Investigation of the Effect of Volume Fraction of Martensite and Different Tempering Conditions on the Microstructure and Mechanical Properties of St52 Dual-Phase Steel Used in the Automotive Industry

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Abstract

Dual-phase steels are a new class of low-strength alloy steels consisting mainly of ferrite and martensite phases. Dual-phase steels due to their special microstructure represent good mechanical properties and abrasion resistance. In this study, ST52 steel was selected as the prototype specimen because this type of steel after converting to the dual- phase steel will be used in automotive industry. After preparing some specimens of this steel, normalizing treatment was done on them. In order to achievement of dual-phase steel structure and evaluate the different tempering conditions, intercritical annealing was performed at 750 °C and 850 °C for 30 minutes on the specimens. Then tempering was carried out on specimens at 300 °C and 600 °C for one and two hours, respectively. The evaluation of microstructure and mechanical properties, revealed that with increment of the temperature during intercritical annealing, the volume fraction of martensite increases and with increment of the tempering temperature, the volume fraction of martensite decreases. Reducing the amount of martensite phase in most specimens caused to reduce the hardness and tensile strength, but the percentage of elongation increased. Also, increment of the tempering time same as tempering temperature had a similar effect on mechanical properties, while the rate of changes was more than the tempering time. Also, the obtained results showed that the highest hardness (450 Vikers) was related to specimen which intercritical treatment and tempering was performed at 850 °C and 300 °C for one hour, respectively. Additionally, this specimen revealed a highest amount of yield strength (1153 MPa) and a tensile strength (1199 MPa).

Keywords: Dual Phase Steel, ST52, Martensite Volume Fraction, Tempering, Hardness, Tensile Strength.

1. Introduction

Automotive companies are continuously looking for ways to improve their vehicles and build cars from materials that, in addition to maintain the safety, reduce fuel consumption. Any material used in the automotive process must have good formability, weldability, coat ability (to protect against corrosion) and should be repairable. One group of such materials that can meet these expectations is dual-phase steels [1]. Using dual-phase steels with 590 Mpa tensile strength in car bodies, car companies have found that these materials have excellent ductility without losing their tensile strength [2]. Dual-phase steel refers to a type of steel which that the hard phase of martensite is placed in ferrite as a soft matrix. The term of dual-phase in this steel refers to the presence of two phases of martensite and ferrite in it, although the possibility of the presence of residual pearlite, bainite and austenite phases in this structure is also possible [2].
The unique structure of dual-phase steel is caused that some researchers categorize it in the category of metal-matrix composites [3, 4] and even tried to make a dual-phase steel composite artificially, and research and study on it [5, 6].

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Despite of all the advantages above mentioned, the use of dual-phase steel also has some limitations. The most important limitation of the use of dual-phase steel is interface segregation which occurs in the ferrite-martensite interface. Changing the morphology of the martensite phase (size, shape, distribution), formation of the bainite phase in the structure of dual-phase steel and the modification of ferrite grains are solutions suggested by researchers to overcome the limitations of dual-phase steel [7]. There are various methods for making dual-phase steel, one of the most important of them is the intercritical annealing heat treatment method [8, 9].
The properties of dual-phase steel are affected by the interaction between its structural components (ferrite and martensite). Volume fraction and morphology of ferrite and martensite phases [10, 11], presence and effect of boundaries and dislocations [9, 12] and ferrite grain size [13, 14] can be considered as a series of factors affecting the mechanical properties of dual-phase steel.
It can be said that the volume fraction of martensite is the main factor affecting the mechanical properties of dual-phase steels. Determining the amount of primary martensite can be performed after intercritical annealing treatment. While after tempering treatment, primary martensite will convert to the return martensite. In this paper, the effect of different tempering conditions and volume

fraction of martensite on the microstructure and mechanical properties of St52 dual-phase steel has been studied.

2. Materials and Methods

St52 rod with 25 mm in diameter was used in this study. The chemical composition of this alloy is presented in Table. 1.

Table. 1. Chemical composition(wt.%) of St52 steel [12].

S	P	Mn	Si	C
0.030	0.030	1.500	0.500	0.200

In order to prepare the required specimens, the rod was cut into specimens with 250 mm in thickness. At first, normalizing treatment was performed for all specimens at 950 °C for 30 minutes to create a same initial structure and then cooled in air.
Then, in order to create dual-phase structure some of the specimens were subjected on intercritical annealing heat treatment according to C1 cycle, and same treatment were performed for the remained specimens with C2 cycle(Fig .1). The AFE1700L furnace made by Atra Company was used to perform this treatment.

