Study on microstructure and texture of high-strength plastic cold-rolled dual-phase DP980 steel

W W Wang, L Liu and G Y Li

1Metallurgical Technology Institute of Central Iron & Steel Research Institute, Beijing, 100081, China

E-mail: jingweiniao007@163.com

Abstract: In order to improve the strength and plasticity of cold-rolled dual-phase DP980 steel, the relationship between process structure and properties were systematically studied by adjusting continuous annealing process parameters. The microstructure, recrystallized grains, phase distribution, and texture of different phases at different annealing temperatures were analyzed by OM, SEM, and EBSD. At the same time, the effect of continuous annealing temperature on the strength and plasticity were studied by mechanical tensile tests. The results obtained show that by optimizing and adjusting the continuous annealing process, not only a small amount of residual austenite can be obtained on the structure of cold rolled ferrite and martensite dual phase steel, but also recrystallized grains can be refined. Finally, cold-rolled DP980 steel with YS/TS < 0.5 and high elongation A50 < 15% can be obtained, and its strength/plasticity balance can be increased to 15-20 GPa%, which is also favorable for its formability.

1. Introduction

Advanced high-strength steels (AHSS) of 800MPa grade and above are widely used in car industry. The AHSS first-generation steels include dual-phase steels (DP), transformation-induced plasticity steels (TRIP), complex phases steels (CP), hot-formed boron steels, etc. They are mainly based on ferrite, bainite or martensite, and the strength/plasticity balance is at the level of 8-10 GPa%, which makes it quite problematic to meet the light-weight and safety requirements for automobiles. The second generation of AHSS is represented by high-alloy steels based on austenite, such as twinning-induced plasticity steels (TWIP) and austenitic stainless steels (ASS). Although the strength/plasticity balance of these steels reaches a high level of 50 GPa%, the cost of these steels is relatively high due to the high alloy content in the steels and the difficulty in production process control. The third generation of AHSS with high strength and plasticity, has high content of alloy, low yield, complex process and the strength-plasticity balance reached 20-30 GPa%, which belongs to the preliminary application stage. Therefore, the market urgently needs advanced high strength steel [1-6] with comprehensive consideration of composition, process, performance and cost. At present, the main scholars at home and abroad improve the strength and plasticity of the first generation of advanced automotive steels, such as DP, TRIP, complex-phase (CP) steels, martensitic steels (MS), etc., by means of new technologies and texture research, and controlling the strength/plasticity balance above the level of 15-25 GPa% and the intensity level of 980MPa, which can meet the needs of the automotive industry for the first generation of advanced high strength and plasticity with large and wide range. The demand for automotive steels can also play a further role in meeting the needs of different customers [7-12].
The research results not only meet the current demand for high performance automobile materials in the automotive industry, but also play a very important role in promoting automotive lightweight, improving safety, saving energy and reducing PM2.5 emissions. They also have very important theoretical research value and practical significance.

2. Materials and methods of experiment
Chemical compositions of Cold rolled dual phase steel DP980 with low C-Si-Mn-Nb-Cr system is C:0.13 to 0.15%, Si:0.5 to 0.6%, Mn:1.8 to 2.2%, Als:0.04 to 0.06%, Nb:<0.04%, Cr:<0.4% to ensure good weldability and good formability. Continuous Annealing Simulator (CCT-AWY) of ULVAC SINKO RIKO was simulated after conventional hot rolling, pickling and cold rolling. The annealing temperature in the two-phase region is 760-840℃, and the isothermal temperature remains 90-120 s. After 20-30 s slow cooling time, it slowly cools down to 680-740℃, then rapidly cools down to less than Ms at a cooling rate of less than 70 ℃/s, about 290-310℃. At this temperature, the isothermal temperature remains 300-450 s, and the final cooling temperature is 170 C. The time ranges from 100 to 130 seconds, then air-cooled to room temperature. The mechanical properties were tested on the tensile testing machine of the National Iron and Steel Material Testing Center. Microstructure, morphology and volume fraction of each phase were observed under Leica microscope. Microstructure and grain size were measured at FEI Quanta 650 FEG. EBSD test was carried out by TESCAN MAIA3 field emission scanning electron microscope, and residual austenite content was determined at different annealing temperatures.

3. Experimental results and analysis
3.1. Effect of Different Annealing Temperatures on Microstructure
Figure 1 shows the microstructures of DP980 at different annealing temperatures. With the increase of annealing temperature, the banded structure disappears, the ferrite grain size becomes finer, and the grain size is gradually uniform. Because of the existence of ferrite grains with uneven grain size, the mechanical properties will be affected to some extent. The main reason is that the stages of grain formation are different in different sizes. The large ferrite grains belong to primary ferrite, which grow up after incomplete austenitization in a two-phase zone. The grains distribute along rolling direction. The grains are rougher between 17 and 29 microns, while the small ferrite grains belong to secondary ferrite. The ferrite is a pre-eutectoid ferrite grain formed in the slow cooling process after annealing in the dual-phase region. Because of another phase transformation, the grain size is smaller, about 1-4 μm. This small grain size is very important for the improvement of strength and elongation, as well as for the homogeneity of the structure.

