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Improment in Mechanical Properties Plain Low Carbon Steel Via Cold Rolling and Intercritical Annealing

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Abstract

In this paper, a simple modified process is introduced to improve the mechanical properties of plain low carbon steel. The plain low carbon steel sheet with mainly ferrite and minor amount of pearlite starting microstructure was simply cold-rolled to a reduction of 50% and subsequently intercritical annealed at various temperatures. The specimen intercritical annealed at 850°C revealed dual phase ferrite-martensite and exhibited excellent mechanical properties when compared to specimens intercritical annealed at 800°C and 750°C, as well as the as-received specimen.

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Keywords: Plain low carbon steel; Dual phase steel; Cold working; Intercritical annealing; Microstructure

1. Introduction

Nowadays, industrial applications of steel sheet forming are looking for material with plastic deformation potential and high strength. This challenge is not easy to achieve, because usually an increase in the strength steel was always accompanied with decreased elongation[1]. Many researchers have developed several processing techniques to improve the mechanical properties of the steel, for example, Park et al[2] have used equal channel angular pressing (ECAP) and Song et al[3] have used warm deformation.

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However, these processes also have disadvantages as they are difficult to use in mass production and large dimension for ECAP, and huge deformation at high temperature is a major drawback of warm-rolling.

In recent years, there has been growing interest in the dual phase steel due to its excellent mechanical properties in term of strength and ductility[4-6]. Although many considerable researches have been done about improving the mechanical properties of dual phase steels, but still more investigations are needed to predict these properties precisely. Furthermore, researchers have largely concentrated on using higher carbon content (>0.15 wt.%)[2,3,7,8] and high alloy[9,10] steels which pose problems with weldability. Therefore, the present paper is to show another simple process to improve the mechanical properties of plain low carbon steel (carbon content 0.06 wt.%). The key of the process is to start from cold rolling and subsequently intercritical annealing.

2. Material and experimental procedures

Hot-rolled sheets of commercial plain low carbon steel containing Fe-0.06C, 0.14Mn, 0.01P, 0.01S (all wt%) were used. The sheets with a size of 5 mm in thickness, 25 mm in width and 100 mm in length were cut from the plate and then cold-rolled to a reduction of 50% in multi-passes at room temperature using a laboratory rolling mill (roll diameter: 80 mm, speed: 10 rpm). The cold-rolled specimens were intercritical annealed at various temperatures ranging from 750°C to 850°C for 5 min before ice-water quenching. The process is indicated in Fig. 1.

Microstructural observation by optical microscopy (OM) was carried out for the specimens at various stages of the processing. The microstructure was revealed by 2% nital. Hardness test was done by a load of 100g by using a Vickers Microhardness tester machine (Model: LM 2448 AT). Tensile test at room temperature was also done by the use of the specimens 10 mm in gage length and 5 mm in gage width. The test was conducted by using an INSTRON 5982 digital control testing machine with a cross-head velocity of 5 mm/min.

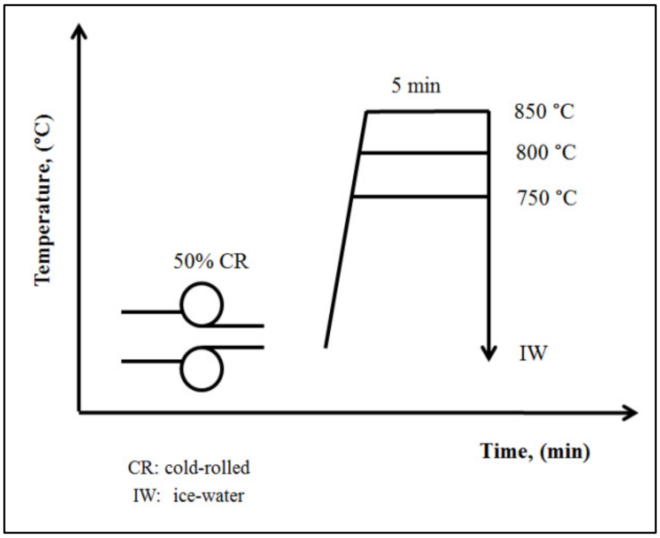

Fig. 1. Heat treatments scheme of investigated plain low carbon steel.

