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Investigation of Abnormal Mechanical Behavior of a Low Alloy Spring Steel containing 0.5wt%C-1.7wt%Si Under Bainitic- Martensitic- Retained Austenitic Condition

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1. Introduction

In recent years, research on high-strength steels has increased with the goal of achieving high strength and toughness along with reducing thickness, increasing resource storage and energy, reducing production costs, and reducing environmental pollution. For a long time, the complex effect of retained austenite on the mechanical properties of high strength steels has been taken into consideration, and completely contradictory results have been reported. Some researchers have reported that the retained austenite delayed the necking phenomenon in steel during tensile behaviour and caused the increase of homogeneous plastic deformation and significant work hardening by the TRIP phenomenon. In this research, the effect of phase transformation and microstructure on the mechanical properties of a low-alloy steel with high silicon content was performed under the heat treatment process with the aim of achieving multiphase microstructures to optimize the high level of strength and toughness.

2. Material and Experimental Process

In the present study, a low-alloy steel plate (0.529wt%C-0.721wt%Mn-1.67wt%Si-balanced Fe) with 1 mm thickness after determination of critical temperatures involving Ac_1=765°C, Ac_3 = 835 °C, M_s=281 °C and Bs=470°C was reaustenitized at 900 °C for 5 minutes and then transferred into the 350 ºC salt bath and were kept between 5s to 5h followed with water quenching. Microstructural investigations were performed by using optical and scanning electron microscopes. Mechanical tests including tensile and macrohardness measurements were performed. In the following, specimens are shown with an index including temperature and holding time in the bainitic region.

3. Results and Discussion

3.1. Microstructural Investigation. Microstructural observation carried out by optical microscope (Figure 1) indicate that the volume fraction of retained austnite phase (white areas) increased up to 200 s and by further increasing isothermal holding time decreased. On the other hand, these observations also showed that the dark lath of the bainite phase is formed after 10 seconds, and the bainite volume fraction increases by holding time. It is worth noting that the studies were carried out by Toji et al. also showed that the presence of silicon causes the growth of the bainite with lath morphology, which is confirmed in the present research.

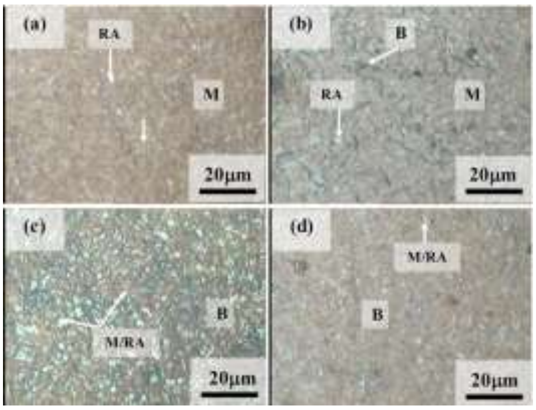

Figure 1. Optical microscopy images for the specimens: (a) 350 ºC-5s, (b) 350 ºC-30s (c) 350 ºC-200s and (d) 350 ºC-1h

In order to characterize more details of microstructure, the specimens held for 200s, 1 and 5 h were performed by using a scanning electron microscope (Figure 2). In these figures, bainite areas are dark gray areas and the martensite-retained austenite with blocky shape region are light gray. As can be seen in figure 2 (c), after 5 h holding time, finely microstructure included blocks of martensite-retained austenite.

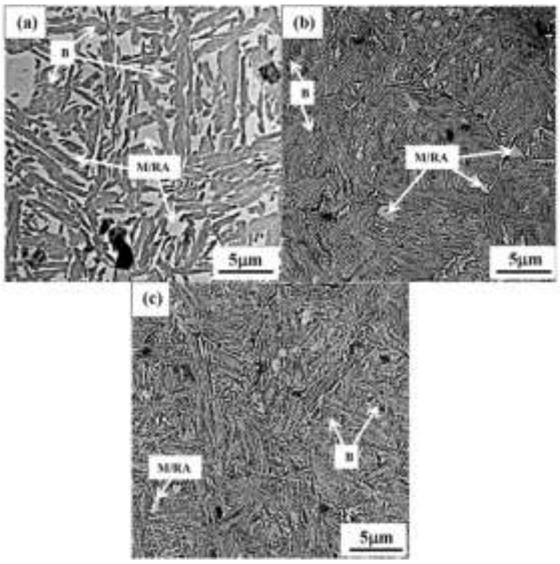

Figure 2. Scanning electron microscopy images for: (a) 350ºC-200s, (b) 350 ºC-1h and (c) 350 ºC-5h

