Prediction of Springback in Long Channels

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Abstract Sheet metal forming is one of the most preferred manufacturing processes in automotive and aerospace industries. However, due to increase in fuel prices and more stringent environmental regulation, these industries are facing many challenges to meet the criteria. Due to this, many efforts in design and manufacturing were considered and presented. Those efforts were implementing lighter-weight materials like aluminum and magnesium (but they have higher elasticity as compared to steel) and implementing higher-strength steel with lower thickness. The main challenge found in both cases is springback after deformation. Springback is the elastic recovery after the part is unloaded. In this paper, the 3D channels with large length were deformed numerically and springback at different section was predicted. For this purpose, tailor-welded blank was considered. The geometric change along the long axis was also discussed. In addition, the effect of flange springback on wall springback was also analyzed. It was found that different section produced different springback and greater influence of flange springback. To validate the numerical simulation approach, the experiments on one case were performed and compared.

KEY WORDS: Channel forming; Springback; Numerical simulation; Tailor-welded blanks

1 Introduction

The substantial increase in demand of sheet metal parts which were not only in big industries (e.g., aerospace and automotive industries) but also in many small industries was observed due to the inexpensiveness and the quality it brings into play. A sheet metal part provides many capabilities as well as flexibility; however, it also brings in the weight issues for fuel economy. For this purpose, many industries, laboratories and researchers are working on to reduce the weight of the component, not only to increase

the fuel efficiency in the automotive but in general to handle the parts with ease and safety.

While reviewing the light-weight options, studies are mostly focused on alternative material, for example aluminum, magnesium, titanium over steel. However, these materials bring more challenges like planar anisotropy, springback, early fracture, edge cracking. One of the process innovations which could reduce to eliminate some of the challenges is tailor-welded blank (TWB). In TWB, two sheets of similar or dissimilar metals and/or thicknesses are joined side by side and further formed to a part. The advantages it brings are increasing stiffness to weight ratio, part count reduction and inexpensive manufacturing cost [1–3]. Many studies have been performed on TWB. During deformation it was found that mostly deformation happens in the weaker material which causes early failure [4]. It was also found that due to difference in blank holding force the weaker blank slides toward the stronger blank and shifts the desired weld line position. However, the proper blank

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holding force on the weld line section would reduce the movement and failure [5]. Further, it was observed that the weld line movement will increase with increase in the offset distance between the centerline of the part and the weld line [6]. Along with the aforementioned, one of the greater challenges it brings is the springback of the parts due to dissimilar material strengths and/or thicknesses [7].

Elastic recovery is the change in shape of the parts after the load is been released. This phenomenon is also known as springback in sheet metal stamping. This is the most commonly occurred phenomenon in sheet metal-formed components where one or two dimensions are much larger than the third one [8]. Some studies refer this to the amount of elastic energy stored in the component during the stamping process [9]. This shape error is referred as a manufacturing defect due to trouble in assembly operation [10]. This factor depends on the amount of strain the material goes during deformation. Higher springback occurred at higher strain. These higher strains are mostly due to higher tension which further increases the friction between the tool and sheet metal [11]. It has also been investigated that the springback depends on the material and process parameters. Higher springback is also due to the occurrence of cyclic loading on sheet metal when it deforms over the die radius and then straightens out [12]. The influencing process parameters for the strong springback are in descending order: punch corner radius, die corner radius, blank holding force, supporting force and lubrication [13]. It was mentioned that the ratio of tensile strength to elastic modulus has proportional effect on the amount of springback [14]. Study has also been performed on reducing the springback by passing the electricity [15].

Aspects of springback in TWB are also studied in some literature. On springback of cup wall rings, it was observed that component blank orientation provided differences in the elastic recovery [7]. The springback parameter, i.e., yield stress ratio with respect to modulus of elasticity and thickness was defined and found proportional to the springback angle [16]. This parameter was also found to be useful for predicting the springback for stir friction TWB [17]. Differences in springback due to thickness were also observed. It was noticed that the springback on thicker side decreased because of the combine springback effect on thinner side and weld line [18]. Differences in material properties provide different springback due to similar blank holding force, and thus, the control force would be needed for a symmetric part [19].

