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# Fracture Characteristics of B1500HS Steel Hot Blank Parts

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*Warm and hot blanking processes were developed for solving problems in piercing and trimming of press-hardened parts, some fine blank parts with comprehensive mechanical properties could be produced by hot blanking. To establish the optimum blanking processes and evaluate the effect of blanking temperature on the sheared section surface and fracture direction. Along with the fracture mechanism and microstructure of the parts, a series of hot blanking experiments for B1500HS steels were carried out at different blanking temperatures (450–800°C) and an 8% die clearance. The experimental results show that with the blanking temperature, the smooth (burnish) zone width increases, and the fracture direction becomes nearly normal. The sheared section surface of the parts mainly demonstrates ductile fracture mainly, accompanied by local brittle fracture over the blanking temperature range of 450–600°C. A ductile fracture region contains a great amount of fine equiaxed dimples over the blanking temperature range of 650–800°C, their microstructure is of complete martensite.*

***Keywords***: hot blanking, sheared section, fracture, microstructure, boron steel.

**Introduction.** Warm and hot blanking procedures were introduced to solve the problems in piercing and trimming of press-hardened parts. In addition, the hot stamping technology also significantly improved the forming properties of ultra-high strength steels and the mechanical properties of parts, where the steel sheets were heated to the austenite state, consequently formed and quenched in a die [1–3]. The hot stamping was used to produce various high-precision blank parts with good mechanical properties, such as gears, truss plates, cams, racks, and certain other plate parts for transmission, instead of traditional processes of cold punching followed by the heat treatment, thus solving the problem of size or shape variation of parts during their heat treatment.

Numerous experimental and numerical simulation results on warm and hot blanking were reported [4–8], where the effect of blanking temperature, die clearance, and cooling methods on the shear section quality, maximum blanking force, and punched hole diameter was evaluated to solve the piercing and trimming problems of press-hardened parts and ultra-high strength steel sheets. However, studies on hot blanking of fine parts are scarce.

The blanking temperature significantly affects the microstructure and mechanical properties of the parts, further affects the stress state, forming process, and fracture mechanism of materials during the hot blanking. In the paper, the effect of the blanking temperature on the sheared section characteristics, fracture perpendicularity, fracture mechanism and microstructure of the hot blank parts were analyzed.

## 1. Material and Methods.

***1.1. Material Description.*** In this study, cold-rolled strips of boron steel with a thickness of 1.6 mm were used for the tests. The original microstructure of the cold-rolled B1500HS steel strips consists of 80% (by volume fraction) ferrite and 20% of pearlite. The chemical composition of the boron steels B1500HS is as follows: C (0.23%), Si (0.25%), Mn (1.35%), S (0.006%), P (0.015%), Cr (0.19%), Mo (0.04%), and B (0.003%) [9].

***1.2. Experimental Scheme and Equipment for Hot Blanking.*** Boron steel samples with a thickness of 1.6 mm and a size of 45×40 mm were placed in a resistance heating furnace, heated to 900°C for 10 min to reach the austenite state. Then, samples were cooled down in the air to different blanking temperatures (450, 500, 550, 600, 650, 700, 750, and 800℃) and rapidly plaxed into the blanking die installed on a CNC universal testing machine. In the test, the punch diameter is 19.87 mm, the die clearance ratios is 8% and the blanking rate of the CNC universal testing machine is approximately 200 mm/min. During the hot blanking experiment, samples were contacted with the punch and then deformed until the ductile fracture. The blank parts were pressed and quenched between the punch and kicker under the action of the upper and lower forces, a higher cooling rate was obtained due to the faster heat transfer rate of die steel and the smaller size of parts. The blank parts were quenched to room temperature in the die with a following blanking at the test temperature. To ensure the consistency of test conditions and a better cooling effect of die, 3–6 tests were performed under each test condition to avoid accidental results and reduce the test errors.

## 2. Results and Discussion.

***2.1. Microstructure.*** The tendency of cooling curves is similar, but the cooling times at the forming temperatures differ with blanking temperatures. The cooling curves of hot blank parts go through the different transformation region of CCT diagrams for different blanking temperatures. Figure 1 shows the microstructure of parts with various blanking temperatures. A mixed microstructure of ferrite, pearlite, and granular bainite exist in the sample at the blanking temperatures of 450 and 500℃, whereas at the blanking temperature of 550℃, a small amount of martensitic transformation is observed, in addition to granular bainite, ferrite, and pearlite. In contrast, the sample microstructure at the blanking temperature of 600℃ consists of ferrite, granular bainite, and brown-yellow martensite.

