



International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017,
Cambridge, United Kingdom

Testing an Injection Forging Process for the Production of Automotive Fasteners

Senyong Chen^a, Yi Qin^{a, *}, Chee-Mun Choy^b and J.G. Chen^b

^a Centre for Precision Manufacturing, DMEM, The University of Strathclyde, Glasgow, UK

^b Ritia (Shanghai) Auto Standard Component Co. Ltd, Shanghai, China

Abstract

Competition in the automotive fasteners production has been fierce and there are needs for higher quality, lower manufacturing-cost and fast delivery. To meet such needs, injection forging of automotive fasteners for possible industrial production has been investigated, considering its potential of forming complex-shaped components with shorter process chains. Initially, a comparison study on existing multi-stage forming and injection forging was conducted, supported by FE simulations, through which the feasibility of using injection forging for producing one type of fasteners was established preliminarily. The process was then tested through forming experiments based on which component accuracy, formed-material hardness and grain-flow lines were examined to evaluate the quality of the fasteners formed. Further, a manufacturing trial was carried out in the industry to examine the process feasibility in the industrial environment. Besides the parts with good quality having been achieved, the requirement for higher forming-force and the consequence as larger die-deflections were also identified through these studies. Based on the results obtained, improvements on the process and tool-design were proposed, focusing on the forming-force reduction and higher part-dimension accuracy.

© 2017 The Authors. Published by Elsevier Ltd.

Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.

Keywords: Injection Forging; Multistep Forging, Automotive Fastener, FE Simulation

* Corresponding author. Tel.: +44 141548 3130.

E-mail address: qin.yi@starth.ac.uk

1. Introduction

Although cold forging/extrusion has already been a mature technology for forming automotive components, there are still gaps for further improvements. For example, competition in the automotive fasteners production has been fierce and there are needs for higher quality, lower manufacturing-cost and fast delivery. To meet these requirements, manufacturing practitioners have to continue technological improvement and innovations. At the same time, injection forging (a kind of radial extrusion) represents a forming process able to form complex component-forms with shorter process chains, comparing to other simple forming processes such as heading, upsetting and forward extrusion. To-date, the solid/hollow flanged parts [1], universal joints [2], gears [3], hollow gear-shafts [4], etc. have been produced successfully with injection forging or similar process-configurations in small volume productions and with relatively low forming-speeds. To assess injection forging in a high-speed mass-production, injection forging was compared with a traditional multi-steps forging process through conducting FE simulations of forging of automotive fasteners [5]. This paper reports experimental verification of these simulation results and further investigation into the feasibility of industrial production of a particular type of automotive fasteners by injection forging.

2. Process configuration

Fig. 1 presents a conventional multistep forging process for making hexagon bolt. To secure the final forged hexagon bolt, the forming usually goes through five steps. In the first operation, the round bar is forward-extruded to reduce the diameter in the bottom section. Then, it is upset in the second operation. Next, the head is compressed by a punch to form a cavity. The hexagon head takes a shape in the last two forming operations. After the forming stage, a bolt will go through thread rolling, heat treatment and surface treatment before it is finally checked.

To shorten the forming stage, a concept of injection forging was introduced. As can be seen from Fig. 1, it intends to combine the first three operations into one operation. The process concept is shown in Fig. 2, in which a floating-die design is used. In this design, the die inserts move with the punch, simultaneously, at the same velocity. The ejection pin remains static during the forming. It can, therefore, support the billet until the final dimension is produced. In this way, the initial billet is formed directly into the intermediate form with a cavity by radial and backwards metal flow.

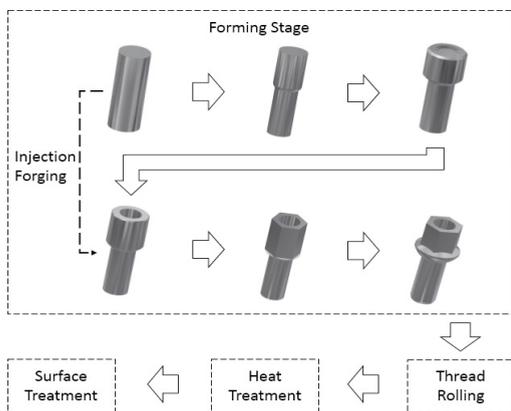


Fig. 1: Illustration of the steps of production of a hexagon bolt

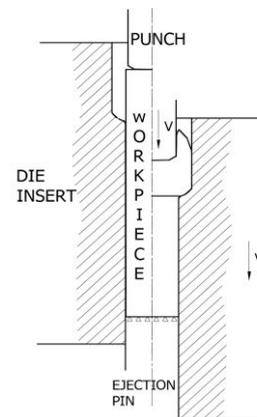


Fig. 2: Illustration of injection forging process introduced

3. Modelling, Experiment and Manufacturing Trials

3.1. FE modelling

In this study, two FE code software, ABAQUS and DEFORM, were used. To re-mesh in the analysis in order to overcome mesh distortions, Arbitrary Lagrangian Eulerian (ALE) adaptive meshing was used in ABAQUS. In

