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# Effect of Intercritical Heat Treatment on Mechanical Properties of a Microalloyed Steel

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**Keywords:** Dual phase; intercritical heat treatment; microalloyed steel.

**Abstract.** In this paper, the effect of intercritical heat treatment on the microstructure and mechanical properties of a microalloyed steel was investigated. The intercritical heat treatment procedure was performed at various temperatures to obtain different martensite volume fractions in the steel. In addition, annealing and normalizing treatments were also applied to the steel for comparison. After completing the heat treatment processes, microstructural characterization of the steel specimens was made and the martensite volume fractions in the intercritically heat treated steel samples were determined. The martensite volume fractions were found to be 30%, 53% and 77% for the steel that was heat treated intercritically at the temperatures of 737 ºC, 754 ºC and 779 ºC, respectively. Next, some important mechanical properties of the steel specimens were found by applying tensile testing. A significant increase in the tensile strength was recorded in the steel samples which were intercritically heat treated in comparison to the annealed and normalized ones. On the other hand, the ductility of the intercritically heat treated samples decreased with increasing martensite content rapidly.

## Introduction

There has been a significant interest on the steel with dual phase microstructure especially for automotive applications due to its improved mechanical properties. This type of steel consists of both hard martensite and soft ferrite phases which are formed by applying intercritical heat treatment. Dual phase steels are generally low carbon and/or low alloy steels which have low hardenability in depth. In this type of steel, while the ferrite provides ductility and toughness, the martensite increases hardness and tensile strength to a great extent [1-15].

Tavares et al. [8] investigated the mechanical properties of dual phase steel, 0.12% C and 0.83% Mn which was intercritically treated and tempered. They stated a significant increase in toughness of the steel after tempering treatments. In a different work [9], the microstructural and mechanical characterizations of dual phase steel with a very low carbon content of 0.05% and 2.26% Mn were studied. In addition, Lis et al. [10] conducted a study on the tensile properties of C-Mn dual phase steel after thermomechanical rolling and intercritical heat treatment procedure.

Moreover, the properties of some dual phase steels, which were annealed intercritically and then hot rolled, were investigated by Sun and Pugh [11]. It was shown that the tensile strength and elongation of these steels were affected by the morphology of the martensite significantly. Erdoğan and Tekeli [12] examined the influence of martensite fraction and particle size on the tensile properties of surface carburized AISI 8620 steel with a dual phase core microstructure, whereas Liang et al. [13] studied the change in the tensile and yield strengths of a dual phase steel consisting of 0.11% C, 0.3% Si, 1.8% Mn and 0.028% Nb with respect to quenching temperature. Charpy impact toughness of DP590 steel containing 0.08 wt% C and 1.24 wt% Mn was compared to AISI

1018 steel [14]. It was seen that DP590 had higher impact toughness than AISI 1018. In a recent study, Sarwar et al. [15] examined the effect of martensite morphology on the tensile properties of low alloy steel containing small amounts of Mn and Si. They pointed out that the tensile strength of the steel increased while the contact area between martensite and ferrite increased [15].

In this study, the effect of intercritical heat treatment on the microstructure and mechanical properties of a microalloyed steel was presented. Various heat treatments; intercritical treatment, annealing, normalizing and martensitic transformation were applied to this steel for comparison.

## Material and method

The steel, containing 0.28% C, 1.45% Mn, 0.21% Cr, 0.20% Si, 0.13% V and 0.01% Nb in weight percentages, was supplied from the market. First of all, various heat treatments, which are given in Table 1, were applied to this steel. These are intercritical annealing at three different temperatures, annealing, normalizing and fully martensitic transformation. In the intercritical heat treatment, steel specimens were soaked at various temperatures for 30 min to reach two phase region consisting of ferrite and austenite phases together. And then, they were quenched in agitated water to get ferrite and martensite phases in the microstructure. On the other hand, one group of the steel specimens was heated to austenite region 900 ºC and quenched into water to maintain fully martensitic transformation. In addition to these thermal treatments, the annealing and normalizing were also applied to the steel specimens (Table 1). Secondly, microstructural examinations on the heat treated samples were made with an optical microscope. Etching of the samples was carried out using an etchant of 5% nital solution. In the intercritically heat treated samples, the martensite volume fraction of the steel was obtained by point counting on the micrographs. Finally, the standard tension testing was utilized for mechanical characterization of the samples using the ASTM standards [16]. Tension tests were made at a test speed of 2 mm/min. Three measurements for each specimen were done and their average values were recorded.

