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Characterization of Mechanical Properties of Boron Steel Sheet in Hot Bending Process with Various Parameters

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Abstract

Hot press forming is a new forming process which also names as hot stamping. It can greatly enhance the formability of forming parts. This paper researches the formability of boron steel sheet in hot bending process which is a kind of hot press forming. In the text, the influence of hot press forming processing parameters, such as the heating temperature, blank holding force, punch speed and punch and die radius, on the mechanics properties and microstructure of the hot bending parts was analyzed by tension test and the metallographic observation on the parts with various processing parameters. The relationship between blank holding force and punch load was also presented.

Key Words: hot press forming, hot bending, hot bending process parameters, boron steel, mechanical property

1 Introduction

HSS is now commonly employed in various structural reinforcements and crash protection systems in different automobile applications. High strength steels are also employed in several other applications such as agricultural implements and mining equipment that are prone to high wear. Although high strength steel has a high strength and greater deformation, it has the disadvantages that it has too much springback when formed at room temperature; it is easily cracked, and it is difficult to form it into complicated structures. These problems have been recently overcome by a new forming technique that heats the quenchable steel when processing. At a high temperature (650 to 850°C), the material has an excellent formability, so that complex shapes can be formed in a single stroke. The blanks are stamped and cooled under pressure for a specific amount of time according to the sheet thickness after the drawing depth is reached. During this period the formed part is cooled in the closed die set. In order to enhance the strength of the forming steel, hot forming plus quenching has been researched over the past few years, and the tensile strength target of over 1500MPa has finally been achieved.

Lee et al [1] investigated the mechanical characteristics of boron steel according to the conditions of heat treatment in a feasibility study on a high strength boron steel alloy. Lee et al [2] also investigated the relationship between the microstructure and the mechanical properties of a boron steel alloy. Kim et al [3] carried out a finite element analysis and experimental study on the thermal deformation behavior of a boron steel alloy. Xing et al [4] performed an experimental analysis on the spring back of a boron steel alloy.

This paper thus aims at investigating the properties of hot bending parts and attempts to develop a general approach that will be able to offer accurate evaluations of the influence of process parameters on the properties of final sheet components produced in hot forming.

2 Experimental

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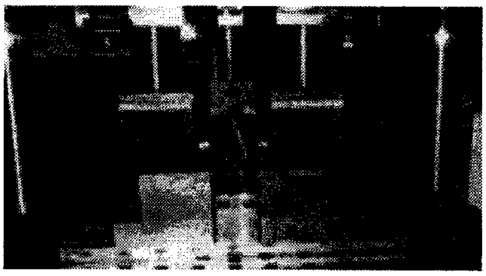
The HPF process is a forming method used to fabricate hyper-strength components through rapid cooling while forming a steel sheet heated to over 900°C by cold dies. The complicated engineering components are therefore easily formed because they are formed at a high temperature where the formability is better than that of room temperature. Then the advantage of hot press forming structural components with high strength and complex geometries can be formed. Fig. 1 show a photograph of the experimental apparatus used in this study for the hot bending process. The experiment blank used in this experiment was boron steel which has the chemical composition and mechanical properties shown in Table. 1. The sheet was separately heated to 700°C, 800°C, 900°C and 950°C and totally heated for 5 minutes so that the sheet material can have an austenitic microstructure over the entire blank [5].

Table.1 Chemical composition and mechanical properties of tested material

Material	Chemical composition (mass %)					Mechanical properties		
	C	Si	Mn	Cr	B	YS(MPa)	TS(MPa)	El (%)
BCJ239	0.2123	0.0806	1.484	0.4063	0.0016	469	659	20



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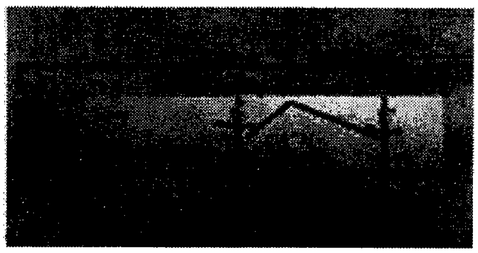