DEFORM, distorted areas were re-meshed automatically. In order to analyse forming accuracy by considering elastic-plastic deformations and elastic recovery of the material, an axis-symmetric model was developed with ABAQUS. The result of component accuracy was analysed on the 2D profile and the dimension errors indicate the forging accuracy. The dimensional errors were assessed mainly on the radial dimensions of the components, which were bolt-head diameter D and rod diameter d (refer to Fig. 3). In comparison of component accuracy, the forging process was divided into two phases, as shown below:

- Loading: in this stage, the component was constrained by tools. Therefore, the tool deflection could be reflected by the component dimensional errors;
- Unloading: the contact between the tool and the workpiece was removed. It was intended to analyse the contraction of the die and springback of the component.

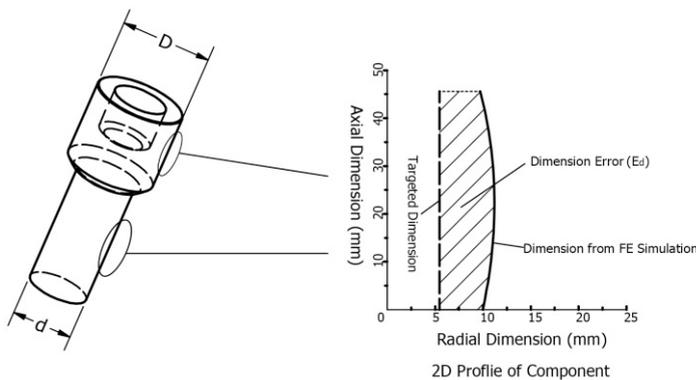


Fig. 3: Parameters D and d used in the analysis of dimensional errors e_d .

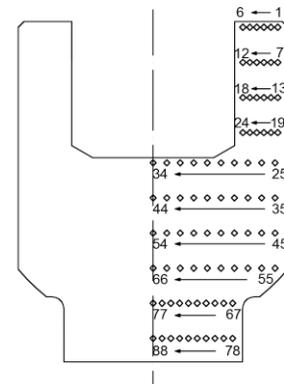


Fig. 4: Indenting positions used in the hardness test.

For both models, the simulation was carried out by assuming a constant velocity of the punch travel (around 120 pieces per minute are to be produced). The coefficient of friction was determined based on a ring test which was suggested to be 0.055. AISI 1010 was selected as the workpiece material. The material of the die inserts was WC, other tool-parts were made of AISI H13. The material properties were taken from the literatures [6] and [7].

3.2. Experimental set-up

A 3,000 kN vertical hydraulic press was used for the forming experiment. The sample material was cut from a branch of the wire coil of AISI 1010. The raw material experienced wire drawing and then phosphating. Before the forming process, the billets and tools were measured on the dimensions. These were then cleaned with alcohol and dried with a blow gun until the surfaces did not any smut, oil or grease, before conducting the experiment.

After forging, two post-measurements were conducted: hardness test and grain flow analysis. Because the component was symmetrical, the hardness test was conducted only on a half of the specimen from the centre line, as shown in Fig. 4. For the grain-flow line analysis, it was conducted only on the head of the bolt which is the most critical part of the fastener using.

3.3. Manufacturing trials

To test the injection forging for possible volume-production, the manufacturing try-out was carried in factory. In this test, the forging tools were mounted onto an FORMAX 2000 cold header. The billet was cut by the trimming tool in the cold header and transferred to the die by the transfer finger. Three forging-speeds, 80 strokes per minute (SPM), 100 SPM and 120 SPM, were tried respectively. The forming-force was monitored by the built-in transducers.

4. Results and discussion

4.1. Comparison of injection forging and multistep forging

The table shows typical results from the simulations which indicate that injection forging would need a higher forging force, comparing to a single-step forging in multi-step forging. Nevertheless, its total energy consumption would be lower.

