FEM Analysis And Experimental Investigation For Lateral Extrusion Of Hexagonal Head

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ABSTRACT

The growing interest in the dynamic simulation modeling of metal forming processes in recent years has brought about the development of different techniques. The finite element technique is eminently suitable for analyzing lateral extrusion of hexagonal sections. Variations in load and flow direction of metal are greatly affected by the extruded geometry in this process. Keeping in view the above factors as an objective, an experimental die-punch set-up for lateral extrusion is designed and the process is simulated using finite element method both for estimation of load requirement and metal flow patterns. The series of experiments have been carried out to find the extrusion load and the direction of metal flow at different die geometry, taking commercial lead as the billet material. The predictions both in extrusion load and the deformed configuration are in good agreement with the experiment qualitatively under different geometry conditions. Progressive flow of metal at different die geometry has been investigated.

Keywords – Flow stress, Friction factor, Forming load, Metal flow, Strain-effective

I. INTRODUCTION

Lateral extrusion is a bulk metal forming operation in which the cross-sectional area of a billet is reduced and changed into a desired shape by forcing it through a die. It offers a product with a central boss section having complete or segmented protrusions. The research work in this field is not as plentiful as for other extrusion process. Complex parts such as collar flanges, spur gear forms, splines with a shaft are a few examples of the products produced by lateral extrusion. With regard to the variety of materials to be deformed, corresponding to higher demands for strength, and resistant to fatigue, heat and corrosion a continued diversification has been taken place so far, by the users of such work pieces. The advantages in conjunction with the numerous possibilities of shapes that can be manufactured by lateral extrusion have led to the increase in use of it such as material savings when compared with machining and other metal forming processes, good dimensional, and form error tolerance. Besides steel, heavy alloys such as aluminum, zinc, copper and their alloys, may be deformed and shaped by the above said process due to the advantages in conjunction with the numerous possibilities in material savings and good dimensional accuracy.

Recently theoretical and experimental studies on the process of lateral extrusion have been done by different researchers [1-5]. Early studies on lateral extrusion were carried out by Parsons et al. [6] under the name of "injection upsetting". Balendra and Hijazi [7-8] have studied effect of process parameters on metal flow and load requirement for complete protrusion. Lee et al. [9] also studied the effect of punch diameter, die radius and friction factor on the forming load by finite element method (FEM) on combination of side extrusion and forward or backward extrusion. The first study, according to the authors' knowledge, on lateral extrusion of segmented protrusions, such as splines, has been presented by Plancak et al. [10]. Balendra [11, 12] presented several works to define the range of the process, die filling and its limitation due to flaws. The major process parameters of lateral extrusion of the solid billets are the aspect ratio of the primary deforming zone, the corner radius and the ratio of the stroke [13]. Mizuno et al. [14] used the simple ideal deformation method to approximate the forming load and the punch pressure. He also conducted a series of experiments to obtain the strain history, and thereby, he estimated the stress. The FEM was also employed to simulate the lateral extrusion of solid billets for different geometries by several researchers [15, 16]. Lee et al. [17] and, Choi and Hwang [18] studied the effect of punch diameter and the friction factor on the forming load by the FEM on the combination of lateral and forward or backward extrusion.

This paper presents a FEM and experimental study to investigate the influence of the number of sides and same shapes of different dimensions on forming load and die filling. The three dimensional FE analyses has been used to investigate the effect of some important geometrical parameters such as billet height, die volume as well as process condition such as friction on the process. The FE results are compared with experimental data in terms of forming load and material flow in different regions. The comparison between the theoretical and the experimental results show good agreement. The simulation and experimental results show the effectiveness of above mentioned parameters on the forming load and material flow.

II. PRINCIPLE OF LATERAL EXTRUSION

The principle of the lateral extrusion process and the geometrical parameters utilized in this work has been showed in Fig. 1. A cylindrical billet is driven down by the punch, against the lower flat die, which is stationary, extruding it radially into the die cavity. Here the figure shows the initial (left side) and final (right side) position of the punch in the process while the direction of material flow is perpendicular to punch movement direction.

