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Novel Procedure for Production of Duplex Martensitic-Ferritic Plain Low Carbon Steels

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1- Introduction

The γ→α transformation start temperature (Ar_3) decreases with increasing cooling rate. Then, at a critical cooling rate corresponding to the nose of the 'c' curve on a TTT diagram, transformation is suppressed. In plain low carbon steels, it was previously demonstrated that very high cooling rates are required to suppress γ→α transformation and produce martensite phase. For example, in low carbon steel with 0.05 wt.% carbon content cooling rates higher than 10000 K/s is required to produce lath martensite. These high cooling rates cannot be achieved by normal quenching media such as water and brine. Therefore, microstructures obtained after water quenching always contain products of diffusional transformation. Hydrostatic pressure is another important factor that can affect γ→α transformation temperature. The Ae_3 temperature decreases with increasing imposed hydrostatic pressure. In other words, austenite phase can be stabilized at lower temperatures compared with normal conditions (P=0.1 MPa) by imposing hydrostatic pressure. The Ae_3 temperature can be measured using Equation 1:

$$Ae_3(P) = Ae_3(P_0) - 1100 \times (P - P_0) \qquad (1)$$

where, P_0 is atmospheric pressure and P is the imposed hydrostatic pressure (GPa).

By gradual increase of hydrostatic pressure, the Ae_3 and Ar_3 temperatures decrease progressively. On the other hand, the specimen temperature decreases with time. If the amount of pressure is enough compared to the cooling rate so that the specimen temperature remains greater than $Ae_3(P)$ during process, the γ→α transformation is delayed. If this condition lasts up to the time that $Ae_3(P)$ and specimen temperature become lower than Ar_1 (P=1atm), then full martensite can be formed by sudden release of hydrostatic pressure. This procedure will be explained using schematic TTT diagrams in conjunction with experimental results confirming the claimed approach.

2- Experimental

The chemical composition of the steel used in the present study was 0.033C, 0.12Si, 0.8Mn, 0.008S, 0.007P, 0.004N and balance Fe. Cylindrical samples with 40 mm length and 14 mm diameter were cut from as received plate. Specimens were heated to the selected temperatures (650, 930 and 1000°C) and then inserted into a channel of a cold die. Afterwards, a punch was inserted into the channel and then samples were subjected to severe compression until the breakdown of ram under pressure. Samples were cooled in contact with die after releasing pressure. Optical microscopy was then used to reveal the final microstructure of the samples. For this reason, samples were cut into two halves and optical micrographs were taken from the center of each sample.

3- Results and Discussion

3-1-Normal transformation

Fig. 1(a) shows the initial microstructure of the steel used in the present study. As it is seen, the microstructure is composed of 95% ferrite with mean grain size of 32μm and the remaining is pearlite. The cylindrical specimens were heated to 930°C and cooled in different medium after 20-minute soaking. As shown in Fig. 1(b), the final microstructure after air cooling is polygonal ferrite with grain size of 21μm. In addition, the microstructure comprising of widmanstaten and acicular ferrite was developed after water quenching from 930°C (Fig. 1(c)).

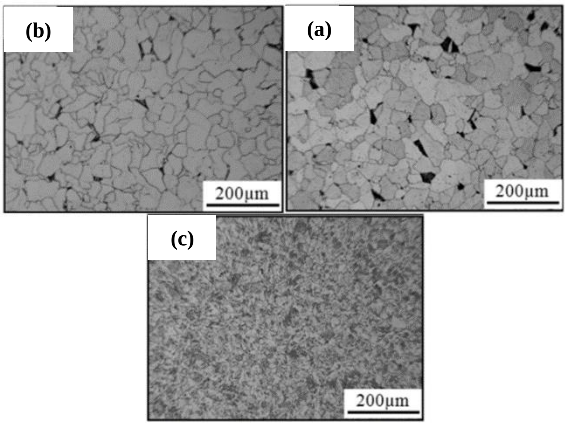

Fig. 1 a) Initial microstructure; b) Microstructure after air cooling from 930°C; and c) Microstructure after water quenching from 930°C

3-2- Transformation under pressure

Fig. 2 shows the final microstructure obtained by the mentioned procedure at different starting temperatures (Ts=650, 930 and 1100°C). As it is shown, when the starting temperature is selected to be 650°C, a microstructure consisting of polygonal ferrite grains is produced similar to the initial or air-cooled conditions (Fig. 2(a)). In contrast, a mixture of 20% grain boundary ferrite and 80% lath martensite is produced when the starting temperature is 930°C (Fig. 2(b)). The dark phase in this figure is

