Effects of Alloying and Step Cooling Conditions on the Microstructures and Mechanical Properties of 780Y Hot-Rolled Dual Phase Steels

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Along with the intensifying of energy crisis and environmental problems, energy saving and safety have become the most important issues for the automobile industry. To meet these challenges, weight reduction is most effective, which has lead to the fast development and application of advanced high strength steels. Among these, dual phase (DP) steels have attracted much attention due to their superior properties. In this study, the effects of alloying and hot rolling conditions on the final microstructures and the related mechanical properties of hot-rolled DP780Y steels are discussed. Controlled rolling patterns, especially step cooling temperature and duration time, during the sheet traveling on a run-out table were simulated by a thermomechanical simulator to produce DP 780Y steels as a kind of low carbon steel containing small amounts of manganese (Mn) and phosphorus (P). The microstructures and quantitative analysis of the volume fractions and the fracture surface of the phases were characterized by optical Microscopy (OM), scanning electron microscopy (SEM), and an image analyzer, respectively. It was found that the alloy contents of the Mn and P elements not only affected the microstructure of the ferrite and martensite phase morphologies, proportions and formations, but also affected the performance of the final steel. In addition, increasing the cooling temperature and duration time decreased the yield and tensile strength, but increased the total elongation. The results showed that with the appropriate proportion of alloy addition and the cooling process control, an optimized balanced combination of high strength and good elongation can be obtained.

Keywords: Dual phase steel, Alloy, Step cooling, Microstructure, Mechanical property

1. INTRODUCTION

High strength dual phase (DP) steels with a composite microstructure of soft ferrite and hard martensite offer the greater fuel economy for the automobile industry through weight reduction for the same size of parts, in addition to superior formability and safety when compared to traditional high strength low alloy steel. Hot rolled high strength DP 780Y steels in particular, with their superior strength-elongation characteristics, lower yield ratio and higher n-values have been highlighted as having the material properties required for complicated shaped auto parts application such as wheel disc and body structure components. Recently, considerable research efforts have been put into further improving the strength and elongation of high strength DP steels through thermomechanical treatments to obtain the best balance between microstructure and mechanical property[1-6]. Thomas et al.[1-2] have shown the strong dependence of the tensile property of DP steel on its martensite morphology. Tomita[3] pointed out that the

fine martensite randomly dispersed in ferrite gave a better combination of strength and elongation. In addition, Bag et al.[4] found that an optimum volume fraction of martensite phase is the key to get excellent tensile property and toughness. From these viewpoints, the mechanical properties of DP steels are very sensitive to the microstructure and morphology of ferrite and martensite phase.

It is known that the DP microstructure is produced by cooling the steel from the two phase (austenite (γ) + ferrite) intercritical region, between A_1 and A_3 temperature, at a sufficiently high rate for the transformation of martensite (M)[7] . However, most of the previous works had focused on thermomechanical treatments and mechanical properties. The role of controlled rolling patterns, especially the step cooling conditions, on the microstructure and mechanical properties of high strength hot-rolled dual phase steels is not clear now. Besides, the chemical composition of these steels is also another major important factor in determining the step cooling temperature and duration time

for governing the transformation of martensite. However, the combinations of chemical compositions and step cooling parameters on microstructure and morphology (size, shape and distribution) of constituents in high strength DP steel, and the correlation between the microstructure and the mechanical properties of DP steel, are also not yet clear.

In the present study, efforts have been made to develop a low carbon high strength DP 780Y steel by hot rolling and simulated thermo-mechanical processing. The influence of the steel compositions and various processing parameters on the microstructure and corresponding properties of the steel was discussed and explored.

2. EXPERIMENTAL METHOD

2.1 Hot rolling process

The chemical compositions of the DP 780Y steels (Steels A and B) used in the present study are shown in Table 1. The contents of manganese (Mn) and phosphorus (P) are controlled to obtain the different morphologies and volume fractions of the second phase. Steel ingots were made by vacuum induction melting. The as-cast ingots were heated at 1200°C for 1h under an argon atmosphere, and then were hot rolled from 160 to 3mm thick plates in austenite region near Ar_3 temperature followed by the air and water two-step cooling to simulate the process on the runout table. The first step air cooling process was stopped and held at an intermediate temperature of 625°C for 10 seconds for ferrite transformation. The remaining austenite is transformed to martensite in the second rapid water cooling stage to a temperature below 400°C, and the DP microstructure is finally formed.