Table 1. Heat treatment procedure used in this study

| Heat treatment | Temperature [ºC] | Time [min] | Quenching Media |
|---|---|---|---|
| Intercritical treatment | 737 | 30 | Water at 25 ºC with agitation |
| Intercritical treatment | 754 | 30 | Water at 25 ºC with agitation |
| Intercritical treatment | 779 | 30 | Water at 25 ºC with agitation |
| Fully martensitic transformation | 900 | 30 | Water at 25 ºC with agitation |
| Full annealing | 900 | 30 | In the furnace |
| Normalizing | 900 | 30 | In the air |

## Results and discussion

Microstructures of the samples subjected to intercritical heat treatment at three different temperatures are shown in Fig. 1. Both the martensite (dark regions) and the ferrite phases (white areas) are seen apparently in the specimens. In addition to that increasing the intercritical temperature increases the martensite content of the steel as expected. The martensite volume fractions are recorded as 30%, 53% and 77% for the treatments at temperatures of 737 ºC, 754 ºC and 779 ºC, respectively.

Fig. 2 illustrates the microstructures of the steel after the treatments of annealing, normalizing and fully martensitic transformation processes. In the annealed and normalized steel specimens, the ferrite and pearlite phases are observed, whereas only the martensite phase is seen in the steel quenched directly from the austenite region at 900 ºC. One can see that grains are much smaller in the normalized steel compared to the annealed one due to the fact that normalizing provides faster cooling condition than annealing.

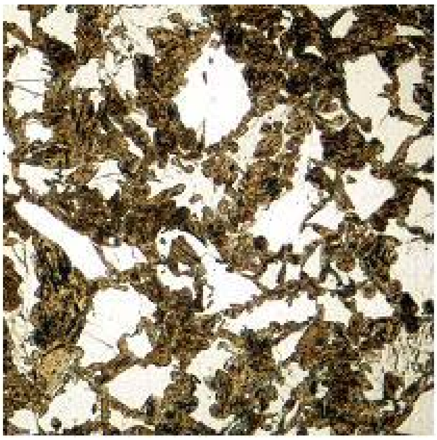
Tensile testing results for the investigated specimens are represented in Fig. 3. The effect of martensite fraction on the strength and ductility can be seen clearly. The tensile strength is found to be ~ 830 MPa for the steel having 30% martensite but it becomes ~1380 MPa when the martensite volume fraction is increased to 77%. The maximum tensile strength value is found for the fully martensitic structure while the lowest one is obtained for the annealed specimen.

The hard martensite phase improves the strength of the intercritically treated specimens whereas the fine grains in the normalized specimen increases the strength of the steel compared to the annealed one having larger grains. Another important benefit gained from the dual phase structure is the annihilation of the serrations at the yield point which are observed at the annealed steel.

## Conclusions

According to the experimental results, main conclusions can be drawn as follows:

- Intercritically heat treated steel samples showed higher strength values compared to the annealed and normalized ones. Therefore, the application of the intercritical heat treatment on the micro-alloyed steel could provide a significant weight and cost saving with respect to other candidate steels having higher alloy content or non-martensitic microstructures.
- Discontinuous yield point was removed by forming the dual phase (ferrite and martensite) microstructure.
- A significant reduction in the ductility of the steel took place due to the increase in the martensite volume fraction but it can be tolerated by tempering of the dual phase steel without causing a hard decline in its strength [8].

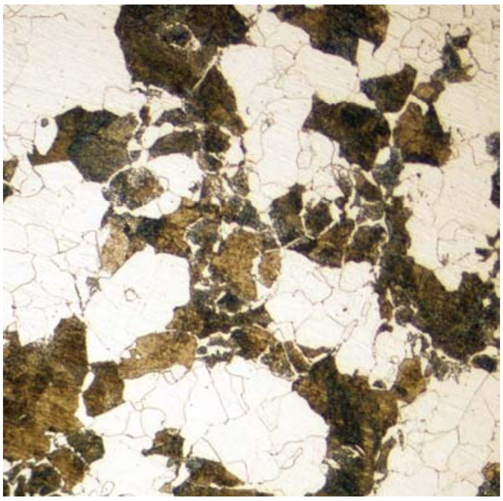


(a)

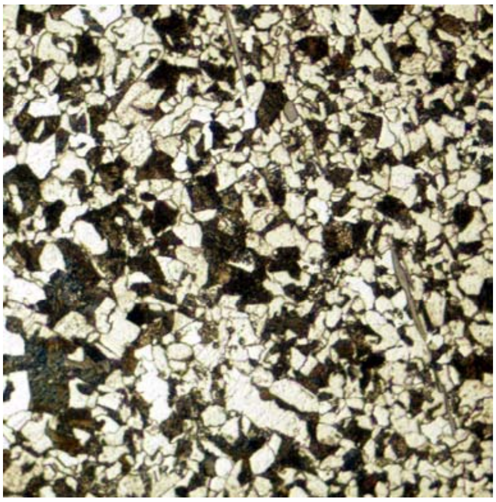
(b)

