardening exponent decreases.

These results are related to changing of bainite morphology from lower bainite to upper bainite.