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3.2. Mechanical Properties Investigation

Tensile tests are shown in Figure 3. The results of tensile strength variations show that at first, with an increase in the holding time from 5 to 50 s in the molten salt bath 350 ^oC, an increase of tensile strength has been occurred from 1850 to 2052MPa, and then decreased to 1386MPa in 300s treated samples, and again with increasing the holding time to 1h is unexpectedly increased up to the value of 1460MPa and is stabilized at approximately this level of strength. Also, the comparison of the elongation results (Figure 2) shows an almost inverse trend relative to the tensile strength variations that are developed. The maximum peak in tensile strength values was observed in the samples 350^{o}C-50s due to the presence and interaction of extremely fine multiphases microstructures including 60.1vol.% martensite, 36.2vol.% bainite, and 3.7vol.% retained austenite. For the holding times longer than 50s, the tensile strength decreases due to the bainitic transformation happening and increasing the volume fraction of bainite phase. Then, by holding time increasing in the molten salt bath up to 1h, the tensile strength is increased again to 1460 MPa.

The macrohardness data (Figure 4) shows the similar trends of tensile and yield strength, an unusual behaviour involving a maximum and minimum peaks was developed in hardness data.

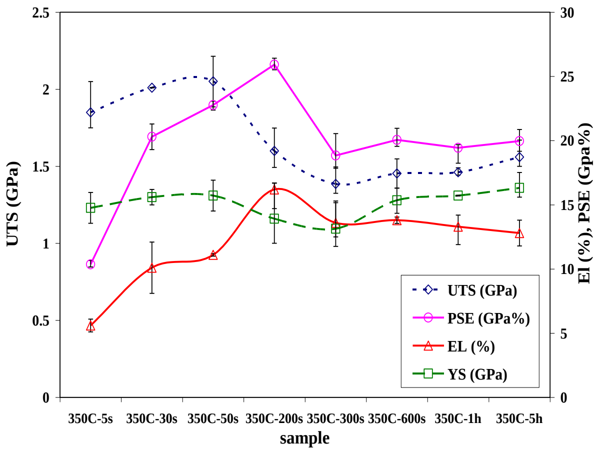

Figure 3. Chart of tensile and yield strength and elongation variation according to holding time in the salt bath 350 ^oC

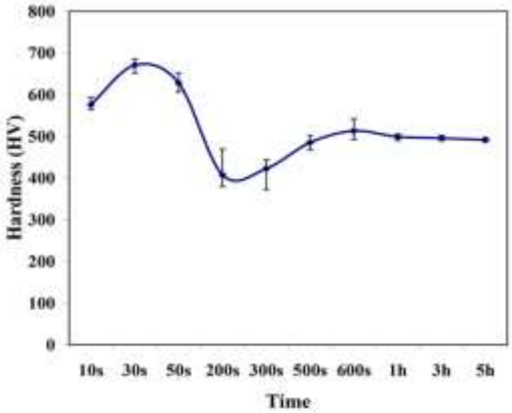

Figure 4. Macrohardness variation for the specimens held in the salt bath 350 ^oC for different times

4. Conclusion

The results of the application of heat treatment processes on mechanical properties and microstructural changes of the low alloy steel showed that the microcompositic microstructures can be formed including a mixture of martensite-bainite-retained austenite microphases. The mechanical properties of these specimens proved that the tensile strength of the developed microstructures was varied from 2007 to 2052MPa, which is much higher than the reported tensile strength for advanced third-generation of high strength steels. Tensile strength variations by holding time in the molten salt bath include a maximum value for the specimens held for 50s and is equal to 2052MPa, and a minimum value was achieved for the specimens held for 300s, which is equal to 1386MPa.