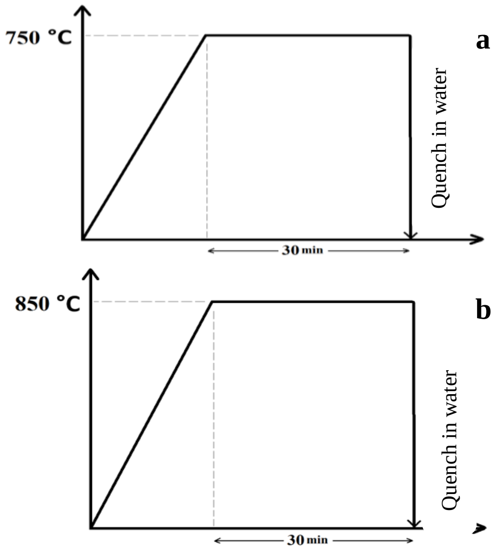

Fig. 1. Intercritical annealing heat treatment: a) cycle C1, b) cycle C2.

After intercritical annealing heat treatment, the specimens were subjected to tempering treatment. Tempering was performed with three separate cycles as illustrated in Fig. 2. For evaluation of microstructure, the specimens after preparing and polishing with alumina powder, etched with 4% nital solution. OM and SEM observations were carried out by Leitz model microscope and Mira II FEG-SEM scanning electron microscope, respectively.

In order to evaluate tensile behavior of this heat treated steel, the standard specimens for the tensile test were prepared according to the A370 standard and the tensile test was performed by the Gotech model machine with maximum force of 2 tons and rate of 2 mm / min for tensile. Hardness of heat treated specimens was mesaured by the Wolpert macrohardness device (Die Tester 7021) in accordance with the HV10 standard.

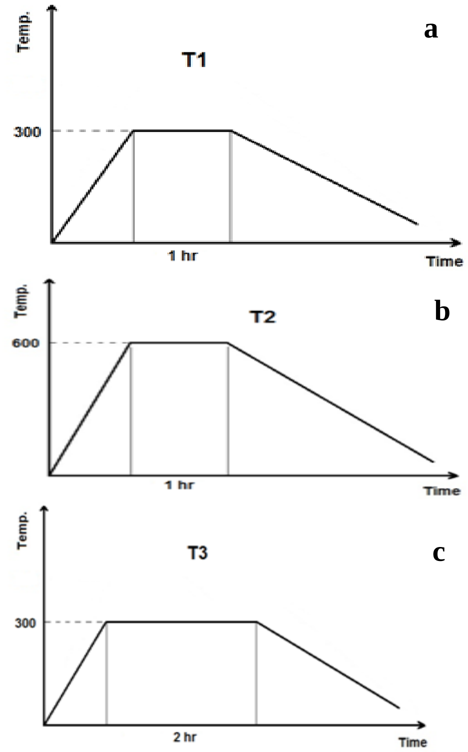

Fig. 2. Designed cycles for tempering heat treatment a) at 300 °C for 1 hour, b) at 600 °C for 1 hour, c) at 300 °C for 2 hours.

3. Results and Discussions

Fig. 3. shows the microstructure of St52 steel after normalizing treatment. It is obvious that the microstructure of this steel contains pearlite which dispersed in the ferrite matrix.

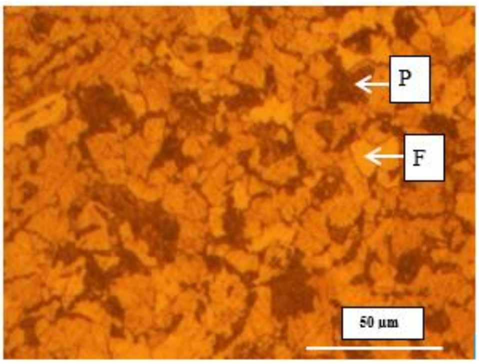

Fig. 3. Optical microscope image of St52 steel after normalizing heat treatment.

