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TENSILE STRENGTH AND DUCTILITY OF FERRITE-MARTENSITE DUAL PHASE STEELS

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Abstract

The aim of this paper was to evaluate tensile properties of low carbon ferrite-martensite dual phase steel. For this purpose, 2 mm thick steel sheet was intercritically heat treated, followed by water quenching to obtain different volume fractions of martensite (V_m). Microstructural investigations and tensile test were carried out. Yield strength, ultimate tensile strength and ductility were correlated to martensite volume fraction. The results showed that dual phase steels with an equal amount of ferrite and martensite have excellent mechanical properties. Further increase in V_m was found to decrease tensile strengths and ductility. The increasing and then decreasing trend in tensile strength is in contrast to the law of mixture.
Key words: ferrite-martensite dual phase steel, tensile strength, ductility, micro-structural investigations

Introduction

Dual phase steels are an important branch of high strength low alloy (HSLA) steels. These materials have a combination of specific mechanical properties such as high tensile strength, high work hardening rate at early stages of plastic deformation as well as good ductility, which distinguishes them among HSLA steels [1]. These favorable properties are definitely related to typical microstructure of dual phase steels in which, soft ferritic network provides good ductility; while, hard particles and martensite phase play the load bearing role. This microstructure, in fact, shows some kind of metallic composite. Beside these features, properties such as continuous yielding behavior, uniform plastic deformation and high elongation (good formability) are important features of dual phase steels [2,3].

Intercritical heat treatment is the way to enhance low alloys (carbon content less than 0.2%) steels to dual phase microstructure with superior strength–ductility

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combination. This thermal treatment contains heating the specimens in intercritical temperature range to obtain ferrite and austenite followed by quenching to obtain dual-phase (martensite-plus-ferrite) structure.

Over the past few years, noticeable investigations have been directed toward developing microstructural and mechanical properties and also flow and work hardening behavior of dual phase steels [4-7]. Although considerable research have been done about work hardening behavior and tensile properties of dual phase steels, but still more investigations are necessary to predict these properties more precisely. Furthermore some previous surveys are in contrast in some aspects. In the present work the SAE 1010 sheet steel was intercritically heat treated and the effect of martensite content on work hardening behavior and tensile properties was examined. It should be noted that since the heat treated steel as a sheet has more applicable results in automotive industry, the examinations were carried out on sheet and also most of the previous issues discussed about bar specimens.

Experimental procedure

The steel used in the present investigation was 2mm in thickness SAE 1010 sheet steel. The chemical composition of this steel is Fe-0.111C-0.534Mn-0.70Si-0.034Ni-0.026Cr-0.019S-0.016P. As can be seen in Fig. 1 the microstructure of the as-received sample consists of ferrite and some perlite on grain boundaries.

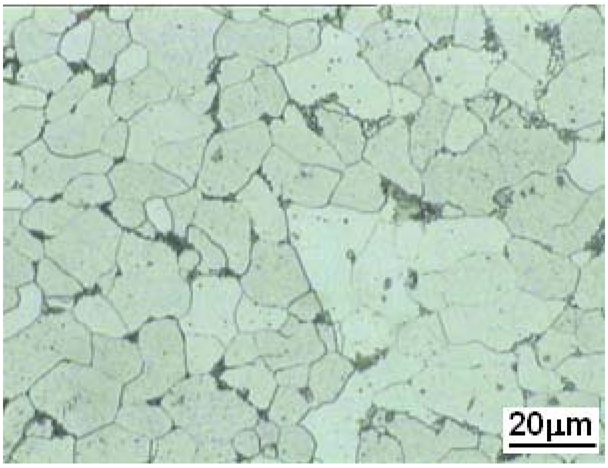


Fig 1 Microstructure of as-received steel

The heat treatment which is used in this work is shown in Fig. 2. All of the specimens were heated in intercritical temperature range (between A_{C1} and A_{C3}) except one specimen which was heat treated above A_{C3}. All the specimens were hold for 20min in muffely furnace and followed by water quenching (WQ). For this study, the A_{C1} and A_{C3} temperatures were calculated to be 736 and 852 ^oC, according to [8]. The heat treated samples are designated by capital letter, as shown in Fig. 2. The as-received sample is designated by R.

