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Manufacturing of tailor-rolled blanks with thickness variations in both the longitudinal and latitudinal directions

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ABSTRACT

A tailor-rolled blank is a semi-finished part that can be used to produce stamping parts with continuous thickness variations. This study investigates a cold manufacturing process to fabricate a TRB with variable thickness variations in both the longitudinal and latitudinal directions. The effect of the rolling process on the characteristics of the transition zone and the deformation behaviors of the blanks were investigated using various processing conditions. The dimensional variations at the transition zones were analyzed based on the cross-sectional thickness profiles of the formed blanks. The results show that manufacturing such a TRB requires an extra process to reduce dimensional instabilities caused by superimposed transition zones in both directions. To manufacture sound blanks with acceptable dimensions, this study proposes a trial method that uses blanks with circular and square holes instead of solid blank.

1. Introduction

Tailored blanks are semi-finished products that are typically made from blanks with local variation of the thickness and material properties. The tailored blanks have advantages of saving weight, reducing the number of stamped parts, and minimizing materials loss. Tailor-welded blanks (TWBs) and tailor-rolled blanks (TRBs) are examples that are widely applied in the vehicle industry. TWBs comprise blanks of different thicknesses or material properties that are joined through a welding process. TWBs have been widely applied to stamped vehicle parts. Zhu et al. (2008) applied TWBs to inner door panel, aiming at reducing the weight and enhancing the crashworthiness performances in side-impact collisions. Lee et al. (2017) fabricated vehicle center-pillar reinforcements from steel TWBs, and Shi et al. (2007) applied TWBs to front side rails to reduce the weight of vehicle body. Merklein et al. (2012) investigated orbital forming of sheet metal to fabricate tailored blanks with locally controlled sheet thinning and thickening. Schulte et al. (2017) studied the design, manufacturing and further processing of tailored blanks in a sheet-bulk metal forming process using a combination of deep drawing and upsetting with numerical models and the results were verified by experimental tests. However, the formability of TWBs is decreased by the stress concentration generated in the welding zone as the thickness ratio increases. Abbasi et al. (2012) studied the effect of weld line movement on the formability and stress-strain distributions. The results showed that formability can be maximized when the major stress and rolling direction were along the weld line. They also concluded that the effect of geometric discontinuities on reducing formability was greater than the effect of the weld region. Merklein et al. (2014) reported that the weld line moves when a stress concentration occurs in a TWB, which can result in damage to the mold and breakage of the welded portion.

To overcome these problems, TRBs were developed using flexible rolling. As reviewed by Grüber et al. (2015), the basic idea of flexible rolling was first introduced by Mannesmann in 1891. Thereafter, a continuous rolling process for the manufacturing of semi-finished products with a defined thickness distribution has been developed by Institute of Metal Forming (IBF). A TRB can have continuous thickness alterations in a single blank in the longitudinal direction, which is achieved by controlling the roll gap during the rolling process. Compared with a TWB, a TRB can show enhanced formability due to the reduced stress concentration. Numerous studies have been performed to utilize TRBs to fabricate structural parts.

Liu (2011) implemented variable gauge rolling (VGR) to produce flat products with different thicknesses, which could be used to replace conventional flat products in order to save metals and reduce structure mass. Kopp et al. (2005) presented two production processes of flexibly rolled blanks, one with longitudinal and the other one with latitudinal thickness transitions. Hildenbrand et al. (2016) presented a new concept to manufacture tailored blanks that enables the rolling of the material using a defined die cavity on the tool surface and thus allows

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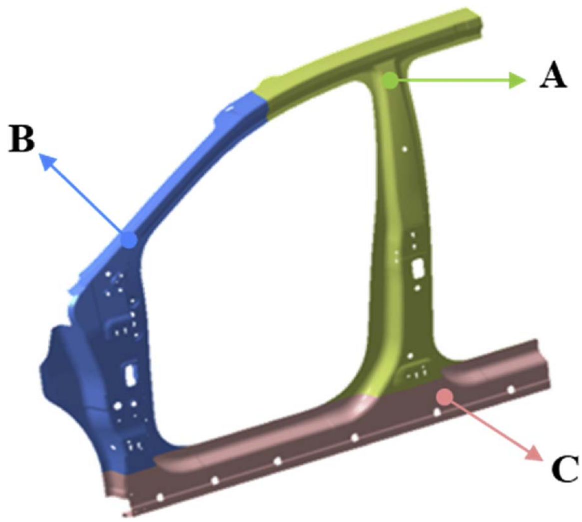

Fig. 1. Auto-body door ring parts.

