Effect of continuous annealing process on microstructure, texture and properties of cold rolled dual phase steel

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Abstract: In order to improve the strength and plasticity of cold rolled dual phase steel DP980, the relationship between annealing process and properties were systematically studied by adjusting continuous annealing process parameters with 800-840°C. The primary ferrite, the secondary ferrite, recrystallized ferrite grains, island martensite distribution, precipitate and texture of different phases at different annealing temperatures were analyzed by methods with OM, SEM, TEM and EBSD. The effect of continuous annealing temperature on the strength and plasticity of dual phase steel DP980 were researched by mechanical tensile test in addition. The results show that recrystallized ferrite grains and the secondary ferrite can be refined by optimizing and adjusting the continuous annealing process, at same time, a small amount of retained austenite is distributed beside the island martensite on the microstructure of DP980. The precipitates NbC particle size is about 50~150 nm. Finally, the fine uniform microstructure, the dispersed martensite and fine precipitates are beneficial to the improvement of the strength and plasticity which increase the strength plasticity balance to a level of 15 -18GPa%.

1. Introduction

With the rapid development of automobile manufacturing industry, a large number of cold-rolled dual phase steel plates of various grades are widely used in the structural parts, reinforcement parts and anti-collision parts of automobile beams, pillars and car bodies, providing important materials for automobile lightweight, energy-saving and environmental protection and safety and anti-collision [1-2]. In order to further improve the strength, plasticity and formability of cold-rolled dual phase steel, new technologies have been developed and improved in the aspects of chemical composition, production process and microstructure [3-4]. However, with the increase of mechanical properties, the formability decreases, and for automobile manufacturers, mold loss and springback are large, which makes forming difficult. At present, DP590 and DP780 are widely used, but cold rolling DP980 has not been mass produced and applied in China. One of the main reasons for the limitation of its large-scale application is that with the increase of yield strength and tensile strength, the plasticity and formability decrease significantly, which makes stamping more difficult and difficult to meet the requirements of subsequent processing. Appropriate reduction of yield strength and ultra-low yield ratio (< 0.5) is conducive to stamping. It is also considered that the introduction of retained austenite is an effective method [5-7]. Retained austenite can improve the formability of dual phase steel, which is more conducive to the
processing and forming of automobile components and obtaining high geometric accuracy. In this paper, the effect of continuous annealing process on Microstructure and mechanical properties was studied by optimizing and adjusting continuous annealing process. The proportion, ferrite grain size, morphology and distribution of each phase at different annealing temperatures were analyzed by means of microscopic means. A small amount of retained austenite was introduced into the microstructure of refined cold-rolled ferrite and island martensite dual phase steel, and the level of 15-25 GPa% and the intensity level of 980MPa can be obtained by means of new technology and texture research at the same time. It provides theoretical research and technical support for the development and production of cold-rolled dual phase steel DP980 automobile sheet with ultra-low yield ratio, high elongation and good formability in the modern automobile production line[8-12].

2. Materials and methods of experiment
Chemical compositions of Cold rolled dual phase steel with low C-Si-Mn-Nb-Cr is C:0.13 to 0.15%, Si:0.4 to 0.6%, Mn:1.75 to 1.9%, Als:0.04 to 0.06%, Nb:≤0.03%, Cr:≤0.4%. After conventional hot rolling, pickling and cold rolling, the annealing temperature is 800-840℃, and the isothermal temperature remains 90-100s. After 25-30 s slow cooling time, it slowly cools down to 680-720℃, then rapidly cools down to the isothermal temperature which is about 290-310℃and remains 360-420s at a cooling rate of less than 70 ℃/s with continuous annealing simulator (CCT-AWY).Finally, the final cooling temperature is about 170 ℃, then air-cooled to room temperature. The optical metallographic microstructure morphology and volume fraction of each phase were observed under Leica microscope and SEM Microstructure were measured at FEI Quanta 650 FEG. TEM morphology of microstructure and precipitates were measured at FEI Tecnai G2 F20. EBSD morphology and residual austenite content of DP980 was carried out by TESCAN MAIA3 field emission scanning electron microscope. The mechanical properties were tested on the tensile testing machine of the National Iron and Steel Material Testing Center of China.

3. Experimental results and analysis
3.1 Effect of Different Annealing Temperatures on Microstructure
Fig. 1 shows the optical metallographic microstructure morphology of DP980 at different annealing temperatures. It can be seen that there are two kinds of ferrite grains with different grain sizes in the metallographic structure, which is mainly due to the different formation stages. The large size ferrite grains are left after cold rolling and annealing process, and the small size ferrite grains are pre eutectoid ferrite grains formed in the slow cooling process after dual phase annealing, so the grain size is small. The primary ferrite grain size is 10 ~ 25μm, and the secondary ferrite grain size is 1 ~ 4μm. With the increase of annealing temperature, the banded structure disappears and the ferrite grain size becomes smaller. The grain size has an effect on the mechanical properties, which is very important to improve the strength and plasticity of DP980.

Fig. 1 The optical metallographic microstructure morphology of DP980 at different annealing temperatures
(a) 800℃; (b) 820℃; (c) 840℃;
Fig. 2 shows SEM morphology of DP980 with different annealing temperatures. The SEM morphology is mainly composed of the primary ferrite, the secondary ferrite, island martensite and a small amount of retained austenite distributed on the ferrite matrix from 800℃ to 840℃. With the increase of annealing temperature, the secondary ferrite grains can be refined, the martensite content increases and high density dislocations can be obtained by optimizing and adjusting the continuous annealing process parameters.

