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STUDY ON SPRINGBACK IN DEEP DRAWN TAILOR WELDED BLANKS

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ABSTRACT: Tailor-welded blanks have strength and thickness mismatch leading to non-uniform deformation imposing complex stress states in the formed part. In this study, numerical simulations are performed to determine the stress states and their influence on the springback behavior of deep-drawn tailor-welded blanks. The tailor-welded blank models consisting of different steels were simulated and the springback is evaluated using split ring test. The results provide an insight on the material combination and weld region location on the springback of TWB's. The tailor-welded blanks subjected to same forming conditions may result in different springback behavior, depending on the material combination and the blanks orientation. The springback also depends on the section geometry and location of the splitting region in the formed part. Increasing section modulus significantly reduces the springback behavior in a blank.

KEYWORDS: Tailor-welded blanks, Springback, FEM, Split ring test.

1. INTRODUCTION

Tailor-welded blanks (TWB) have found immense applications in automobile, aerospace and other allied industries in producing part consisting of different materials. The advantages of using TWB's are: part-count reduction, improved stiffness/weight ratio, and overall reduction in the manufacturing costs [1-3]. The combined effects of welding and forming create complex internal states of stress among component blanks and thus leading to more complex springback behavior. Previous works by the authors suggest that the strength difference and blank anisotropy has significant influence on the flow characteristics of the TWB [4]. Most of the deformation is concentrated on the weaker blank and hence the weld line moves towards the stronger blank. Different techniques have been proposed to restrict weld line movement [5, 6]. Although most welding techniques produce huge influence on the whole [7], the weld line has negligible influence [8]. This is true, especially for springback prediction in laser welded blanks, for which the weld line width can be considered small [9]. Springback prediction is more sensitive to numerical parameters, tolerances and procedures [10]. Previous works by the authors suggest that FE ratio of 1 can predict springback closely [11]. In this study, numerical simulations were performed to determine the springback in deep-drawn tailor-welded blanks. The tailor-welded blank model consists of DC06 and DP600 blanks. The chosen materials exhibit different mechanical properties: DC06 is mild steel with strong orthotropic behavior while DP600 is a high strength steel with a plastic behavior close to planar isotropy. Circular TWB's with various rolling directions combinations were modeled and subjected to deep drawing process. The finite

element simulations of the deep drawing process were carried out using DD3IMP [12]. The springback phenomenon is evaluated using split ring test [13]. In this test, a ring cut from the axi-symmetric drawn cup and then split along different planes. Cutting the ring from the cup and splitting the ring at different planes are performed using DD3TRIM [14]. The numerical models and the split ring test procedure are described in section 2. Discussion on the springback results is presented in section 3 followed by the conclusion from this study in section 4.

2. DEEP DRAWING SIMULATIONS

2.1 MATERIAL

Deep drawing simulations were performed using DD3IMP, an in-house finite element code developed for sheet metal forming process simulations [12]. Two steels, DC06 and DP600, with quite different flow characteristics are considered in this study. The aim is to study the different stress states at different locations in the formed part and hence the springback behavior. The mechanical behavior is described with isotropic work hardening using Swift law,

$$Y = C(\epsilon_0 + \bar{\epsilon}^p)^n. \quad (1)$$

C , ϵ_0 and n , are the material parameters. Y is the flow stress, $\bar{\epsilon}^p$ is the equivalent plastic strain. The constitutive parameters used in the numerical simulations for both steels are presented in Table 1. The elastic behavior is assumed to be isotropic and constant (Young's Modulus (E) = 210 GPa and Poisson's ratio (ν) = 0.3). A constant friction coefficient of 0.08 was

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used between the forming tools and the component blanks. DC06 exhibits a weak planar anisotropy of the flow stress ($r_0 = 2.53$, $r_{45} = 1.84$ and $r_{90} = 2.72$) while DP600 is nearly isotropic regarding the flow stress ($r_0 = 1.01$, $r_{45} = 0.76$ and $r_{90} = 0.98$).

Table 1: Constitutive parameters for the materials

	Y_0 (MPa)	C (MPa)	n
DC06	123.6	529.5	0.268
DP600	330.3	1093	0.187

A semi-circular blank of 170 mm diameter and 1 mm thick, as shown in Figure 1, having both materials was considered. Due to geometrical symmetry only half of the blank was considered in the numerical model, as shown in Figure 1.

The springback prediction depends on the mesh density as precise springback prediction is possible by using FE ratio close to 1 [11], for solid elements with selective reduced integration. The FE ratio is defined as the ratio of the finite element length or width over finite element thickness. Using similar fine elements all through the blank will increase their number prohibitively and hence only the ring area was meshed with finer mesh as shown in the figure. Two layers of elements were considered through thickness.

