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Research paper

Numerical and Experimental Investigation on the Effect of Billet Preforming in the Flange Forming

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Abstract

Finite element method and experiments have been used to study a cold forming method for fabrication of a flange using the effect of billet preforming. Three dimensional finite element methods carried out to obtain the forming load, die filling, material flow, effective stress, effective strain with DEFORM-3D software, and a series of experimental works has been performed using lead metal with four types of billet preforming in the first stage. Pressing process has been done using computerized hydraulic press machine with 100 tons. The forming sequence is carried out in two stages. In the first stage, the cylindrical billet is preformed by upsetting and in the second stage forming it in a die. Results indicate that the process of formation is influenced by preforming of billet with fixed volume in the final stage of pressing, improve the mechanical properties of the metal and thus facilitates the final deformation process with less stress and better flow of the metal inside the die. Simulation results show that the effective stress, maximum principal stress, effective strain, velocity and damage are maximum at locations where flange open out and rib growth begins across the geometrical interlocking between the two halves of die-set and the component surface.

Keywords: *Simulation, flange, dies, cold forming.*

1. Introduction

Metal forming is one of the prime mode for forming the metals into useful form through application of forces. Basically, metal forming comprises of bulk metal forming and sheet metal forming technologies. Bulk metal forming includes processes such as extrusion, rolling, drawing and forging etc. while on the other hand sheet metal forming includes processes like deep drawing, flanging, hemming, electromagnetic forming etc [1].
Mechanical forming operations include all forming operations that take place on the metals and alloys in solid case without any melted. All these processes go on under the influence of mechanical forces by using special equipment and hardware that are securing these powers and bring about the change required in the forms or metal bodies, alloys that can performed these operations either cold or hot[2]. The ability of metals and alloys to any change in the shape by effect of mechanical forces related with structure and the crystal lattice of the metal. So there is considerable variation in ability of metals or alloys to mechanical forming [3]. Mechanical forming performed under forces or stresses exceed yield strength of metals or alloys that any change or deformity in the form will be elasticity with accompanied by usually changes in the mechanical and physical properties of metals for deformed metal [4].
The mathematical model of the plastic deformation process implies an approximate description of this process, which allows one to find the distribution of velocities, deformations, temperatures, stresses in the plastic flow region, calculate the probability of metal failure and determine the optimal conditions for its shaping [5]. DEFORM-3D Software is one of the powerful FEM based commercial pieces of software, which is specialized for metal forming operation like extrusion, forging and so on. The software is effective at saving costs and delays of trial-error approach industrial forming operations[6]. Several researchers have studied forming using FEM- analysis in both 2D and 3D versions [7-9].
The purpose of this paper is to analyze the problem of die filling, press load, stress analysis and material flow to obtain a final product of the flange free from defects.

2. Finite Element Modeling

The processes is modeled as three dimensional finite element analysis using DEFORM-3D Software[5]. In order to analyze the draft and die, first their 3D models should be generated. The 3D model of the flange is generated in the AutoCAD. The 3D models of primary billet , and pre-form of top and bottom dies are prepared in the AutoCAD software and exported to the DEFORM software in STL format as shown in Fig.1a. Discretized model of die and billet assembly and initial contact between die and billet shown in Fig.1b. Fig. 2. shows the main window of the DEFORM program in the mode of visualizing the beginning of the deformation process of the deposited billet,without preforming that the simulation are before the flange forming with a results of stress and load of top die. Fig.3 illustrates a number of implementation of the flange forming process of work piece geometry in process simulation.

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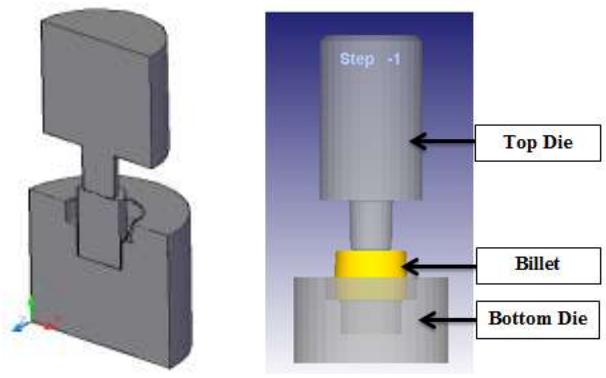

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Figure 1:. a-Preparation in the AutoCAD software and exported to the DEFORM software in STL format b- Discretized model of die and billet assembly