This work will carry out the investigation of springback at different section of the tailor-welded blank with similar/dissimilar and/or thicknesses. Two materials with good difference in mechanical properties were considered. The influence of the higher-strength material on the lower-strength material springback was noticed and analyzed.

Further comparisons were made in between baseline and different case as well as in between different cases. In addition to validate the numerical approach, experiment on one case was performed and results were compared.

2 Numerical Methodology and Simulations

The stress–strain curves for two materials used in this work are shown in Fig. 1. Both material curves are generated using power law. The equation for power law is given in Eq. (1). The power law parameters are given in Table 1. The lower yield strength material is considered as soft material, and higher yield strength material is considered as hard material. The hard material yield strength intentionally kept twice the soft material yield strength to observe a direct relation in terms of strength on springback.

$$\sigma = K\varepsilon^n, \quad (1)$$

where σ is true stress, ε is true strain, K is strength coefficient, and n is strain hardening exponent.

Channel forming model for tailor-welded blank which is used to simulate the channel and springback is shown in Fig. 2. As mentioned earlier, that hard material strength is twice the softer one. Similarly, two sheet thicknesses were considered, i.e., 0.6 and 1.2 mm. Sheet length (i.e., perpendicular to the page) used was 50 mm for each material. Thus, four tailor-welded blanks were generated for channel forming and springback analysis using different materials and blank holder forces (F_h): SMSTS—soft blank (1.2 mm, $F_h = 15$ kN) & soft blank (1.2 mm, $F_h = 15$ kN); SMDT—soft blank (1.2 mm, $F_h = 10$ kN) & soft blank (0.6 mm, $F_h = 20$ N); DMST—hard blank (1.2 mm, $F_h = 20$ kN) & soft blank (1.2 mm, $F_h = 10$ kN); DMDT—soft blank (1.2 mm, $F_h = 15$ kN) & hard blank (0.6 mm, $F_h = 15$ kN).

Fig. 1 True stress–strain curve of the soft and hard materials

Table 1 Power law parameters for both material curves

Material	Yield strength (MPa)	Strength coefficient K (MPa)	Strain hardening exponent n
Soft material	251	600	0.2
Hard material	503	1200	0.2

Fig. 2 Channel forming model for channel and springback simulation

To analyze the springback of edges of the each blank material as well as of the weld line, the channel forming tests were investigated using ABAQUS/Explicit 6.13-2 and springback was simulated in ABAQUS/Standard 6.13-2. The three-dimensional model was used to capture all edges springback. Only half model was simulated due to symmetry. The die, punch and blank holder were assumed as rigid surfaces, while the blank was considered as deformable body. The blank was meshed with S4R shell elements. Five integration points through thickness were used to accurately capture the bending effect. Maximum element size used was 2 mm. The interaction between blank and the toolings was assumed as surface-to-surface contact with a coefficient of friction of 0.1. The blank holder force applied on sheet metal was sufficient to slide the metal during channel forming. Figure 3 shows the springback measurement in terms of angle at channel wall “ θ_1 ” and at flange “ θ_2 .”

3 Results and Discussion

All four cases were simulated, and results are shown in this section. Figure 4 provides the force displacement curve for all four cases. It is well understood that higher strength in

Fig. 3 Springback measurement at channel wall and at flange **Fig. 4** Channel forming force displacement curve for all four cases

combination with higher sheet thickness exerts higher force on punch. Same can be seen in Fig. 4. The higher force exerted on punch is by DMST; i.e., higher-strength material as well as higher thickness for one section and lower-strength material with higher thickness were considered for this case, which overall brings together a hardest part. The lowest force was exerted by SMDT because it considers the lower-strength material and one of the blank thicknesses is the smallest. DMDT also exerts force very close to the lowest one as this case considers one of the blanks as higher strength but lower thickness.

The desired shape and the springback shape for SMSTS are shown in Fig. 5. All 2D profiles for front edge and back edge and weld line coincide as it is nothing but using same strength material and same thickness. The springback angle at wall and at flange for front edge, weld line and back edge is provided in Table 2.