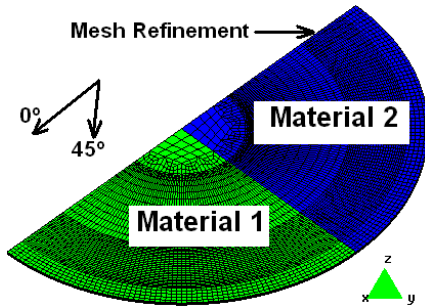


Figure 1: Tailor-welded blank

In order to restrict large differential material flow, due to strength mismatch in the component blanks, two different blank holder forces are used in the process [15]. The blank holder was modeled as a segmented tool and a higher value of constant force of 144 kN was applied for DC06 and a constant force of 72 kN was applied for DP600 steel. This restricts material flow in the weaker blank and hence reduces thinning.

2.2 SPLIT RING TEST

The springback behavior of the TWB's was determined by using split ring test proposed by DEMERI [13, 16]. It consists of three steps as followed:

1. Deep draw a cylindrical cup to a depth of 60 mm from a circular TWB.
2. Cut a ring at the middle section of the deep drawn cup by removing the top and the bottom portions, Figure 2.
3. Split the ring at a required plane to determine the gap, Figure 3.

Figure 2 shows the cup deep drawn to a depth of 60 mm with the ring cut around the middle of the cup. A ring of 20 mm width is cut and the gap that develops was used to compute the springback. In order to investigate the role of stress states and the section geometry, two other rings of 10 mm width were also cut at the same location, sharing the width of 20 mm wide ring.

The cutting and splitting of the ring is carried using DD3TRIM, an in-house finite element code developed for trimming 3D finite solid elements. The ring was split vertically, along z-axis, as shown in Figure 3. After splitting, the ring expands leaving a gap between the split edges as shown in the figure. The springback was computed from the gap that develops in the split ring.

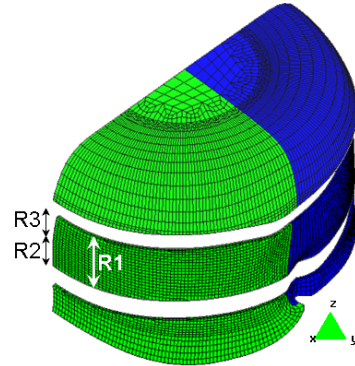


Figure 2: Deep drawn cup and the ring

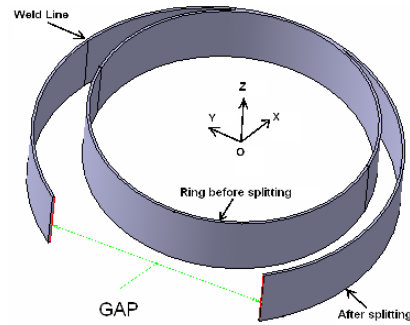


Figure 3: The split ring

3. SPRINGBACK RESULTS AND DISCUSSION

3.1 THICKNESS DISTRIBUTION

Presence of blanks of different strengths alters the deformation behavior of individual blank in a tailor welded blank. Deformation occurs in the component blanks depending on the loading direction and the weld line location. Most deformation occurs at the weaker blank leading to possible failure in this area. Applying different blank holder forces, depending on the material strength, greatly reduces the localized deformation. Figure 4 shows the thickness variation along the OX axis in the deep drawn tailor welded blank. The results from two TWB combinations are shown in the figure. "RD"

indicates the result from TWB in which the rolling direction of component blanks are oriented along OX axis, while “45°” indicate the rolling direction of the blanks are oriented 45 degrees to the OX axis.

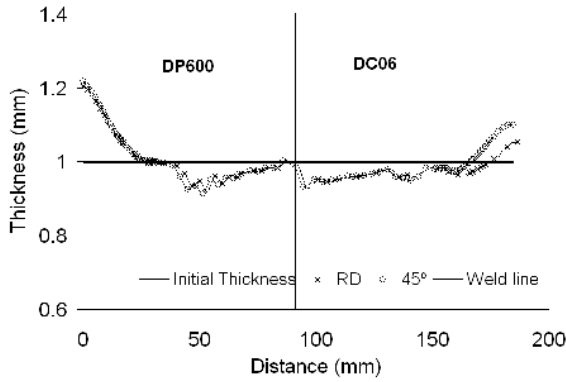


Figure 4: Thickness distribution in the cup

In the case of DP600, the thickness distribution remains similar in both combinations as the material has r-value close to unity. Marginal thickness difference is observed between the two cases at the punch radius. DC06 has high r-value and hence the flow characteristics along rolling direction and 45° to rolling direction are different. Hence large difference in the thickness between the two cases can be observed at the cup wall and the flange. The thickness difference at the punch radius in DP600 is a consequence of the difference in the material flow of DC06. Hence, the flow characteristic of the TWB is governed by the flow characteristics and interaction between the component blanks. An eccentric drawing is imminent in such cases which lead to preferential material flow and consequently weld line displacement. Weld line displacement in a formed part is a good indicator of the deformation pattern in the tailor welded blank. In such combinations of component blanks the deformation pattern is altered to a larger extent thus creating complex stress state within the formed part. As a consequence, the springback in such part becomes highly unpredictable.

3.2 SPRINGBACK GAP

A 20 mm wide ring was cut at the mid section of the cup. Two other rings are cut from the originally drawn cup to study the effect of section geometry on springback. These two rings are 10 mm wide, as shown in Figure 2. The springback was computed from the gap that develops between the split edges of the ring. Table 2 presents the computed values of springback gap.

