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Analysis of Filling Capacity during Rubber Pad Sheet Metal Forming Process

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Abstract:

Rubber-pad forming process of round sheet blanks into axisymmetric cups is studied by numerical and experimental approaches. In the experiments, round metal sheets are formed into the axisymmetric cups by pressing them between a rubber pad and a former block with desirable shape. To investigate influences of different parameters on the filling capacity, former block with complex shape has design and manufacture, blank material of low carbon steel (ST12) with thickness 0.5 mm ,three polyurethane rubber with different hardness (50,60 and 70) shore A and rubber pad having three different thickness (40,60 and 80) mm . ANSYS Workbench utilized to perform the numerical part of this research. The results showed that the produced filling capacity is significantly affected by rubber pad hardness, rubber pad thickness as well as rubber pad layer order.

Keywords

Rubber pad forming, sheet metal forming, rubber hardness, rubber thickness, filling capacity, numerical modeling, ANSYS Workbench.

1. Introduction

An effective method of decreasing the initial tooling costs and simplifying the forming process is to replace metallic tools with a Flexible-die forming (FDF) process. Such flexible tools supplement the traditionally matched rigid steel tooling [1]. FDF technique utilizes a flexible pressure-carrying medium instead of metallic die or punch. The medium might be gas (expanding or pressured air), liquid (oil or water), or elastic body (a pad of rubber) [2]. In last decade, sheet flexible-die forming techniques have been broadly used in industries like aerospace and automotive factories. The concept of the rubber-pad forming can also be used for drawing, embossing, bending and punching sheet metals into variety of shapes and contours [3]. These processes reduces the number of manufacturing stages and therefore tool and production costs. Using rubber tool offers the advantage of a comparatively feasible and secure processing of the drawing operation. The punching process with a rubber tool is capable of producing components, which are impossible, or very difficult to produce using conventional tools [4].

Abbas et al. [4] have investigated experimentally the rubber pad forming process of metal sheet. Some process variables like thickness of blank, type of material, rubber pad thickness and the geometry of the die are studied. The results showed that the forming load is inversely proportional to sheet for same forming travel. In addition, it has found for increasing the rubber pad thickness improved the necessary forming energy.

Elyasi et al. [5] have introduced the influences of convex and concave former and rubber features on rubber pad sheet metal forming process. In their paper, the blank material has steel 316 having thickness of 0.1 mm and a rubber pad with a of 85 Shore A hardness was employed to produced final products. The results have showed that, for a similar subjected forming load, the convex former presented less filling capacity than the concave former. Moreover, when increasing forming load, no significant increase in filling capacity occurs with both formers, but increasing the forming load leads to rupture in rubber pad. The Influence of material thickness and type on the rubber pad sheet metal forming process studied in the paper of Niknejd and Karami [6] their findings presented that the radius of bending for the formed parts increase when width cavity of former block enhanced, therefore the forming load reduces. The results also showed that the forming load increases with increases sheet initial thickness. Koubaa et al [7] have investigated the ability of rubber pad forming , by comparison tube bulging using rubber and hydroforming bulging. In order to compare, a numerical simulation model has created for each forming process and discussed. A noteworthy result has been utilizing rubber as a pressure-carrying medium has recommended to enhancing thickness distribution and improving formability.

The hardness of rubber becomes prominent effect in performing the required product shape, Tandogan and Eyercioglu [8] have studied the effect of

Polyurethane hardness on forming of dome shaped parts, Polyurethane materials with 60 and 80 shore A, Aluminum sheet (Al 1100) with 0.5 mm thickness has used as blank material in experimental work and numerical modeling. The results have showed that harder polyurethane is proper to draw the blank in the desired shape. Though, more forming load is needed compared to softer polyurethane. The results also revealed that the rubber pad forming is very applicable for forming parts without excessive thinning. Forming of some complex grooves on bipolar plate is one of the most important challenges facing sheet metal forming operations W. Hongyu et al. [9] focused on rubber pad forming of some complicated channels by studying the influence of geometrical variables in experimental and numerical simulation. The concave punch, the tendency of the results about stress and shapes can be used to design a better punch in rubber pad forming. Results have showed that channels formed by convex punch that have better than these formed by concave punch, the tendency of the results about stress and shapes can be used to design a better punch in rubber pad forming.

2. Theoretical Considerations

One of the main difficulties in the sheet metal forming with rubber pad is the rubber ability to push the workpiece to take the form of cavity. Based on the desired shape the rubber capability varying for one deformation style to another, consequently it is more difficult to fill cavity under concave deformation style as demonstrated in figure 1, while it is easier to fill the cavity with the convex style [53].