Table 1: Comparison of forging forces and forging energy requirements of multistep forging and injection forging

Process	Multistep Forging (stage 1)	Multistep Forging (stage 2)	Multistep Forging (stage 3)	Injection Forging
Max. Force (kN)	207.916	229.920	182.928	270.864
Forging Energy (kJ)	1290	517	748	2280
Total Energy = 2555				

Table 2 presents the results relating to the dimensional deviation of the workpiece after extrusion/forging (before unloading) and after tool-releasing (after unloading). The first one reflects the amount of the die-deflections while the second indicates the level of the springback after the forming pressure is removed fully. It is shown that large tool deflections would occur in injection forging, in the section d , which, for example, generated around a 0.028 mm dimensional error, due to a large forming-force having to be applied to achieve a completed shape.

After releasing the forming tool, the springback would be a main factor contributing to the increase of the dimensional errors. The mean errors could increase by around two times than those before springback, in the section D for both multistep forging and injection forging. However, in multistep forging, there was no significant change in the $\bar{\epsilon}_d$ before and after springback of the workpiece. These indicate that the higher forming pressure sustained in the die during the forming the more springback of the workpiece may occur after the pressure is released.

Table 2: Comparison of the dimensional deviation for multistep forging and injection forging.

Process		Multistep forging (step 1)	Multistep forging (step 2)	Multistep forging (step 3)	Injection Forging
Mean Error $\bar{\epsilon}_D$ (mm)	Before Springback	0.020	0.014	0.014	0.017
	After Springback	0.039	0.027	0.032	0.038
Mean Error $\bar{\epsilon}_d$ (mm)	Before Springback	0.014	0.009	0.006	0.028
	After Springback	0.013	0.013	0.006	0.057

4.2. Experimental results

Fig. 5 shows the forging force recorded in the experiment in comparison with a simulation result of injection forging. It indicates a good agreement in force growth tendency. The estimated value from the simulation is slightly large, being approximately 18% larger. This could be due to several reasons such as the material model used, boundary conditions simplified and meshing scheme used in the FE model.

After the experiment, the grain flow lines of the sample parts were investigated. The most of these were not very obvious for the extruded wall-sections, and only the flow lines in the centre of the specimens were significantly visible, as shown in Fig. 6. Compared with the simulation results, the grain flow lines are not perfectly symmetric, which may be due to non-uniform material micro-structures across each section of the billet, the non-symmetric conditions at the tool–workpiece interfaces, and even imperfect tooling/machine conditions.

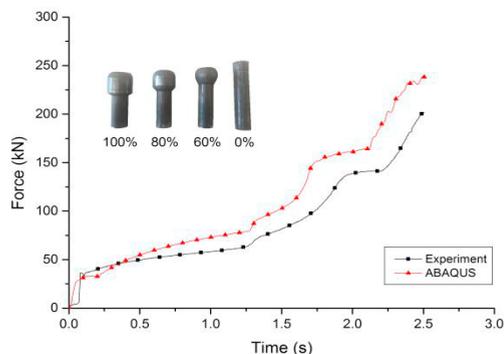


Fig. 5: Comparison of the forging force obtained from the experiment and the simulation



Fig. 6: Grain flow lines shown under the microscope

Fig. 7 shows the hardness distribution of a specimen. The maximum hardness is located at the part A where the bore is formed and high straining is induced. The hardness gradually decreases in the part B and C, where relatively smaller strains were produced during the forging. Such a distribution and change was predicted perfectly by the FE simulation (Fig. 8), in the form of the distribution of effective plastic strains of the specimen. The level of the strains at the part A1, B1 and C1 matches that of the hardness measured at A, B and C respectively.

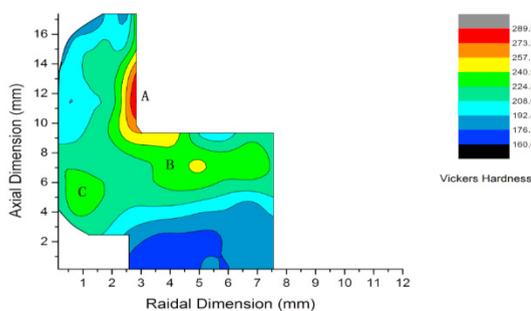


Fig. 7: The contour of hardness of the workpiece

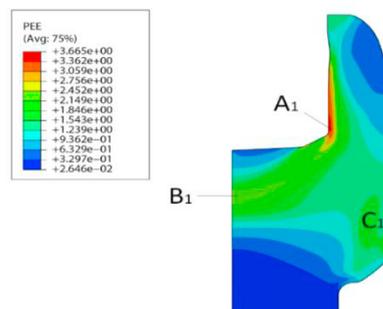


Fig. 8: Effective strain distribution of the workpiece

4.3. Manufacturing trials

Fig. 9 shows the forging force curve in low, medium and high forging speed respectively. As results show, with increase of the forging speed, the forging force requirement increased significantly. In the highest speed, the peak force could reach around 280 kN.

