International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:4, 2009

Injection Forging of Splines Using Numerical and Experimental Study

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***Abstract*—**Injection forging is a Nett-shape manufacturing process in which one or two punches move axially causing a radial flow into a die cavity in a form which is prescribed by the exit-geometry, such as pulley, flanges, gears and splines on a shaft. This paper presents an experimental and numerical study of the injection forging of splines in terms of load requirement and material flow. Three dimensional finite element analyses are used to investigate the effect of some important parameters in this process. The experiment has been carried out using solid commercial lead billets with two different billet diameters and four different dies.

***Keywords*—**Injection forging, splines, material flow, FEM

I. INTRODUCTION

EXTRUSION is one of metal forming processes that have a large area of applications. Extrusion process is a high speed production process which has an advantage of being economical relative to other production processes.

The injection forging also termed as radial extrusion, lateral extrusion, sideway extrusion or radial forging is an important branch of the extrusion process in which the cylindrical solid or tubular billet contained in the chamber is pressed by one or two opposite simple punches, causing the radial material flow through a fixed die cavity. The machine components with complex flange geometry or segmented protrusions such as gears and splines, which are very difficult to produce by the conventional forging, can be easily produced by the injection forging to near or net shaped parts.

The injection forging method will allow reducing the subsequent operations such as machining. Its important characteristics features of this method in relation to conventional forging are that it consumes low energy and offers better die filling for complex parts. Balendra and Qin [1, 2, and 3] have studied effects of process parameters on material flow and load requirement for complete flanges. They have been defined an aspect ratio of primary deformation zone (the ratio of gap height to billet initial diameter, T=s/d) for complete flanged part produced by this method. When T<0.8 acceptable material flow can be obtained but required force increase since metal flows into narrow die gap. Lee et al [4] and choi et al [5] 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.

Altinbalik studied the barreling profile and effect of aspect ratio on material flow in lateral extrusion of gear-like forms by using upper bound solution and experimentally [6].

Du Ko et al studied the effect of die geometry parameters on material flow in this process. They showed a certain pattern in the material flow in each deformation case and studied the some die geometry parameters on the material flow into the flange gap by FE simulation method [7].

This paper presents an experimental and numerical study of the injection forging of splines in terms of load requirement and material flow. The major process parameters considered in this work are the initial billet diameter, the number of spline teeth and die corner radius. Three dimensional finite element analyses are used to investigate the effect of mentioned parameters on forging load and material flow in this process. The experiments has been carried out using solid commercial lead billets with two different billet diameters and four different dies, to validate the numerical results and to increase the knowledge about the mechanics of this process.

II. NUMERICAL MODELING

In this work, injection forging of splines is investigated. The process is modeled as three dimensional finite element analyses using DEFORM ^{TM} 3D software [8].

The finite element code is based on the flow formation approach using an updated Lagrangian procedure. The finite element 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. The present analyses adopt the following assumptions: (1) the tool material is typically much harder than the workpiece material, it is customary to neglect its deformation and model the tool as a rigid object. (2) The workpiece material used in our model is solid commercial lead billets and model as a rigid-plastic material. (3) The friction factors between the workpiece and tools are constant.

The die geometry and flange dimension of injection forging process is shown in figure1.

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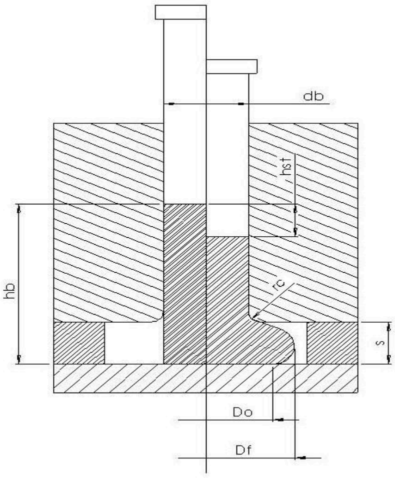

Fig.1. Die geometry and flange dimension

III. EXPRIMENTAL WORK

The experimental setup in this study consists of two parts; part1: Extracting of material properties used for numerical modeling and part2: measurement of process parameters that will be used for verification of modeling results.

In the part1, two sets of experiments are conducted to obtaining stress-strain relationship and friction factor between die and workpiece.

Commercially pure lead was used as experiment material due to its ability to forming at room temperature [6]. The cylindrical billet was machined to product 20mm in diameter and 30mm in height as workpiece for compression test.

Shallow concentric grooves were turned on the ends of the specimens, so as to facilitate the retention of lubricant during compression testing.

