The Effect of Pre-compression Deformation on the Mechanical and Bending Properties of DP590

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Abstract. The effect of the pre-compression deformation on the mechanical property of dual phase steel DP590 which is developed early and used extensively in automotive industry is investigated in this paper. The tensile performance, the flow curve, strain hardening index and three-point bending strength in different pre-strain condition are measured. The microstructure and tension fracture are observed respectively by using of microscope and by using SEM. The results show that the compression pre-strain 5% then tension deformation, the DP590 has a pronounced Bauschinger effect, but compression pre-strain 5% processing has no effect on the bending strength. The pre-compressive strain 10%, makes Bauschinger effect disappear, and the bending strength is increased. Based on the microstructure, flow characteristics, working hardening characteristics and the stress state analysis under different experiments for the DP590, the relevant experimental results are clarified.

Keywords: Dual phase steel · Pre-compression · Bauschinger effect

1 Introduction

Dual-phase steel is the earliest advanced high strength steel used in the automobile industry. This kind of steel has low initial yield strength, high working rate, good formability, and good comprehensive performance of formed components. Therefore, it is the earliest development advanced high strength steel in the automobile industry and it is also advanced high strength steel with the largest dosage and more varieties. Many components have to go through pre-deformation, so the study of pre-deformation to understand the deformation mechanism of dual-phase steel, the influencing factors of strengthening, and giving full play to the potential of dual-phase steel in the application, and reasonably formulate the forming process of dual-phase steel, will have important reference value. The purpose of this paper is to study the influence of pre-compressed deformation dual-phase steel on the mechanical properties and cold bending properties, and to explore the reasons for this effect.

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2 Materials and Methods for the Experiment

Experimental steel is hot rolled dual-phase steel DP590, 5.3 mm thick, chemical composition is (wt.%) C 0.078, Si 0.77, Mn 1.2, Cr 0.408, Al 0.10, S 0.0.002, P 0.006, gauge length of ordinary tensile sample is 20 × 120 × 5.3 mm, directly cut from the hot rolled plate, pre-strain is performed on a special fixture, shown in Fig. 1.

The size of the pre-strain sample is 160 × 38 × 5.3 mm, After the sample is compressed on a pre-compressed fixture. In the tensile test sample of 120 × 20 × 5.3 mm is cut from pre-strain sample. Tensile test according to GB / T 5028-2008 (ISO 10275) on the SANS CMT5305 equipment. The bending test sample used in three-point bending test is 120 × 30 × 5.3 mm which cut from pre-compressed sample. The various test sample is shown in Fig. 2.

The loading speed of the bending test is 3 mm/min, the distance between the supporting rollers is 60 mm, the tension samples were averaged from the three samples for each group. Bending test data is also averaged from the three samples. The longitudinal direction of all specimens is parallel to the rolling direction. Measuring the flow curves during uniaxial tension and curves of bending stress and displacement. The schematic diagram of the sample fulcrum distance at the three-point bending is shown in Fig. 3.

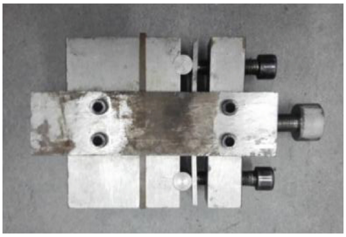
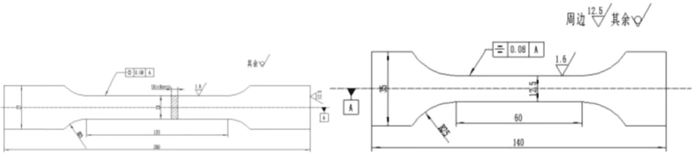
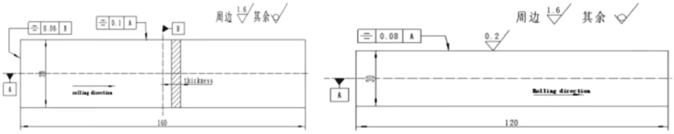


Fig. 1. Pre-strain fixture.



a. Sample of raw materials

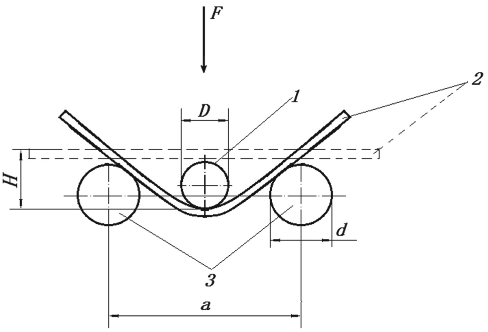
b. Sample after prestrain



c. Sample of compressed prestrain

d. Sample of three-point bending test

Fig. 2. Various specimens used in the laboratory.



