Homogenization and differentiation of property of tailor rolled blank of dual phase steel

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Abstract. The tailor rolled blank of dual phase steel (DP-TRB) is benefit for light weight of automobiles, and contribute to the energy conservation and emission reduction of the auto industry. Two kinds of annealing process, austenitizing completely followed by cooling to intercritical temperature and intercritical annealing, is studied. In intercritical annealing, an inflection point in mechanical property is found at 1.5mm thickness zone (25% rolling reduction) and has big property difference between different thickness. In the process of completing austenitizing followed by cooling to intercritical temperature, the homogenized mechanical property is shown and the difference in strength between thicknesses is 20MPa. And in this process, the influence of rolling is totally eliminated. These results can guide industrial production.

1. Introduction
Dual phase steel is a kind of important material for light vehicle with the advantages of High strength, good plasticity, low yield ratio [1-2]. And cold rolled dual phase steel is mainly produced by continuous intercritical annealing with a wide application. Tailor rolled blank have the advantage of changing thickness according the load, can light weight with structure optimizing [3-5]. Tailor rolled blank of dual phase steel (DP-TRB) combine the advantages of above two light vehicle methods, would get a more effective light vehicle.

The studies of TRB mainly focus on low strength materials such as low alloy high strength steel, aluminum alloy in recent years. As a new kind material for TRB, there is much research for DP-TRB to do. First of all is the mechanical property rules with thickness. This paper study property rules by two kinds of continuous annealing methods for DP-TRB, one is the conventional process for cold rolled dual phase steel, the other is the annealing process simulation hot rolling dual phase steel process.

2. Experimental procedure

2.1. Experimental material
The raw material for this study is commercial dual phase steel with thickness of 2.0mm and composition (wt. %) is 0.1C-0.417Si-1.78Mn. Yield strength is 360MPa, ultimate tensile strength is 620MPa, and total elongation is 28%. The microstructure of raw material is shown in Figure 1. Most
of martensite distribute in ferrite grain boundary, and some martensite concentrate on rolling direction, form the band structure.

Figure 1. Microstructure of raw material.

2.2. Rolling process
The TRBs with three equal thickness zone 1.2mm, 1.5mm, 1.8mm (represent 40%, 25%, 10% rolling reduction) were obtained by variable gauge cold rolling (single pass). The slope of the transition zone is 1:100, and detailed size is shown in Figure 2.

Figure 2. The sketch map of DP-TRB.

2.3. Continuous annealing process
The TRBs were annealed at CAS-200 continuous annealing simulation machine. And two kinds of annealing process was applied in this study:
1) Conventional process[6-7]: TRBs is heated to intercritical temperature, holding, followed a slow cooling, then fast cooling to overaging temperature, overaging 5 minutes, finally cooling to room temperature. And it's shown in Figure 3 process1.
2) Simulation of hot rolling process: TRBs is heated to austenitizing temperature, holding, followed a slow cooling to intercritical temperature, then fast cooling to overaging temperature, overaging 5 minutes, finally cooling to room temperature. And it's shown in Figure 3 process2 and process3.

Figure 3. The annealing process of DP-TRB.
Metallographic and tensile specimens were cut from annealed TRBs (every equal thickness zone). Subsequently, the metallographic specimens were mechanically polished and chemically etched with 4% Nital. Microstructure observations by OM and SEM were performed on the TD-ND plane. Tension test specimens with a gage length of 50 mm and gage width of 25 mm were machined. The tensile tests of the heat-treated specimens were carried out at room temperature and a rate of 1mm/min (strain rate: 0.0033s⁻¹).