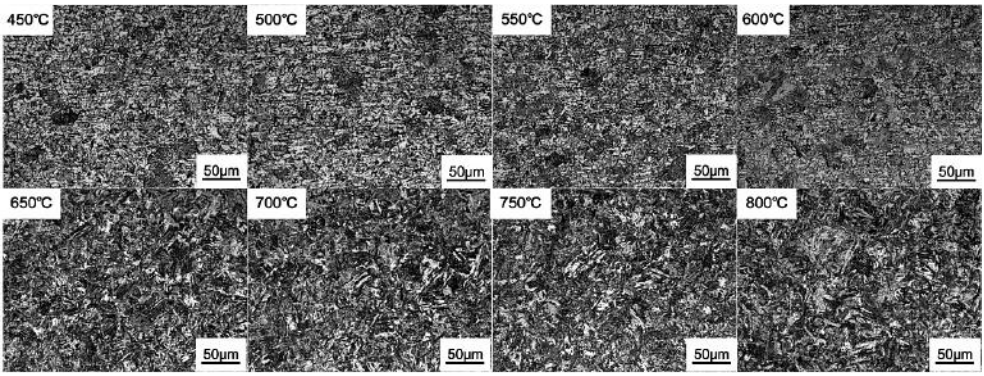

Fig. 1. Microstructure of blank parts at different temperatures.

As the blanking temperature increases, the sample quenching temperature increases. When the samples were blanked and quenched inside the die at the blanking temperatures of 650–800℃, the cooling rate of hot blank parts reaches up to 160 ℃/s as the sample is in contact with the punch, die, and kicker. The average cooling rate of the blanked part exceeds the critical cooling rate of a fully martensitic transformation (approximately 20–30 ℃/s for B1500HS [9, 10]). The microstructures of the parts are completely martensitic with high strength, hardness, and wear resistance characteristics.

***2.2. Sheared Section Characteristics.*** As the blanking temperature increases, the burnish and rollover zone width increases, the fracture zone width decreases. The burnish and rollover zone widths are approximately 80% of the steel sheet thickness at the blanking temperature of 800℃, as shown in Fig. 2. With the blanking temperature, the material plasticity and ductility grow, whereas the deformation resistance of the material decreases. The material sustains plastic shear deformation, increasing the burnish zone width.

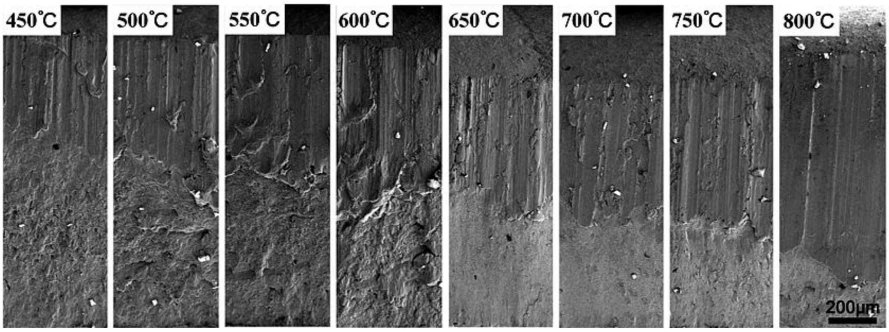

Fig. 2. Sheared section surface SEM-images at various blanking temperatures.

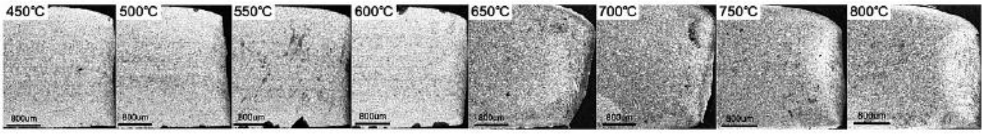

Fig. 3. Blank part sheared region cross-sectional profiles at various blanking temperatures.

The sheared section profiles of the blank parts with the various blanking temperatures are shown in Fig. 3. The perpendicularity of the sheared section is better as the blanking temperature is 450–600°C, whereas the microstructures of the parts are the mixed microstructure of ferrite, pearlite, bainite, or a low amount of martensite, which has poor mechanical properties. As the blanking temperature increases between 650–800°C, the microstructure is martensite with better mechanical properties, the sheared section is nearly normal, due to elastic recovery, microstructure transformation, and cooling shrinkage.

***2.3. Sheared Section Surface of Blank Parts.*** The material in the die clearance flows plastically along the thickness direction of the steel sheet under the blanking force effect, forming the burnish zone. The latter surface has different microstructure at various blanking temperatures. The local stress level of material is higher due to different strength of different microstructures, resulting in the microcracking of the two-phase interface, and then stripping within the burnish zone. When blanking temperature is in the range of 450–600°C, pearlite and bainite with high strength and poor plasticity are transformed, so the stripping extent of the burnish zone is more serious. When the blanking temperature grows from 650 to 800°C, austenite strength gradually decreases, and the austenite plasticity improves. The plasticity of fully austenite sheet also improves, and the burnish zone becomes significantly smoother (Fig. 4).