3. Results and discussion

Fig. 2. illustrates microstructure of plain low carbon steel, cold deformation and heat treated specimen. It can be seen in Figure 2a, the microstructure of the as-received specimen comprises of mainly ferrite (F) with minor amount of pearlite (P). The average ferrite grain size is about 11.5 µm. Fig. 2.b shows the microstructure of 50% cold-rolled specimen. The ferrite grains and the pearlite colonies are elongated along the rolling direction of the sheet. Similar

microstructures have been observed by Yang et al[10]. The microstructural evolutions during intercritical annealing to various temperatures are presented in Fig. 2.c-e. As can be observed that the volume fraction of martensite (M) increase with increasing the intercritical annealing temperature. Movahed et al[11] reported that in the ferrite-austenite dual phase region by referring to the lever rule, the volume fraction of austenite increases with the increas of temperature, then will transform to martensite upon quenching in water. It can be seen in Fig. 2.c-e that by increasing the intercritical temperature, the volume fraction of martensite increases (shown in Fig. 2. c,d and e as M) at a higher rate.

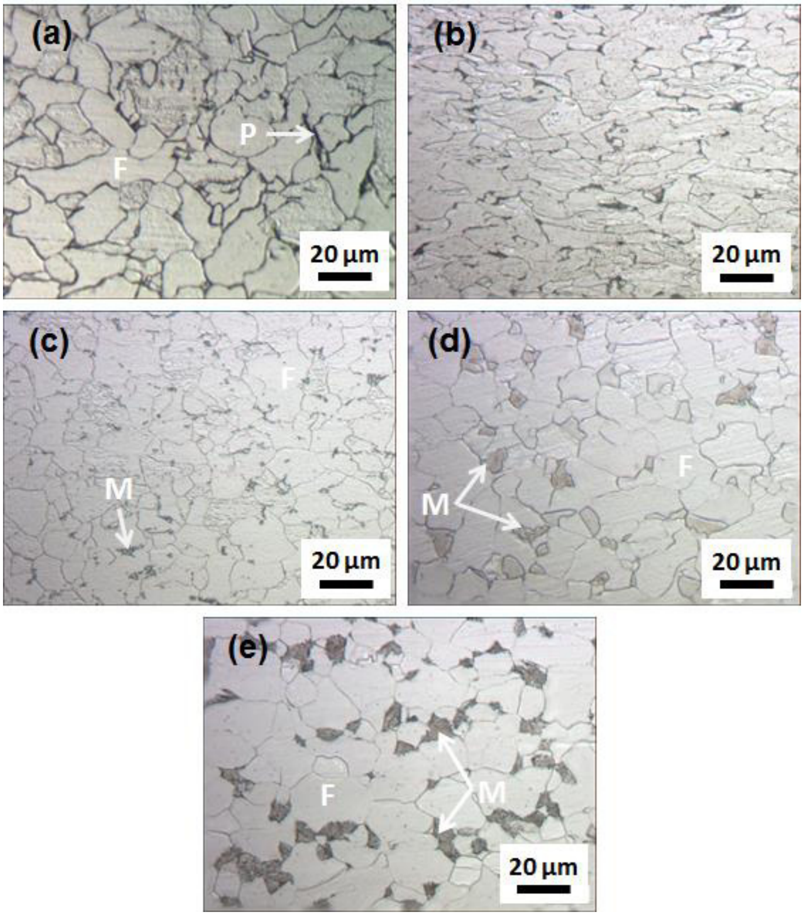

Fig. 2. Microstructures of plain low carbon, cold-rolled and heat treated specimens. (a) as-received, (b) 50% cold-rolled (c) intercritical annealed at 750°C, (d) intercritical annealed at 800°C and (e) intercritical annealed at 850°C for 5 min. Observed from transverse direction (TD).