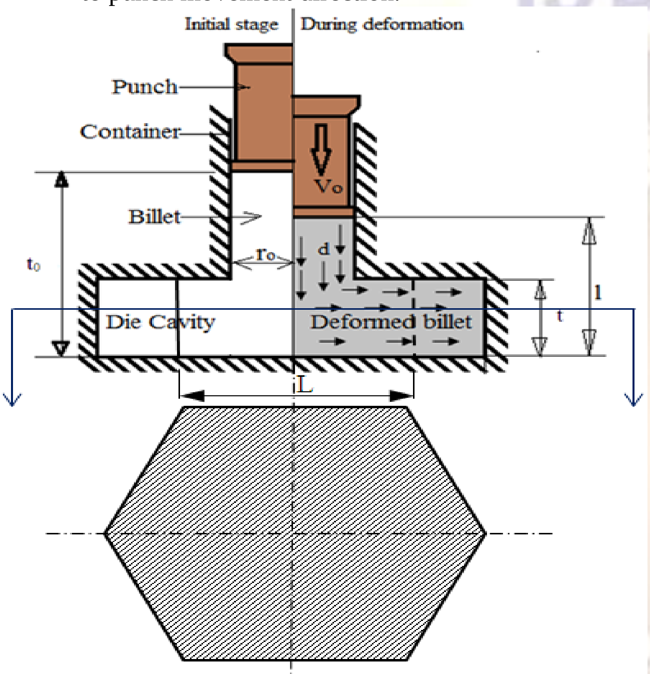


Figure 1.The schematic illustration of the lateral extrusion process and die parameters.

III. FEM ANALYSES

The geometry of this process is inherently three dimensional, and should be modeled as such. Numerical simulation of the lateral extrusion is modeled as three dimensional FE analyses using DEFORMTM 3D® software. The FE code is based on the flow formation approach using an updated Lagrangian procedure. This software uses a direct iteration method and the Newton-Raphson method to solve the nonlinear equations. In the solution procedure, the direct iteration method is used to generate a suitable initial estimate for the Newton-Raphson method, which is then used to obtain a rapid final convergence. Penalty formulation is used for analyses of the contact between the tool and the work piece. The frictional behavior follows Coulomb's sliding friction law as long as the frictional stress is smaller than a maximum shear stress which is expressed in equation 1 [19].

$$\sigma_s = \frac{\mu \sigma_y}{1.7} \qquad (1)$$

Thereafter, the shear stress remains constant at this value. The work piece is modeled using tetrahedral elements. The present simulation modeling and analyses of the process adopt the following considerations: (1) the tool material is typically much harder than the work piece material, it is customary to neglect its deformation and so the tool was considered as a rigid object. (2) The work piece material used in our model is solid commercial lead billets and so it was considered as a rigid-plastic material with Von Misses yield criterion, isotropic hardening. (3) The friction factor between the work piece and tools is constant. The die geometry and flange dimension parameters of lateral extrusion process, used in this study, is given in Fig. 1.

IV. EXPERIMENTAL DETAILS

The experimental setup in this study consists of two parts; (1) extracting of material properties used for FE analyses and (2) validation of the presented FE model. In the first part, two sets of experiments are conducted to obtain stress-strain relationship and friction factor between die and workpiece. tellurium lead was used as initial workpiece material due to its ability to forming easily at room temperature [20]. In compression test, the cylindrical billet with 30 mm in diameter and 50 mm in height was used as a compression test sample. According to Rastegaev standard specimens, shallow concentric grooves were performed on the ends of the cylindrical billets, so as to facilitate the retention of lubricant during compression test [21].

The procedure used for the compression test involved lubrication of the ends of the specimens with grease, so that it was allowed to the lubricant to retention in the grooves. The compression test specimen was performed via a 600 kN INSTRON, hydraulic press under pressing speed of 1 mm/min at room temperature. Fig. 2 shows the sample before and after compression test. The final height of compressed specimen was about 20.5 mm. Fig. 3 shows the true stress-strain curve for solid lead billet, obtained from a compression test. The material stress-strain relation can be modeled by equation 2.

$$\sigma_f = A\epsilon^b \ MPa \qquad (2)$$

Figure 2. Shape of specimen before and after compression test.