The volume fraction of martensite in dual-phase steels under C1 and C2 cycles after intercritical annealing heat treatment was calculated using Clemex vision and Image G quantitative metallographic software. In this way, the volume fraction of martensite in dual-phase steels under C1 and C2 cycles were obtained 40% and 62%, respectively. Optical and electron microscope images of the tempered specimens in different conditions are shown in Fig. 4. and Fig. 5. As can be seen in (Fig. 4.a), the martensite phase is well defined in the dual-phase specimen tempered at 300 ℃ for one hour, and the percentage of this phase is measured by the mentioned software at 38%. (Fig. 4.c) shows that with considering constant time and by increasing the tempering temperature to 600 ℃ , the martensite blades are smaller than in (Fig. 4.a) and the martensite percentage is reduced to 33%. Comparison of electron microscope images of these specimens also revealed that with increasing tempering temperature at constant time of tempering, the grains and the martensite blades became smaller. In this way, the calculated martensite phase in (Fig. 4.e) was obtained 12%. By comparison of (Fig. 4.e) and (Fig. 4.a), it is obvious that with increasing tempering time at constant temperature, the percentage of martensite has been decreased and the martensite blades have become smaller. The letters M, P, F and C in the optical and electron microscope images indicate the phases of martensite, pearlite, ferrite and cementite, respectively.

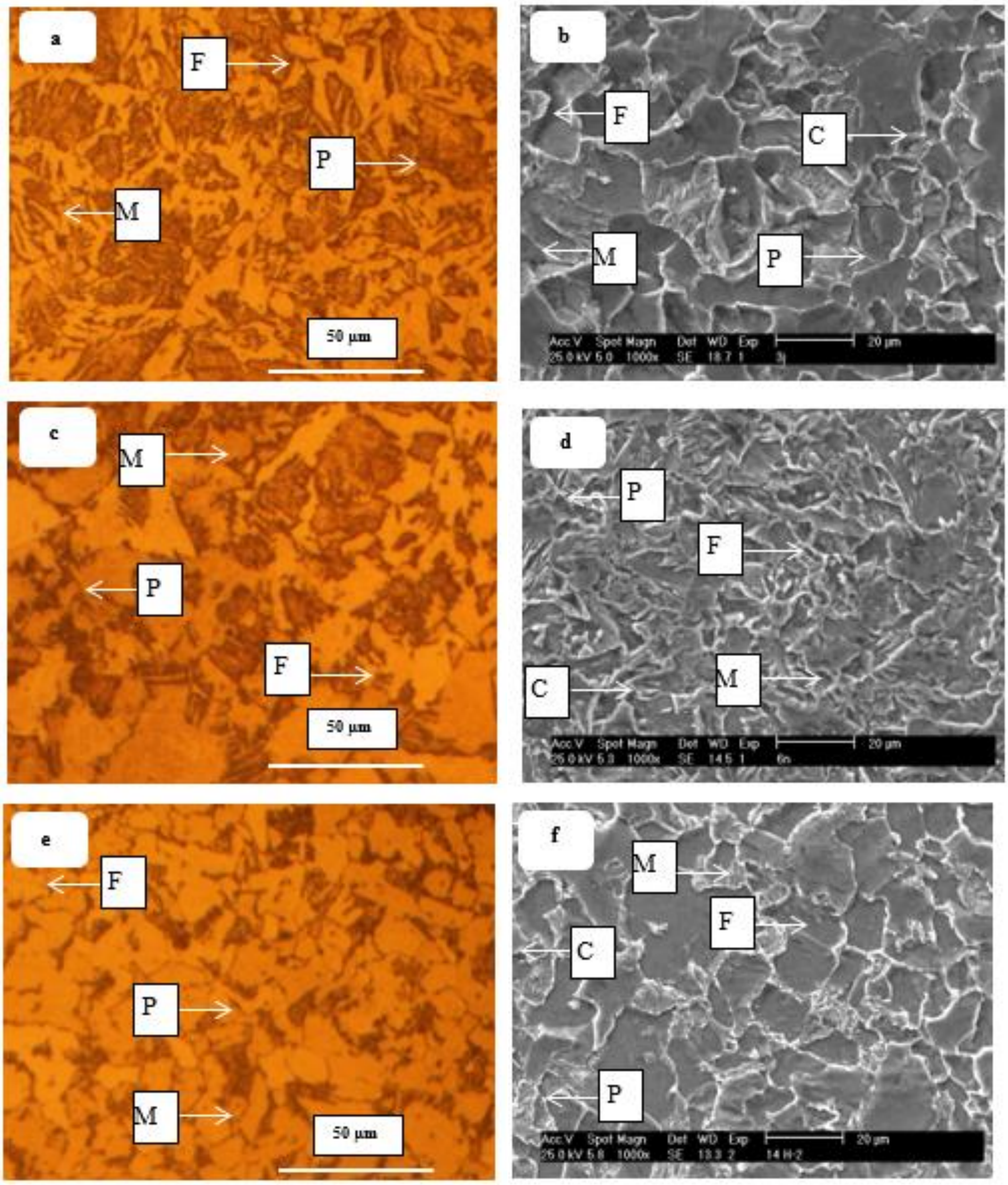

Fig. 4. Optical and electron microscope images of dual-phase steel with intercritical annealing at 750 ℃ and tempered at a- b) 300 ℃ for 1 hour, c- d) 600 ℃ for 1 hour, e-f) 300 ℃ for 2 hours.