![Microstructure morphology of DP980 at different annealing temperatures](image)

Figure 1. Microstructure morphology of DP980 at different annealing temperatures: (a)760℃; (b)800℃; (c)840℃.
Figure 2 shows SEM morphology of DP980 at different annealing temperatures. It can be seen that the main morphologies of island martensite are distributed on the ferrite matrix at different annealing temperatures. The carbides are small and the martensite content is small at 780°C. With an increase in annealing temperature from 780 to 840°C, the martensite content of high-density dislocations increases, and the morphology of block and island mixtures gradually becomes island-like, while a small amount of slab bainite and a very small amount of residual austenite also are present.

![Figure 2. Morphology of SEM of DP980 at different annealing temperatures (5000×): (a)780°C; (b)820°C; (c)840°C.](image)

Figure 3 is a graph showing the recrystallized grain size distribution and recrystallized grain morphology of DP980 at different annealing temperatures. As the annealing temperature increases, the grain size increases appropriately, and the crystal grains of d ≤ 2 μm account for 70% or more. At the same time, the morphology and proportion of recrystallized grains (blue), subgrain crystal grains (yellow) and deformed grains (red) were analyzed under different annealing temperatures (Figure 3), and the annealing temperature was in the range of 800-820 °C. The ratio of internal recrystallized grains is 69%, which was about 50% higher than the ratio of recrystallized grains at 840 °C, the proportion of crystallites in the subcrystalline structure was decreased by about 40%, the proportion of deformed grains was also decreased by a small amount, and the grain size tends to decrease, which can affect the mechanical properties.

![Figure 3. Distribution of recrystallized grain size and morphology at different annealing temperatures of DP980: (a) 800°C; (b) 820°C; (c) 840°C.](image)

Figure 4 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. Most of the DP980 cold-rolled dual-phase steels
are BCC body-centered cubic ferrite phase (red), and a small amount (0.015–0.1%) of small particle FCC face-centered cubic structure with a size of about 1 μm exists. The retained austenite phase (blue) is mainly distributed next to the martensite and at the grain boundaries. As the critical annealing temperature increases, the fine grains gradually become uniform and the number of grain boundaries 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.

**Figure 4.** Morphology of EBSD of DP980 at different annealing temperatures: (a)800°C; (b)820°C; (c)840°C.

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

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 rolling and continuous annealing treatment, the orientation distribution state of polycrystals can deviate significantly from the random distribution state, showing a certain regularity. In order to further understand the formation of cold-rolled dual-phase steel under different annealing conditions, the texture of DP980 dual phase steel after cold rolling annealing was studied in detail (figures 5 and 6, and table 1).

**Figure 5.** Effect of different annealing temperature on texture and composition: (a)780°C; (b)800°C; (c)840°C.

The results show that with the increase of annealing temperature, the annealing texture component increases obviously, and the shear texture component decreases gradually. The remaining texture components have no obvious characteristics and are randomly generated. The annealing texture is obviously strengthened to facilitate the yielding and tensile strength of the DP980.
Figure 6. Comparison of texture polarograms at different annealing temperatures: (a)780℃; (b)800℃; (c)820℃; (d)840℃.

Table 1. Effect of Annealing Temperature on Texture and Composition (780-820℃).

| Number | Color | Texture type | Component /% |
|--------|-------|--------------|---------------|
|        |       | 780℃ | 800℃ | 820℃ | 840℃ |
| 1      | Red   |       |       |       |       |
| 2      | Green |       |       |       |       |
| 3      | Yellow|       |       |       |       |
| 4      | Blue  |       |       |       |       |
| 5      | Purple|       |       |       |       |
| 6      | Blue  |       |       |       |       |
| 7      | Green |       |       |       |       |

3.3. Effect of annealing temperature in different two-phase regions on mechanical properties of dual-phase steel

Figure 7 shows the strong plasticity index under different annealing temperatures. The austenitizing temperature in the two-phase region has a great influence on the final mechanical properties of the dual phase steel. In the low temperature heating zone of 760~780 °C, the tensile strength of the dual phase steel increases, the yield strength decreases, the yield ratio decreases, the work hardening value increases, and the elongation decreases slightly. The two-phase zone is heated at medium temperature of 800~820 °C, and the mechanical properties of the dual phase steel are basically stable. The high temperature zone of the two-phase zone is heated at 840°C, and good elongation can be obtained if sufficient slow cooling is carried out. When the annealing temperature is 760 °C, the tensile strength meets the mechanical properties of 900 MPa; when the annealing temperature ranges from 780 to 820°C, Rel=495~538MPa, Rm=995~1022MPa, YS/TS=0.48~0.53, A50=13.5~15.5%, Agt=9.0~11.8%, n=0.15~0.18, r=0.63~0.90, strong plastic product 15GPa%, higher than the conventional with 10~12 GPa%; when the annealing temperature is 800°C, the recrystallization grain ratio is raised to 69%, and the cube texture is the most favorable for ferrite with excellent elongation due to strength/plasticity matching best, which corresponds to the observation of microstructure, and the highest elongation and low yield ratio are more conducive to subsequent forming.