Fig. 3 shows the TEM morphology of microstructure and precipitates at 840℃ of DP980. It can be seen that island martensite with the size of 1-3μm and high density dislocation lines are distributed on the ferrite matrix (Fig.3(a)). The morphology of the precipitates which is niobium carbide is massive and spherical precipitates. The precipitates particle size is about 150 nm and the smaller one is about 50 nm (Fig.3(b), (c), (d)) which is NbC. The dispersed martensite and fine precipitates are beneficial to the improvement of the strength and plasticity.
Fig. 4 is a graph showing the distribution of recrystallized grain size and morphology of DP980 at different annealing temperatures. It can be seen that the morphology and proportion of recrystallized grains is blue, sub grain crystal grains is yellow and deformed grains is red. As the annealing temperature increases, the grain size increases appropriately, and the recrystal grains of d ≤ 2 μm account for 70% or more in the range of 800-820 °C. The ratio of internal recrystallized grains is 70% at 800 °C, which was about 50% higher than the ratio of recrystallized grains at 840 °C and the proportion of crystallites in the sub crystalline structure was decreased by about 40%. Different types of grain size and content have great influence on mechanical properties.

![Fig. 4](image1.png)

Fig. 4 The distribution of recrystallized grain size and morphology of DP980 at different annealing temperatures

(a) 800°C; (b) 820°C; (c) 840°C;

Fig. 5 is the EBSD morphology and phase distribution of DP980 dual phase steel retreating sample at annealing temperature of 800~840 °C. The thick black line is >15° large angle grain boundary and the fine black line is 2-15°. Small angle grain boundary. It can be seen that the ferrite which is red of body-centered cubic phase (BCC), and the retained austenite phase with a small amount (0.015~0.1%) which is blue of small particle face-centered cubic structure (FCC). The size of retained austenite phase about 1 μm exists in the DP980 cold-rolled dual-phase steels. As the critical annealing temperature increases, the fine grains gradually become uniform and the number of grain boundaries

![Fig. 5](image2.png)

Fig. 5 Morphology of EBSD of DP980 at different annealing temperatures

(a) 800°C; (b) 820°C; (c) 840°C;
decreases. These fine uniform ferrite and diffusely distributed island martensite structure combined with a small amount of retained austenite TRIP effect are beneficial to the mechanical properties.

3.2 Effect of annealing temperature in different two-phase regions on the texture of dual phase steel

Fig. 6 is a graph showing the effect of different annealing temperature on texture and composition. It can be seen that the orientation of each grain of the dual phase steel in space is arbitrary, and there is no certain orientation relationship between the crystal grains. After cold rolled and continuous annealing treatment, the orientation distribution state of polycrystals can deviate significantly from the random distribution state at different annealing conditions. With the increase of annealing temperature, the shear texture decreases and the annealing texture increases obviously. The shear texture and annealing texture have a certain influence on the mechanical properties of the DP980.

![Fig.6 Effect of different annealing temperature on texture and composition](image)

(a) 800°C; (b) 820°C; (c) 840°C;

3.3 Effect of annealing temperature in different annealing temperature on mechanical properties of dual phase steel

When the annealing temperature ranges from 800 to 840 °C, DP980 with Rel=420-470MPa, Rm=1000~1025MPa, YS/TS=0.42~0.48, Aso=18~20%, Agt=9.0~12%, n=0.15~0.18, r=0.7~0.90, which the strength plasticity balance to a level of 15 -20GPa%, higher than the conventional DP980 with 10~12 GPa%; When the annealing temperature ranges from 800 °C to 840 °C, due to the uniform grain size, fine grains will lead to high elongation of the dual phase steel. At the same time, combined with the trip effect of a small amount of retained austenite with high elongation and ultra-low yield ratio can be obtained of DP980.

Based on the above analysis results, as the annealing temperature increases and the rapid cooling rate, not only the fine uniform ferrite structure can be obtained on the structure of DP980, but also a small amount of residual austenite phase with FCC structure can be obtained on the structure of DP980. Finally, retained austenite, island martensite and fine precipitates NbC particle can be obtained. Finally, retained austenite, island martensite and fine precipitate can increase the strength plasticity balance to a level of 15-18GPa%, which improves the strength and plasticity as well as the formability.

4. Summary
(1) A small amount of residual austenite phase with FCC structure can be obtained on the structure of DP980 by optimizing and adjusting the continuous annealing process parameters;
(2) The TEM morphology of the precipitates which is niobium carbide is massive and spherical precipitates. The precipitates particle size is about 50~150 nm. The dispersed martensite and fine precipitates are beneficial to the improvement of the strength and plasticity.

(3) With the increase of annealing temperature, the shear texture decreases and the annealing texture increases obviously. The shear texture and annealing texture have a certain influence on the mechanical properties of the DP980.

(4) The recrystallized ferrite grains and the secondary ferrite can be refined by optimizing and adjusting the continuous annealing process, the precipitates NbC particle size is about 50~150 nm. The fine uniform microstructure, the dispersed martensite and fine precipitates are beneficial to the improvement of the strength and plasticity which increase the strength plasticity balance to a level of 15~18GPa%.

Acknowledgment

Fund Project: Special Funding for National Key R&D Program of China (2017YFB0304000).

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