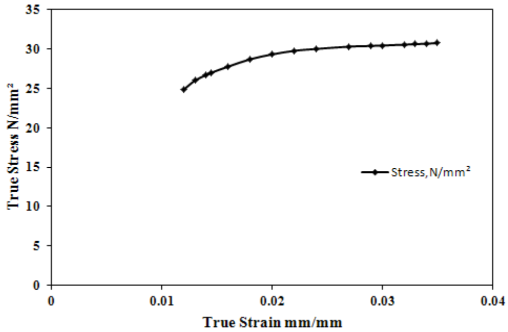


Figure 3. Stress-strain curve for lead.

where 'A' and 'b' are strength coefficient and strain-hardening exponent of the material which are equal to 54.5 MPa and 0.162, respectively. The effects of the friction condition on the forming load and material flow is analyzed. The friction coefficient in this work was determined by the ring test. The friction coefficient 'm' as determined from the above test was found to be 0.21. Fig. 4 illustrates the sample before and after ring test.

Figure 4. Lead specimen, before and after ring test.

In the second part, the effects of process parameters are investigated. The form and details of the apparatus have been fully described in the previous paper [22]. The experiments are done using 1000kN UTM. Schematic view of experimental set up is shown in Fig. 5. The dies used in this work were of heat- treated EN31 steel of overall three different dimensions and of Hexagonal shapes. With respect to the cylindrical container all the orifices being symmetrically located. The material extruded was tellurium lead. The load throughout the tests was recorded at intervals of 1mm of punch travel. The hydraulic testing machine used was controlled to advance at the requisite speed of 1mm/min using a digital dial gauge.

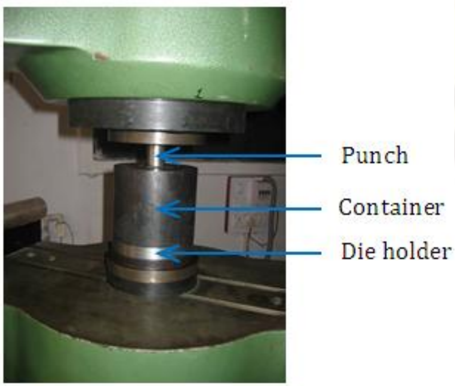


Figure 5. Experimental set up.

4.1 Process parameters

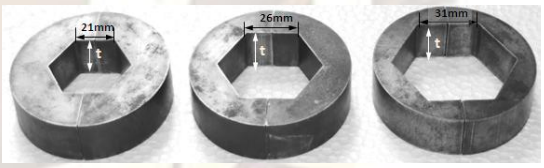
There are several geometrical parameters that influence the forming load and material flow into the die cavity. The major process parameters are identifies as die thickness (t), die cross-sectional area and friction coefficient (m) between die and workpiece. These parameters are summarized in Table 1. To investigate the influence of above mentioned parameters on the forming load and material flow, three dimensional FE analysis and experimental tests for different values of major process parameters selected.

Table 1 Process parameters.

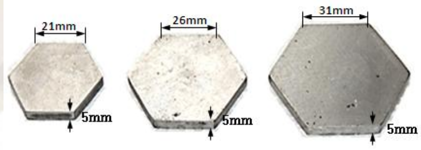
Parameters	Value with units
Die depth or thickness	10, 15 and 20 mm
Die cross-section	190.96, 292.72 and 416.12 mm^2
Friction coefficient(m)	0.21

4.2 Flat dies used for experiment

The flat dies used in the present series of experiments are made of two split halves for easy removal of the extruded product as shown in Fig. 6(a). The orifices are so made that the respective centers of gravity lie on the billet axis. These dies are produced by wire cut EDM from 20 mm thick flat plates oil- hardened and non-shrinking EN31 hot rolled tool steel. After machining, each die set is first normalized at a temperature of 930^{0}C in a reducing atmosphere and then hardened by quenching in oil from the above temperature to attain a hardness, R_c, of 60-65. Packing plates are made by the same process as flat dies (Fig. 6(b)). These plates are used for reduction of height or thickness of hexagonal lateral extrusion flat dies.



(a) Hexagonal lateral extrusion die with t=20mm.

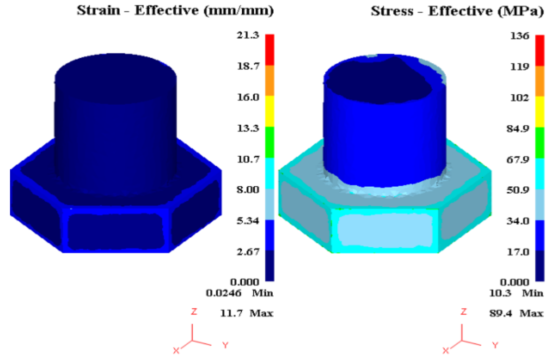


(b) Packing plates used for reductionof die thickness.
Figure 6. Lateral extrusion dies with packining plates.