Figure 6 provides the springback shape for SMDT. The observable difference in springback occurs in between front edge, weld line and back edge. From Table 3, it can be seen that the back edge (0.6 mm thickness) is less springback than front edge (1.2 mm thickness) than weld line at channel wall. This observation agrees with the published result [18]. The thicker side wall springback reduces because of the effect from thin side and weld springback. However, at flange back edge is less springback than weld line than front edge.

The springback shape and springback angles for DMST case are shown in Fig. 7 and Table 4. Noticeable differences in springback can be seen in all three edges. The back edge (lower-strength material) springback is less than the weld line than the front edge (higher-strength material) at both channel wall and flange.

Figure 8 provides the springback shape for DMDT. Again observable differences can be seen in springback between front edge, weld line and back edge. From Table 5, it is noted that the front edge (lower-strength material and 1.2 mm thickness) springback is less than back edge (higher-strength material and 0.6 mm thickness) than weld line at channel wall. But at flange back edge is less springback than weld line than front edge.

Tables 6 and 7 provide the level of springback at front edge, weld line and back edge for each case studied. It is observed that depending on the strength and thickness the springback has differences in different edges of the tailor-welded blank. It is found that springback is low to middle at channel wall for back edge, because either lower

Table 2 Springback angle at wall and flange for front edge, weld line and back edge for the case SMSTS

Springback angle	Front edge	Weld line	Back edge
Wall angle θ_1	4.37	4.85	4.31
Flange angle θ_2	7.15	7.15	7.15

Fig. 6 2D profiles of desired shape and shape after load release of both edges and weld line for SMDT

Table 3 Springback angle at wall and flange for front edge, weld line and back edge for the case SMDT

Springback angle	Front edge	Weld line	Back edge
Wall angle θ_1	3.67	4.74	2.53
Flange angle θ_2	6.04	5.83	4.54

Fig. 5 2D profiles of desired shape and shape after load release of both edges and weld line for SMSTS

Fig. 7 2D profiles of desired shape and shape after load release of both edges and weld line for DMST

Table 4 Springback angle at wall and flange for front edge, weld line and back edge for case DMST

Springback angle	Front edge	Weld line	Back edge
Wall angle θ_1	8.60	8.29	7.05
Flange angle θ_2	12.74	11.96	11.22

Fig. 8 2D profiles of desired shape and shape after load release of both edges and weld line for DMDT**Table 5** Springback angle at wall and flange for front edge, weld line and back edge for case DMDT

Springback angle	Front edge	Weld line	Back edge
Wall angle θ_1	4.24	6.52	4.46
Flange angle θ_2	7.43	7.25	5.55

Table 6 Springback level at channel wall for all case

Case	Springback level at channel wall		
	Front edge	Weld line	Back edge
SMSTS	Same	Same	Same
SMDT	Middle	High	Low
DMST	High	Middle	Low
DMDT	Low	High	Middle

strength or lower thickness was used in combination for this side of the blank. For front edge, the springback is higher if higher strength in combination with higher or same thickness is used. The weld line seems to get affected by the front and back edge springback. This behavior is in

Table 7 Springback level at channel flange for all case

Case	Springback level at channel flange		
	Front edge	Weld line	Back edge
SMSTS	Same	Same	Same
SMDT	High	Middle	Low
DMST	High	Middle	Low
DMDT	High	Middle	Low

Fig. 9 Experimental deformed channels for SMDT case (painted white for scan) **Fig. 10** Force–displacement curve during channel forming for SMDT case

relation with the springback level at flange. The springback at flange for front edge is higher than weld line than for back edge. This may be due to either higher weight or same weight with a blank higher strength with no constrain. Thus, front edge gets high-to-middle springback at channel wall because the front edge got higher springback at flange and similar can be found with back edge.