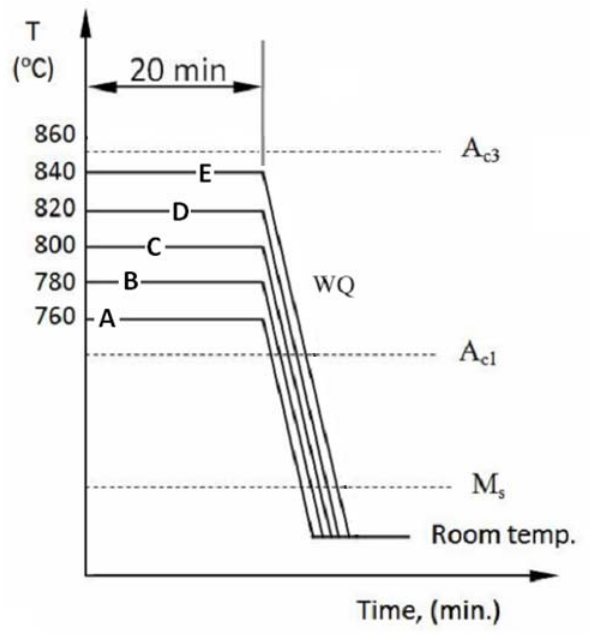


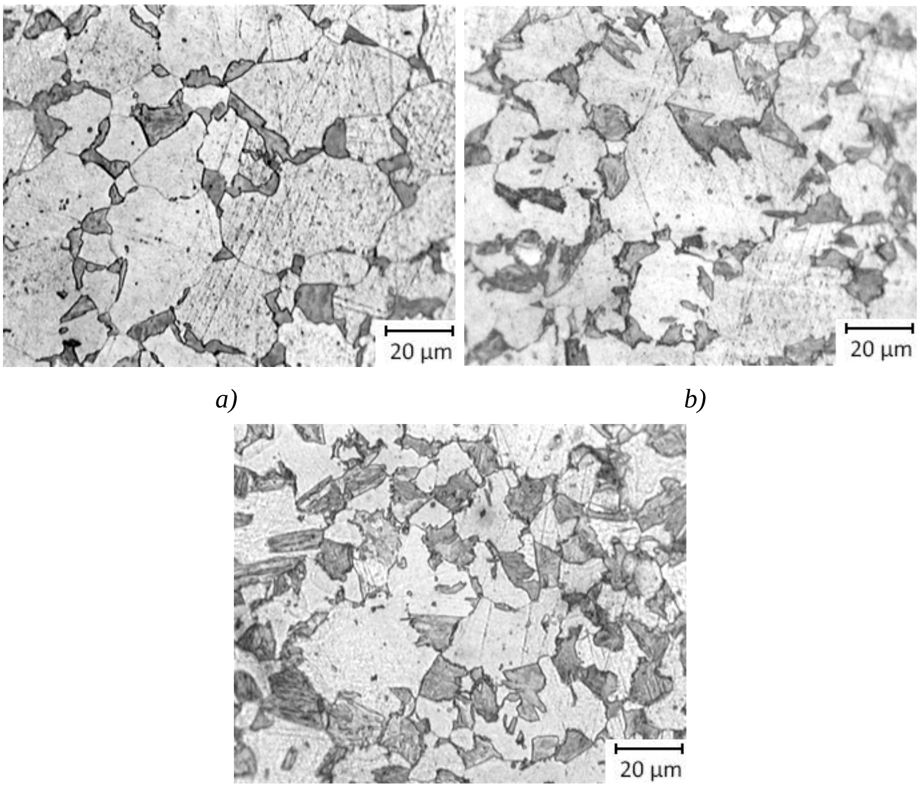
Fig 2 Schematic illustration of heat treatment cycle used in this study

Metallographic specimens were prepared according to the standard procedure from the as-received and heat-treated samples and etched with 2% nital solution. Microscopic examinations were carried out by optical microscope. The volume fraction of the martensite was measured by Point count technique according to ASTM E 562. The tensile test was conducted on as-received and heat treated specimens with 50mm gage length and 200mm overall length using an INSTRON testing machine with cross-head speed of 10 mm/min at room temperature in accordance to ASTM E8M. Key parameters obtained from stress-strain curves include yield strength (σ_{YS}), ultimate tensile strength (σ_{UTS}), uniform elongation (UEL) and total elongation (TEL).

Results and discussion

Microstructural investigation

Microstructures of the heat treated samples (A, C and E) are shown in Fig. 3. Increase of V_m is clearly observed in Fig. 3a, b and c. By considering the carbon content and the appearance of the packs, martensite should be lamellar (lath) type. From data shown in Fig. 4 it can be seen that V_m increases by increasing the heat treatment temperature. This complies with lever rule in the ferrite-austenite dual phase region. According to the lever rule, increasing the temperature increases the austenite volume fraction, which then will transform to martensite upon quenching in the water. It worth noticing that by increasing the temperature, V_m increases at higher rate.



a) *b)*

c)

Fig. 3 The microstructures of the heat treated samples at various intercritical temperatures of a) 760 ℃ b) 800℃ and c) 820℃