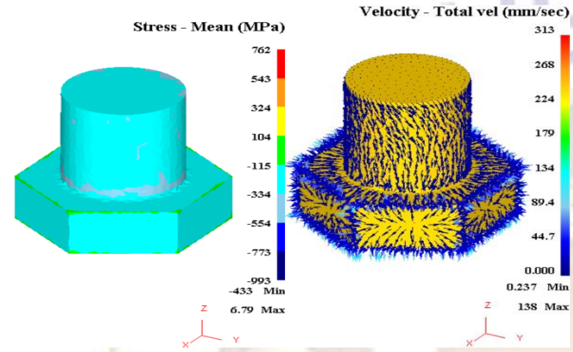
V. RESULTS AND DISCUSSION

5.1 Stress, strain and velocity flow analysis

Simulation analysis was carried out for strain-effective, stress-effective, mean-stress and total velocity flow of 26 mm side and 15mm thick lateral extruded product (hexagonal head with round shaft).



(a) Strain-effective (b) Stress-effective



(c) Stress-mean (d) Total velocity

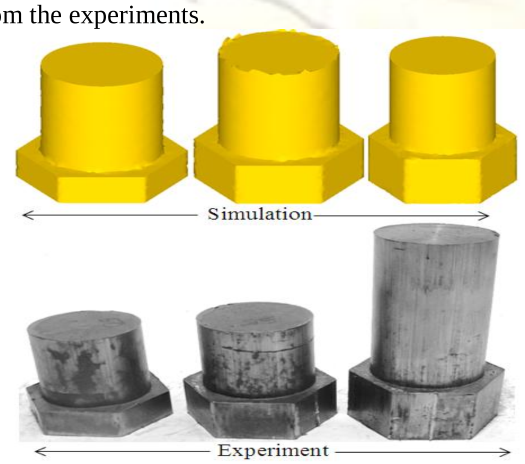
Figure 7. Stress, strain and total velocity of hexagonal headed with round shaft.

Three dimensional distributions of stress, strain and total velocity are shown in Fig. 7. From the said distribution, it has been observed that the maximum effective stress, strain and mean stresses are at the corner of die cavity (both bottom and top). In finite element analysis, the distribution of total velocity shows the flow direction for nodal point of each discretizes tetrahedral elements. In experimental it's the velocity of metal flow.

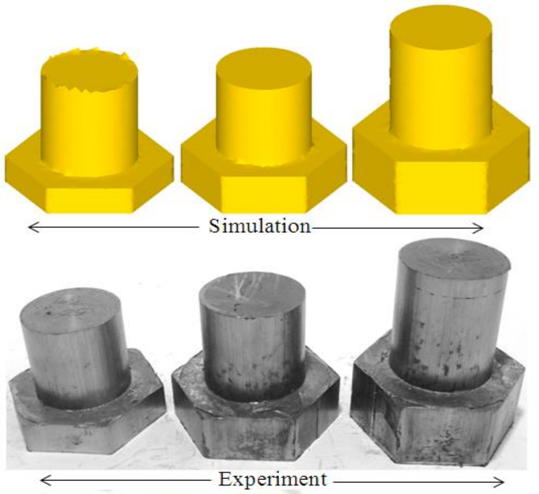
5.2 Comparison of results

5.2.1 Lateral extruded shapes

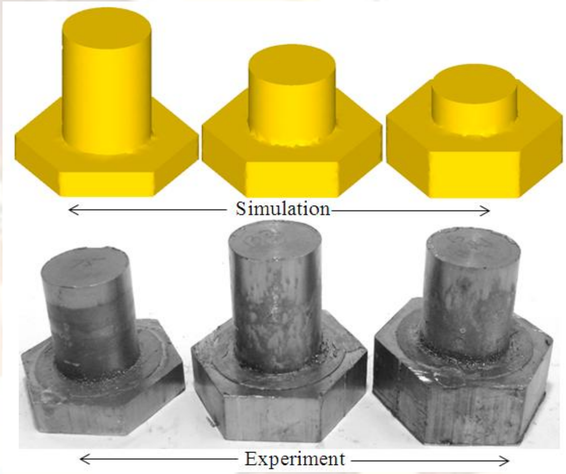
Simulation and experimental shapes of lateral extrusion are shown in Fig. 8. Shapes from proposed model are qualitatively agreed with that from the experiments.



