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Flow characteristics of aluminum coated boron steel in hot press forming

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Abstract: The flow characteristics of aluminum coated boron steel in hot press forming were investigated. Furthermore, the effects of aluminum coated layer on press forming were analyzed during deep drawing. The results show that aluminum coated boron steel exhibits a high sensitivity on temperature and strain rate. Aluminum coating layer appears in surface flaking in a temperature range of 700−800 ℃, but smooth surface is formed above 900 ℃.

Key words: hot press forming; aluminum coated boron steel; deep drawing; thermo-mechanical properties

1 Introduction

Most of automobile companies have some problems concerning manufacturing the steel sheet, and manufacturing types are various. When producing thin ultra-high-strength steel components with the press hardening process (hot stamping), it is essential that the final component achieves desirable material properties. Above all, under the complicated condition of stamping process, transformation of steel sheet without defects is a matter of concern. The vehicle steel sheet stamping process is a continuous pressing process and consists of drawing process for panel shape determination and following process. Especially, the process involves voluminous contact of mold and sheet, therefore friction force has much effect on stamping drawability. The aim of hot stamping is to produce structural components from ultra-high-strength steels. In addition to the temperature-related improvement in the forming properties of these steels, hot stamping makes it possible to further increase the strength of the materials during forming. And hot stamping is a non-isothermal forming process for sheet metals, where forming and quenching take place in one combined process step[1−5]. Boron steel exhibits excellent formability at elevated temperature. It cannot be formed into complex geometry with traditional high strength steel. In addition, near-zero springback attributed to in-die cooling gives boron steel an unparalleled edge in dimension control and subsequent assembly process[6]. Generally, in hot stamping, the blank is heated at the austenitization temperature or above, and quenching by stamping tools is carried out immediately after forming. A high work hardening rate favorably influences formability by resisting local necking during component manufacture and also results in higher tensile strengths in the manufactured component[7]. In this work, by using the high temperature tensile test and deep drawing test, the boron steel is concerned at the high temperature deformation.

2 Experimental

2.1 High temperature tensile test

To determine the thermo-mechanical characteristics of material, the flow behavior of the boron steel was investigated using a MTS material testing system in temperature range of 100−900 ℃ and strain rate of 0.02 and 0.2 s^{-1}. In specimen tensile test, KS B 0802−13B was applied. The material temperature was measured using a thermocouple contacted to the surface of the specimen.

The specimens were placed in a furnace heated in static air at temperatures from 100 to 900 ℃ for 5 min. The axial displacement and the axial tensile force were measured continuously during the experiments.

2.2 Deep drawing test

The warm deep drawing experiments of aluminum coated boron steels were carried out using an Erichsen

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testing system. A rigid blank holder was used to adjust blank holding forces to avoid wrinkling of blanks. The specimens were heated up to 800−950 ℃ and held for 3 min. And then, it was pressed at punch speed of 5 mm/s and rapidly cooled.

3 Results and discussion

3.1 High temperature tensile properties

The sensitivity of forming behavior of boron steel on temperature was investigated in strain rates of 0.2 and 0.02 s^{-1}. Fig.1 shows the true stress—strain response of the aluminum coated boron steel (Fig.1(a)) and uncoated boron steel (Fig.1(b)) at various temperatures between 100 ℃ and 900 ℃, and representative true stress—strain curves are displayed for strain rate of 0.2 s^{-1}. As expected, the strength decreases as temperature increases. It must be noticed that there are fluctuations in the flow curves at 100 ℃ and 900 ℃, which are evidences of dynamic recrystallization of single peak type[8]. The curves show an initial work hardening, which is balanced by the dynamic recovery so that a steady state is eventually reached. For the aluminum coated boron steel tested at 900 ℃, it is even possible to detect the effects of dynamic recrystallization, which is seen as a fall from peak stress of around 130 MPa and peak strain of about 0.31. The flow curve characteristics show that the temperature has a significant influence on the forming behavior of boron steel. Stress of aluminum coated boron steel is higher than that of uncoated boron steel at temperature above 600 ℃; but at temperature below 500 ℃, stress has a reversed tendency. Increasing the temperature leads to a significant reduction of the flow stress and a decrease in work hardening exponent, resulting in a noticeable decrease of the slope of the true stress—strain curves. At temperature above 600 ℃, the flow curve appears as almost a plane curve after the initial strain hardening with increasing temperature. This plane curve is due to temperature induced dynamic recovery processes balancing the strain hardening, which occurs in the deformation of the material[4, 9].