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lath martensite and light grain boundary phase is ferrite. Hardness of the dark inter-granular phase was measured as 320 HV and for the grain boundary light phase this value was about 235 HV. The final microstructure after water quenching is composed of acicular and widmanstaten ferrite. Therefore, the formation of 80% lath martensite in plain low carbon steel with 0.033 wt.% C is surprising and could not be attributed to the effect of cooling rate. For further confirmation, a higher starting temperature (Ts=1100°C) was selected and a ferrite phase was obtained after processing (Fig. 2(c)). Martensite phase is not observed in the obtained microstructure with starting temperature of 1100°C. It is worth noting that the cooling rate at 1100°C must be higher than 930°C due to the higher temperature difference between the die and specimen.

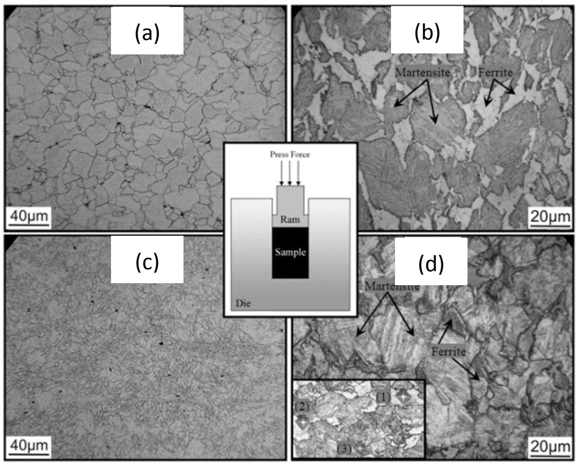

Fig. 2 Microstructures produced by cooling under severe pressure at starting temperature of a) 650°C; b) 930°C; c) 1100°C; and d) 930°C color etching

The schematic representation of the mentioned mechanism is shown in Fig. 3. In this process, γ→α transformation is suppressed due to decreasing $Ae_3(P)$ temperature by imposing hydrostatic pressure during continuous cooling. Then, hydrostatic pressure is released suddenly at the end of process. If the sample temperature (T_f) is lower than Ar_1 at the moment of pressure release, full martensite will be formed. Also, a duplex microstructure consisting of martensite and ferrite phases is developed when the sample temperature is between Ar_3 and Ar_1 (Fig. 2(b)). This condition is achieved at 930°C in the present work. If the starting temperature is high enough, the sample temperature (T_f) immediately before releasing the pressure will be higher than Ar_3. In this case, the final microstructure is 100% ferrite phase (Fig. 2(c)). This case occurred at preheating temperature of 1100°C. It is worth noting that the key point in this work is a sudden release of pressure at the end of the process. If pressure is released gradually then there will be sufficient time for γ→α transformation to occur.

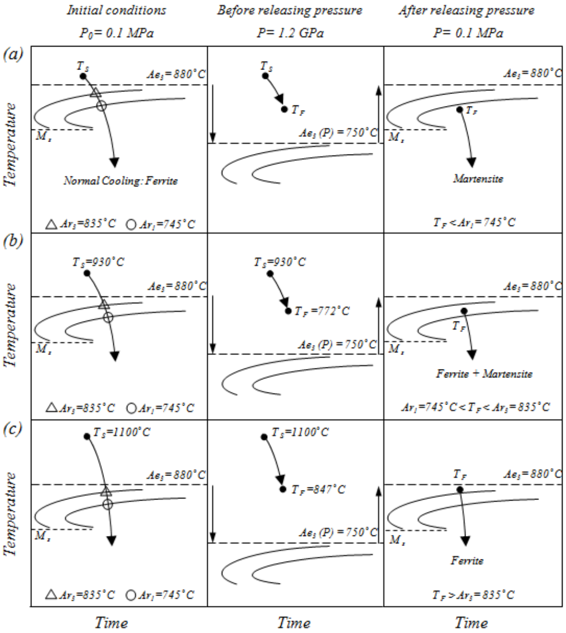

Fig. 3 Mechanism of martensite formation in plain low carbon steels by applying hydrostatic pressure during continuous cooling from austenite region

4- Conclusions

In the present study, hydrostatic pressure was imposed on a plain low carbon steel during cooling from the austenite region. A mixture of 80% martensite and 20% ferrite was produced at starting temperature of 930°C. In contrast, a microstructure consisting of 100% ferrite phase was developed at 1100°C. It was inferred that martensite phase is formed not due to the effect of cooling rate but the effect of hydrostatic pressure on the austenite to ferrite transformation start temperature.