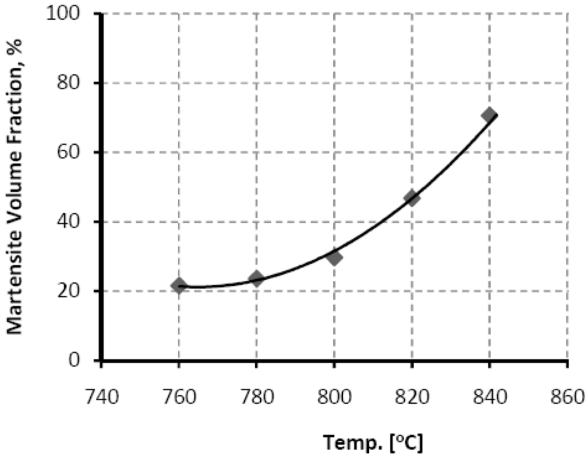


Fig. 4 The variation of martensite volume fraction (V_m%) as a function of intercritical temperature

One of the key controlling parameters for mechanical properties of the dual phase steels in carbon content of the martensite phase. The Carbon content of the martensite can be calculated according to the rule of mixtures (equation1) [9].

$$C_0 = C_f V_f + C_m V_m \qquad (1)$$

where C_0 is the steel mean carbon content and C_f and C_M are the carbon content of ferrite and martensite phases, respectively. V_f and V_M are the ferrite and martensite volume fractions. In this equation, the carbon content is assumed to be 0.015, which is the solubility limit of the carbon in ferrite phase. Fig 5 shows variation of carbon content of the steels with martensite volume fraction. As can be seen, the carbon content of the martensite phase decreases by increasing the martensite volume fraction.

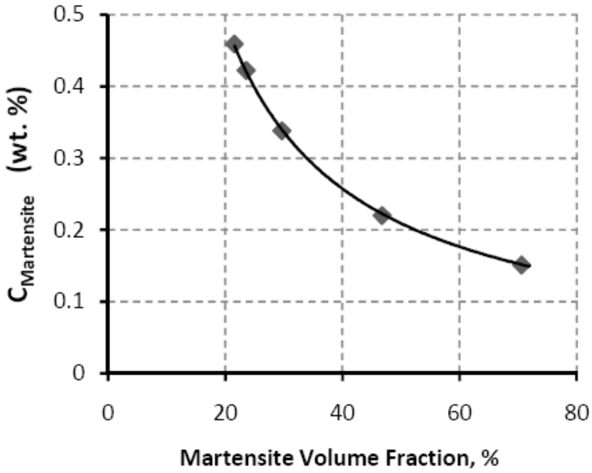


Fig. 5The variation of martensite carbon content as a function of martensite volume fraction (V_m%)

Tensile properties

Yield strength and tensile strength

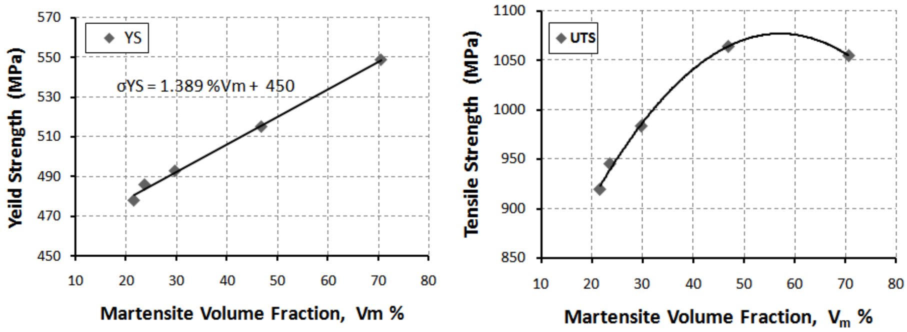
The strength values of the investigated dual phase steels are higher than the strength of the as-received steel. The higher strengths of the dual phase steels are known to be due to the presence of the harder second phase (martensite) [10,11].

The variation of yield and ultimate strengths of the heat treated samples as a function of the martensite volume fraction are illustrated in Fig.6. It can be seen that the yield strength of these steels is linearly increased by increasing the V_m, while, the ultimate strength first increases by increasing martensite volume fraction and then remains nearly constant.

In fact, maximum ultimate strength is obtained at 50% martensite volume fraction. This trend is in contrast to the law of mixture. According to the law of mixture,tensile strength of a dual phase steel ($\sigma_{u,DP}$) can be written as equation (1):

$$\sigma_{u,DP} = \sigma_{u,m} V_m + \sigma_{u,f}(1 - V_m) \\ = \sigma_{u,f} + (\sigma_{u,m} - \sigma_{u,f}) V_m \qquad (2)$$

where, $\sigma_{u,m}$ is tensile strength of the martensite, $\sigma_{u,f}$ the tensile strength of the ferrite.



a) *b)*

Fig.6 Effect of martensite volume fraction on the a) yield strength and b) ultimate tensile strength for investigated steel martensite volume fraction

Considering tensile strength of martensite and ferrite independent of volume fraction and morphology of ferrite and martensite, $\sigma_{u,DP}$ can be written as follows:

$$\sigma_{u,DP} = A + BV_m \qquad (3)$$

where A and B are constant.