1. bending loading roller
2. 30×120 test samples
3. supporting roller

D. roller diameter,4mm
d. diameter of the support roller,60mm
a. central pivot distance of the branch roller

Fig. 3. Fixture and fulcrum for three-point bending test.

Calculation equations about the bending moment, cross-section moment and bending stress were shown in equations group:

$$M = \frac{FL}{4},\quad W = \frac{bh^2}{6},\quad \sigma = \frac{M}{W} = \frac{3FL}{2bh^2}$$

Metallographic samples were corroded by using of 4% nitric acid alcohol, and the metallographic structure was observed on a Leica-DMI300 metallographic microscope, the tensile fracture was observed with SEM (FE quanta 20 Type).

3 Experimental Results and Analysis

Tension samples were cut from raw materials paralleled to the rolling cutting samples. The mechanical of the samples for raw materials and after the pre-compressive strain are listed in Table 1.

The flow curve of the engineering stress strain of DP590 under different states is shown in Fig. 4, Analyzing the data in Table 1 and the curves of Fig. 4, It can be seen that the initial yield strength of DP590 raw materials without pre-strain is low. The strain handing index n1 is comparable to n2. After the pre-compression strain 5% the initial yield strength is lower than the original yield strength during tension. The initial strain hardening index n1 increased significantly, but n2 decreases obviously. This is very close to the characteristics of Bauschinger effect defined by literature [1], this indicates that the steel has a significant Bauschinger effect. The Bauschinger effect usually refers to some dependence of the flow behavior (flow stress and rate of working hardening) of a metal alloy on the strain history and stress state: that is, in plastic deformation, flow stress of reverse deformation (e. g. compression) is often less than flow stress of initial forward direction deformation (e. g. tensile). However, after a stress reversal, there is a transient increase in the working hardening rate. The data listed in Fig. 4 and Table 1 can show that the compression pre-strain of 5% can significantly reduce the yield strength during the follow tension, but the tensile strength basically maintains the level of the original raw materials, while the initial hardening index n1 increases significantly, but the strain hardening index n2 decreases significantly. Interestingly, as can be seen from the data in Fig. 4 and Table 1, the 5% compressive pre-strain increased the total elongation rate

Table 1. Mechanical properties of DP590 in different states.

Condition	Young's modulus, MPa	Compression strength of 0.2%, MPa	Flexural Strength, MPa	Strain Hardening Exponent (n1)	Strain Hardening Exponent (n2)	Compressive Strain (r)	Elongation (A80), %
Raw Material	193803	418.8	636.33	0.16	0.17	0.63	25.45
Pre-strain 5%	195728	397.95	639.19	0.27	0.1	–	31.42
Pre-strain 10%	198830	438.62	662.94	0.26	0.08	–	18.6

Note: The data listed in the table are the average of the three samples, the above data are parallel to the rolling sampling data, n1 is the value of the hardening index between 0.2 and 2%, n2 is that between 2 and 6%, the total elongation rate of the pre-strained sample is the value of the A50 sample.

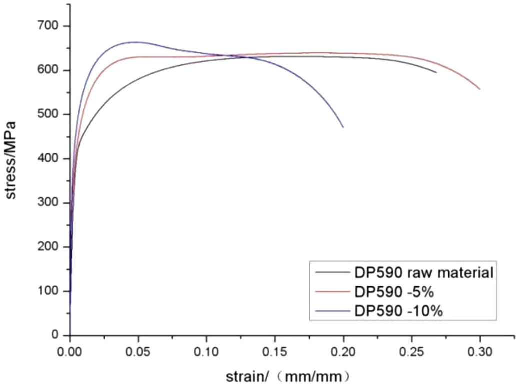


Fig. 4. Flow curve of engineering stress strain of DP590 in different states.

from 25.5% to 31.4%, and the uniform elongation rate from 21% to 25%. The reasons for the beneficial effect of the uniform elongation rate and total elongation rate due to after pre-compression deformation and the subsequent tensile deformation need further study.

