CONVENTIONAL COLD ROLLING AND INTERCRITICAL ANNEALING OF PLAIN LOW CARBON STEEL

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Abstract- In this study a simple method is introduced to produce dual phase ferrite-martensite structure in plain low carbon steel. This simple method is based on cold-rolling of ferrite-pearlite structures and interical annealing treatments before ice-water quenching. The specimens intercritical annealed at 850ºC revealed the optimum mechanical properties in term of hardness, strength and uniform elongation.

Keywords- Cold Working, Dual Phase Steel, Intercritical Annealing, Microstructure, Plain Low Carbon.

I. INTRODUCTION

It has been the biggest challenge faced by the steel industry for the last couple of decades to produce automotive materials which fulfill the requirements like, light weight materials to improve fuel efficient vehicles, safety and crashworthiness performance without increasing cost[1-4].
To meet this challenge the steel industry has developed advanced high strength steels (AHSS) including dual phase (DP) and transformation induced plasticity (TRIP) steels. These steels display excellent combination of cold formability and strength, compared to conventional low carbon steels[3,4].

Dual phase (DP) steels are currently materials of increasing commercial interest for automotive application due to these materials have a combination of special mechanical properties[5,6],
but the main challenge in producing DP steels is to achieve grain refinement at the same time making them cost effective. Recent researchers have been developed several processing techniques to induce grain refinement in steels, for example, Park et al[7] have used equal channel angular pressing (ECAP) and Song et al[8] have used warm deformation. However, these processes also have the disadvantages as that they are difficult to use in the mass production and large dimension for ECAP and huge deformation at high temperature is a major drawback of warm-rolling. Furthermore, all these processing routes use higher carbon content (>0.15 wt.%) steels which pose problems with weldability.

Therefore, this present paper is to show another simple process to obtain DP steels by conventional cold-rolling of ferrite-pearlite structures and subsequent intercritical annealing of plain low carbon steel.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

The material used in the present investigation is a commercial plain low carbon steel. The details chemical composition is given in Table 1.

As can be seen in Figure 1, the microstructure of the as received sample consists of mainly ferrite with small amount of pearlite. Samples with a size of 5 mm in thickness, 25 mm in width and 100 mm in length were cut from the plate and then subsequently cold-rolled to a reduction of 75% in multi-passes at room temperature using a laboratory rolling mill. The cold-rolled specimens were then intercritical annealed at temperatures ranging from 750℃ to 850℃ for 5 min before ice-water quenching. The process is shown in Figure 2.

Table1: Chemical composition of the steel studied (wt.%)

C	Mn	P	S	Fe
0.06	0.14	0.01	0.01	Bal.

Microstructural observations by optical microscopy (OM) was carried out for the specimens at various stages of the processing. All the microstructures were observed from the transverse direction (TD) of the sheets. The microstructures of OM was revealed by 2% nital.

Hardness test was done by load of 100 g by using a Vickers microhardness testing machine. The tensile test was conducted on specimens with 10 mm in gage length and 5 mm in gage width using an INSTRON testing machine with a cross-head velocity of 5 mm/min.

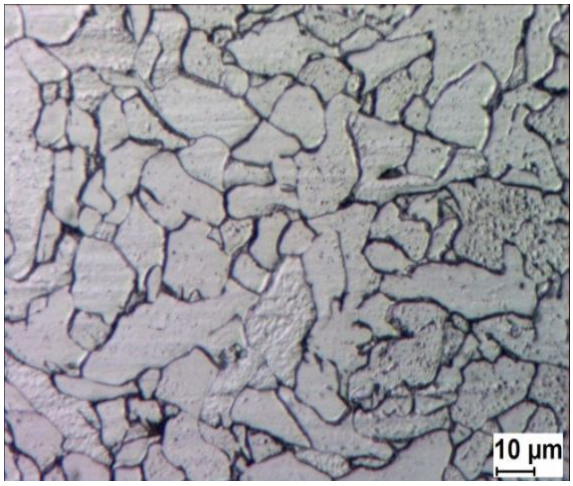

Fig.1. Optical micrograph of the as received steel.

