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Numerical and experimental investigations on mechanical trimming process for hot stamped ultra-high strength parts

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ABSTRACT

In this paper, the mechanical trimming process for hot stamped ultra-high strength parts was studied, in which the properties of fracture profile were analyzed and the effects of process parameters were evaluated. The research was carried out by FEM simulation with comparison and chosen of damage models, where the critical damage values were obtained through an iterative "predictor-corrector approach". In addition, an experimental trimming tool was designed to study the effects of variable process parameters and verify the simulation results. By comparison, it was found that the Oyane damage model agreed with the experimental results better than others. The simulation and experimental results showed that the quality of trimmed hot stamped surface was poor with not straight profile and small burnish zone, but it can be improved by choosing proper trimming angle and blade radius. Such phenomena were discussed and explained in terms of stress state. Tensile stress accelerates the damage value while compress stress inhibits it. This paper helps to better understand the mechanical properties of hot stamped ultra-high strength steel.

1. Introduction

Light weight and high safety are both important in automobile industry, and using hot stamping process to produce high strength steel parts has been regarded as one of the main solutions for such requirements. As Karbasian and Tekkaya (2010) demonstrated, hot stamping was a combination technology of stamping process and heat treatment. The boron steel blank is heated up to about 900 °C and kept in the furnace for three to five minutes to ensure homogenous austenitization, then the blank is quickly transferred to the press to conduct the forming and quenching processes simultaneously, which was also stated by Hu et al. (2013). The strength of boron steel after hot stamping process reaches 1500 MPa or even more.

The extreme high strength and low elongation of hot stamped parts bring tough challenges for post-stamping processes, such as trimming, blanking, and punching. For trimming process, three main methods have been presented, including laser cutting, warm cutting and hard cutting. As Liu et al. (2014) mentioned, most hot stamped parts were trimmed by laser because of its high performance on cutting thick and hard materials. And there was no problem of tool wear or cutting edge failure in laser cutting, according to the investigation written by Rossini et al. (2015). However, Horling et al. (2005) found that the cycling time of laser cutting process was much longer than mechanical trimming process. So et al. (2012) investigated that warm cutting had been presented as an energy saving method for hot stamped parts in recent years, and Choi et al. (2014) described the application of warm cutting in details. The trimming process happens during the quenching stage at elevated temperature, which shortens the process chain and reduces the cutting force evidently, but it makes high demands to the forming tool. Moreover, the size of blank should be precisely calculated before forming process by considering the effects of phase transformation and temperature change, which is quite difficult for complex products. In order to avoid this problem, Mori et al. (2012) developed a punching process after hot stamping by using local resistance heating method, in which the shearing zone was heated by passing electric current between the sheet holder and the knockout. Horling et al. (2005) demonstrated that hard cut-

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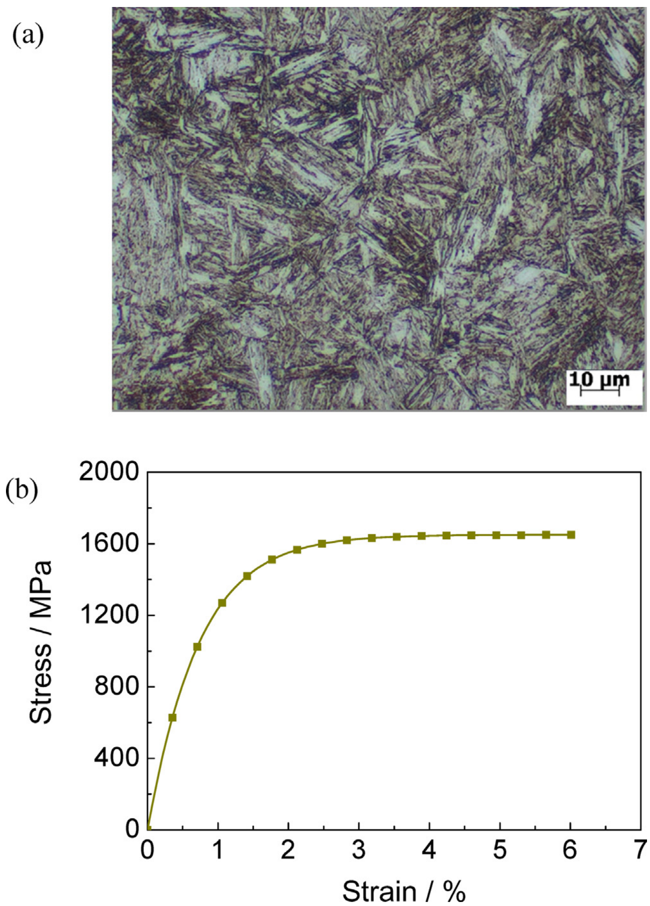