Based on the above analysis results, as the annealing temperature increases, the amount of austenite is increased, and the martensite content increases during the cooling process. During the heat treatment of the two-phase region, a large amount of carbon and nitrogen compounds in the ferrite are dissolved.
or partially dissolved, which cannot be precipitated in the rapid cooling process or re-precipitated with very small particles, so the dislocation line will cut through the particles without bending At the same time, due to the formation of fine secondary ferrite during the slow cooling process after the two-phase treatment, the elements such as C and Mn are transferred to the untransformed austenite, and the ferrite is relatively pure. The two factors are combined to make the dual phase steel with an ultra-low yield strength. When the annealing temperature ranges from 780 to 820 °C, due to the uniform grain size, fine grains can lead to higher elongation of the dual phase steel, and a small amount of residual austenite can be obtained the effect, which has high elongation and ultra-low yield ratio of DP980.

![Figure 7. Mechanical properties at different annealing temperatures.](image)

4. Summary

(1) There is a small amount of residual austenite phase (blue) of small particle FCC (face-centered cubic) structure with a size of about 1μm in DP980 steel, which is mainly distributed along the martensite and at the grain boundary. Although the content of retained austenite is low, the size is finer and more stable. The fine uniform ferrite structure, retained austenite and dispersed island-shaped martensite increase the strong plastic product to a level of 16 GPa%.

(2) As the annealing temperature increases, the grain size increases appropriately, and the crystal grains having a grain size d≤2μm in the recrystallized grains account for more than 70%. The ratio of recrystallized grain with annealing crystal temperature in the range of 800-820°C is significantly increased by about 60% compared with 780 and 840°C, and the grain ratio of the subcrystalline structure is decreased by about 55%, and the proportion of deformed crystal grains is also fine and uniform, causing a change in mechanical properties.

(3) With the increase of annealing temperature, the annealing texture component increased significantly, and the shear texture component gradually decreased. The remaining texture components have no obvious characteristics and are randomly generated. The annealing texture is obviously strengthened to facilitate the yielding and tensile strength of DP980

(4) Cold-rolled dual-phase steel DP980 with a low yield ratio and high elongation (A_{50}≥15%) can be obtained.

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References

[1] Alibeyki M, Mirzadeh H and Najafi M 2018 Fine-grained dual phase steel via intercritical annealing of cold-rolled martensite *Vacuum* **155** 147-52

[2] Singh R K, Chandrawanshi M and Sudharshan R, et al. 2018 Optimizing annealing parameters with gleeble simulation for cold rolled continuous annealed dual phase steel sheet. *Mater. Today: Proceed.* **5**(2) 7303-9

[3] Philippot C, Bellavoine M and Dumont M, et al. 2018 Influence of heating rate on ferrite recrystallization and austenite formation in cold-rolled microalloyed dual-phase steels *Metall. Mater. Trans. A* 2018 1-12

[4] Li X and Wang X G 2018 Production practice of process optimization of 780 mpa cold rolled dual phase steel *Iron Steel Vanadium Titanium* **39**(1) 160-4

[5] Chen L S et al 2014 Mn partitioning behavior and its effect on structure and mechanical property of C-Si-Mn dual-phase steel *J. Iron Steel Res.* **26**(5) 72-6

[6] Tang X C et al 2018 Structure and thermoplastic properties on 1200 mpa cold-rolled dual phase steel *Mater. Rev.* **32**(16) 2870-5

[7] Wang K Q et al 2012 Effect of slow cooling process on microstructure and properties of C-Mn-Cr cold rolled dual phase steel *J. Iron Steel Res.* **24**(2) 44-8

[8] Wang W W et al 2016 Effect of continuous annealing process on microstructure and properties of DP780 containing niobium *Iron Steel* **51**(6) 71-5

[9] Singh N K et al 2011 Mechanical behavior of advanced high strength steel at high strain rates *Appl. Mech. Mater.* **82** 178-83

[10] Niu F et al 2010 Effect of Cr on transformation, microstructure and properties of ultra-high strength cold-rolled dual phase steel *J. Iron Steel Res.* **22**(7) 47-50

[11] Shahriary M S et al 2012 The effect of dynamic strain aging on room temperature mechanical properties of high martensite dual phase (HMDP) steel *Mater. Sci. Eng. A* **550**(6) 325-32

[12] Kuang S and Qi X M 2015 Numerical analysis on austenitization of cold-rolled dual phase steel during continuous annealing heating and soaking stage *Heat Treatm. Metals* **40**(12) 49-53