4 Experimental Validation

To validate the simulation, experiments were performed on similar material with different thickness (SMDT) case. The mild steel with thickness of 1.524 and 0.889 mm was used. The sheet metal specimen of 35 mm width and 203.2 mm length was prepared and then arc-welded together on the length edge. After welding, the welding section was grinded to remove any excess material to bring the weld section

Fig. 11 Superimposed 3D reference and deformed channel for SMDT case

Fig. 12 Superimposed 2D section of reference and deformed channel for SMDT case for wall and flange angle measurement

to the specimen thickness level. Further specimens were annealed for 1 h at 550 °C to make sure that the material will not have any abrupt microstructure from welding process which could have influenced the springback results. Three samples were created for experiments. The similar channel forming setup was machined with some changes in dimension for ease in manufacturing but will not affect the result trend. The changed dimensions are centerline to punch wall is 15.875 mm, centerline to die wall is 19.05 mm, and the radius for both punch and die is 6.35 mm. After annealing, the sample was secured in between the blank holder and die with the help of screws. The screws were fastened enough to provide the sliding during deformation. The punch was allowed to descend with 5 mm/min for 50 mm of depth. After deformation, the sample was safely removed not to interact with the elastic recovery. All three experiments were performed in similar way. The deformed specimens are shown in Fig. 9, and the force displacement curve for one experiment is shown in Fig. 10.

To analyze the geometry change after deformation, the formed specimens (Fig. 9) were painted with matte white aerosol paint for scanning. The ZScanner 700 3D was used to scan the deformed specimen in 3D space. This scanner scans the part on a plane with positioning target points, which allows the scanner to orient the part in 3D space and generates a point cloud of the part in the scanning software. The 3D desired cad model was then imported to the scanning software for reference purpose. The reference and the specimen image were then oriented such that their bases coincide each other. The 3D reference part and the scanned part are shown in Fig. 11. The section planes were then created on the front edge (thicker side), weld line and the back edge (thinner side), and superimposed images were captured as shown in Fig. 12. For each image, the difference in wall angle and flange angle was measured and noted in Table 8.

It was found that the data from experiment no. 2 outliers when comparing the trend with experiment nos. 1 and 3,

Table 8 Springback angle at channel wall and flange for SMDT case

Experiment	Springback angle	Thick front edge	Weld line	Thin back edge
No. 1	Wall angle θ_1	4.60	6.38	4.12
No. 2	Wall angle θ_1	1.13	4.78	4.41
No. 3	Wall angle θ_1	3.75	4.12	3.01
Average		4.18	5.25	3.56
No. 1	Flange angle θ_2	14.03	14.03	9.92
No. 2	Flange angle θ_2	11.86	12.63	9.46
No. 3	Flange angle θ_2	11.31	11.76	9.46
Average		12.67	12.89	9.69

Table 9 Comparison of springback level at channel wall and flange for SMDT case

Section	Springback level at channel wall		Springback level at channel flange	
	Experiment	Simulation	Experiment	Simulation
Front edge	4.18 (medium)	3.67 (medium)	12.67 (medium)	6.04 (high)
Weld line	5.25 (high)	4.74 (high)	12.89 (high)	5.83 (medium)
Back edge	3.56 (low)	2.53 (low)	9.69 (low)	4.54 (low)

and thus, that data point was ignored in the average calculation. However, for flange angle all experiments provide the similar trend. Table 8 also provides the average values for wall and flange angle by considering the data points from experiment nos. 1 and 3 which then compared with the simulation results. The direct comparison is not possible as the setup and material mechanical behavior are considered in simulation, and these are different than experiments. However, the trend is having close comparison. The values of flange angle for front edge and weld line is too close to identify the high and medium level of springback and considered as same level, and similar observation was found in simulations (Table 9).

5 Conclusion

To analyze the springback in long channels, four cases of tailor-welded blanks were considered and simulated. Two strength materials were considered with twice the difference, and two thicknesses 1.2 and 0.6 mm were considered. From the obtained results, it was found that the springback angles were different if any of the blank has different thickness or strength or both. Similar trend was observed in the flange springback angle, i.e., higher at front edge, middle at weld line and low at back edge, because of no constrain as well as the weight of the material in combination with higher strength. If the combinations would have been flipped, the results would have been opposite. However, springback at channel wall has different story due to constrain from bottom and from flange. It is concluded that edge would provide middle-to-high springback (depending on combination of strength and thickness) if that edge will have higher springback at flange. The other edge will be having low-to-middle springback (again depending on combination of strength and thickness) if that edge will have lower springback. The weld line will have

middle-to-high springback as this is getting affected by front and back edge springback level.

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