The procedure used for the compression test involved lubrication of the ends of the specimens with grease, so that the lubricant was allowed to retain in the grooves. The test specimen was centralized between the platens of the compression rig before load was applied. Tests were carried out at the ram speed of about 5mm/min. Figure.2 show the initial lead billet and final compressed specimen, the final height of compressed specimen was about 15mm.

Fig. 2. Initial and final compressed lead specimen

Figure.3 shows the true stress-strain curve for solid lead billet, obtained from a compression test.

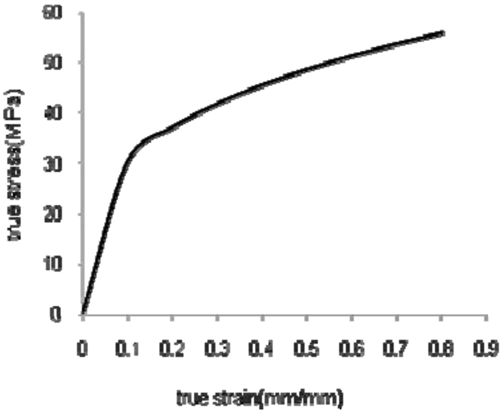

Fig. 3. True Stress-strain curve

The stress-strain equation of the curve fitted is:

$$\bar{\sigma} = 59.8\bar{\varepsilon}^{0.296}(MPa) \tag{1}$$

The friction coefficient in this work was determined by the barrel compression test, suggested byEbrahimiand Najafizadeh [9] under the same lubricating conditions.

The barrel compression test carried out based on the model explained in Ref [9], without lubricants and a value of m=0.21 is obtained and used for the numerical modeling.

In the second part of experiments, the effects of process parameters are investigated. A 100mt Amsler hydraulic press with constant ram speed of 5mm/min was used to perform the experiments. Figure.4 shows the experimental test rig setup for these experiments, and the die assembly has been show in Fig.5.

Fig. 4. experimental test rig setup

Fig. 5. injection forging die assembly

Two different containers with 20 and 23mm inner diameters and three different dies cavity with two, three and six teeth were made from 1.2344 DIN tool steel and hardened to 51 HRC (Fig.6).

Fig. 6. Toothed dies cavity (2-3-6)

The inner diameter of the dies cavity is 25mm and the height of the teeth is 15mm, thus the aspect ratios of the primary deformation zone, which is ratio of teeth height to billet diameter, were obtained as T1=15/20=0.47 and T2=15/23=0.65.

Experimental setup were designed to manner that the length of teeth provided for toothed dies are different but the volume of die cavity for all toothed dies cavity are the same.

The billet may bend or deform asymmetrically at higher specific flange thickness (T>1.65) and the thinning/unevenness of the flange thickness occurs mainly for smaller aspect ratios of the primary deformation zone (T<0.5). On the other hand, as the area through which the material flows gets smaller the required force to deform the material becomes larger [2]. Transition radii at the exit form the injection chamber was 1mm.The dimensions of the teeth for two, three and six teethed dies are different but the volume of the die gap is the same.

The commercial lead billets obtained from the lead ingot were put in a crucible and melted in furnace before casting them into already prepared sand moulds. The cast leads of dimensions 32mm in diameter and 140mm in height were machined into smaller lead specimens of dimensions 20 and 23mm in diameter by 55mm in height. The experiments were carried out without any lubricant on the contact surfaces of billets and die-sets.

IV. RESULTS AND DISCUSSION

In this section, we will study the effects of major process parameters such as; initial billet diameter, Number of spline teeth and die corner radius on forging load and material flow.

A. The effect of initial billet diameter and spline teeth number

Figures 7, 8 shows the forging load versus punch stroke curves for 2, 3, 4 and 6 toothed splines which were forged from the billets with two different aspect ratios, obtained from three dimensional numerical simulations.