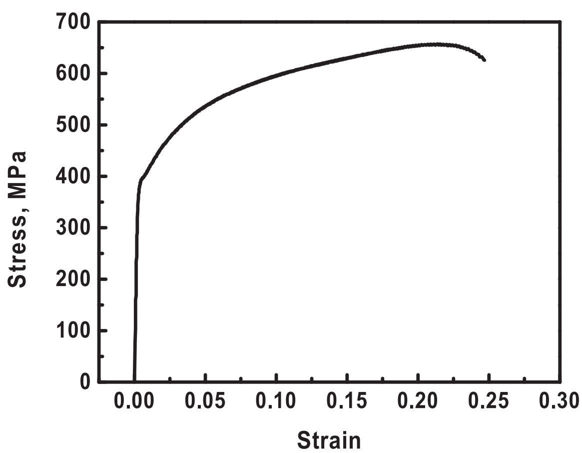

Fig. 2. Tensile stress-strain curve of SABC 1470.

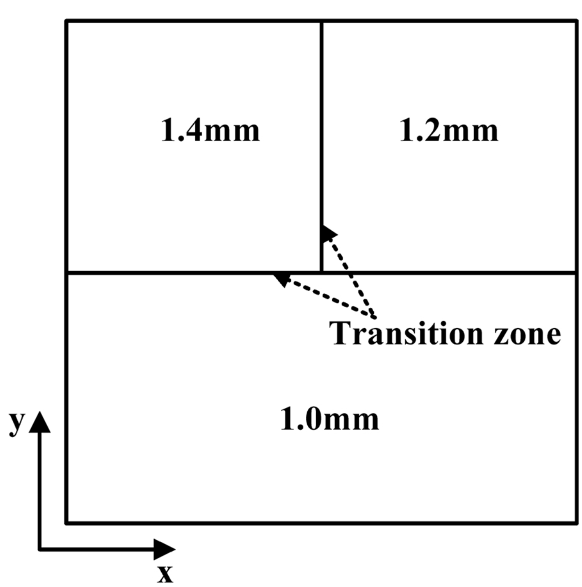

Fig. 3. Schematic of a TRB with variable thickness.

sheet thickening on the opposite side of the blank side during rolling. Hirt et al. (2005) emphasized that TRBs can enable higher drawing depths than TWBs and thus enhance the range of possible applications. Duan et al. (2016) applied TRBs to front longitudinal beam (FLB), which is deformable part under vehicle frontal impact and its deformation pattern can greatly influence the vehicle safety. The lightweight design method has been proposed to minimize the weight of FLB-inner. Hirt and Dávalos-Julca (2012) showed the feasibility of creating tailored strips by strip profile rolling using adapted roll geometries in roll forming. Zadpoor et al. (2008) studied the effect of the direction of the transition line on the mechanical behavior of a TRB. Urban et al. (2006) showed that the high pressure sheet metal forming (HPSMF) of TRBs can help to decrease the weight of cars and achieve a higher product quality while decreasing the cost of the production. Kleiner et al. (2004) simulated and optimized the high pressure sheet metal forming process by linking the finite element models with optimized tooling. Krux et al. (2005) also investigated high-pressure sheet-metal forming in combination with the use of a TRB fabricated by a flexible rolling process. Meyer et al. (2008) used TRBs to increase the maximum depth of deep drawing in comparison to blanks with a constant thickness.

Fig. 1 shows an auto-body door ring, which requires thickness changes in both the longitudinal and latitudinal directions. The desirable part thicknesses are B, A, and C in decreasing order. In the previous research, the thickness characteristics in the only the longitudinal direction were the main focus, but simultaneous thickness variations in the latitudinal direction have not been reported. Therefore, a TRB with variable thickness variations in not only the longitudinal direction but also the latitudinal direction was investigated in this study. The effect of the rolling process on the characteristics of the transition zone and the deformation behaviors of blanks were investigated using various processing conditions. The dimensional variations in the transition zones were analyzed based on the cross-sectional thickness profiles of formed blanks. To manufacture sound blanks with acceptable dimensions, this study proposes a trial method that uses blanks with circular and square holes instead of solid blank.

2. Experimental methods

2.1. Rolling experiments

Cold rolling experiments were performed to manufacture the TRB using a 600-ton 2 high rolling mill. The roll gap control was performed by hydraulic auto position controller (APC). The diameter and width of the work roll were 155 mm and 500 mm, respectively, and the maximum rolling speed was 100 m/min. The material used for the rolling experiment was SABC 1470, and the stress-strain curve is shown in Fig. 2. The length and width of the blank were both 320 mm, and the thickness was 1.4 mm.

Fig. 3 shows the dimensions of the TRB to be fabricated in the rolling experiments. The thicknesses of the zones are 1.4 mm, 1.2 mm, and 1.0 mm, respectively. Controlled rolling was performed to fabricate the TRB with different thicknesses in different directions. Fig. 4 shows a schematic of the method used. Fig. 4(a) shows the method of stopping the rolls when the blank reaches the target point during the rolling process. This process is defined as the “constant roll gap process.” Fig. 4(b) shows the method of raising the upper roll when the blank reaches the target point. This process is defined as the “variable roll gap process.” In both processes, a blank with a thickness of 1.4 mm was first rolled to 1.2 mm, and then secondary rolling was performed to a thickness of 1.0 mm after rotation by 90 degrees.