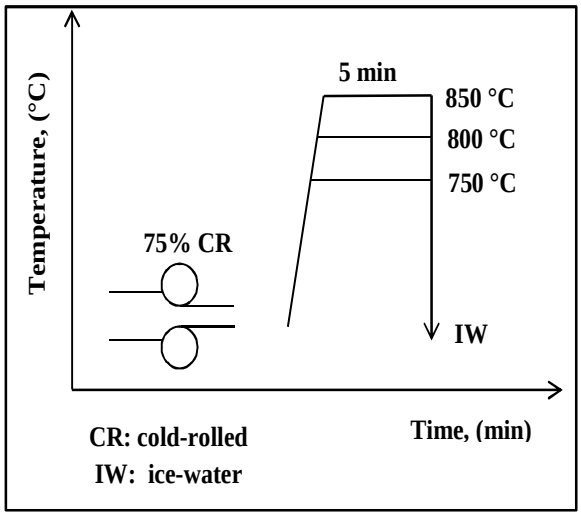

Fig.2. Schematic representation of thermomechanical processes.

RESULTS AND DISCUSSION

Figure 3 displays a microstructure of the 75% cold-rolled specimen. Most of the area reveals the ferrite grains and pearlite colonies are elongated along the rolling direction of the sheet. The similar microstructures have been observed by previous work[9,10]. Yang et al[10] found the ferrite revealed equiaxed and elongated dislocation cells. The cells contained irregularly distributed concentrations of tangled dislocations.

Figure 4 shows intercritical annealing and ice-water quenching produced DP microstructures of polygonal ferrite and martensite. The amount of martensite increase with increasing intercritical annealing temperature and there is no evidence of pearlite or bainite formation from austenite was optically observed after ice-water quenching. A similar result has been observed by Qu et al[2] and Movahed et al[5]. Alfirano et al[11] reported that more martensite will be formed at higher in heating temperature and the longer in holding time. When the temperature is increased above A1, it is not only austenite formed from pearlite, but also dissolution of ferrite.

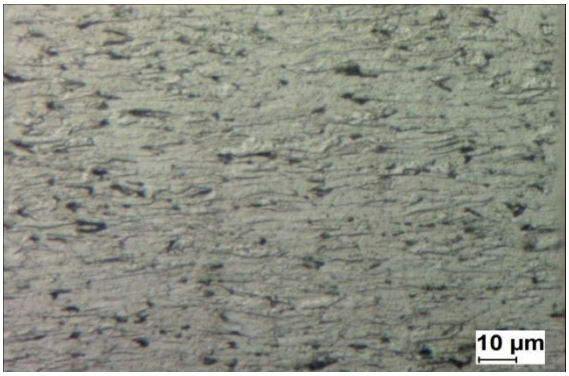

Fig.3. Microstructure of plain low carbon steel 75% cold-rolled. The starting microstructure was a dulex structure domposed of ferrite and small amount of pearlite. Observed from TD.