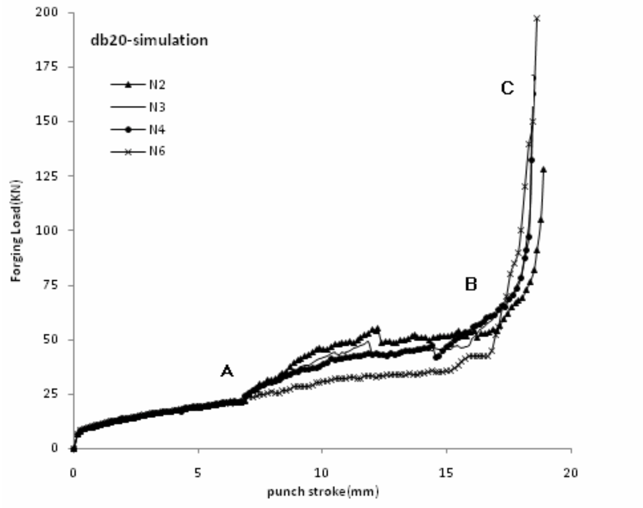

Fig. 7. Effect of teeth number on numerical forging load (db=20mm)

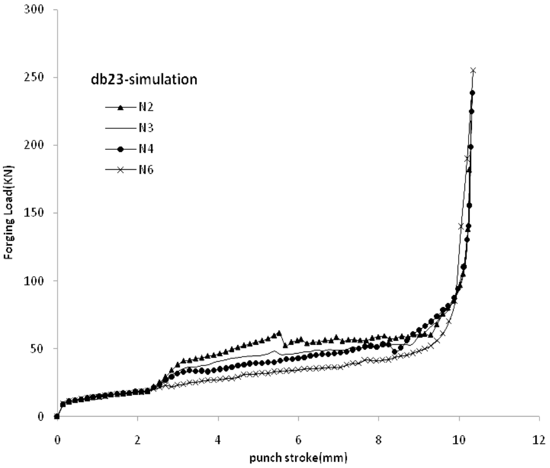

Fig. 8. Effect of teeth number on numerical forging load (db=23mm)

The accuracy of the numerical model is investigated through comparison with experimental results in the same conditions. Two different billets in diameter (20 and 23mm) and three different 2, 3 and 6 toothed die cavity made for experiments procedure. Figures 9, 10 show the obtained experimental results.

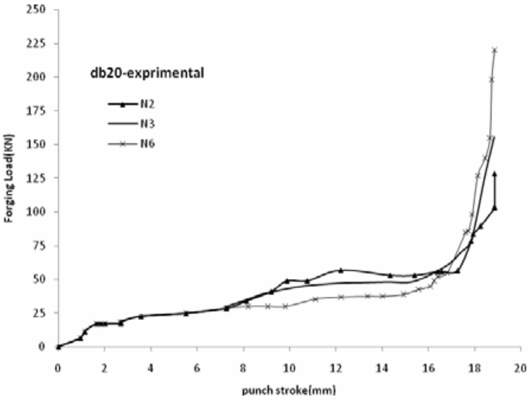

Fig. 9. Effect of teeth number on experimental forging load (db=20mm)

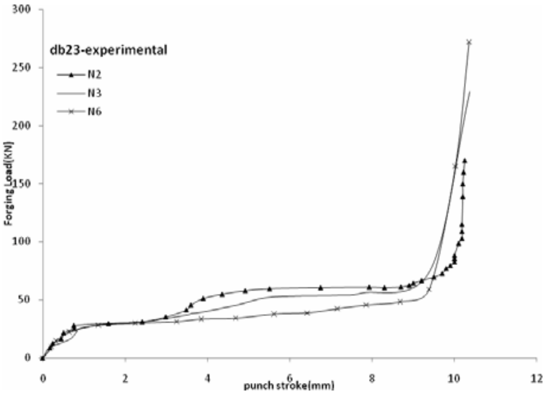

Fig. 10. Effect of teeth number on experimental forging load (db=23mm)

It is observed in the figures that the experimental and numerical results are close, with a maximum difference of about 9%, which is reasonable given the possible measurement errors and modeling approximations. The curves have three regions, namely, the simple upsetting, the tooth formation and the corner filling. As the punch move down simple upsetting formation occurs until the spline root diameter reaches 25mm (O-A in figures). As the stroke increase, tooth formation begins and continues until the front side of the metal in the gap touches the front wall of the gap (A-B in figures). The corner filling period starts at B and finishes at C. [6].

It is observed from these figures, as the initial billet diameters increase, the forging load increase along the any stage of the deformation. It is obvious from figures that the forming load values decrease when increasing teeth number in tooth formation region (A-B in figures). With a further increase in the punch displacement, and the beginning of corner filling region, the forming load values increase considerably when the metal goes into the gaps provided for the lower teeth number parts compared to the upper teeth number parts. Because the contact surface area of the gaps for upper teeth number parts is bigger than that of lower teeth number parts. Although the same amount of the metal goes into the gaps to form the teeth in all dies, the forming load is different for each case due to frictional resistance over the gap walls.