After pre-compression strain 10% the subsequent tension, initial yield strength increased significantly, n1 rise significantly, n2 is significantly decreased. The compression pre-strain 10%, ferrite obvious deformation, martensite also began obvious deformation, plastic strain incompatibility degree of dual-phase steel is decreased, the extent of working hardening of the whole material, eventually result in increasing of yield strength and tensile strength, decreasing of the total elongation.

Sampling along the rolling direction, microstructure is shown in Fig. 5.

In order to compare the morphology of the tensile fracture after pre-compression strain, the fracture is observed by SEM microscopy. Generally, the tensile fracture is

(a) (b) (c)

Fig. 5. Raw materials are cut from parallel to the rolling direction (a), microstructure which is after a 5% pre-strain period (b), microstructure which is after a 10% pre-strain period (c).

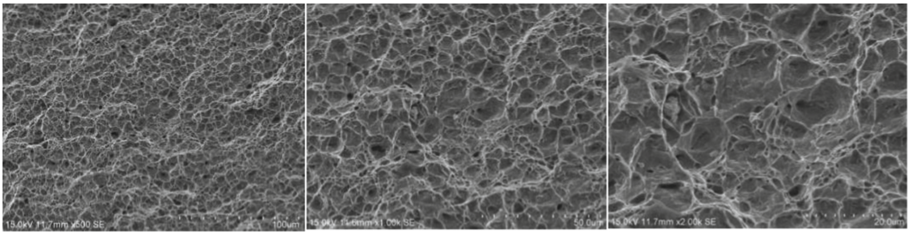


Fig. 6. Radiation zone of the raw material parallel to the rolling fracture.

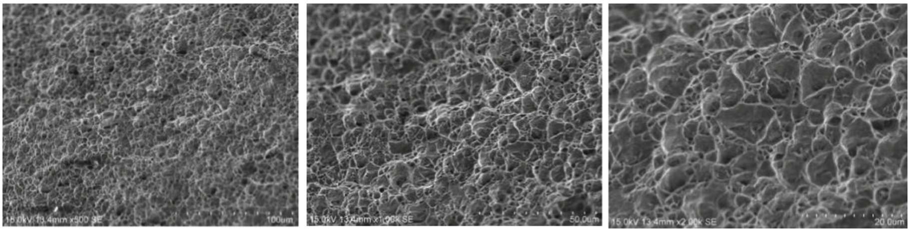


Fig. 7. Radiation zone of a tensile fracture parallel to the rolling direction after 5% pre-compressive strain.

divided into three zones, namely, fiber area, radiation area, and shear lip. The morphology of the three zones is different. For fracture morphology comparison, we selected radial zones of rapidly expanded crack with various strain history, see Figs. 6, 7, and 8, Fig. 6 shows the radial zones of raw material tension fracture with different magnifications. Figure 7 is the radial zones of tension fracture after 5% pre-compression. Figure 8 is the radial zones of tension fracture after 10% pre-compression.

Three zones for the tension fracture after 10% pre-compression strain is shown in Fig. 9. The morphology of the three zones is markedly different. The fiber zone is located in the middle of the fracture, which macroscopic is coarse fibrous. The fiber zone is a traction fracture. The crack core is formed in the fiber region during tension. Local contraction of tensile specimens in this area causes three-direction stress. However, the stress in the tension axis direction is maximum. The final tensile fracture is shown in Fig. 9(a). The radiation area of the tensile fracture for experimental steel is shown in