Table 1   Chemical composition of steels (wt%)

Steel	Fe	C	Mn	P	S	others
A	bal.	0.12	1.50	0.02	0.005	0.55
B	bal.	0.10	1.28	0.04	0.005	0.52

2.2 Thermo-mechanical processing (TMP)

To investigate the effect of the steel chemical compositions and controlled rolling patterns on microstructure and its morphologies, the thermo-mechanical processing, especially step cooling temperature and duration time during the sheet traveling on runout table, were simulated by a Gleeble 1500 thermomechanical simulator in the laboratory. The step cooling treatments were conducted at 625°C and duration times were 3, 5, and 10 seconds.

2.3 Tensile testing

Tensile specimens (JIS No.5) were cut from the rolled plates in the transverse direction. The tensile tests were performed using an MTS machine having a 500kN load capacity. All the tests were carried out at the crosshead speed of 2mm/min in a normal atmosphere. The proof stress was taken at 0.2% offset. Uniform elongation was designated as the elongation at which the load began to decrease, i.e. at the onset of necking. After testing, the fracture surface of the broken specimen including the necked region was examined by Scanning Electron Microscopy (SEM). In this manner, microcracking in different parts of the specimens could be examined.

2.4 Microstructures and quantitative analysis

After the DP 780Y steel specimens were etched by a nital solution, their microstructure, phase morphology and chemical composition were characterized by Optical Microscopy (OM), Scanning Electron Microscopy (SEM) and an Electron Probe Microanalyzer (EPMA). The volume fraction of the constituent ferrite and martensite (V_m) phase, and the grain size were measured by using an image analyzer.

3. RESULTS AND DISCUSSION

3.1 Microstructure

The microstructures of the two hot rolled DP 780Y steels, Steel A and Steel B, are shown in Fig.1. These two microstructures fundamentally consist of polygonal ferrite and dispersed martensite. However, the microstructure of the Steel B (Figure 1 (b)) is finer and the phases are well dispersed compared with the Steel A. It has been reported that the higher Mn element content increases the hardenability effect on the fraction and morphology of the second phase during the phase transformation of hot rolling[7]. On the other hand, a sufficient ferrite percentage is obtained by the ferrite forming element of P. Therefore, for Steel B, the lower Mn and higher P contents enhance the ferrite transformation at higher temperature, which results in a fine dispersion of austenite phase during the cooling step[8] and finally obtains a uniform distribution of fine martensite phase dispersed over the ferrite matrix.

3.2 Tensile properties

Figure 2 shows the stress-strain curves of the hot rolled DP Steels A and B. The result shows that for either Steel A or Steel B, the structure gives rise to continuous yielding, which is one of the typical characteristics of dual phase steels. However, Steel A, having a coarse martensite and polygonal ferrite structure, is characterized by a much lower elongation but higher yield and tensile strength compared to Steel B (Fig.2). In order to understand the reasons for the

CSC SEI 20.0kV ×1,500 10μm WD11mm   CSC SEI 20.0kV ×1,500 10μm WD11mm

(a)   (b)
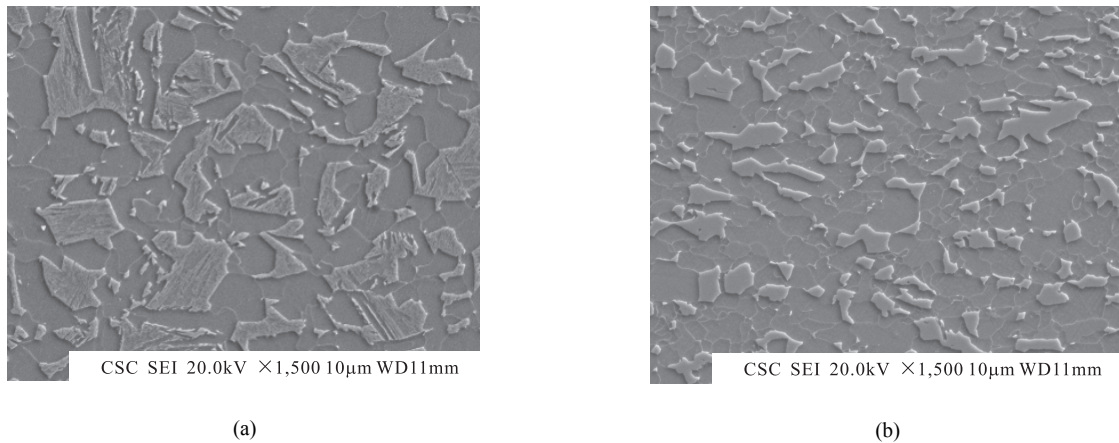
Fig.1. SEM micrographs of the hot rolled DP 780Y steels: (a) Steel A, and; (b) Steel B.
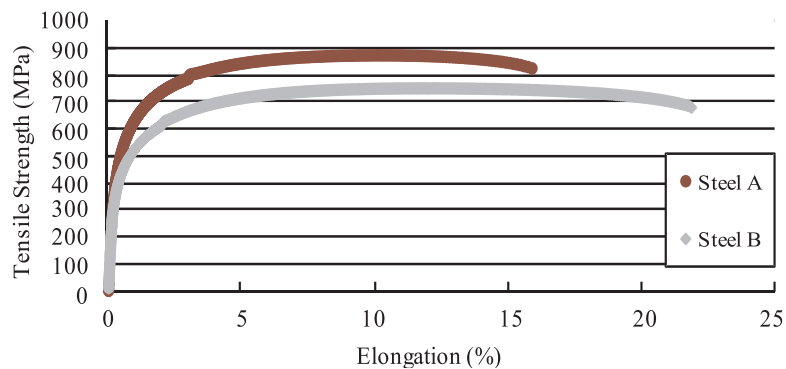
Fig.2. The stress-strain curves of the hot rolled DP 780Y Steels A and B.