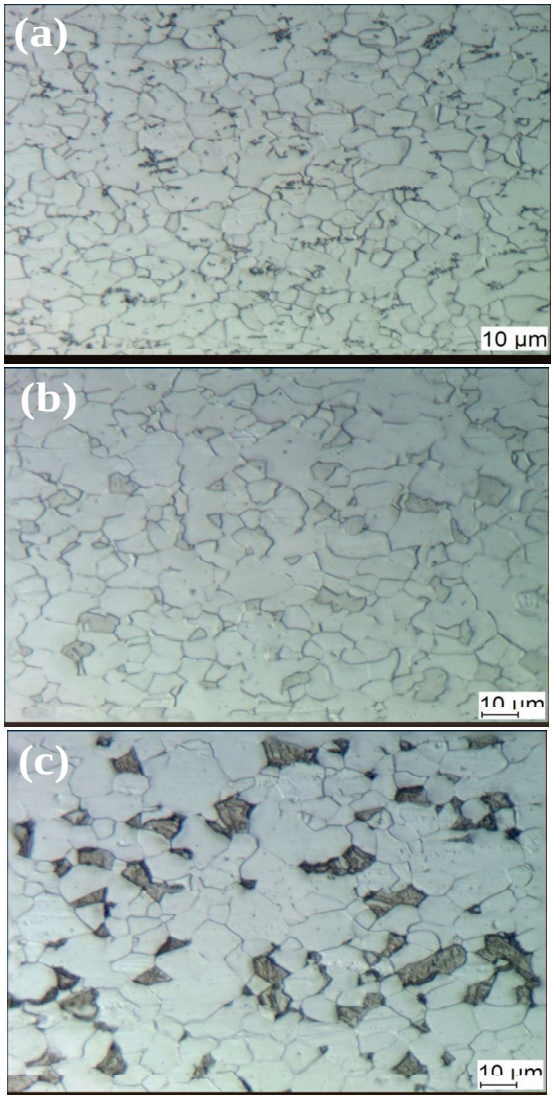

Fig.4. The microstructures of the heat-treated specimens at various intercritical temperature of (a) 750℃, (b) 800℃, (c) 850℃ for 5 min and then ice-water quenching.

Holding time while the heating process objects to provide an opportunity for atoms to diffuse in austenite. The bcc structure will not form if the steel is cooled rapidly from the austenitic region which has a fcc structure due to the time which needed to

complete the transformation into bcc is not enough. Therefore, the carbon was trapped, so that bct structure or so-called martensite was form[12]. It can be seen from the Figure 4(a), very small martensite areas have formed at 750℃ from austenite with ferrite recrystallization produced during intercritical annealing of the cold-rolled specimen. As the temperature is increased to 850 °C, there are more martensite phase is occurred as well as recrystallization of cold worked ferrite Figure 4(b).

Figure 5 exhibits the microhardness value of plain low carbon steel, cold-rolled and subsequent intercrical annealing temperature. Microhardness of as received steel is 94.1 HV. As cold-rolled of specimen results in improvement of the microhardness to 170.79 HV, due to stain hardening, achieved by dislocation-dislocation interaction. As the specimen intercritical annealed at 750℃ for 5 min after cold-rolled, it can be observed that the microhardness drops to 143.28 HV. It is because of the reduction of dislocation density[13]. However, the microhardness value of specimen intercritical annealed at 750℃ is higher than the microhardness value of specimen in the as received condition and continues increase with increasing the intercritcal temperature. The higher microhardness of the dual phase steels is known to be due to the presence of the martensite phase.

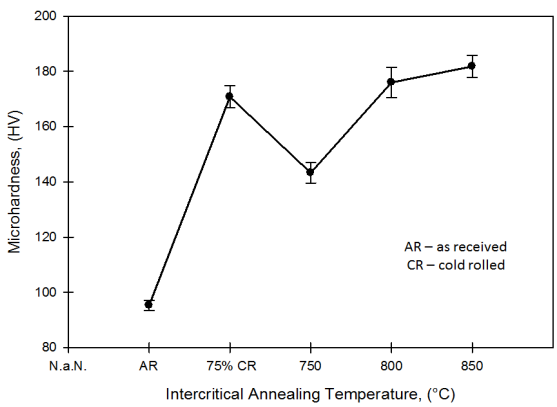

Fig.5. Evolution of microharness (HV) value of plain low carbon steel, cold-rolled and subsequent intercritical annealing.