Figures 11, 12 show the obtained maximum forging load, in the final stage of forming and complete die filling, for two different billets in diameter 20, 23 mm and different number of die teeth.

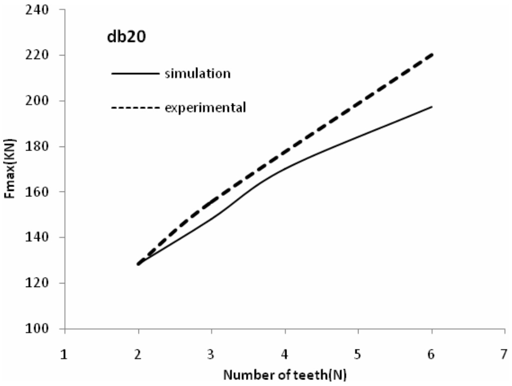

Fig. 11. Effect of teeth number on maximum forging load (db=20mm)

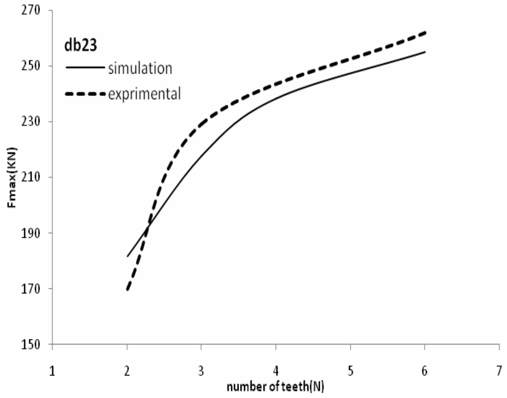

Fig. 12. Effect of teeth number on maximum forging load (db=23mm)

Figure 13 show the teeth formation stages for two teeth parts, which obtained from simulation and experimental method. It is observed from this figure that the experimental and numerical metal flow predictions are close. As seen from this figure, the filling of the gaps of the teeth is not uniform from top to bottom and some barreling take place before the complete filling has been obtained. Figure 14 show the teeth formation stages for 3 and 6 teeth parts that obtained from experimental works.

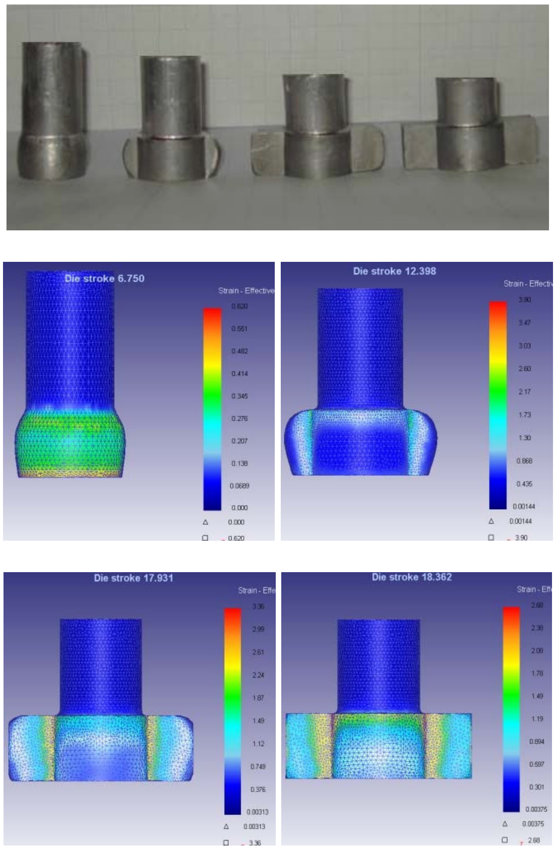

Fig. 13. Teeth formation stages for two teeth parts

Fig. 14. Teeth formation stages for 3 and 6 teeth parts

B. The effect of die corner radius (rc)

The simulation work were performed for the two teeth die, billet initial diameter in 17mm and die corner radius, rc has five values, 0.5, 1, 2, 3, 4mm. This parameter is important die design item. Figure 15 illustrate the effect of die corner radius on the required forming load. As shown in this figure, die corner radius has a little effect on forming load. By increasing die corner radius, the maximum forging load increase too.