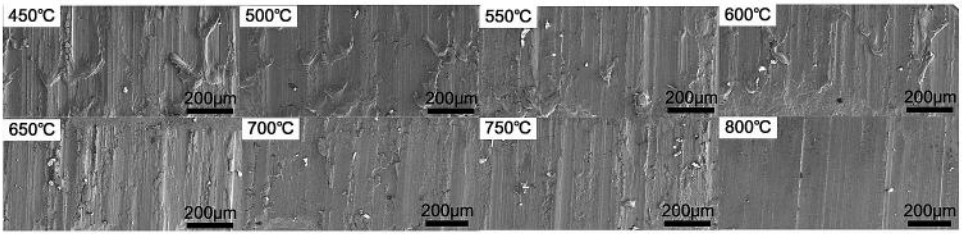

Fig. 4. Burnish microtopography of sheared surfaces at various blanking temperatures.

During the thermal deformation, the material is subjected to a certain degree of external load and at a certain temperature, where the impurities firstly detach or dissolute in the grain boundary, consequently forming the hollow nuclei. Then, the growth of the cavities would lead to a material local loading area decrease, which causes the non-uniformity of the stress field in the material, the dislocation aggregation, the nucleation and growth of a higher number of cavities. The cavities are interconnected forming microcracks and the macroscopic fracture eventually appeared [11, 12]. The fracture morphology of the fracture zone is mainly ductile fracture along with local brittle fracture as the blanking temperature is 450–600°C, and numerous parabolic-shaped dimples and brittle fractures appear, as is shown in Fig. 5.

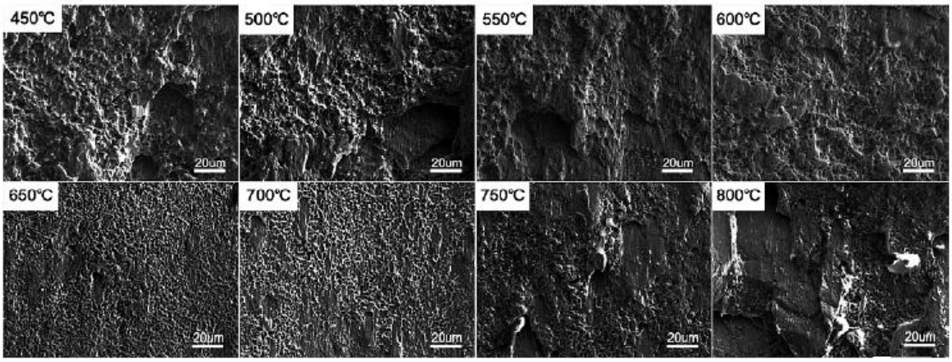

Fig. 5. Fracture microtopography of sheared surface at various blanking temperatures.

Ferrite and austenite with low strength and good plasticity cause a high amount of dimples of a parabolic shape to form by shear and tear forces. On the other hand, the larger plastic deformation leads to the ferrite lattice distortion and the material hardening, furthermore, bainite or pearlite have low toughness, causing the cracking of the ferrite region or two-phase interface, eventually resulting in the local brittle fracture.

The fracture mode in the fracture zone is mainly ductile fracture when the blanking temperature is in the 650–800°C range, and numerous small-sized equiaxed dimples appear. With the blanking temperature, the number dimples in the fracture zone decreases, while their dimensions grow. As is seen in Fig. 3, fracture angles of the blank parts are the highest at blanking temperatures of 650 and 700°C. Therefore, the fracture zone of the blank part sustains mainly the normal tensile stress during the fracture and separation of the material. The stress distributes evenly on the fracture surface. The microvoids uniformly grow in the three orthogonal directions of space, gradually forming equiaxed dimples. As the blanking temperature increases, the fracture perpendicularity improves, and the fracture zone width decreases. The material in the sheared section at blanking temperature of 800°C was seriously torn, the tearing surface width exceeding 50% of the fracture zone. In addition, a large number of elongated dimples with parabolic shape was observed.

**Conclusions.** The B1500HS steel samples were utilized in a series of hot blanking experiments. The results obtained made it possible to draw the following conclusions.

1. With the blanking temperature, the burnish zone width increases, and the fracture zone width decreases. The burnish and rollover zone width accounts for more than 80% of the sheet thickness at the blanking temperature of 800°C and die clearance ratio of 8%.

2. The sheared section becomes nearly normal as the blanking temperature is 450–600°C, whereas the microstructure of the parts combines ferrite, pearlite, bainite, or a low amount of martensite, which has poor mechanical properties. As the blanking temperature increases between 650–800°C, the microstructure of parts is martensite with better mechanical properties, and the sheared section becomes nearly normal.

3. At the blanking temperature in the range of 450–600°C, the extent of stripping in the burnish zone is more severe. When the parts consisting of pure austenite were blanked at 650–800°C, the burnish zone became smoother.

4. The fracture modes of the fracture zone at blanking temperatures of 450–600°C are mainly ductile mode accompanied by local brittle mode, whereas a large amount of fine equiaxed dimples exist in the fracture zone at blanking temperatures of 650–800°C. With the blanking temperature, the number of dimples decreases and their dimensions grow. At the blanking temperature of 800°C, the material in the sheared section undergoes a serious tearing, the tearing area exceeding 50% of the fracture zone. In addition, a large number of elongated parabolic-shaped dimples is observed.

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