The high forging speed resulted in severe scratching on the component surface, seen in Fig. 10. Due to the great forging force, the shear stress between the workpiece and the die inserts stayed at a high level. This shear stress broke down the adhesion between the phosphate coating and the component surface. This is obvious when the forging speed was 120 SPM. The coating on the rod part was removed totally, and the substrate surface was scratched. With reduction of the forging speed to 100 SPM, the coating remained on the top of the rod part. However, in the bottom part, the coating was still damaged partially. It suggests that the bottom part of the workpiece sustained more severe contact stresses. This problem was resolved at the low-speed forging during which coating covered the component well across the whole part-surfaces. Compared with the rod part, the coating in the head part of the component was kept well regardless of the forging speed. It may indicate that the shear stress in this part was not severe.

Because the component forged in this study is an intermediate product of the process chain producing the fastener, it is a requirement to maintain the phosphate coating intact as much as possible in order to have a better friction condition in the following forging step. Therefore, in this coating condition, the forging speed of 120 SPM

was identified to be not suitable with this forging configuration for the forging of such a fastener. Alternatively, thicker and stronger phosphate coating may be introduced in order to resist the high shear stress in high speed forging.

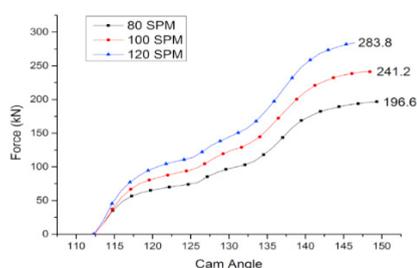


Fig. 9. The forces recorded in manufacturing trials for different forging speeds



Fig. 10. Illustration of the starches at the component surfaces formed

5. Conclusions

In this study, injection forging of automotive fasteners as an alternative to multistep forging was investigated through FE simulation, experiment and manufacturing trials, from which the following conclusions may be drawn:

- (1) The forming experiment in injection forging confirmed the FE model for general simulation of the forging process and hence, for generating useful information for the comparison to multistep forging.
- (2) Through the comparison study via FE simulations, general feasibility of using injection forging to replace the first three-steps of the multistep forging of the automotive fastener could be established.
- (3) Initial manufacturing trials suggested that the process will have to be restricted to the certain forging speeds to prevent damages to the phosphate coating on the billet, if the process is to be adopt in production.

For practical uses, tool design and manufacture optimisation will have to be considered to address larger forging force and increased die-deflections in injection forging, in order to maintain good tool-life and component accuracy. These include properly designing the die-structure, including pre-stressing die and selecting good die-material as appropriate; reducing the impact force during forging; proper die-bore design to compensate for the springback of the workpiece, etc. Redistributing the forging pressures should also be considered in the future tool-designs.

Acknowledgements

The authors would like to thank Ritai (Shanghai) Auto Standard Component Co., LTD for supporting the project by manufacturing forming-tools and by conducting experiments and manufacturing trials in the company.

References

- [1] R. Balendra and Y. Qin, "Injection forging: Engineering and Research," *Journal of Materials Processing Technology*, vol. 145, no. 2, pp. 189–206, Jan. 2004.
- [2] L. M. Alves and P. a. Martins, "Injection Forging of Solid Asymmetric Branched Components," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 227, no. 6, pp. 898–907, 2013.
- [3] M. Plan, M. Rosochowska, and P. Skakun, "Radial Extrusion of Gear Like Components – Numerical Analysis," *Technical Gazette*, vol. 20, no. 5, pp. 891–896, 2013.
- [4] Y. Ma, Y. Qin, and R. Balendra, "Forming of Hollow Gear-Shafts with Pressure-Assisted Injection Forging (PAIF)," *Journal of Materials Processing Technology*, vol. 167, no. 2, pp. 294–301, 2005.
- [5] S. Chen and Y. Qin, "Comparison Study of Multistep Forging and Injection Forging of Automobile Fasteners," in *MATEC Web of Conferences*, 2015.
- [6] Y. Lee, J. Lee, and T. Ishikawa, "Analysis of the Elastic Characteristics at Forging Die for the Cold Forged Dimensional Accuracy," *Journal of Materials Processing Technology*, vol. 130–131, pp. 532–539, Dec. 2002.
- [7] H. T. Yeo, Y. Choi, and K. D. Hur, "Analysis and Design of the Prestressed Cold Extrusion Die," *The International Journal of Advanced Manufacturing Technology*, vol. 18, no. 1, pp. 54–61, Jul. 2001.