(Initial contact between die and billet shown)

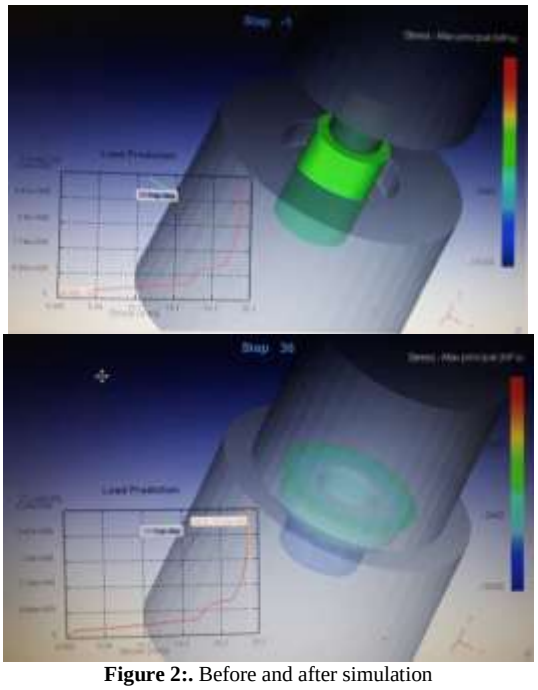

Figure 2:. Before and after simulation

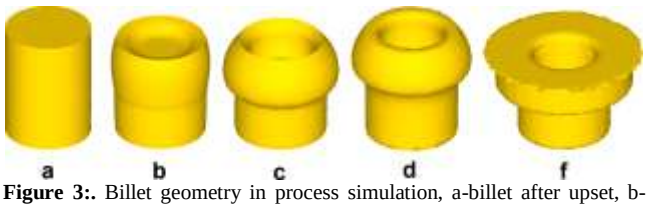

Figure 3:. Billet geometry in process simulation, a-billet after upset, b-after 25% change in the substance, c- after50% change in the substance, d-after 75% change in the substance , e- after 100%

3. Experiments-Process Description

In order to get the product it needs design and manufacturing of metal die according to the required measurements of the metal deformed, and performing the metal experiments by pressing metal in two stages to form the metal within the die and with less defects. Amount of lead metal prepared, melted, and poured in a special die with its two halves in order to get a cylindrical piece of 20 mm diameter and 60 mm height to perform experiments for manufacturing flange by cold forming in the die as shown in Fig.4a. For calculating the metal volume used in the pressing process mechanical AutoCAD program implemented depending on the volume of the internal die product, which represents the volume of the metal pressing as shown in Fig.4b.

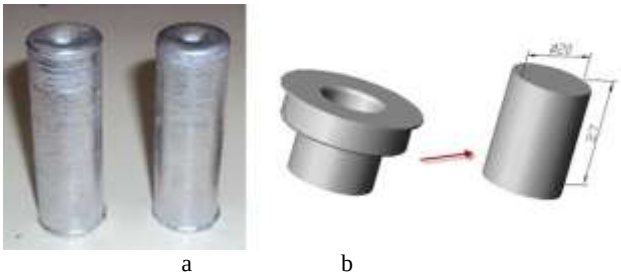

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Figure 4:. a- Preparation sample, b- calculating the sample volume

Punch and die used for forming the flange shows in Fig.5a. The dies manufactured with the dimensions as marked in high-resolution operating machines made of annealed stainless steel metal. Hardening process for the die done by electric furnace by placing parts of the die in furnace with temperature of 870 oC inside the furnace for an hour oil quenching were carried out.

Pressing process has been done using computerized hydraulic press machine with 100 tons ability as shown in Fig.5b with accessories of measuring instruments for loading and displacement. Relationship between loading and displacement during the pressing process recorded.

a b

Figure 5:. a- parts of die, b- hydraulic pressing machine

4. PRE-Form Stage

Addition of a pre-form stage to forging process will ease the forging of billet in the final die. In the pre-form stage the billet will achieve the suitable diameter based on the diameter of final die [7]. During pre-form stage, the initial pressing stage includes pressing the sample (20 mm diameter, 27 mm height) by hydraulic machine to different heights to get different diameters as shown in Fig.6 to perform practical experiments for pressing flange in the second stage and to get the product less defects.