(c)

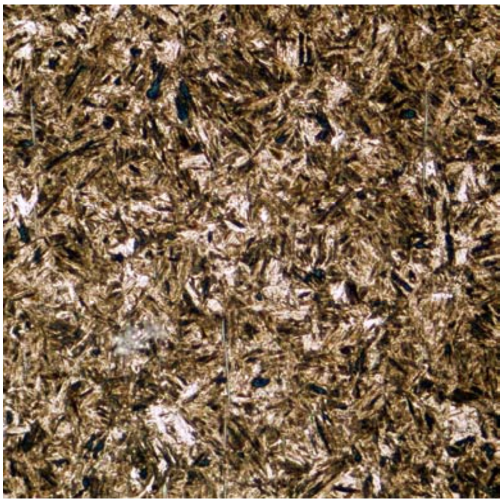
Figure 1. Microstructure of the intercritically heat treated steels at: a) 737 ºC, b) 754 ºC and c) 779 ºC (500X)



(a)



(b)



(c)

Figure 2. Microstructures of the steel after a) annealing, b) normalizing and c) full martensitic transformation (500X).

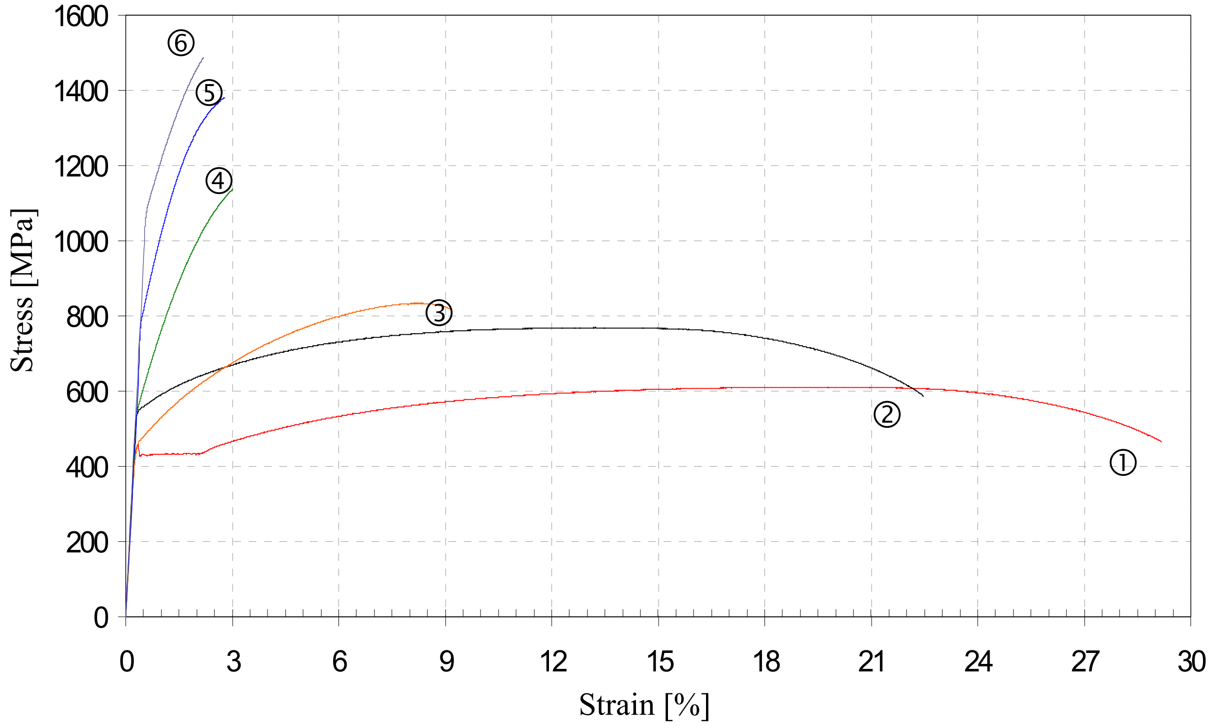



Figure 3. Tensile behavior of the steel subjected to 1) annealing, 2) normalizing, 3) intercritical treatment at 737 ºC, 4) intercritical treatment at 754 ºC, 5) intercritical treatment at 779 ºC and 6) intercritical treatment at 900 ºC.

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