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# Role of counterpunch for square-cup drawing of tailored blank composed of thick/thin sheets

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ABSTRACT

The deep drawability of tailored blanks (TBs) composed of thick and thin sheets is considerably lower than that of their component sheets, since the plane-strain stretching mode is more likely to occur in such TBs as a result of the movement of the weld line at the bottom of the cup during forming. To improve the deep drawability of TBs, a new forming technology using a counterpunch is proposed, where the movement of the weld line during forming is strongly constrained by the counterpunch pressure. From the results of square-cup drawing experiments on several types of TB of mild steel/high-strength steel sheets, it was found that the limiting cup height increases markedly with increasing counterpunch pressure. One good feature of this forming technology is that the action of counterpunch pressure is necessary only on the thicker (or stronger) sheet part, not on the entire cup bottom.



## 1. Introduction

Tailored blanks (TBs), which are composed of more than two sheets with different thicknesses or strengths weld-joined together, are commonly used in manufacturing automotive structures and inner panels. To reduce the weight of automotive bodies and improve crashworthiness, we can design an optimum TB which has thicker or stronger sheets at critical parts of a panel so as to increase stiffness and strength locally. The deformation characteristics and forming limits of TBs made by various welding processes, such as laser welding and mash seam welding, have been investigated in the past by many researchers.

Azuma et al. (1990) investigated the press formability of laser welded blanks in several types of forming test, namely stretching, flanging and deep drawing. The formability of TBs was evaluated with reference to the material strength ratio, thickness ratio and the forming pattern. Chan et al. (2003) studied LDH (Limiting Dome Height) and FLD (Forming Limit Diagram) of TBs with different thickness combinations from 0.5 mm to 1.0 mm thick. The effect of thickness ratio on forming limit was presented by Swift round-bottom cup tests. The forming limit especially in the plane-strain stretching mode was decreased with increasing thickness ratio. Panda et al. (2007) reported tensile properties and formability in stretch forming of tailor welded IF steel sheets. They measured the tensile properties of the welded specimens in both longitudinal and transverse directions, and then showed major and minor strain distributions in the stretch-formed TB samples with different thickness or different surface conditions. Saunders and Wagoner (1996) discussed formability and weld line movement of TBs under several combinations of thickness, strength and welding process. The weld line movement during forming process is an important indicator of overall deformation pattern of TBs. It is determined by the mechanical properties of individual component sheets of TBs and the restraining forces, with little influence of local weld properties.

The weld line movement and its influence on formability have been major concern in TBs forming problems, especially deep drawing. For example, weld line movement and material flow of TBs in square-cup drawing (Hayashi et al., 1998) and round-cup drawing (Meinders et al., 2000) are reported. They pointed out that the limiting cup height of TBs is significantly affected by the initial arrangement of weld line and strain localization occurs in thinner (or weaker) sheet part. Choi et al. (2000) investigated weld line movement and thickness distribution of TBs in square-cup drawing experimentally and analytically using square and circular blanks with different initial weld line arrangement. From analytical results of the weld line movement and the thickness strain in central and diagonal directions of formed square cups, it was confirmed that they become larger with increasing the distance between

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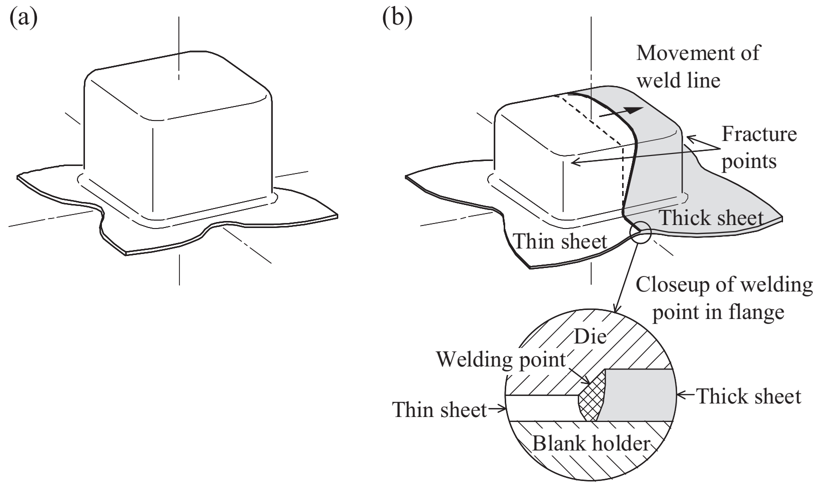


**Fig. 1.** Material flow in square-cup drawing: (a) mono-sheet and (b) tailored blank composed of thick and thin sheets.

center line and the initial weld line. As for the similar analytical studies by using FE simulation, Zimniak and Piela (2000) carried out thermomechanical analysis including the welding process and the stamping process in square-cup drawing, Padmanabhan et al. (2007) investigated the effect of anisotropy and orientation of rolling direction in blank sheets of mild steel/dual phase steel TBs, and later Padmanabhan et al. (2008) determined the formability of aluminum/steel TBs as weaker and stronger materials.