In view of the foregoing, there are many factors affecting the filling capacity in rubber pad sheet metal forming process:

1. Characteristics of the rubber.
2. Deformation style (geometry of cavity and former block).
3. Mechanical properties of workpiece.

In order to calculate the filling percentage (FC) the equation (3-13) is used.

$$FC = \frac{A_f}{A_C} \times 100\%$$

Where:

A_C= the cavity area.

A_f= the filled area.

3. Numerical simulation

Finite element analysis (FEA) is adopted ANASYS Workbench (18.2) to perform the numerical modeling of RPSMF process, Two material models has used to define of material used :

1. Multilinear isotropic hardening assumption is used to define material properties of workpiece (blank material). Table 1 presents the elastic constant that obtained from tensile test of sheet material.

2. Mooney–Rivlin model is used to define material properties of rubber pad material based on the rubber hardness as shown in table 2.

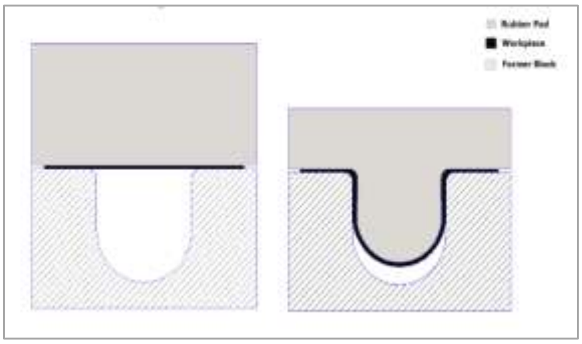

Figure 1. Capacity of rubber to fill cavity (before deformation to left and after deformation to right).

Table 1. Mechanical properties of blank material.

Material property	Modulus of elasticity (E)	Poisson's ratio(ν)	Yield stress (σ_y)
Magnitude	200 GPa	0.3	220 MPa

Table 2. Mooney-Rivlin constant based on Shore hardness [5].

Shore A	All values in MPa			
	G	E	C10	C01
50	0.755	2.397	0.302	0.076
60	1.185	4.268	0.474	0.118
70	1.839	7.289	0.736	0.184

The numerical modelling work in this research adopted 2D axisymmetric as shown in figure 1 geometry accompanied by the use of appropriate constraint in order to represent a full physical model as described in the following:

1. Define axis of symmetry at the left edge of the former block, blank and rubber pad.
2. Fixed support at the lower edge of rubber pad to present die lower plate.
3. Frictionless support at the right edge of the rubber pad to restrict rubber movement in a horizontal direction while it free to move in a vertical direction.
4. Applying velocity at former block upper edge subrogate press head movement.

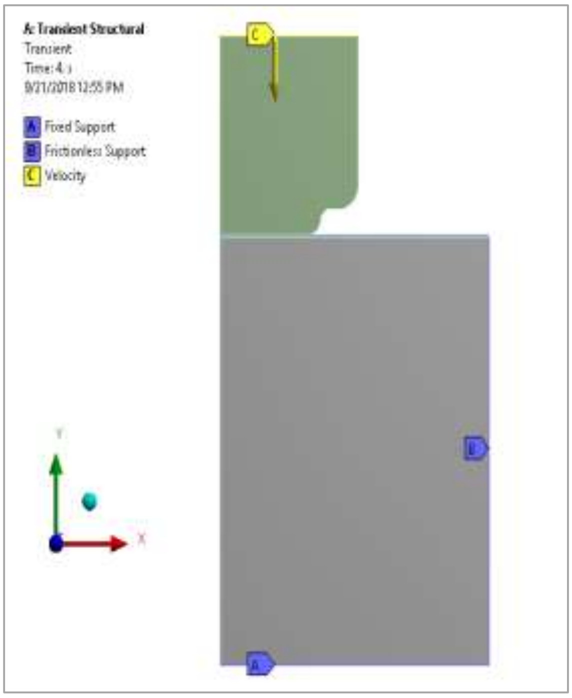

Figure 2. Constraints applied on numerical model.

2. Experimental Work

A low carbon steel is chosen to be the material of workpiece to be drawn in rubber pad sheet metal forming (RPSMF), this choice was because it possess good drawability. This material is taken as sheet with thickness (t_o= 0.5mm), the reason in choice this thickness due to the problems in drawing of sheet arises with decreasing thickness gauge, subsequently by using RPSMF trying to eliminate this problem. Circular blanks of 80 mm diameter were cut out from sheet. A chemical composition test was carried out by using spectrometer device to check the manufacture certificate of material as shown in Table 3. In order to determine the mechanical properties of sheet material, tensile test specimens were cut from the materials according to ASTM (E8M) standard. The tensile test was performed on computerized universal testing machine (WDW-200E).