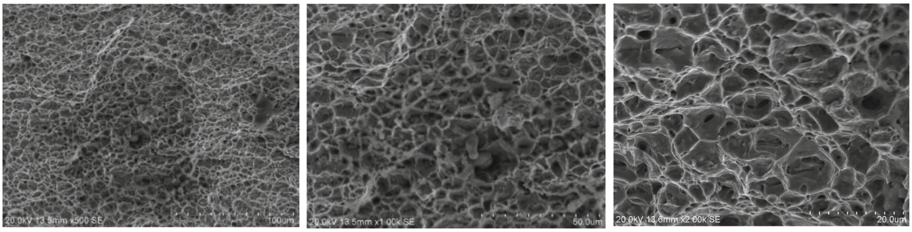
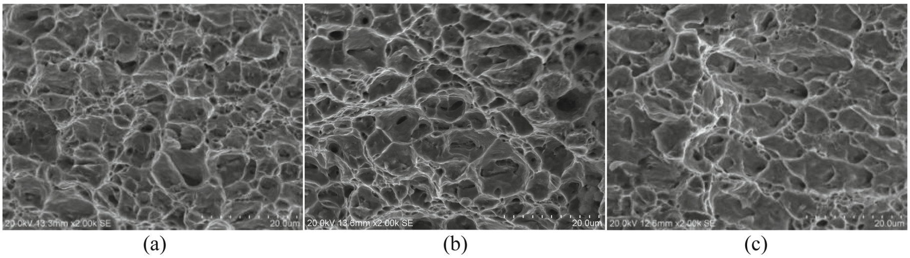


Fig. 8. Radiation zone of a tensile fracture parallel to the rolling direction after 10% pre-compressive strain.



(a) (b) (c)

Fig. 9. Tension fracture the fiber zone (a), radiation zone (b), shear lip (c) after 10% compression.

Fig. 9(b), which is immediately adjacent to the fiber zone. The zone is a transition zone that is cracks from slow to fast propagation. The radiation area has radiation patterns, which is the direction of radiation is parallel to the direction of crack propagation. The third area is the shear lip, it is the final stage of the tensile fracture process. The angle of shear surface with the tensile stress axis is 45°. It is a typical shear model fracture, which is crack for fast unstable propagation, and is an unstable fracture that occurs under planar stress, A material with a larger radioactive area will show its ductility decreasing [2]. It can be seen that from fracture with three different state: the appropriate stress between phase introduced by 5% of the pre-compression strain make ferrite strengthen and the strength difference between ferrite and martensite will be decreased, and the deformation compatibility between two phase will be increased which resulted in ductility increasing of sample and of increasing the radioactive zone in the fracture. When the pre-compression deformation amount is further increased to 10%, martensite also produces deformation, and there is a high internal stress in martensite. The rapid propagation area and radiation area of the fracture, there are more martensite fracture, so the total elongation rate decrease [3].

The bending stress also increases with the increase of pre-compression strain, but 5% pre-compression strain has little influence on the bending stress, and 10% pre-compression strain significantly improves the bending strength. As can be seen from the bending flow curve of Fig. 10, the measured data on the relationship between bending strength and pre-compression strain are shown in Table 2.

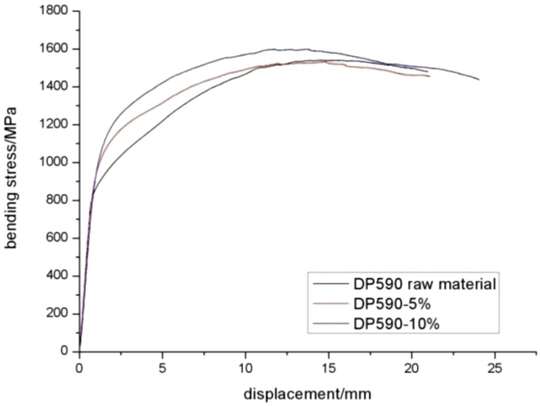


Fig. 10. Flow curve of the bending stress.

Table 2. Bending property of DP590 in different states.

	Condition	Flexural Strength, MPa
1	Raw Material	1543.15
2	Pre-strain 5%	1546.92
3	Pre-strain 10%	1603.59

The curve in Fig. 10 shows that the bending displacement decreased after pre-compression strain, but the bending strength after 10% pre-compression strain was significantly increased compared to the bending strength after 5% pre-compression strain, but the bending displacement did not decrease. This result is very important for application.

4 Conclusion

(1) The pre-compression strain of 5% can slightly increase the tensile strength, but it can significantly increase the total elongation rate, and the pre-compression strain 10% can significantly increase the strength, but the total elongation rate decreases significantly.
(2) The pre-compression strain of 5% has little effect on the bending strength, but the pre-compression strain of 10% can significantly increase the bending strength and the amount of displacement during bending.
(3) The reasons for the effect of pre-compression strain on tensile and bending properties need further analysis.

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