Controlling the Mechanical Properties of Carbon Steel by Thermomechanical Treatment

Mohsen Balavar1, a), Hamed Mirzadeh1, b)

1 School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran

a) mohsen_balavar@ut.ac.ir
b) Corresponding author: hmirzadeh@ut.ac.ir

Abstract. The effect of thermomechanical processing and heat treatment on the microstructure and mechanical properties of low carbon steel was studied. It was revealed that the dual phase ferritic-martensitic microstructure shows a good combination of tensile strength and ductility along with superior work hardening response. On the other hand, the bimodal-sized structure containing ultrafine grained (UFG) and micron-sized ferrite phase can be easily produced by cold rolling and annealing of the dual phase starting microstructure. This steel showed high yield stress, tensile strength, and ductility, but poor work hardening ability. The full annealed ferritic-pearlitic sheet with banded morphology exhibited low strength and high total elongation with the appearance of the yield point phenomenon. The martensitic steels, however, had high tensile strength and low ductility. By comparing the tensile properties of these steels, it was shown that it is possible to control the mechanical properties of low carbon steel by simple processing routes.

INTRODUCTION

The effect of the refined grain size on the enhancement of mechanical properties of polycrystalline materials is well known. As a result, severe plastic deformation (SPD) techniques [1], thermo-mechanical processing routes [2] and thermal processes [3] are frequently used for this purpose. Thermal processes use phase transformations to stimulate nucleation on the prior grain boundaries while SPD techniques are based on the high strain applied to the materials and subsequent grain subdivision. However, thermomechanical processing methods are based on the plastic deformation and heat treatment and can induce intense grain refinement. They are the most commonly used methods in the industry and always there is a need to optimize the available methods or introduce new ones. Regarding low-carbon steels, a thermomechanical process based on the cold rolling and annealing of martensite has been developed for ferrite grain refinement [4], where the responsible mechanisms has been recently unraveled to be continuous recrystallization [5]. If a dual phase ferritic-martensitic structure is used as the starting material for cold rolling and annealing, a microstructure containing larger ferrite grain size in the prior ferritic areas and ultrafine ferrite grain size in the prior martensitic areas might be form, which is known as the bimodal structure [6]. It is claimed that such a structure shows good strength-ductility balance. The present work aims to study these effects in a low carbon steel to control its mechanical properties.

EXPERIMENTAL

A 0.12C-0.16Si-1.11Mn steel was used in this work. The A1 and A3 temperatures were respectively estimated as ~ 1003 K (730 °C) and ~ 1170 K (897 °C) based on Trzaska and Park equations [7]. The sheets were austenitized at 1323 K (1050 °C) followed by furnace cooling to room temperature to develop a fully annealed microstructure with ferrite grain size of ~ 35 μm as the starting microstructure (Figure 1). The full annealed specimen was heated to 1323 K (1050 °C) for 15 min and then water quenched (WQ) to obtain martensitic microstructure, which was subsequently soaked at 1123 K (850 °C) for 15 min and then water quenched to produce the dual phase ferritic-martensitic structure. This DP steel was cold rolled with reduction in thickness of 70% followed by tempering for 45
min at 823 K (550 °C) to obtain the bimodal structure as shown in Figure 2. Etching in the 2% Nital solution was used to reveal microstructural features for optical microscopy (Olympus Vanox optical microscope). The tensile specimen was prepared according to JIS Z 2201 standard with the gage length of 12 mm.

FIGURE 1. The microstructure of the full annealed sheet.

FIGURE 2. Schematic representation of the thermomechanical treatment used to achieve the bimodal-sized microstructure.

RESULT AND DISCUSSION

Figure 3 shows the obtained dual phase microstructure. It can be seen that the pearlite phase and some of the surrounding ferrite phase transform to martensite and the rest of microstructure is ferrite. Result of tensile test for the full annealed sheet, martensitic sheet, and dual phase steel are shown in Figure 4. The yield point phenomenon for the full annealed sheet with pearlite-ferrite microstructure can be easily seen, in which after the upper yield point, dislocations are released from the Cottrell atmospheres and the stress drops to the lower yield point and local plastic deformation spread grain to grain, producing the yield-point elongation. After that, the normal work hardening regime recovers. After producing dual phase steel, yield point phenomenon vanishes due to the presence of free dislocation around the martensite particles [8]. The slope of the stress-strain curve for dual phase steel is much higher than that of the full annealed sheet. As a result, the dual phase steel has higher strength and has a proper total elongation at the same time. Finally, the martensitic specimen shows very high strength and low elongation that was predictable.
After rolling and annealing of DP steel at 823 K (550 °C) for 45 minute, the martensitic areas of dual phase steel transform to fine ferritic structure as shown in Figure 5 (observed as dark areas because of the fine grain size and presence of many grain boundaries). Therefore, the bimodal ferritic microstructure has been achieved. The tensile curve of this steel along with the DP steel is shown in Figure 6. It can be seen that both steels have the same elongation value. While the DP steel shows somewhat higher tensile strength, the bimodal steel shows much higher yield strength. However, the bimodal steel shows poor work-hardening ability and large yield-point elongation. Therefore, it can be seen that by these simple processing routed, it is possible to control the mechanical properties of low-carbon steel.
CONCLUSIONS

In summary, it was revealed that the full-annealed ferritic-pearlitic steel shows low strength and high ductility but the martensitic steel shows high strength and low ductility. By producing ferritic-martensitic dual phase steel, a combination of good strength-ductility can be achieved due to high work-hardening capacity of this steel. The bimodal-sized ferritic structure can be easily produced by cold rolling and annealing of dual phase microstructure, which shows high tensile strength and ductility. Moreover, it shows much higher yield strength compared with the dual phase steel but with poor work-hardening ability and large yield-point elongation.

REFERENCES