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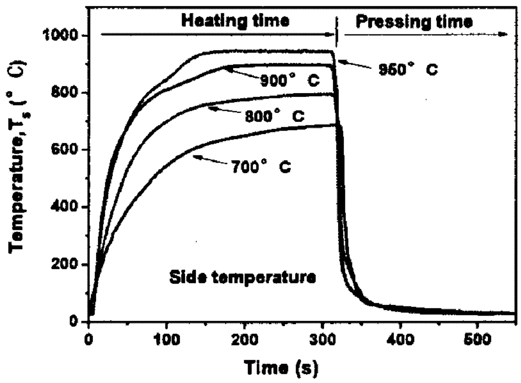
Fig. 1 Structure details of bending die and positions of thermocouple

3 Result Analysis and Discussion

From Fig. 2 we can see the blank temperature variation at different heating temperatures. The cooling rates of center part and side part are quite different from each other. Side part has much larger cooling rate than that of center part.



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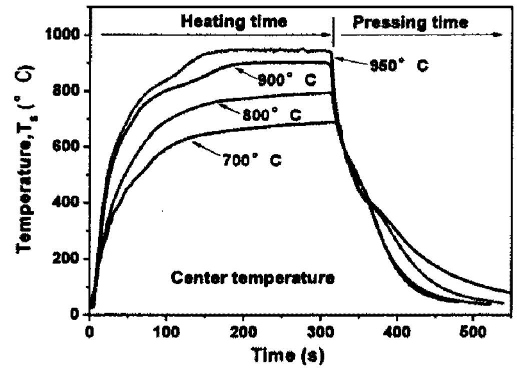

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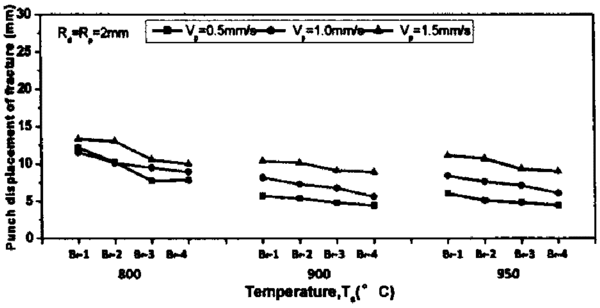
Fig. 2 Blank temperature evolution of side temperature(ST) and center temperature(CT)

Punch displacement of fracture contrast at different temperatures and different punch and die radius was shown in Fig. 3. Once fix the punch and die radius of 2mm, lower heating temperature, lower blank holding force and higher punching speed can lead to deeper cracking displacement which means better formability. Opposite result happens when fixing the heating temperature, larger punch and die radius and lower punching speed resulted in deeper cracking displacement or even no crack happened when the punch speed is less than 1mm/s.



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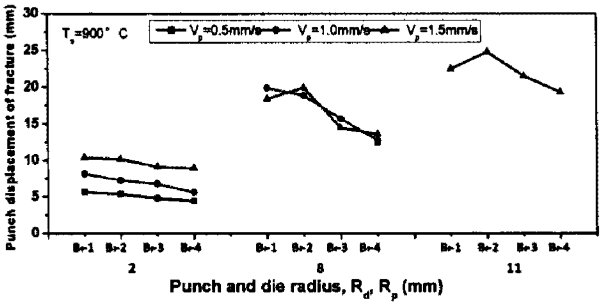

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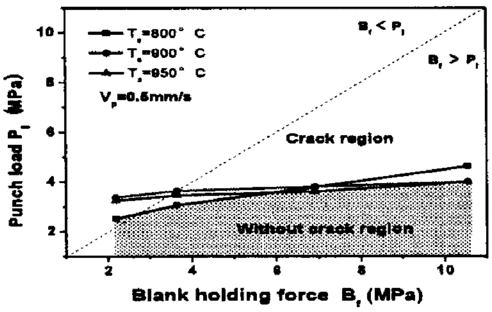
Fig. 3 Punch displacement of fracture at different temperature, (T_s) and different punch and die radius, (R_d, R_p)



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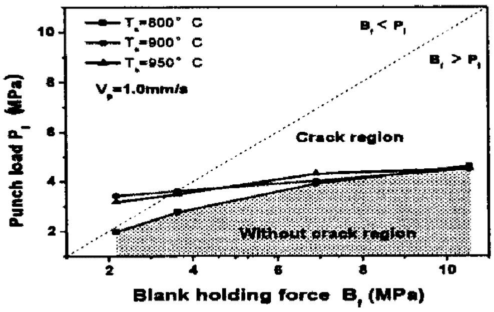