3. Result and discussion

3.1. Microstructure
The microstructure of every equal thickness zone in different process is shown in Figure 4. As be seen in Figure 4(a-c), the microstructure of process 1 is like the microstructure after rolling, a large number of martensite is distributed in parallel along the rolling direction. Some martensite concentrate on the center of the thickness direction in 1.2mm specimen of process1, in Figure 4(a). A similar phenomenon is shown in Figure 5(b-c), a big long banded martensite structure in the center of the thickness direction in the 1.5mm and 1.8mm specimens of process 1. Comparing the Figure 4(a-c), the phenomenon that martensite is parallel to rolling direction become less while the thickness increase. Different thickness means different rolling reduction in TRB, 1.2mm specimens have the biggest rolling reduction. In the intercritical annealing process, the austenite nucleate and growth in the high C area where is the location of martensite after rolling. Then these austenite transform to martensite in fast cooling. Thus the martensite after annealing is affected by martensite after rolling. And the above phenomenon formed. As for center banded structure, a clear center concentrated martensite is found in original microstructure in Figure1, and this kind structure would affect the microstructure after annealing.

The microstructure of different equal thickness zone in process 2 is shown in Figure 4(d-f), the martensite island is bigger than martensite annealed at intercritical temperature. And the phenomenon that martensite is parallel to rolling direction is weaker too. The big martensite island with substructure is found in Figure 5(e-f). Due to the low austenitizing temperature, the C concentration in austenite is not uniform, the location of martensite is still the high C area. The ferrite form at low C area in slow cooling, austenite which would transform to martensite nucleate at high C area. Thus, rolling like microstructure still exist. In other hand, the C diffusion extends the high C area, the bigger size of martensite island is shown.

![Figure 4. Microstructure observed by OM.](image-url)
The microstructure of equal thickness zone is shown in Figure 4(g-i). There some martensite is still parallel to the rolling direction in 1.2mm and 1.5mm, meanwhile, the martensite of 1.8mm have a totally random distribution. The ferrite grain boundary is clear at this process and ferrite have a bigger size than other process. The most martensite of the 1.5mm and 1.8mm specimens is parallel to ferrite grain boundary. And same as process2, martensite with substructure is found in Figure 5(h-i).

The banded structure always exists when comparing the microstructure of different process. As mentioned above, this structure is due to the C distribution of rolling microstructure. With the annealing temperature increasing and austenitizing, the diffusion capacity of C increase, the limit of the area of high C area increase. Thus the distribution and size of the high C area which transform into martensite in followed step changed, and the banded structure is dying away. Meanwhile, C diffusion extends the size of the martensite, but reduces the stability of martensite. When the annealing temperature is 950°C the C distribution is more uniform and the austenite grain is bigger. In the step of slow cooling, the ferrite nucleate at austenite grain boundary. With the temperature decreasing, the diffusion capacity of C decrease and the length of the diffusion can’t be so long to through austenite grain. The best shape for short range diffusion is lamellar structure, like the pearlite. Thus the layer structure of martensite form at the ferrite interior.

3.2. Mechanical property
A mechanical property comparison between different processes is shown Figure 6. Figure 6(a) figure out the homogenization and differentiation of the yield strength. The process 1 as the conventional process show a clear differentiation and the process 3 be seen as the simulation of hot rolling process has a homogenization distribution of yield strength. Specially, the yield strength of the specimens process 1 do not follow linear relation with thickness. There is an inflection point in 1.5mm which respect 25% rolling reduction, the yield strength of 1.2mm and 1.8mm is less than 1.5mm. On other hand, the yield strength of specimens process 2 show a linear relation with thickness. And the
difference in the yield strength between different thickness decrease with increasing annealing temperature. The same phenomenon can be found in Figure 6(b) about the ultimate tensile strength. And the yield strength of 1.2mm increase with the increasing temperature, but the UTS has the inverse rules. In total, the property of process 3 is not only homogenized (the difference in strength is 20MPa) but the closet to the original property. As discussed in the above section, the influence of rolling gradually eliminate with austenitizing in high temperature. Thus the process 3 shows the homogenized mechanical property.

![Graphs showing mechanical properties](Figure 6. Mechanical property of different process.)

4. Conclusions
1) DP-TRB has the differentiation property when is treated by intercritical annealing. In this process, a property inflection is in 1.5mm thickness zone (25% rolling reduction). At this point, 1.5mm specimen has the biggest strength and lowest elongation.
2) DP-TRB treated at 950°C has the homogenization property, the difference in strength between different thicknesses is 20MPa and its property is the most similar to the original property.

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