Stress-strain curves of the specimens 75% cold-rolled and intercritical annealed are shown in Figure 6. The as received has yield point elongation and reveal well-defined yield poit. Meyers et al[14]reported that this behavior has been attributed to the effect of interstitial solute atoms (carbon) in low carbon steel, called the Cottrell atmosphere, on locking-in the dislocation. In a tensile test, when stress is applied to such steel, it must exceed a certain critical value to unlock the dislocation. The stress necessary to move the dislocation is less than the stress required to unlock them. Therefore, the phenomenon of a sharp yield drop and the appearance of an upper and lower yield point in the tensile stress-strain curve. The 75% cold rolled specimen reaches to very high tensile strength of 682.45 MPa, but uniform elongation of the cold-rolled sheet is limited below 6%. This result is parallel with previous work[13]. However, in the most previous reports, the improved strength for steels was always accompanied with decreased elongation[15-17]. As the specimens intercritical annealing after cold-rolled, it can be seen that the strength increases with increasing the intercritical temperature. It is noteworthy that the specimens intercritical annealed at around 800℃ -850℃ illustrate both high strength and adequate uniform elongation. For example, specimen intercritical annealed at 800℃ reveals 512.45 MPa and uniform elongation 27%, as the temperature is increased to 850℃, the strength exhibits 530.32 MPa, but uniform elongation is decreased to 26.20% due to more martensite phase is formed (Figure 4c). Nevertheless, it is 30.92% higher than the as received material which is the strength only 366.32 MPa. Further observation from Figure 6, it can be seen the stress-strain curves of dual phase steels intercritical annealed at 800℃ - 850℃ exhibit continuous yielding behavior. The continuous yielding of the dual phase ferrite-martensite has been related to the following[5]: (i) occurrence of unpinned dislocations which are created in ferrite matrix through plastic deformation during the transformation of austenite to martensite (ii) these unpinned dislocation, located at the ferrite-martensite boundaries are supposed to be moveable in the early stage of plastic deformation. Maleque et al[18] have reported that the absence of yield point will result in good formability where steel can be deformed easily.

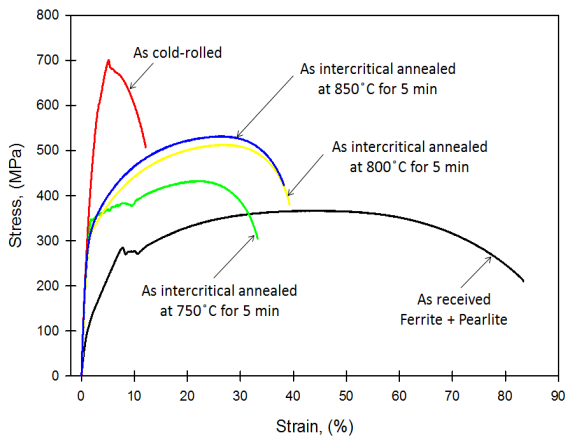

Figure 6. Stress-strain curves of plain low carbon steel of 75% cold-rolled and intercritical annealed at various temperatures for 5 min before ice-water quenching.

Based on the results presented in this study, it can be concluded that the 850℃ intercritical annealed after cold-rolled specimen has optimum mechanical properties in terms of both hardness and tensile strength. This simple method which could be applied to the industrial steel sheet production due to it does not need any new metal working facilities, but it could be used to improve the mechanical properties of plain low carbon steels.

CONCLUSIONS

A simple process to obtain dual phase steels containing ferrite and martensite with different volume fractions of martensite was developed by intercritical annealed of 75% cold-rolled sheet plain low carbon steel (ferrite-pearlite microstructure). It was found that martensite volume fraction increase by increasing intercritical annealing temperature. The specimen intercritical annealed at 850℃ exhibits the optimum mechanical properties in terms of hardness (181.78 HV), strength (530.32 MPa) and uniform elongation (26.20%). The results in this present study, it could be useful for the industrial production of dual phase sheet steel and further study of dual phase ferrite-martensite steels.

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