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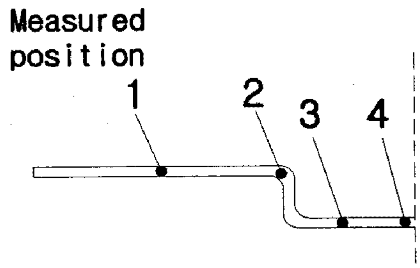
Fig. 4 Relationship between B_f and P_l according to sheet temperature, (T_s)

In most cases, crack happens when $B_f < P_l$, the dashed area shown in Fig. 4 indicate the safe area without fracture. So in order to protect the part integrality, the punch load should be less than the blank holding force regardless of other experiment condition such punch speed, heating temperature and so on. Fasten on the line in the Fig. 4, we can see that the blank holding force is twice as much as the punch load when there is no crack.



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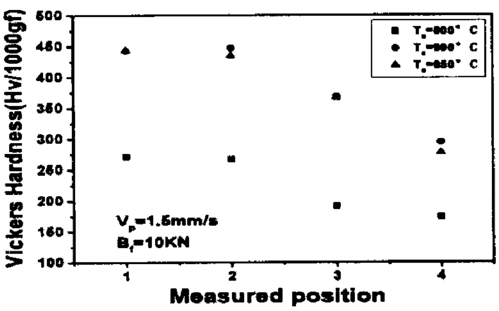

(b)

Fig. 5 Positions to observe hardness and microstructures and the hardness of formed boron sheet

Fig. 5 shows the hardness of different test positions at different conditions (temperature and position). At the condition of 900°C and 950°C, the hardness are obviously much larger than that of 800°C, while the hardness at the position of 1 and 2 are as much as 450Hv which is much higher than position 3 and 4 at the temperature of 900°C and 950°C. So in order to obtain better mechanical hardness, the heating temperature should above 900°C for higher heating temperature results in larger cooling rate in the same cooling time. It is obviously that the least hardness of 900°C is also larger than the largest hardness of 800°C. At the same position, the hardness of 900°C and 950°C may about two times of 800°C. There is almost no difference at the same position between 900°C and 950°C. Fig 6 shows the microstructures of different positions and temperatures. Considering Fig 5, larger hardness matching more Martensite in microstructure was proved. Compare with position 3 and 4, position 1 and 2 have more Martensite in microstructure which leads to difference in hardness. Although there is nearly no hardness difference in 900°C and 950°C, the size of Martensite at 950°C is larger than that of 900°C which leads to difference in tensile and yield strength.

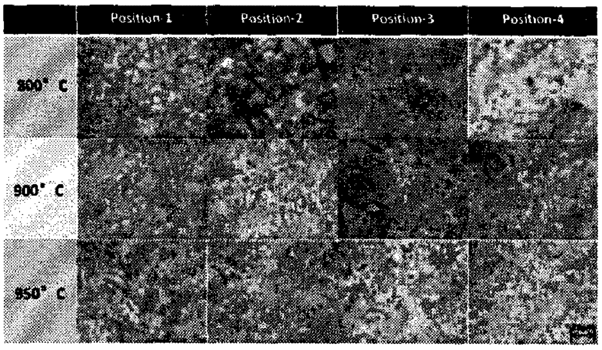

Fig. 6 Microstructures of different measure positions

4 Conclusions

At the same temperature and punch speed, smaller blank holding force leads to deeper forming depth without crack. At the same blank holding force and punch speed, lower sheet temperature leads to deeper forming depth without crack. At the same sheet temperature and blank holding force, higher punch speed leads to deeper forming depth without crack when the punch and die radius is small, however, lower punch speed leads to deeper forming depth without any crack when the punch and die radius is larger than 5mm.

All the fractures cracked at the position of bending lines. The side parts of the bending have better hardness and higher tensile strength compared with the center parts because the microstructure are different due to different cooling rates. Therefore, reducing the heated blank sheet transfer time can enhance the mechanical properties by contract different parts of formed sheet.

So better mechanical properties and formability require higher heating temperature, faster punch speed, appropriate relationship between punch load and blank holding force. A higher heating temperature leads to better mechanical properties, and there was no obvious difference when the temperature is above 900°C, and also larger punch and die radius matches lower punch speed while smaller punch and die radius matches higher punch speed.

Acknowledgement

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