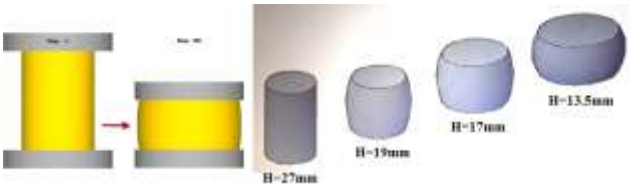

Figure 6:. Forms of billets in the first stage pressing

5. Formation of Flange

After the initial pressing process stage, the resulting sample is placed in the middle of the die in the lip region and closing the mold then the punch inserted to the die. The assembled die is placed between the lower part and moving upper part of the machine until it constants the punch. Then the applying process begins until the punch reaches the rated limit that indicated in the punch circular shaped. Fig.7 illustrates the processing of the preformed billet inside the die and the pressing process.

a b

Figure 7:. a- Preparing the preformed billet inside the die, b- the process of pressing

6. Results and Discussion

Flow simulation of the precision forming process carried out had been henceforth provided critical results which gives a detailed description of the effective stress, stress Max. principal, effective strain, velocity and damage analysis of the component as well as die set used in the process. The effect of stress accumulation, strain distribution, material flow velocity, damage can be clearly visualized and henceforth it can be critically analyzed from the Tab.1 and from Fig.8 to Fig.12 respectively.

Table.1. Results of simulation

No. of Sample	Stress –Effective (MPa)		Stress – Max. principle (MPa)		Strain effective (mm/mm)		Velocity (mm/sec)		Damage	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	78.1	5.52	65	-336	9.45	0.739	113	0.0148	1.10	0.000189
2	72.7	3.24	73.9	-347	13.6	0.497	337	0.0221	1.01	0
3	63.4	4.09	60.6	-328	6.48	0.516	100	0.068	1.92	0
4	76.9	8.36	57.5	-182	16.5	0.219	82.5	0.0167	1.67	0