Table 3: Chemical composition of low carbon steel

Component	C	Si	Mn	S	P	Cr	Ni	Fe
Percentage %	0.093	0.018	0.41	0.024	0.023	0.028	0.022	Rest

Sheet metal forming drawing die was designed and manufactured. To meet the requirement of planned experimental tests certain parts of the die were interchangeable. The following tool has been prepared and manufactured:

1. Former block with complex shape (contain cavity). As illustrated in figure 3.
2. Rubber container. As illustrated in figure 4.
3. Drawing die auxiliaries include (upper plate, lower plate, guides, spring and bolt).

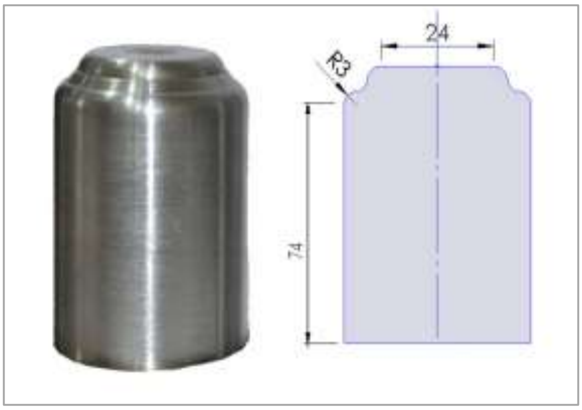

Figure 3. Design and manufactured of former blocks.

Drawing experiments are carried out to obtain cylindrical cups by mounted RPSMF die on the testing machine as shown in Figure 5. The testing machine type is (WDW-200E) has a capacity of (200KN) and stroke speed ranging from 0 to 500 mm/min. After placing sheet blank on the rubber pad upper surface, former block will drop down towards the blank to enforced it inside rubber ,while the rubber generate counter force thereby the blank to take shape of former block gradually. The stroke speed is 100 mm/min is used in experiments.

Figure 4: Cross sectional view and manufactured rubber container.

Figure 5: RPSMF die mounted to computerized testing machine.

5. Results and discussion

Deformation style contains interior profile or cavity requires special dealing in selecting process parameters not only to obtain the longer cup but also to perform the high filling to this cavity. In current research complex former is the only type that contains an internal cavity, therefore figures 6 and 8 demonstrate the effect of Solid Rubber Pad (SRP) and Laminated Rubber Pad LRP respectively on filling capacity. As mentioned in chapter three section 2 the Filling Capacity (FC) will be measured in term of filling percentage as a ratio between cavity area and filled area

5.1 Effect of SRP on Filling Capacity

When rubber pad consists of one piece Solid Rubber Pad, thereby the influencing factors on filling capacity are rubber hardness and rubber thickness as presented in figure 6, it is evident from curves in the graph the dominated factor is rubber hardness, since a clear spacing among rubber hardness curves. Accordingly, the filling percentage decrease with increase in rubber hardness. That results from the leak in the elasticity of harder rubber, therefore it difficult to enforce rubber to fill the cavity.

The thickness of the rubber pad has an obvious effect on filling capacity, but at a lower level than it was with rubber pad hardness. However, for softer rubber (50A and 60A) the filling capacity decrease with increase in rubber pad thickness, in contrary for harder rubber (70A) the filling capacity increase with increase in rubber pad thickness, Attributed to that the softer the rubber the easier to inter narrowness areas under low forming load, whenever the rubber pad at a shorter thickness it pressed quicker between former block and rubber container bottom, thereby enforce it to fill cavity. In contrast, the filling capacity of harder rubber decrease due to poor in elasticity, which makes it press under former block without filling the cavity area, thence longer forming travel improving filling percentage which is achieved through increase rubber thickness.

The filling percentage when SRP is used ranged from 74% to 98%, where the minimum percentage performed when RPT of 40 mm and RPH of 70A, in contrast, the maximum percentage performed when RPT of 40 mm and RPH of 50A.