Also, the influence of the strain rate on the forming behavior of the boron steel was evaluated at different temperatures from 500 to 700 ℃. Two different strain rates of 0.02 and 0.2 s^{-1} were used. Fig.2 shows the temperature-sensitivity of the boron steel for two different strain rates between 500 and 700 ℃. It can be clearly seen that the strain rate has a significant influence

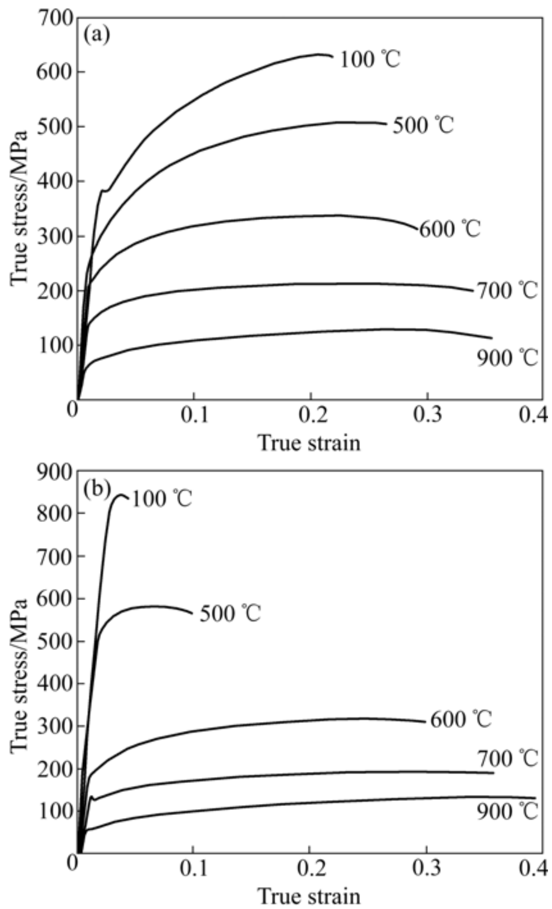

Fig.1 Influence of heating temperature on flow curve characteristics of boron steel ($\dot{\varepsilon}$=0.2 s^{-1}): (a) Al coated boron steel; (b) Uncoated boron steel

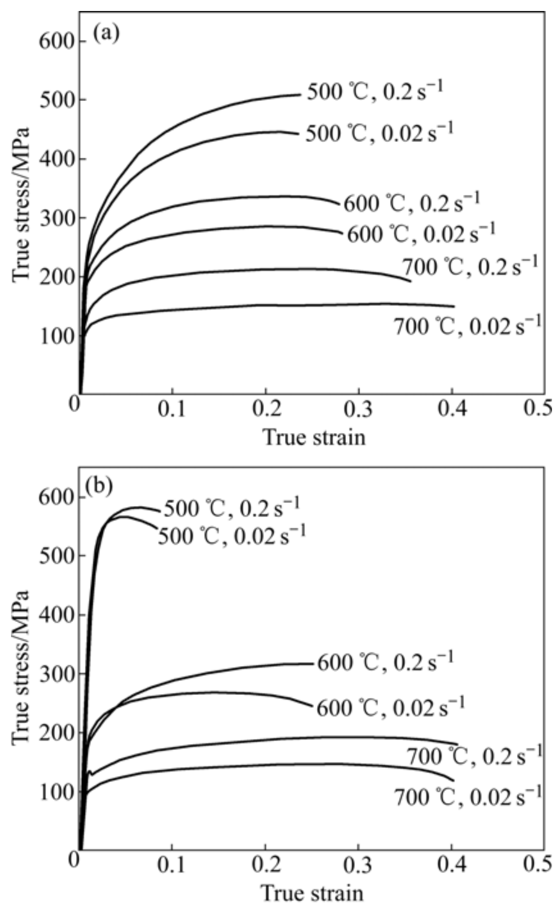

Fig.2 Influence of strain rate on flow curve characteristics at various temperatures: (a) Al coated boron steel; (b) Uncoated boron steel

on the forming behavior of the material. In general, increasing strain rate leads to an appreciable increase of the stress level and the slope of the curve as a consequence of an enforced work hardening of the material, as the material has no enough time for dislocation annihilation or recovery[10].

In these tests, the higher cooling rates could be achieved down to the martensite-starting-temperature (M_s, 420 ℃), although the cooling rate decreases during martensite formation. Determination of stress—strain curves for austenite at temperatures above M_s and austenite+martensite above the martensite-finishing-temperature ($M_f < T < M_s$), enables using higher strain rates. Fig.3 shows the martensite microstructure after tensile test at 900 ℃.