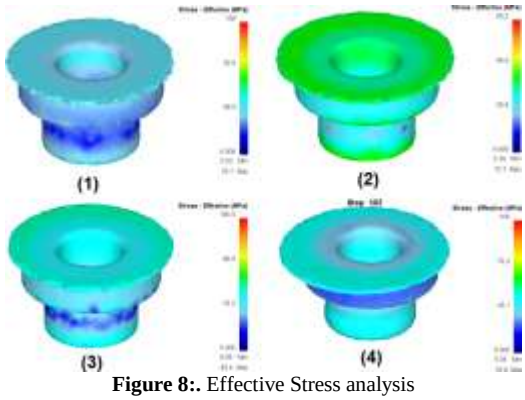

Figure 8:. Effective Stress analysis

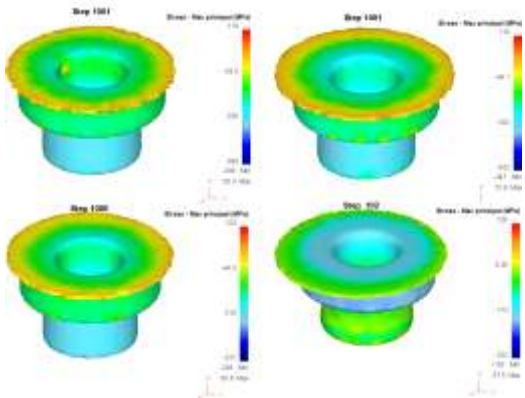

Figure 9:. Stress – Max principle analysis

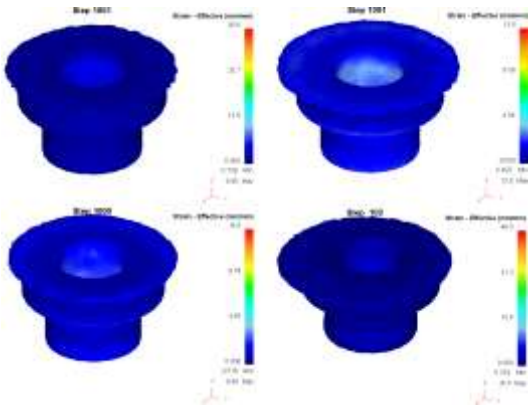

Figure 10:. Strain effective analysis

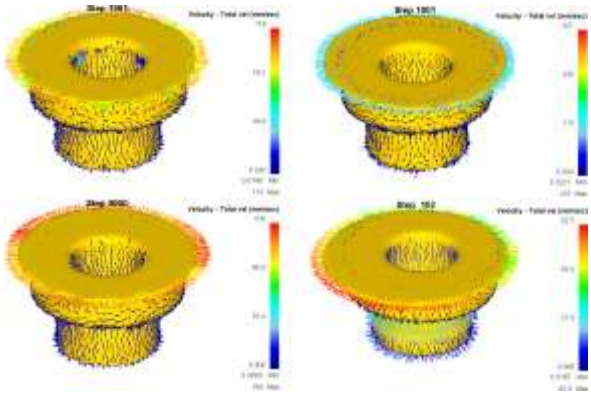

Figure 11:. Velocity analysis

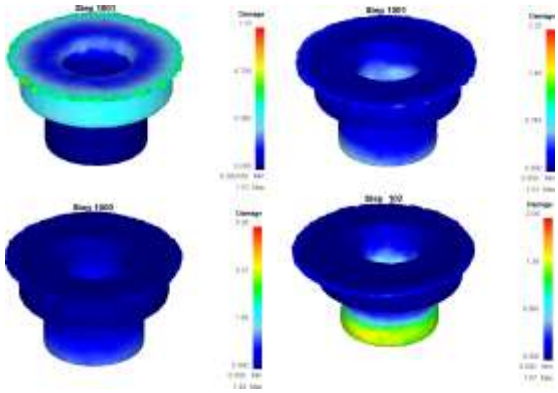

Figure 12:. Damage analysis

The careful observation of the results shows that the effective stress, maximum principal stress, effective strain, velocity and damage are maximum at locations where flange opens out and rib growth begins across the geometrical interlocking between the two halves of die-set and the component surface.

Fig. 8, 9 and 10 shows the effective stress, maximum principal stress and strain distribution along various cross sections of the component, the effective stress varies from a minimum of 3.24 MPa in the sample No.2 to a maximum of 78.1 MPa in the sample No.1. The maximum principal stress varies from a minimum of -347 to 73.9 MPa in the same samples No.2, and the effective strain varies from a minimum of 0.219 to 16.5 mm/mm in the same samples No.4.

Fig. 11 and 12 gives a brief outline of the velocity and damage analysis for the flange, the velocity of flow of material during plastic deformation of the flange varies from a minimum of

0.0148 mm/sec in the sample No.1 to a maximum of 337 mm/sec in the sample No.2 and the damage caused in the flange varies from a minimum of 0.0 in samples No.1,2, and 3 to a maximum of 1.92 in the sample No.3.

In Fig.13 shows the maximum value of preformed billet height (13.5mm) by numerical simulation of the forming process in the DEFORM program. As follows from the simulation results shown in Fig.13, an increase in the preforming height of billet more than 10 mm leads to an increase in metal consumption, as well as, consequently, decrease load and defects occur that are related to the no regular flash and non-filling lower part of the die

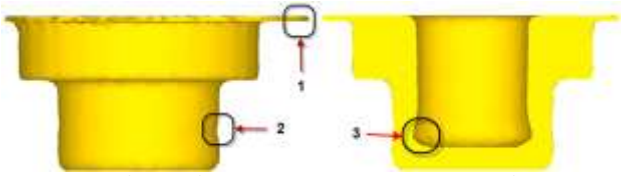

Figure 13:. Defects in flange in three regions 1-no regular flash, 2 and 3-non- filling lower part of flange

Four models of flange prepared practically and simulated numerically, each model has been formed in a different way, so different relationship between load and displacement obtained. Final results of the process of flange pressing carried out in four different forms of the preformed billet inside of the die shown in table (2), which includes applied load (KN) and the displacement of the press (mm) and figures (14-17).

Table.2:. Results of numerical and experimental loads

No. of Sample	Preform billet (mm)	Numerical		Experimental	
		Stroke(mm)	Load (KN)	Stroke (mm)	Load (KN)
1	0.0	24.0	187	21.7	234.5
2	8.0	28.0	195	25.2	195.0
3	9.9	26.1	156	23.3	197.4
4	13.5	22.5	124	21.5	115.8

The first model was formed directly in the die with one stage and without preforming of billet. Load applying and displacement measuring devices attached to the pressing machine recorded the relation shown in figure (14a) and figure (14b) shows the results of simulation. In which load increases continuously with displacement of the punch via good quality product.

