A STUDY ON THE IMPROVMENT OF THE HOT FORGING PROCESS OF CONNECTING ROD USING FINITE ELEMENT METHOD

NGHIÊN CỨU CẢI TIẾN QUÁ TRÌNH DẬP NÓNG CHI TIẾT TAY BIÊN ỨNG DỤNG PHƯƠNG PHÁP PHẦN TỬ HỮU HẠN

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ABSTRACT

In this study, the hot forging process of a connecting rod was performed using both finite element method (FEM) and experimental method (EM). With four workpiece types, the forging processes were conducted using QForm.10.1.6 to evaluate the maxinmum forging force, the temperature contribution, the plascity tress, the filling ability, and detect the laps in the forging products. The best solution was determined based on these evaluated results. With maximum forging force of 372.1kN, the best filling ability, and the most uniform temperature distribution and plastic stress, the workpiece number 1 was determined as the best solution. The results of the simulation processes were successfully verified by the results of the forging experimental.

Keywords: *Hot forging, FEM, Connecting rod, simulation.*

TÓM TẮT

Trong nghiên cứu này, quá trình dập nóng chi tiết tay biên đã được thực hiện bằng cả phương pháp phần tử hữu (FEM) và phương pháp nghiên cứu thực nghiệm (EM). Với bốn dạng phôi, quá trình dập nóng được mô phỏng sử dụng phần mềm QForm.10.1.6 để đánh giá các đặc trưng của quá trình dập như lực dập lớn nhất, phân bố nhiệt độ, phân bố ứng suất, khả năng điền đầy và nhận dạng các khuyết tật trên các sản phẩm dập. Phương án tốt nhất đã được xác định dựa trên các kết quả đánh giá từ quá trình mô phỏng. Với lực dập lớn nhất là 371,1kN, khả năng điền đầy tốt nhất, phân bố nhiệt độ và ứng suất đồng đều nhất, dạng phôi số 1 được xác định là dạng phôi cho kết quả sản phẩm dập tốt nhất. Các kết quả mô phỏng đã được kiểm tra thành công bằng việc đánh giá kết quả từ quá trình dập thực nghiệm trên thực tế.

Từ khóa: *Dập nóng, phương pháp phần tử hữu, tay biên, mô phỏng.*

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1. INTRODUCTION

Forging technology can be described as the metal forming technology to obtain the desired shape. In which, the hot forging technology has been widely applied in the industry for making the well finishining shape of the metal according to the requirment of the products such as the quantity, size, the surface conditions, etc [1].

Nowadays, with high quality, high efficiency, and less generated scrap in the forging processes, hot forging is widely used as a manufacturing method to manufacture the automotive engine parts, motorcycle parts, aerospace components, and so on. in many countries in the world [2, 3].

The important issues in hot forging technology include forging dies, billets - workpieces, blocker, cavity, draft angle, fillet, flash, parting line, shrinkage, etc. [4]. The designing process of this die and cavity structure has been considered all of these issues, so, this designing process is a complicated process. And, therefore, the application of simulation and analysis methods (or Finite Element Methods) that is one of the approach directions chosen by the researchers. One of the tools that is often used to analyze the hot forging process is Qform software [5].

Using FEM, several studies were performed to overcome the limitations of the traditional design approach such as the die trial time, the flash, the laps, and so on. and to improve the quality of the final products [3, 6]. Besides, FEM was applied to determine the optimal geometry of the workpiece [6]. Moreover, by using the FEM, the die fractures in hot forging process were detected and the dies were be optimized to increase the die life [7, 8].

This study was perfomed using both FEM and experimental method to analyze the forging force, the temperature contribution, the plascity tress contribution, the filling ability, to detect the laps in the forging products, and to verify the simulated result though the actual forging processes.

2. MATERIALS AND METHODS

In this study, the research process was performed according to the steps in Fig. 1. Step 1: From the actual production experience of factory workers, four types of workpiece were designed for simulation and experimental

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processes. Step 2: The simulation process was carried out using FEM (Qform software) to evaluate the maxinmum forging force, the temperature contribution, the plascity tress contribution, the filling ability, detect the laps in the forging products, and to determine the best solution in forging simulation process. Step 3: The forging experimental process was conducted to verify the results form the simulation process. Finally, the conclusions were drawn and the applications were proposed.