different mechanical behaviors of the two structures and why failure occurred after a small tensile elongation in the coarse structure (Steel A), a fractographic analysis by SEM was performed.

3.3 Fractography

Examples of the microcracks found behind the main fracture surface of the tensile specimen of two steels are shown in Fig.3. In the case of Steel A, it can be observed that most of the microcracks are initiated at coarse martensite islands and completely traverse this hard constituent, and then stop at the soft ferrite (Figure 3(a)). Other voids also occur at the interfaces between the martensite and ferrite phase.

On the other hand, for Steel B, the microvoids or microcracks are always initiated at the interfaces between the fine martensite and ferrite phase (Figure 3(b)). This was also observed in the fracture surface shown in Fig.4. The fracture surface of Steel A consists of dimple fractures and cleavage fractures, which are formed by brittle fracture in the martensite islands (Figure 4(a)). For Steel B, a well defined dimple

structure (Figure 4(b)) was found, which exhibits the characteristics of a ductile fracture. Recently, correlating investigations of the microstructures and mechanical properties of high strength steels having a mixed structure produced by phase transformation have shown that elongation is strongly affected by the fracture behavior of the second phase[9-10]. However, the loss of elongation can be minimized by controlling such parameters as the size, shape, and distribution of the dispersed phase[12].

The measured values of the volume fraction of the phases and the aspect ratio of the martensite island of Steels A and B are shown in Table 2. In the present case, the factor involving the volume fraction can be eliminated since the two steel structures produce almost the same volume fraction of the martensite phase. With respect to the size effect, many researchers have emphasized that the probability that fracture of dispersed phase increases with the increasing particle size[11]. The shape factor is well illustrated by the aspect ratio of particles and are charged with stress σ, given as follows[12]:

CSC   SEI   20.0kV   ×1,500 10μm WD11mm

(a)

CSC   SEI   20.0kV   ×1,500 10μm WD11mm

(b)
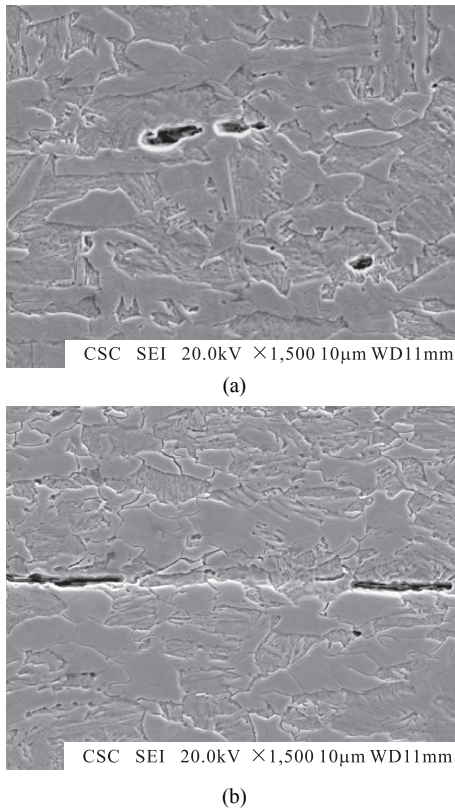
Fig.3.   Examples of microcracks found behind the main fracture surface of the tensile specimens of (a) Steel A, and; (b) Steel B.