Fig. 3. shows the microhardness of plain low carbon, 50% cold-rolled and heat treated specimens with increasing intercritical annealed temperature. The microshardness value of as received steel is 94.10 HV. Microhardness of 50% cold-rolled is higher than as-received condition. Tewary et al[12] stated that the improvement of microhardness value after cold deformation is due to strain hardening, achieving by dislocation-dislocation interaction as well as the interaction of dislocations with twin boundaries. As the specimen intercritical annealed at 750°C, it can be seen that the microhardness was decreased. It is because of the reduction of dislocation density[13] as reported by Tsuji et al[13]. On the other hand, it can be observed that the microhardness of intercritical annealed temperature slightly

increased with increasing the temperature. The higher microhardness of dual phase steel is due to the presence of martensite phase (Fig. 2. c-e).

The more martensite phase will be formed at higher temperature due to the more austenite phase can be formed. Here is the explanation, when temperature is increased above intercritical region (727 ºC) then carbon can dissolve into austenite phase. The austenite phase formation starts from the initial pearlite and ferrite phase by nucleation, occurring promptly during intercritical annealing and then grows rapidly as increasing the temperature. However, austenite is not a stable phase. If the steel is cooled rapidly form the austenite region, the carbon will be trapped because of the time which need to complete the transformation is not enough. Hence, the martensite phase is formed[14]. In general, the microhardness increases due to the refinement of the primary phases after rapid cooling. It is well known that quenching by water produces a supersaturated solid solution and vacancies increase with carbon content in water quenched specimens. Therefore, high hardness corresponds with high resistance to slip and dislocation[15]. Thus, the increase in the microhardness with ice-water quenched steel in the present work can be explained by the increasing relative volume of martensite phase after ice-water quenching (Fig. 2. c-e as M). On the other hand, it can be seen that the microhardness of 50% cold-rolled specimen is higher than all intercritical annealed specimens due to cold-rolled specimen consists of high density of dislocation inside[16] as reported by Saha et al[16].

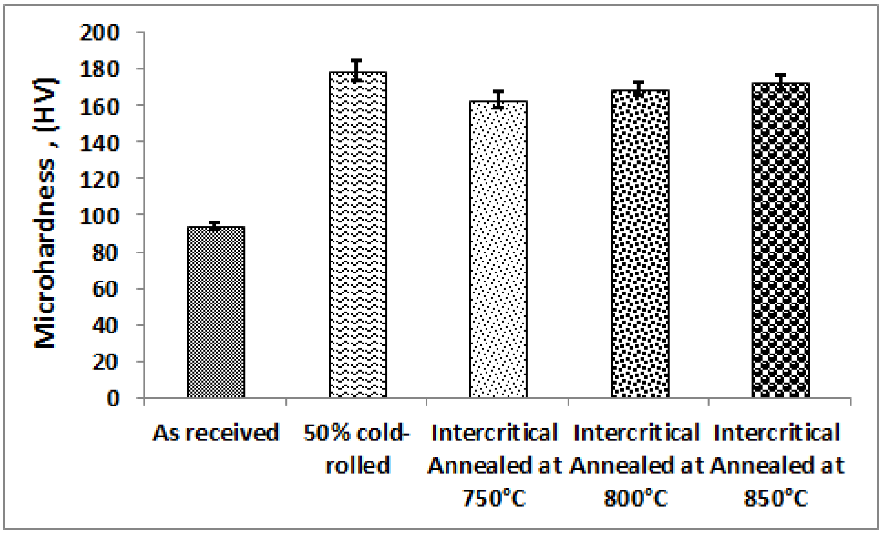

Fig. 3. Microshardness (HV) of plain low carbon steel, 50% cold-rolled and intercritical annealed at various temperature.