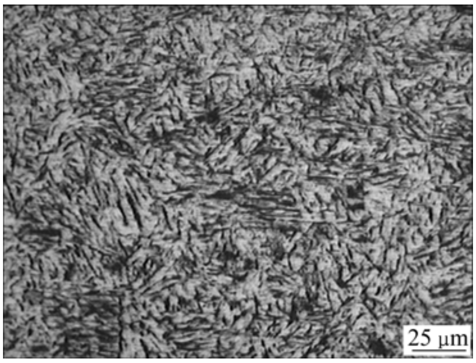

Fig.3 Microstructure of specimen at 900 ℃ after compression

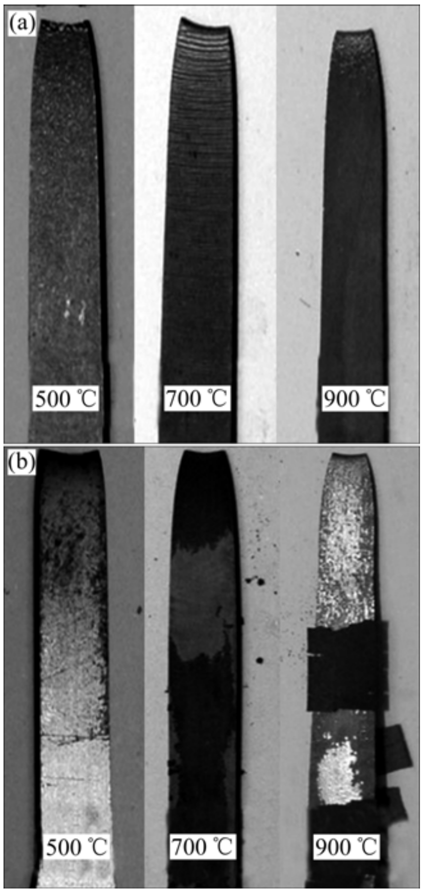

Fig.4 Tensile test specimens at various temperatures ($\dot{\varepsilon}$=0.2 s^{-1}): (a) Al-coated; (b) Uncoated

Fig.4 shows the surface of specimens after high-temperature tensile test. In the case of aluminum coated boron steel, at 500 ℃, surface damage appears, and it can be shown that surface crack of teeth of a comb pattern shape is observed nearby 700−800 ℃. Beyond 900 ℃ such phenomenon does not happen. On the other hand, surface oxidation film on the tensile specimen at 500 ℃ is formed. In addition, surface of the specimen is separated by the surface oxidation film of specimen with increasing temperature.

3.2 Deep drawing properties

Fig.5 shows the specimens after deep drawing test. Surface flaking occurred largely at 800 ℃. It was not formed as inquired shape, but good shaping cup was formed at around 900 ℃. Fig.6 shows the cross sectional microstructures of drawn specimen. In Fig.6(a), coating layers almost all vanished because of surface flaking below 800 ℃, and smooth coating layer of cross section was observed at above 900 ℃. This result is similar to the surface behavior of coating layer.

Aluminum coating layer appeared in surface flaking in a temperature range of 700−800 ℃, but smooth surface was formed above 900 ℃.

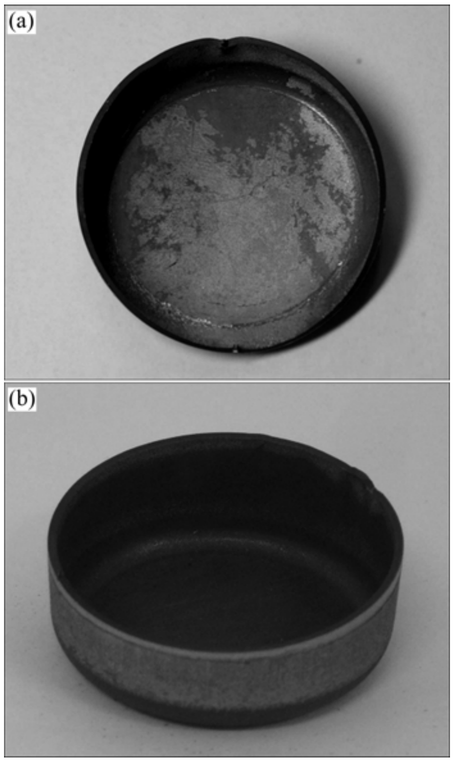

Fig.5 Specimens after deep drawing: (a) 800 ℃; (b) 900 ℃

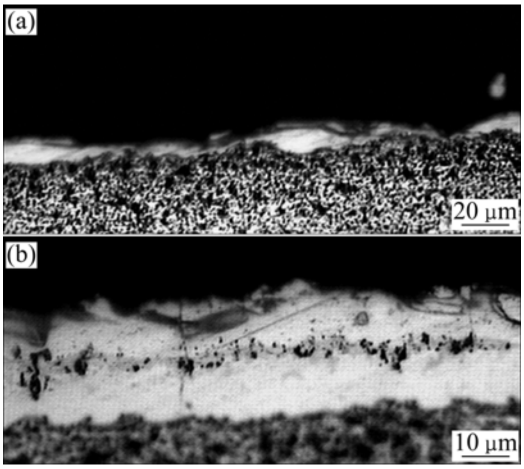

Fig.6 Microstructures after deep drawing: (a) 800 ℃; (b) 900 ℃

4 Conclusions

1) Increasing temperature leads to a significant reduction of the flow stress and a decrease of work hardening exponent, resulting in a noticeable decrease of the slope of the true stress—true strain curves.

2) Increasing test strain rate leads to an appreciable increase of the stress level and the slope of the curve as a consequence of an enforced work hardening of the material.

3) Aluminum coating layer appears in surface flaking in a temperature range of 700−800 ℃, but smooth surface is formed above 900 ℃.

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