(a)Length of side=21mm and thickness, t= 10,15 and 20mm.



(b)Length of side=26mm and thickness, t= 10,15 and 20mm.

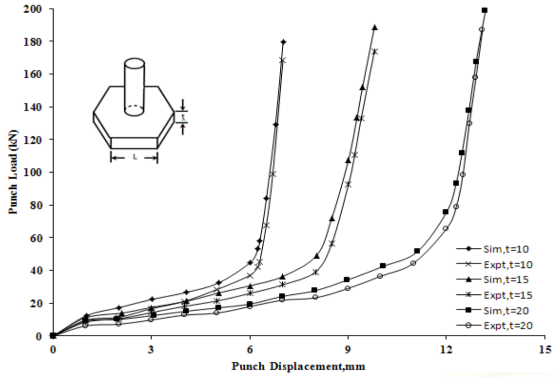


(c)Length of side=31mm and thickness, t= 10, 15 and 20mm

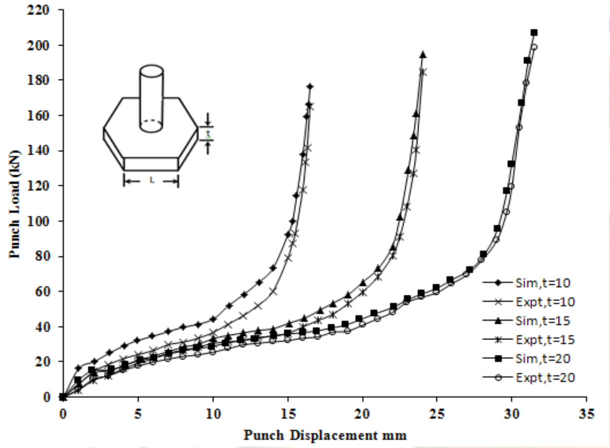
Figure 8. Comparisons of simulation and experimental extruded product.

5.2.2 Variations in forming load with punch movement

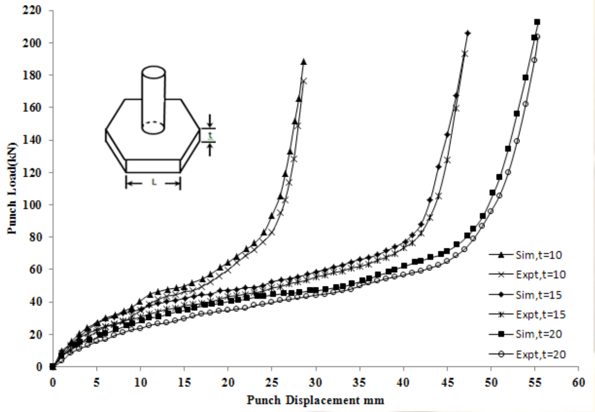
Referring to Fig. 9, it is seen that a typical diagram consists of three principal stages namely: (i) the initial compression stage in which the load gradually increases and reaches a peak value, (ii) a steady-state stage in which the load remains almost constant, and (iii) the unsteady-state stage in which there is a steep rise. The constant in load in the steady-state stage is due to the fact that actual extrusion takes place during this stage and there is an increase of load due to increase of frictional spread area. This process continues till the metal touches the outer boundary. It is observed that the peak loads of initial stage for simulation is more than the experimental value in each case.



(a) Variation of punch load for 21 mm side of hexagonal head.



(b) Variation of punch load for 26 mm side of hexagonal head



(c) Variation of punch load for 31 mm side of hexagonal head.

Figure 9. Variation of punch loads for different die geometry

The experimental initial compression load increases with decreases in thickness of die head but it remains constant in case of simulation. This may be due to the redundant work carried out in the actual process. Further comparing the simulation and experiment, it is also observed that for the last stage corner filling of the die, more punch load is required as die thickness increases. It may be due to the more load requirement as the metal flow path gets elongated. It is observed that the peak load variations between experiments and FE simulation lies within 7% and the peak load increases with increase in the volume of the die geometry as shown in Table 2. In each case, it is also found that the peak load in FE simulation is more than the experimental value.