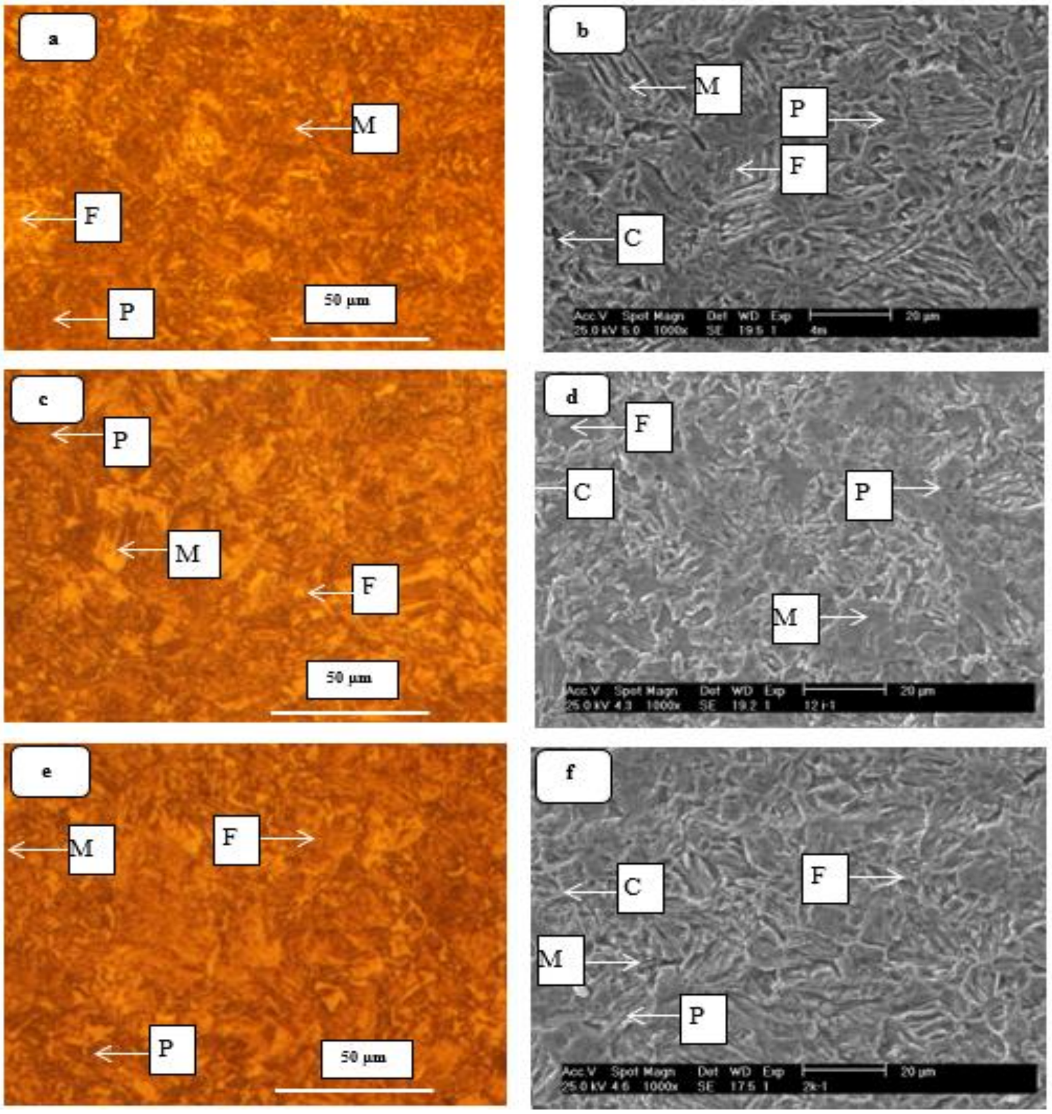

Fig. 5. Optical and electron microscope images of dual- phase steel with intercritical annealing at 850 ℃ and tempered at a- b) 300 ℃ for 1 hour, c- d) 600 ℃ for 1 hour, e- f) 300 ℃ for 2 hours.

