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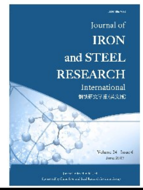

Fracture morphologies of a hot stamped steel and comparisons with several sheet metals

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ABSTRACT

Hot stamping has been widely used in car industry to produce safety components. Most existing researches focused on the stamping and quenching process, but less on the mechanical properties of stamped parts. The fracture behaviors of hot stamped boron steel B1500HS have been studied, and other four commonly used sheet metals with different strengths, including Q235, TRIP780, QP980 and MS1300, were also introduced for comparison. Both uniaxial tests and mechanical trimming tests were performed, and the fracture surfaces under different stress states were observed and discussed. The SEM observations showed that the fracture models are closely related to the stress states, i. e., the tensile surfaces have ductile rupture characters while the trimming surfaces have brittle rupture characters. Compared with other steels, the quenched boron steel has smaller dimple size accompanied by shear planes in the tensile surface, and has smaller burnish zone in the trimming surface, and its cutting surface with ‘S’ like shape is also very different with others. Furthermore, two fitted empirical models were derived to describe the quantitative correlations between the average dimple diameter and the steel strength and between the percentage of burnish zone and the steel strength.

1. Introduction

In order to reduce the vehicle weight and maintain performance and cost competitiveness, advanced high strength steels (AHSS) such as dual phase (DP) steel, transformation induced plasticity steel (TRIP) and martensitic steel have been widely used in the automotive industry[1]. Recently, hot stamping process has been regarded as an effective way to produce ultra-high strength steel auto parts, in which the boron steel can be shaped and quenched simultaneously inside the tool with the final strength over 1500 MPa[2].

Comparing to middle and low strength steels, most high strength steels have poor plasticity and are easy to fracture during the forming process, which depends on the stress state, strain rate, temperature, etc.[3,4]. It is noted that the fracture mechanism is commonly analyzed through surface morphologies. Sun et al. [5] investigated the fracture surfaces of DP600, DP780 and DP980 under tensile loading conditions, and they discovered that the amount of micro-voids near the fracture surface decreases with increasing strength level. Barsoum and Faleskog[6] studied the rupture of two different strength steels including Weldox 420 mid-strength steel and Weldox 960 high-strength steel by using SEM, in which they discovered that the stress state plays an important role in the fracture of both steels. Tasan et al. [7] observed the fracture surface of DP steel specimens along different strain paths; in their work, the DP steel shows a through-thickness shear fracture in all strain paths and the fracture surface is completely filled with dimples.

So and Hoffmann[8] used finite element simulations to study the influences of process parameters including trimming angle, clearance and speed on the section profile of hot stamped 22MnB5 steels parts. Mori et al. [9] developed a punching process using local resistance heating of a shearing zone to shear ultra-high strength steel (22MnB5) sheets, and discovered that as the heating temperature increased, the depth of the shiny burnished surface on the sheared edge also increased but the rough fracture surface decreased. The experimental results of

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Savic et al. [10] indicated that ductile fracture happened to the heat-treated boron steel in a miniature tensile testing stage. Han et al. [11,12] studied the mechanical trimming process for a hot stamped steel and discovered that the fracture mode changes from cleavage fracture for shear-dominated state to dimple fracture for tensile-dominated state as stress triaxiality increases.

Hot stamped parts are usually trimmed by laser instead of mechanical cutting because of its ultrahigh strength[13,14]. However, the shortcoming of laser cutting is also quite obvious, in particular that the cycling time is much longer than that of the mechanical trimming process[15,16]. Warming cutting technology[17,18] has been presented as an optional method, in which the hot stamped part is trimmed during the quenching stage at elevated temperature, shortening the process chain and reducing the cutting force evidently, but the design of the forming tools is complex and the shape of the part should be precisely predicted and controlled. Hard cutting (mechanical cutting) has evident advantages of high efficiency and good precision; it is presently seldom used for hot stamped parts because it is easy to cause tool wear and the tool failure appears relatively early[19]. However, recent development on steels with high hardness and good wear resistance can reduce such risk, and more attentions have been paid to hard cutting in high strength steel products. Besides, the study of mechanical fracture is also important for car crash simulations, in which the hot stamped products are usually used as anti-collision components.

In this paper, the fracture behaviors of quenched hot stamping steel B1500HS were discussed with both uniaxial tensile test and mechanical trimming test. In addition, four typical steels with different strengths, including Q235, TRIP780, QP980 and MS1300, were also introduced and compared. Based on the measurement results, the empirical formulas were derived to describe the relationships between tensile strength and fracture characteristics including the average dimple diameter and the percentage of burnish zone.

2. Material Characteristics and Experimental Design

2.1. Material characteristics

In this paper, the uncoated and cold-rolled boron steel B1500HS produced by Baosteel was referred as the hot stamped steel. Its chemical compositions detected by Ail-3460 spectrometer are given in Table 1, which is similar to 22MnB5 and other commonly used hot stamped steels[2,20].

In order to better understand the fracture characteristics of the high strength steel, four different kinds of cold-rolled steels including Q235, TRIP780, QP980 and MS1300 are introduced, and their chemical compositions are also given in Table 1. Q235 is a commonly used structural steel with low strength but good plasticity[21]. As a typical TRIP steel, TRIP780 offers an outstanding combination of strength and ductility benefited from the transformation induced plasticity effect[22]. QP980 steel produced by Baosteel is designed with the standard of the 3rd generation automotive steel with a good combination of strength and plasticity[23]. MS1300 is a kind of martensitic steel, which has higher strength but lower elongation than QP980 and TRIP780. The above four steels are normally formed at room temperature. These metals together with the quenched B1500HS have a wide range of strength distribution as shown in Table 2, in which other related mechanical

Table 1

Chemical compositions of studied steels (wt. %)

Steel	C	Si	Mn	P	S	Cr	Mo	B
B1500HS	0.23	0.25	1.35	0.015	—	0.19	0.04	0.0030
MS1300	0.16	—	1.65	0.009	0.0070	0.016	—	—
QP980	0.20	1.49	1.82	0.017	0.0043	—	—	—
TRIP780	0.19	0.38	1.68	0.012	0.0024	0.0021	—	0.0021
Q235	0.16	0.14	0.53	0.031	0.0260	—	—	—

Table 2

Mechanical properties of studied materials at room temperature

Steel	Yield strength/MPa	Tensile strength/MPa	Elongation at maximum force/%	Total elongation/%
B1500HS (quenched)	1356	1770	3.18	4.53
MS1300	1210	1470	3.31	6.81
QP980	947	1016	6.71	10.77
TRIP780	520	840	19.01	22.65
Q235	201	415	19.20	34.30