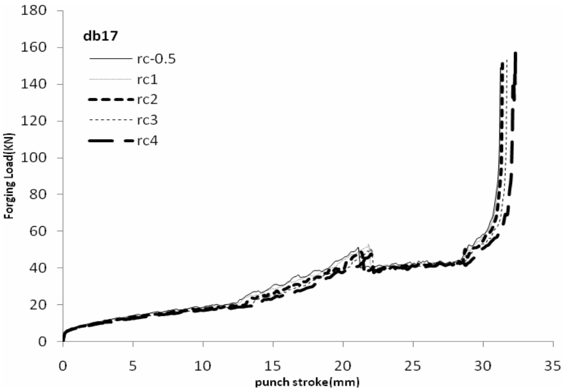

Fig.15. Effect of die corner radius on forging load

Variation of (D0/Df) ratio for different die corner radius and two different strokes S1 (finishing of the simple upsetting stroke) and S2 (finishing of the tooth formation stroke) is given in figure 16.

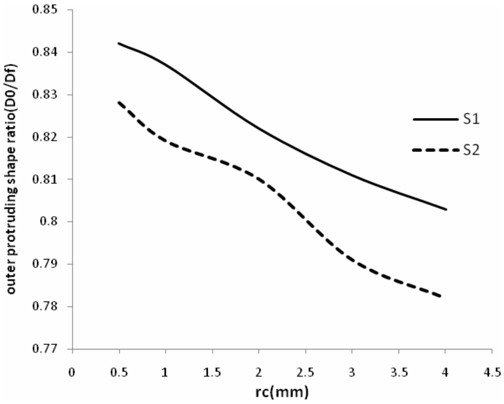

Fig. 16. (D0/Df) ratio for different die corner radius

As it is seen from figure 16 decreasing die corner radius cause to increasing (D0/Df) in same strokes and more homogeneous tooth is formed. Figure 17 show the effective strain distribution in two die corner radius (rc=0.5 and rc=4mm) obtained from three dimensional simulations. It is obvious that the corner radius affects the flowing of materials. When radius is smaller the effective strain distortion is worse and warping may occur. In addition some other defects (for example cracking) may occur.

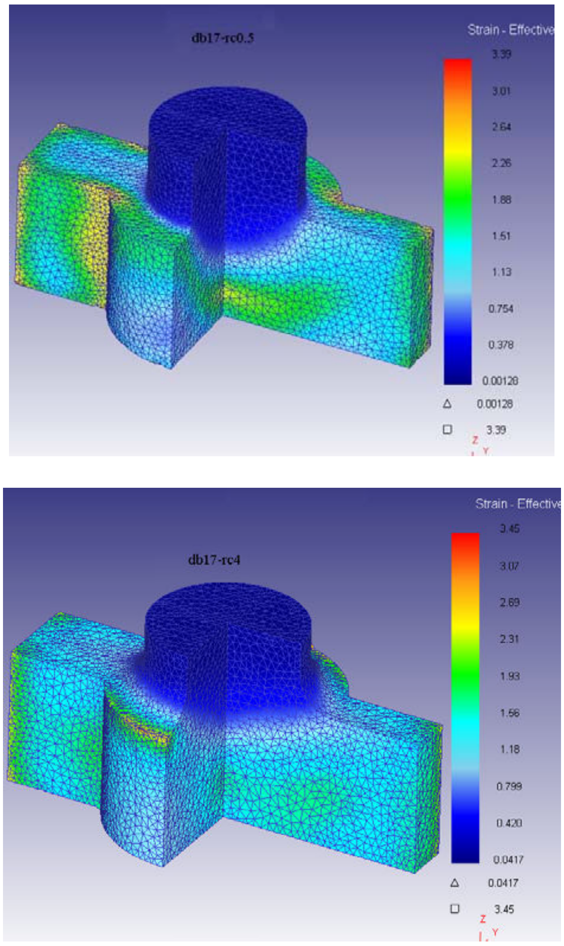

Fig. 17. The effective strain distribution in two die corner radius (rc=0.5 and rc=4mm)

V. CONCLUSION

In this paper, three dimensional FE simulations of the injection forging process are used to study the effect of various process parameters, such as initial billet diameters, the number of tooth and die corner radius on forming load and material flow. The validity of the simulations is established based on experimental results. From the results of this study, the following points may be concluded:

- The forming load decreases with a decreasing billet diameter for a given number of teeth.
- The forming load increases with an increasing number of teeth for a given billet diameter.
- The shape of the tooth profile is not straight and the barreling occurs.
- Die corner radius has a little effect on forming load. By increasing die corner radius, the maximum forging load increase too.
- Decreasing die corner radius cause to increasing (D0/Df) in same strokes and more homogeneous tooth is formed.
- When radius is smaller the effective strain distortion is worse and warping may occur.

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