Fig. 1. Material properties of B1500HS after hot stamping process (a) microstructure and (b) stress-strain curve.

ting had better efficiency and precision comparing to the other two methods. The main problem of hard cutting when it was used for hot stamped parts was possible to cause tool wear and sometimes early tool failure as mentioned by Ghiotti et al. (2011). However, lots of researchers such as Picas et al. (2008) believed that such issue can be diminished with the development on die steels with high hardness and good wear resistance, and the hard cutting technology would be applied in high strength steel products increasingly in the following years.

Finite element method has been widely applied in the field of metal forming. When it is used for mechanical trimming process, Brokken et al. (1998), Hambli and Potiron (2000) indicated that the great challenge was to simulate the severe plastic deformation and to describe the material fracture. The simulation results highly rely on damage models and the corresponding critical values of fracture criteria. Hambli and Reszka (2002) presented a computation methodology allowing for the identification of critical values of fracture criteria, which was based on inverse technique using circular blanking experiments and finite element calibration model. The critical values of ten different fracture criteria were approached and compared through this methodology by using 1060 steel sheet. Wang et al. (2014) selected four phenomenological models including Brozzo, McClintock, Rice-Tracey, and Oyane models to simulate the advanced high-strength sheet blanking process, in which the threshold value for each model was calculated based on the experimental data for forming limit curves and fracture forming limit curves. Eom et al. (2014) carried out finite element simulations to predict tensile tests of cylindrical specimens, in which the damage models of McClintock, Rice-Tracey, Cockroft-Latham, Freudenthal, Brozzo et al. and Oyane et al. (1980) were evaluated by comparing their predictions from the tensile test respectively. Ghosh et al. (2005) simulated the shearing process of aluminum sheet by using GTN, Cockroft-Latham and Shear failure models, and the former two agreed with experimental data better than the later one.

It is noticed that the published works about trimming process mainly focused on those medium and low strength steels or other materials such as aluminum, but seldom on ultra-high strength steels. In this paper, the mechanical trimming process of hot stamped parts is studied through both experimental and numerical methods. An experimental tool with variable trimming clearance, trimming angle and blade sharpness is designed and used to discuss the effects of process parameters on fracture profiles. The commercial FEM codes Abaqus is applied to simulate the trimming process, in which six damage models are chosen to compare and the Oyane model is finally selected.

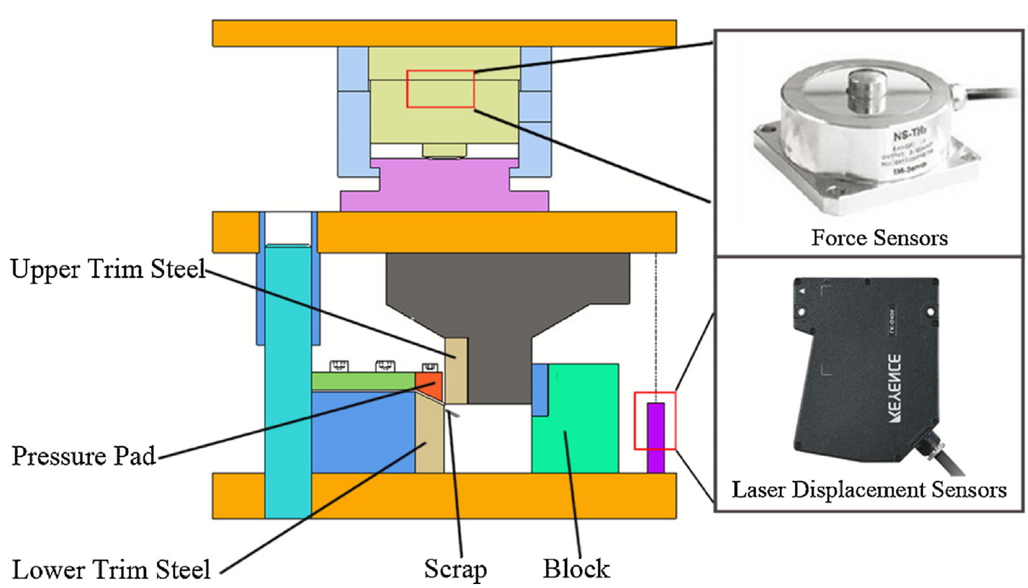

Fig. 2. Schematics of trimming tool for hot stamped part.