As can be seen in the microscopic images (5-a) and (5-c), the microstructure of tempered specimens at different temperature conditions includes ferrite, pearlite and martensite phases. The volume fraction of martensite phase was obtained 53% in (Fig. 5.a) and 51% in (Fig. 5.c), respectively. The results show that by increasing the tempering temperature at a constant time, the volume fraction of martensite decreases. (Fig. 5.e) shows the microstructure of a tempered specimen exposed at 300 °C for two hours. The result of the calculation of martensite phase in this specimen shows the volume fraction of martensite equal to 49% . With comparing the results of (Fig. 5.e) with the results of (Fig. 5.a), it can be concluded that by increasing the time of tempering at a constant temperature, the volume fraction of martensite has been decreased. After calculating the volume fraction of martensite in all tempered specimens, hardness test was performed on them. Fig. 6. shows the hardness changes versus of the volume fraction of the martensite phase in the tempered specimens. It is obvious that, as the volume fraction of martensite increases, the hardness increases.

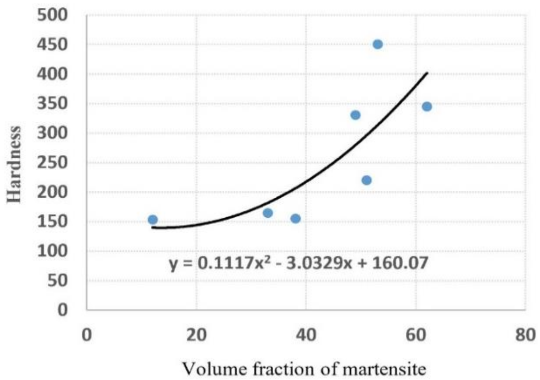

Fig. 6. Hardness changes versus of volume fraction of martensite.

The results related to changes of yield and tensile strengths versus of volume fraction of martensite are shown in Fig. 7.

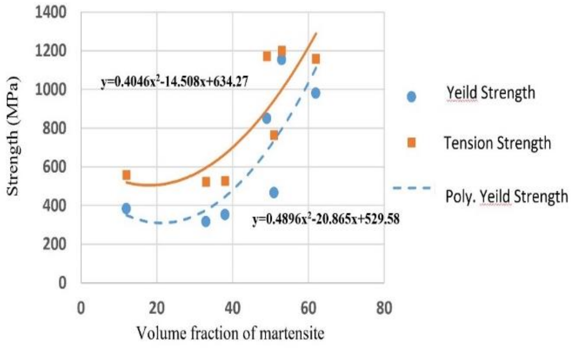

Fig. 7. Strength changes versus of volume fraction of martensite.

As shown in Fig. 7., with increasing volume fraction of martensite, tensile and yield strengths increase. However, it is predicted that further increment in the amount of martensite will lead to a decrease in strength due to creation of the brittleness.

The results showed that, with increasing tempering time, yield and tensile strength increase smoothly. In this way, increasing the tempering time has caused an improvement in the mechanical properties. Additionally, the results show that in one-hour tempering, with increasing tempering temperature, the volume fraction of martensite, yield and tensile strength decrease and this decrement is directly related to the decrement of martensite percentage.

With increasing tempering time, yield and tensile strength decreased, but the amount of decrement in tensile strength was partial. This result showed that partial decrement in the percentage of martensite at this temperature cause to partial decrement on tensile strength. But for changes of yield strength, due to the partial decrease in the volume fraction of martensite, yield strength decreases dramatically and from the obtained results, it can be concluded that the shape and morphology of martensite is effective on yield strength.

According to obtained results, in this type of dual-phase steel, with increasing tempering temperature to 600 °C, yield and tensile strength is reduced dramatically and it can be concluded that tempering treatment at 600 °C has been done completely.

Additionally, the results showed that the effect of tempering temperature on the mechanical properties of dual-phase steel was greater than the tempering time. It seems that the intercritical annealing temperature of 850 °C has a greater effect on mechanical properties than the 750 °C and the main reason is related to the increment of the volume fraction of martensite in this steel.

Also, the highest hardness and strength is obtained from the specimen with intercritical annealing temperature of 850 °C which tempered at 300 °C for 1hour and this condition is the best for this type of steel.

4. Conclusion

1. Intercritical annealing temperature of 850 °C in order to obtain dual-phase ST52 creates better mechanical properties than of 750 °C.
2. By applying of intercritical annealing temperature of 750 °C, increasing of the tempering time has more effective on the mechanical properties than tempering temperature.
3. In dual-phase ST52 with intercritical annealing temperature of 850 °C, increasing the tempering temperature has a greater effect on the mechanical properties than tempering time.
4. The best obtained result is related to mechanical properties of the specimen with intercritical annealing temperature of 850 °C which tempered at 300 °C for 1 hour.

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