Table 2: Springback in the rings

	0° Orientation	45° Orientation
	Gap(mm)	Gap(mm)
R1 (W = 20 mm)	9.46	8.12
R2 (W = 10 mm)	24.57	22.34
R3 (W = 10 mm)	15.18	12.22

The springback gap observed in 20 mm wide ring (R1) is the lowest, in both blank orientations, while the lower 10 mm ring (R2) has higher springback. Moderate springback gap was observed in the upper 10 mm ring (R3). The difference is mostly due to the section geometry and partially due to the stress distribution. The bottom half of the 20 mm wide ring is flat while the top half is partially curved. This occurs due to the large gap between the punch and the die, which leads to a circular cup with a slightly curved wall. This geometric inconsistency increases the section modulus and largely reduces the springback. Due to straight section in the lower ring (R2) largest springback is obtained while with only the partial curvature, the top 10 mm of the ring (R3) results in a moderate springback. Reasonable difference in the springback between 0° orientation and 45° orientation is evident from the table. The anisotropic nature of mild steel (DC06) is the cause for the springback difference between the two blank orientations as large stress variation is observed in DC06 section of the TWB.

3.3 STRESS STATE OF THE RINGS

The stress state in the deep drawn part determines its springback behavior. As a result of the flow of material into the die cavity, the blank thickness varies. Consequently, the cup accumulates different magnitudes of strains at different locations due to bending and unbending process. These accumulated strain distributions which can be characterized by the radial and tangential stresses have direct impact on the springback behavior of the cup. The tangential stress has pronounced contribution towards springback, while the radial stress has a marginal influence.

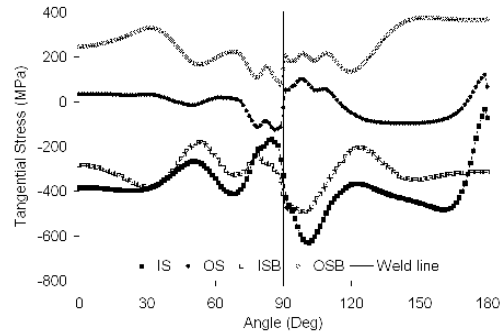


Figure 5: Tangential stress around the 20mm ring (R1) mid-plane (35 mm cup depth)

Figure 5 shows the tangential stress variation in the mid-plane of the 20 mm ring at the inner surface (IS) and outer surface (OS). The results presented in this section pertain to blank rolling direction oriented along OX. The stresses before and after splitting are presented in the figure, indicated by a succeeding “B” in the legend. The inner surface of the ring is in compression while the outer surface is in tension before splitting the ring. After splitting, the outer surface tends to become neutral while the inner surface still has compressive stresses. This is

attributed to the section geometry of the 20 mm ring. By virtue of the tool geometry, the ring has a small curvature at the top portion which limits the complete release of residual stresses. Therefore, the compressive stresses in the inner surface increase a little in the ring after splitting, as shown in the figure.

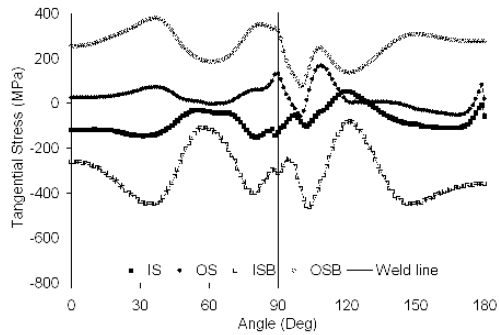


Figure 6: Tangential stress around the 10mm ring (R2) mid-plane (29 mm cup depth)

Figure 6 shows the tangential stress distribution at the mid-plane in the 10 mm ring (R2), before and after splitting. The compressive stress and the tensile stress are observed at the inner and outer surface, respectively. The stresses are relieved to a great extent in this case (R2) compared to 20 mm ring (R1), as evident from the figure. Hence the springback gap computed in this part of the cup is much higher than that estimated for the 20 mm ring (R1). Though the stresses at the outer surface greatly reduce, most part of the stresses at the inner surface stay in the ring, as shown in the figure. Within the cup, the state of stress differs due to the material strength mismatch and consequently the differential flow characteristics. Therefore, the springback behavior also differs at different section in the deep drawn cup.

4. CONCLUSIONS

The results provide an insight on the material combination and weld location on the springback of TWB's. Though the TWB's are subjected to the same forming conditions, different states of equilibrium in the formed component exist depending on the combination of component blanks. This was characterized by cutting and splitting the rings at different sections of the cup. The outer surface of the ring has tensile stresses while the inner surface has compressive stresses. Upon splitting, these stresses are relieved causing a gap in the split edge of the ring. Difference in the springback is observed based on the component blank orientation. Different springback values resulted as a direct consequence of the flow behavior of the differently oriented component blanks and depending on the position of the weld region. Tangential stresses and the section geometry play a dominant role in the springback behavior of a deep drawn TWB cup.

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