Fig. 4. illustrates the stress-strain curves of the as-received, 50% cold-rolled and intercritical annealed specimens to various temperatures. It can be observed that the as-received specimen displays typical tress-strain curve of plain low carbon steel with ferrite-pearlite microstructure; it has yield point elongation and show well-defined yield point. The tensile strength and uniform elongation were 366.32 MPa and 44.10%, respectively. After 50% cold-rolled the strength was increased to 595 MPa, while the uniform elongation was decreased to 10.40%. Tewary et al[12] reported the this type of behavior is due to the strain hardening phenomenon owing to the interaction between the dislocations and twins, procreated by cold deformation. As the specimens intercritical annealed after cold rolling, it can be seen that the strength increased with increasing intercrical annealing temperature and uniform elongation were recovered. The higher strength of dual phase steel is due to the presence of the harder second phase (martensite) which is in agreement with the earlier reports by Mazaheri[8]. It is noteworthy that the specimen intercritical annealed at 850°C indicates both high strength and adequate uniform elongation which is 540.11 MPa and 27.40%, respectively. The strength is 47.44% higher than the as-received specimen. On the other contrary, the

stress-strain curves of as-received specimen exhibited discontinuous yielding. However, after intercritical annealing, continuous yielding is achieved. The martensite transformation, plastic incompatibility between constituent phases and the internal stresses within the ferrite matrix generated from the transformation strains are responsible to the continuous yielding of dual phase steel. Such internal stresses can cause micro-yielding of ferrite at regions around the martensite island under relatively low applied stresses compared to the yield stress of bulk ferrite. As a result, the plastic flow starts simultaneously in many regions within the ferrite matrix throughout the microstructure[8].

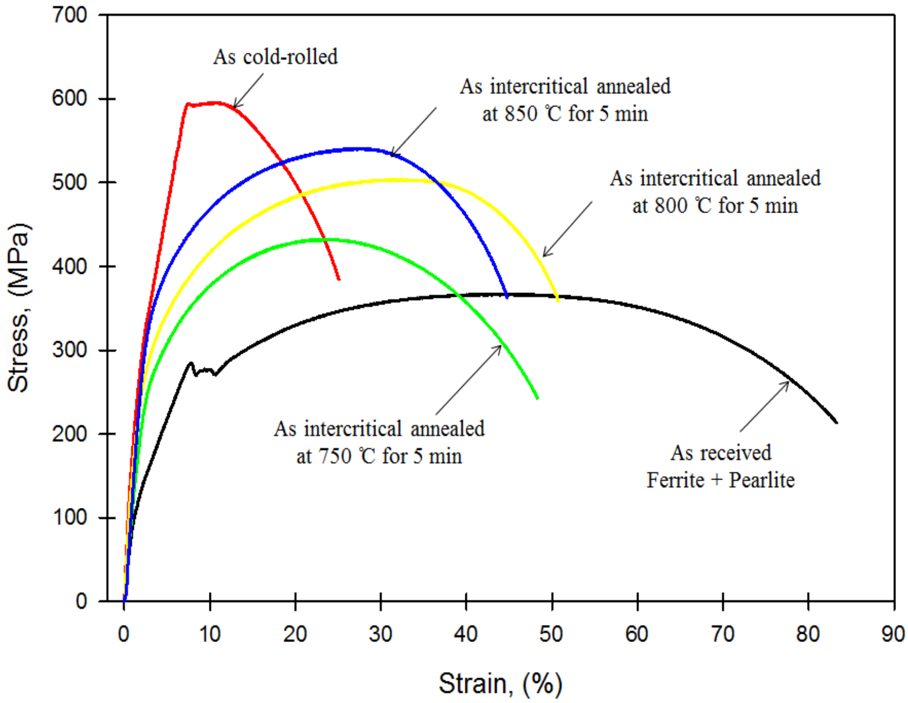

Fig. 4. Stress-strain curves of plain low carbon steel, 50% cold-rolled and intercritical annealed at various temperature.

4. Conclusion

A simple process to improve the mechanical properties of plain low carbon steel was investigated. The plain low carbon steel with mainly ferrite with minor amounts of pearlite microstructure was simply cold-rolled to a reduction of 50% and subsequently intercritical annealed. The specimen intercritical annealed at 850°C exhibited a dual phase microstructure consisted of ferrite-martensite and presented excellent mechanical properties in terms of microhardnsess (172.88 HV), strength (540.11 MPa) and uniform elongation (27.40%), when compared to specimens intercritical annealed at 800°C and 750°C, as well as the as-received specimen. The present processing route appears to be a very simple method which could be applied to the industrial production of steel sheet.

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