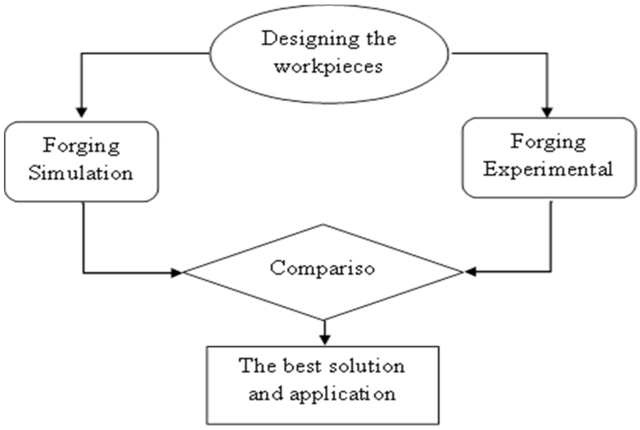


Fig. 1. Flow-chart of research process

The product that was applied in this study was connecting rod. This product is mass-produced by hot forging technology. The geometry of this process was described in Fig. 2.

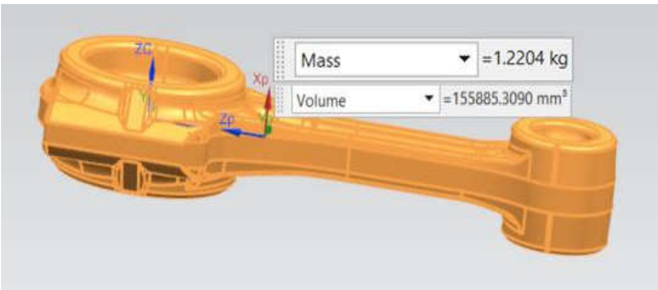


Fig. 2. Product geometry

The workpiece materials were a low carbon steel (JIS S20C). The chemical compositions of the workpiece material were listed in Table 1. Four types of workpiece were used in simulation and experimental processes as described in Fig. 3 and Fig. 4.

Table 1. Chemical composition of JIS carbon steel S20C in percent (Ni+Cr<0.35%)

C	Si	Mn	P	S	Ni	Cr	Cu
0.18-0.23	0.15-0.35	0.3-0.6	≤ 0.03	≤ 0.035	≤ 0.2	≤ 0.2	≤ 0.3

The hot forging process of a connecting rod was performed in 2 steps. In the first step, the workpiece was pre-form in the raw-die. An then, in the last step, the workpiece was formed to obtain the final shape in the finishing die. The geometries of raw and finish dies were designed in one upper die and bottom die as shown in Fig. 5. The material of dies was JIS SKD61 steel alloy with the chemical compositions as listed in Table 2.

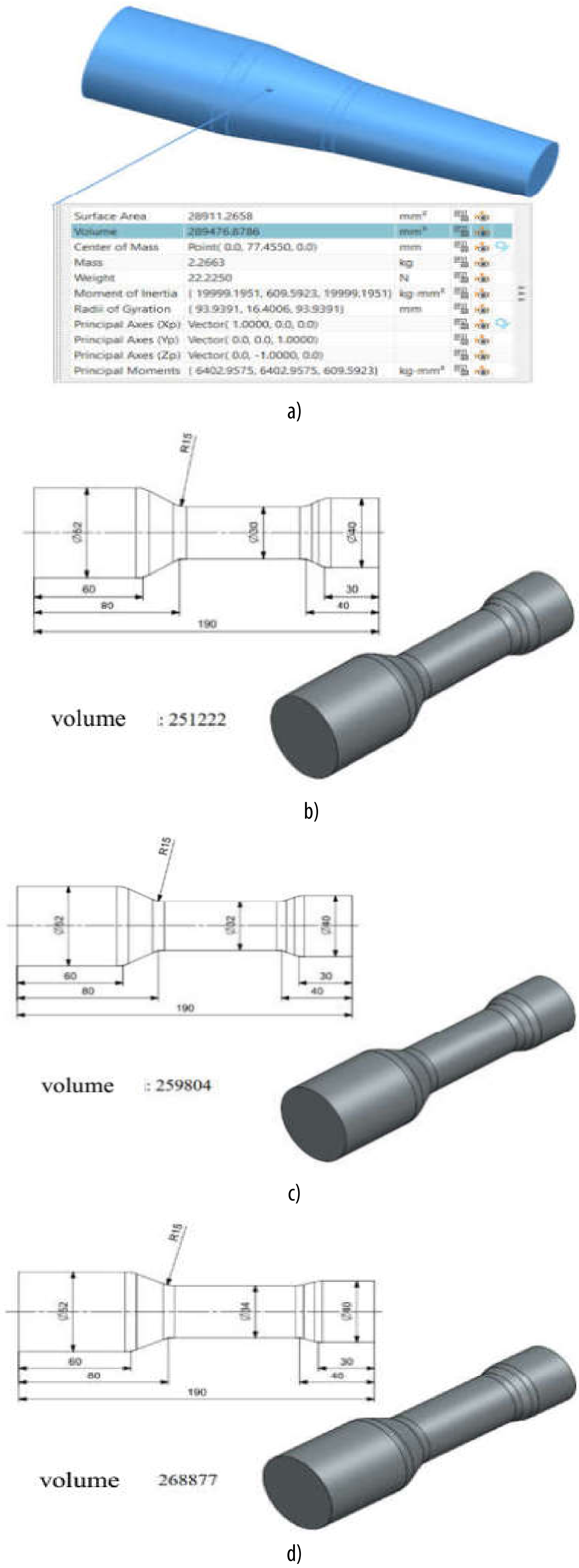
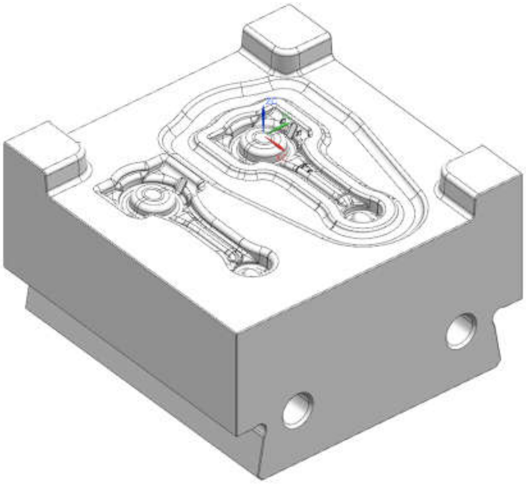