The second model has been performed with a preforming process to 19mm. It was noted that needed load is less than load needed in the first product practically. But some shortages appeared of the metal in the outlet of the die toward outside area due to the presence allowances at the bottom of the die, which led to the loss of a part of the metal. Figure (15) shows the relation between applied load and the punch pressing displacement during the final pressing for the model with preforming billet to 19mm . It is noted that final pressing of metal forming path differs completely as compered with the first model. In this case there is inside die (load swing) where in the first model there is only compression inside the die.

Figure (16) shows the relation between applied load and the punch pressing displacement during preforming billed to 17.1 mm of the final pressing for the third model. It's noted that load in the final more than in previous models as given in the table (1) practically but less than in simulation, and the product quality is better but with increase in metal at the base of the die due to clearance.

The fourth model of the billet with the initial height (27 mm) preformed to higher (13.5 mm) and the final pressing process given in figure (17), which shows unfilled bottom of the die due to shortage of the metal in flange base, and thus the metal has not distributed and not fully filled the die internal space although the load is less than the other the models.

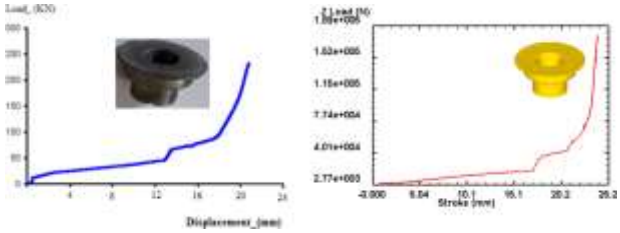

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Figure 14:. load via the punch displacement without preforming billet

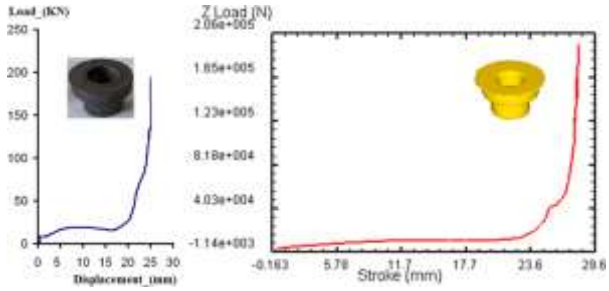

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Figure 15:. load via the punch displacement with preforming billet to 19 mm height

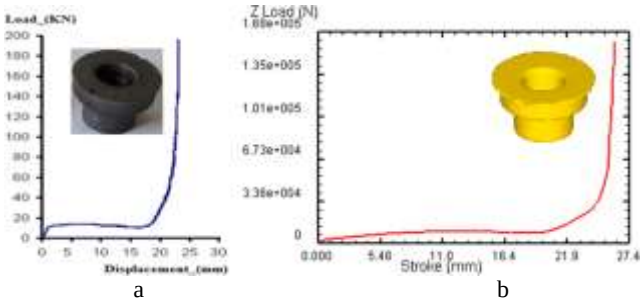

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Figure 16:. load via the punch displacement with preforming billet to 17.1 mm height

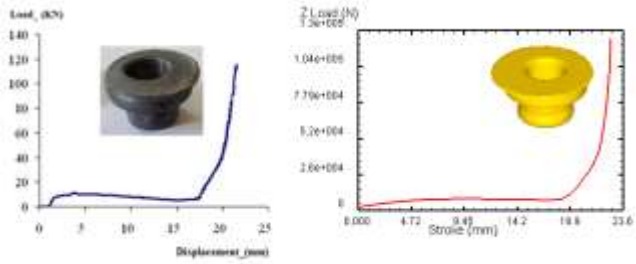

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Figure 17:. load via the punch displacement with preforming billet to 13.5mm height

7. Conclusions

It can be concluded that:

1. Flow simulation of the precision forming process provide critical results description of the induced stresses, damage analysis of the component and the die set used in the process.
2. The effective stress, maximum principal stress, effective strain, velocity and damage are maximum at locations where flange opens out and rib growth begins across the geometrical interlocking between the two halves of die-set and the component surface.
3. Using the DEFORM program, an increase in the preforming height of billet more than 10 mm leads to an increase in metal consumption, decreasing the load and inducing defects.
4. Four models of flange prepared practically, each model has been formed in different way, so Different relationships be-

tween the load and displacement of punch had been obtained for different models.

5. The preforming pressing provides facilities to the final process with less stress and best flow of the metal within the die.

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