Therefore, this model predicts a linear relation between $\sigma_{u,DP}$ and V_m. Some researchers showed that the tensile strength of the dual phase steels obey from law of mixture [12-14]. However, results presented in this work and some of the others work shows that there is not linear relation between $\sigma_{u,DP}$ and V_m.

The strength of a dual phase steels is a function of volume fraction of the constituent phases and their strength. Increasing volume fraction of the martensite has two contradicting effects on the tensile strength:

i) On one hand, the increase in martensite volume fraction increases tensile strength of the DP steel due to increasing volume fraction of harder phase

ii) On the other hand, carbon content of the martensite phase decreases with increasing volume fraction of the martensite. As it is known, the strength of the martensite is mainly determined by its carbon content.

For the investigated DP steels, it seems that for high martensite dual phase steels, the compromise of these two factors has undermined the effect of V_m on the $\sigma_{u,DP}$. Reducing the $\sigma_{u,DP}$ is expected by a further increase in the volume fraction, as reported by some researchers [7].

Ductility

The ductility of the investigated steel has been investigated in terms of uniform elongation (UEL) and total elongation (TEL). Fig. 7 shows the effect of martensite volume fraction on the UEL and TEL for the investigated steels. As can be seen, UEL and TEL increases with increasing V_m, peaking around 50% V_m, and gradually decreasing with further increase in V_m.

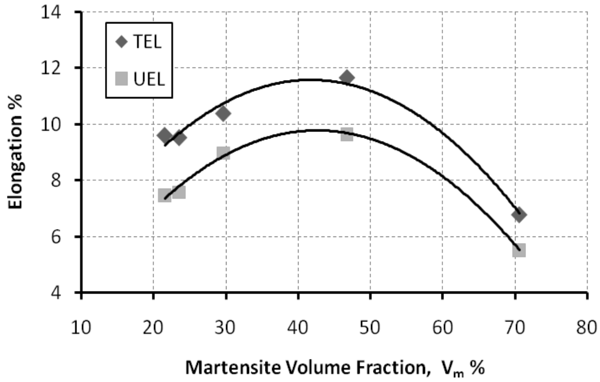


Fig. 7 The variation of the uniform elongation (UEL) and total elongation reduction (TEL) with martensite volume fraction

Most research on the ductility of DP steels show that UEL and TEL decreases with increasing V_m [15-17]. The present observation of the variation of UEL and TEL with V_m is in contradiction to that reported in [15-17]. However, the observed trend in this investigation is in agreement with that reported by Bag et. al. [7] and Kumar et. al. [11]. Increasing UEL and TEL with V_m up to 50%, can be explained as follows:

i) Carbon content of the martensite significantly affects the ductility of the martensite phase. As mentioned above, increasing V_m decreases carbon content of the martensite which in turn leads to increasing ductility of the martensite phase. Increasing ductility of the martensite constituent increases overall ductility of the DP steel.

ii) Byun and Kim [14] have analyzed the long-range internal stresses arising from unrelaxed plastic incompatibility in DP microstructures. Their results showed that when Vm is about 50%, the average of internal stresses in martensite-ferrite DP is zero. This can contribute to higher UEL and TEL when V_m is about 50% [7], as it is observed in this study.

Further increase in V_m beyond to 50% changes the matrix structure from dominantly ferritic to dominantly martensitic and the DP microstructure becomes brittle. This can explain decreasing UEL and TEL in DP steels with V_m>50%.

Conclusion

From this research the following conclusions can be drawn:

The tensile properties of low carbon ferrite-martensite dual phase steel were evaluated in this paper. Tested 2 mm thick steel sheet were intercritically heat treated on different temperatures, and water quenched in order to obtain different volume fractions of martensite (V_m). Martensite volume fraction increases by increasing the intercritical heat treatment temperature, which in turn decreases the carbon content of this phase according to the rule of mixtures. Dual phase steels containing approximately equal amounts of ferrite and martensite phases exhibit the optimum mechanical properties in terms of tensile strength, ductility and fracture energy. The variation of ultimate tensile strength and ductility with volume fraction of martensite exhibits unusual behavior. Tensile strength and elongation increase with increasing V_m, peaking around 50% V_m and decreasing with further increase in V_m.

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