~50μm

(a)

~50μm

(b)
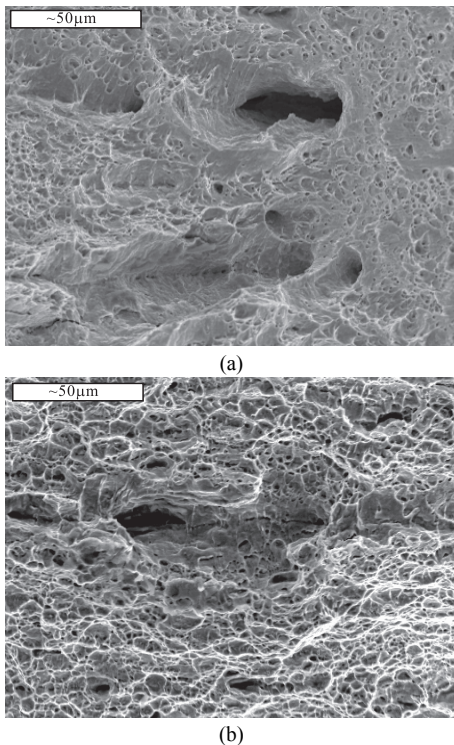
Fig.4.   Fracture surface of the tensile specimen of (a) Steel A, and; (b) Steel B.

Table 2   Values of the volume fraction and aspect ratio of martensite island of steels

| Steel	Volume fraction		Aspect ratio of martensite island
	V_f	V_m	L/W
A	0.61	0.39	1.8
B	0.65	0.35	1.2

$$\sigma \ \propto \frac{L}{W}$$

Where L is the particle length and W is the particle width. The reduction of the aspect ratio L/W reduces the stress and consequently cracking is reduced. Therefore, the larger the aspect ratio of the particle, the easier will be the cracking. The schematic representations of different types of microstructure cracking induced by the tensile test are shown in Fig.5.
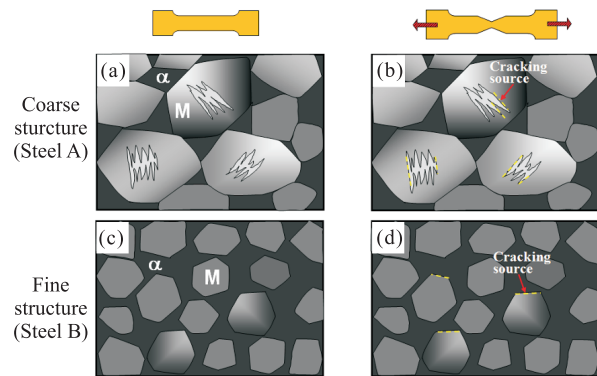
Fig.5.   Schematic representation of different microstructure cracking induced by the tensile test.

It is believed that, in the coarse DP 780Y structure (Steel A), during the early stages of tensile straining, the unfavorable morphology of a large martensite phase restricts the plastic flow of the ferrite grains, causing a high stress level in the specimen[12], which initiates brittle cracking of certain martensite islands, as illustrated by the arrows in Fig.5(b). Furthermore, by quantitative element mapping (Figure 6) and SEM analysis, the existence of a non-homogeneous chemical composition, especially a carbon element (Figure 6(b)), and microstructure (Figure 6(a)) in the coarse martensite islands can additionally render many more sources to induce cracking. Compared with Steel A, the nucleation of microcrack in Steel B appears mainly to be initiated via the decohesion of the ferrite and martensite interface (Figure 5(d)), which is attributed to having fine grains and a uniform composition distribution.
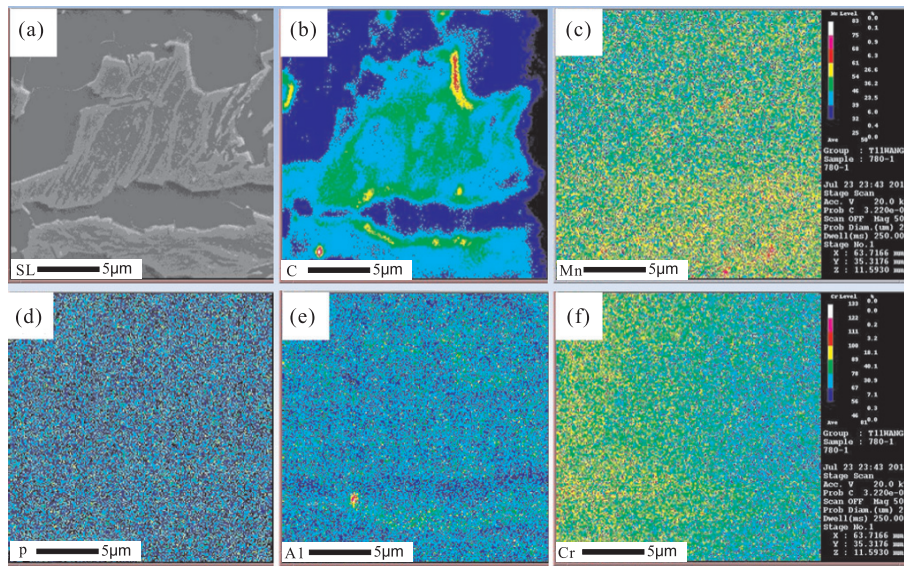
Fig.6. Image and quantitative element mapping of coarse martensite phase of Steel A by EPMA.