From these works, a critical problem of TB forming was found that the formability of TB is generally much lower than that of their component sheets. To explain the reason for that, the material flows of a mono-sheet and a TB in square-cup drawing are schematically shown in Fig. 1(a) and (b), respectively. In this process a mono-sheet deforms keeping its geometrical symmetry (see Fig. 1(a)). In contrast, in TB cup drawing, the weld line moves to a thicker sheet side (see Fig. 1(b)) because the weld line lying on the die face is fixed by the stepped die, but the bottom part of the cup can move freely on the punch surface. The thick sheet pulls the thin sheet strongly during forming. The movement of weld line makes the formability of TBs considerably less, since in such a case, the strain path of a material element located at the vicinity of a punch corner changes from the equi-biaxial stretching mode to the plane-strain stretching mode, where the fracture of the sheet is more likely to occur as previously reported by the present authors (Morishita et al., 2009). Thus a crucial issue in TB forming is how to suppress the movement of weld line. For that, the present authors (Morishita et al., 2009) proposed in the previous work to use a nonsymmetric rectangular blank composed of a small thick sheet and a large thin sheet. Ahmetoglu et al. (1995) improved deep drawability of TB round cups by using segmented blank holder and applying different blank holding forces. In their work, low and high blank holding forces were applied to the thick and thin sheets respectively, thus allowing more material to flow into the die cavity compared to the case where a uniform blank holding force was applied to the both sheets. He et al. (2003) also used the same methodology, and investigated formability of TBs in strip drawing and box drawing with/without blank holding force control. Furthermore, Kinsey et al. (2004) studied the methodology to determine the ratio of blank holding forces by using the segmented blank holder in order to suppress wrinkle in TB s forming.

All the above works suggest that one solution to improve the formability is to control the weld line movement. Based on this approach, Heo et al. (2001a,b) tried to control weld line movement and thickness distribution by using drawbead in square-cup drawing. The drawing tests were carried out with various dimensions of single circular drawbead installed in blank holder. The experimental results showed that the smaller the radius of the drawbead, the larger weld line movement, and the larger the height of the drawbead, the larger thickness strain. Cao and Kinsey (1999) proposed to apply clamping forces at selected locations along the weld lines on the punch surface by using hydraulic driven pins. Kinsey et al. (1999, 2000) presented FE simulation results for both a conventional stamping process and the novel forming process in TBs forming. The analysis showed excellent promise for the clamping method to reduce the weld line movement and the strain in thinner (weaker) sheet part. Also, Kinsey et al. (2001) conducted verification experiments for the formability enhancement on a nonsymmetric test panel of aluminum TBs using the clamping method. Recently, Chen et al. (2008) compared the effectiveness of stepped binder and clamping pin methods by FE simulation and experiment. They investigated the influences of combinations of flat/stepped binder and clamping pins on the formability of TBs such as weld line movement, thickness reduction and critical strain in box drawing. It was found that a combined use of stepped binder and clamping pins provides the best TB forming quality.

In the presented paper, an alternative technology to suppress the movement of weld line is proposed, where the bottom of the cup is clamped with a counterpunch. Although there are some papers reporting the use of a counterpunch for the purpose of controlling sheet thickness change during deep drawing (Muranaka et al., 2004; Iizuka et al., 2006), no attempt have been made to improve the formability of TBs by its use. The target of this study is to obtain the same level of cup height in TB cup drawing as a mono-sheet. At the beginning of this work, the deformation behavior of several types of TBs with different strength ratios is examined by performing conventional square-cup drawing. Then the effectiveness of the use of a counterpunch is verified by performing several TB deep drawing experiments. Moreover, an appropriate design of counterpunches and optimum loading processes are discussed in order to use this method for real industrial applications.

## 2. Experimental procedures

### 2.1. Base materials

Materials used in TBs were surface-treated mild steel sheets of 0.6 mm and 1.2 mm thick, and a high-strength steel sheet of