Table 2 Comparison of Forming loads for different die geometry.

Hexagonal Head				
Die cross-section, mm^2	Thickness (t), mm	Simulation Load (kN)	Experimental Load (kN)	% Error
190.96	10	179.3	168.3	6.1
190.96	15	188.7	173.95	7.8
190.96	20	198.63	186.85	5.9
292.72	10	176.29	165.4	6.1
292.72	15	195.06	184.72	5.3
292.72	20	207.1	198.5	4.2
416.12	10	188.37	176.5	6.3
416.12	15	205.67	193.25	6.03
416.12	20	212.29	203.66	4.06

5.2.3 Progressive change in shape and Material flow patterns

Progressive change in shape of extruded product at different punch movement for both simulation and experimental are shown in Fig. 10. As an illustration, Fig. 11 shows the photograph of the flow pattern for a lateral extrusion of hexagon section at different punch movement for both in FEM analysis and experimental investigation. The gridlines distortion indicates that the process utilizes the maximum amount of redundant work to create the extruded product. It is also clarified that the corner filling takes place first at the bottom of the die during the steady state and then the flow proceeds towards the top corners of the die.

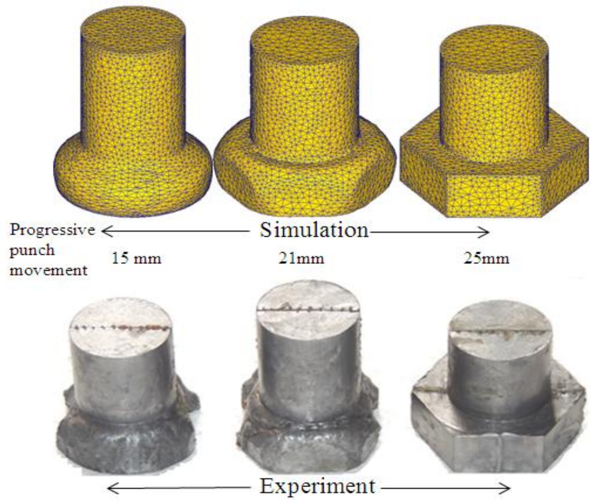


Figure 10. Die filling at different punch movement

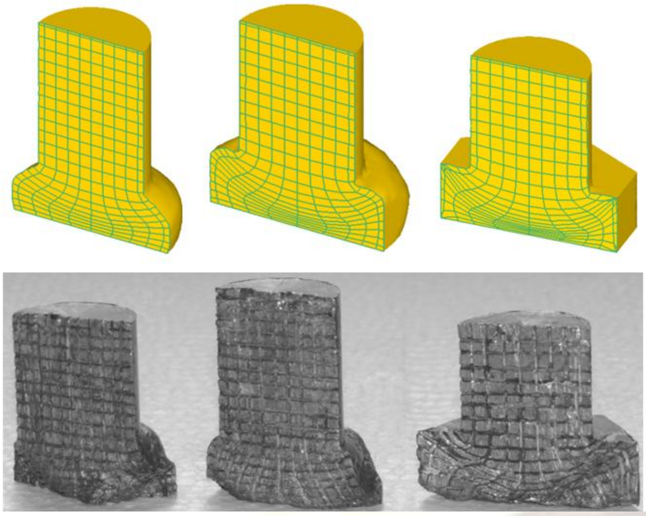


Figure 11. Progressive change of metal flow patterns.

VI. CONCLUSIONS

The FE simulations for the present work have been carried out to study the various process parameters. Again series of experiments have been performed to validate the results obtained from FEM. Based on the above discussion, following conclusions have been derived.

1. Effective strain is more at the edges and corners of the die than at the central boss of the cavity.
2. Effective stress decreases from die edges and corners towards the die faces and then towards central boss. But the mean stress almost remains constant throughout the section except at the edges and corners.
3. From the load ~ displacement graph it is seen that the forming load increases with increase in thickness and cross-sectional area of die cavity.
4. It is concluded from the flow net diagram that the flow of material takes place from the axial line towards the edges and then towards the corners from bottom to top. During the corners fillings of the die load increases abruptly.

The simulation results qualitatively agree with the experimental results in each of the analyses and henceforth further progress of the work can be done quantitatively.

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