3.4 Thermo-mechanical processing

Figure 7 shows the optical micrographs of Steels A and B proceed the thermomechanical simulator by adjusting the cooling temperature to 625°C and duration time for 3, 5, and 10 seconds. The volume fraction of the ferrite phase, depending on the intermediate time, is transformed during the step cooling. For both steels in these figures, high ferrite fractions are attained at the longer cooling time (Figure 7 (c) and (f)). However, at a short duration time, the martensite islands in Steel A are much coarser and harder due to the excess of the martensite phase in volume fraction (Figure 7 (a)), which results in the deterioration of the elongation and yield ratio. Accordingly, the results show that the strict control of step cooling conditions is very important for the formation of the appropriate morphology and fraction of ferrite and martensite phase. Also, the chemical composition is a major factor in DP 780Y steels, governing particularly the critical cooling pattern for the formation of the martensite phase.
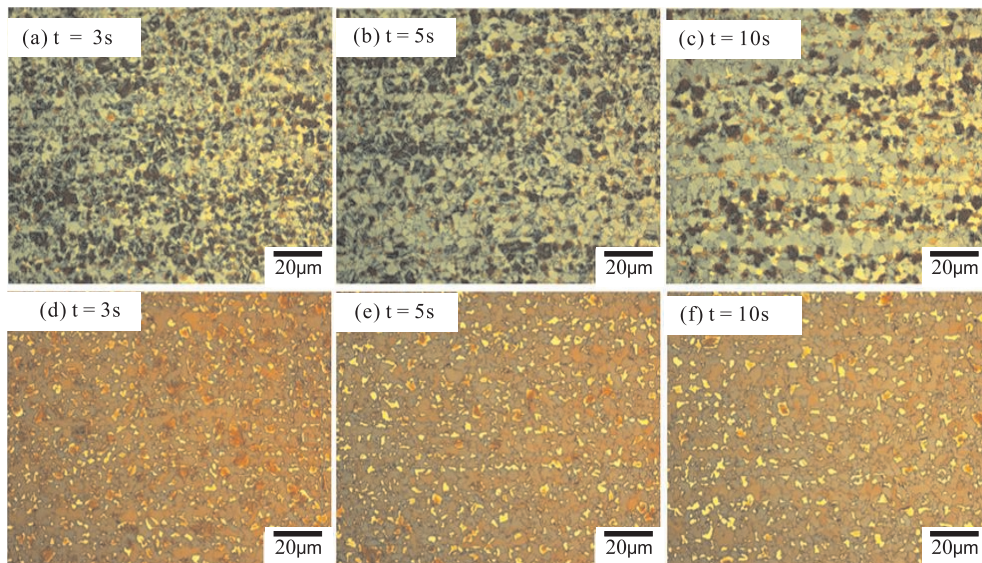
Fig.7. Optical micrographs of the Steels A (a~c) and B (d~f) proceed by the thermomechanical simulator at 625°C with duration times of 3, 5, and 10s, respectively.

4. CONCLUSIONS

A study has been made on the effects of chemical compositions and step cooling parameters on the microstructure and mechanical properties of high strength DP 780Y steel. The results show that the higher Mn content increases the hardenability effect on the fraction and morphology of the second phase. Besides, a higher P content enhances the ferrite transformation and results in a fine and uniform distribution of microstructure. A coarse DP 780Y structure exhibits a smaller value of elongation and higher yield and tensile strength than a fine and well dispersed one. In order to obtain better mechanical properties, for elongation particularly, it is important that the microcracks of martensite phases should be eliminated. This can be done by reducing the size of the martensite islands and controlling their morphology. Furthermore, the chemical composition is of major importance, governing particularly the critical cooling pattern for the formation of the martensite phase. In this respect, an optimum combination of microstructure and mechanical property can be obtained by a suitable addition of alloying element and the use of a step cooling process.

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