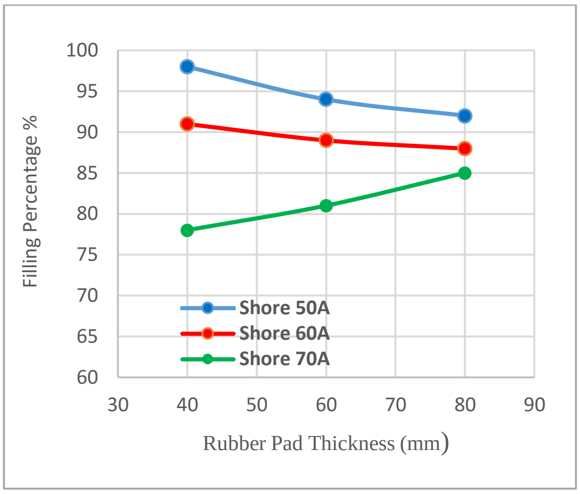

Figure 6. Effect of rubber hardness on filling capacity

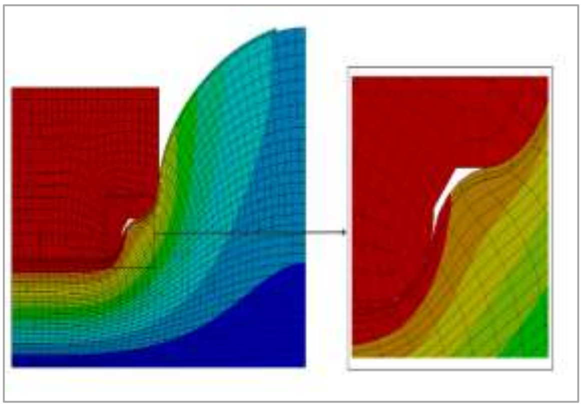

Figure 7. Filling capacity in numerical simulation for SRP

5.1 Effect of LRP on Filling Capacity

Influence of rubber layer order and the rubber pad thickness demonstrated in figure 8. Interestingly, there were similarities between the effect of layer order in LRP and rubber hardness in SRP on filling capacity. Overall, the results in this section indicate that the rubber layer order has a greater effect on the capacity of filling than rubber pad thickness.

The best filling percentage occurred when ascending order was used, although there is a drop in filling percentage when RPT of 80 mm has been used. A possible explanation for this might be that the upper layer was a softer one support by a harder layer which further promoted by a gradual increase in rubber hardness in this arrangement scheme. Figure 9 shows how the rubber material fills the cavity in the numerical model.

A good filling percentage performed using random order, but not as good as the results of ascending order, the reason for this is the middle layer is harder one surround with softer layer and that leads to forming travel with a low filling percentage.

Low filling percentage occurred when descending order was used. These results were predictable and consistent with the interpretation that says the filling ability of harder rubber is poor as in this scheme order the hardness gradually decreases from upper to lower layers.

The filling capacity increase with increase rubber pad thickness for DOL and ROL schemes, in general the filling percentage when LRP has ranged from 70% to 98%, where the minimum percentage performed when RPT of 40 mm and DOL scheme was used, whilst the maximum percentage performed when RPT of 60 mm and AOL scheme was used.

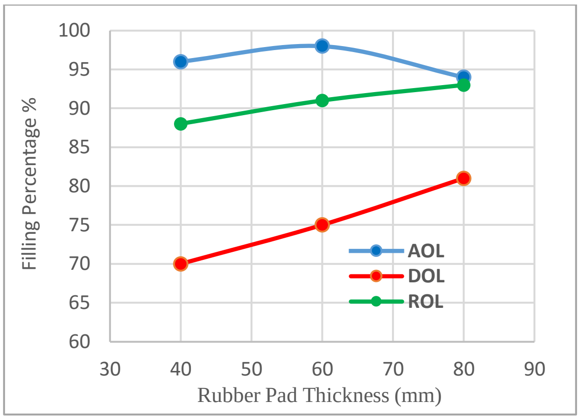

Figure 8. Effect of rubber hardness on filling capacity

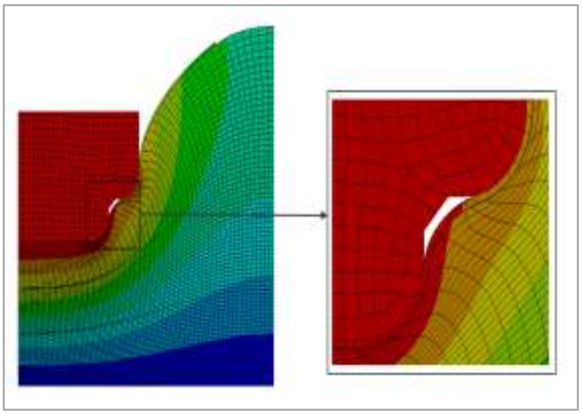

Figure 9. Filling capacity in numerical simulation for LRP

6. Conclusions

Rubber filling capacity decrease with increase in rubber hardness, also for softer rubber (50A and 60A) the filling capacity decrease with increase in RPT, in contrary for harder rubber (70A) the filling capacity increase with the increase in RPT.

The AOL scheme presented best fill capacity, followed by ROL scheme, but poor filling capacity presented using DOL scheme. Increasing RPT improve filling percentages using DOL but reduce filling percentages when AOL and ROL have used.

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