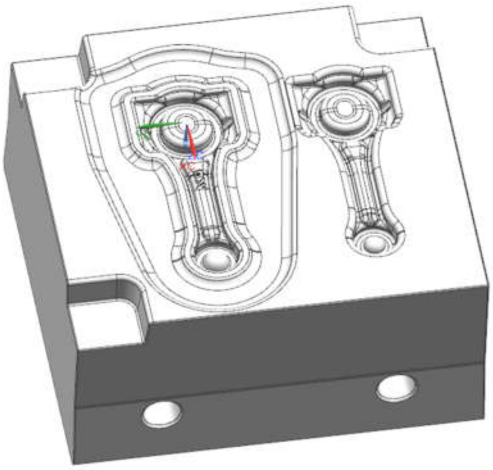
Fig. 3. The geometry of workpieces

a. workpiece 1; b. workpiece 2; c. workpiece 3; d. workpiece 4

Fig. 4. Actual workpieces for forging experimental



Upper die



Bottom die

Fig. 5. The geometry of the forging dies

Table 2. Chemical composition SKD61 steel

C	Si	Mn	Ni	Cr	W	Mo	V
0.4	1.0	0.4	-	5.2	-	1.3	0.9

The experiments were conducted in the Mechanical Press C92K-63 machines. The forging experiments were performed at the temperature of 1200°C to reach the highest deformation rate of the workpiece. The forging conditions were chosen based on the expert's recommendations and the actual mechanical forging machine at the workshop as shown in Table 3.

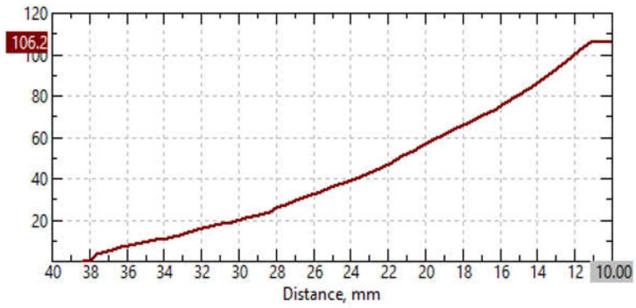
Table 3. Forging experimental conditions

	Raw-Forging	Finish-Forging
Workpiece material	S20C	
Workpiece temperature	1200°C	Inherited from the previous step
Die material	JIS SKD61	
Die temperature	200°C	Inherited from the previous step
Machine	Mechanical Press C92K-63	
Bottom die	Fixed	
Lubrication	Graphite + water	
Stop condition: Distance from upper-die to bottom-die	10mm	0mm

3. RESULTS AND DISCUSSION

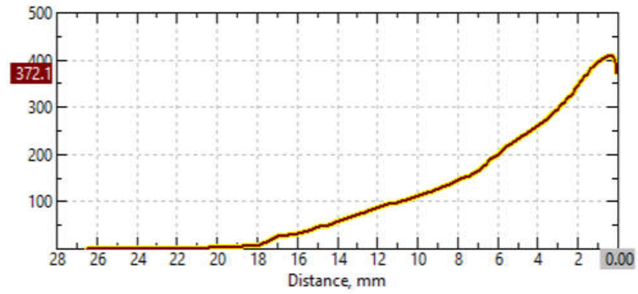
3.1. Evaluation of the maximum forging force

The evaluated results of the forging force was described in Fig. 6. These results showed that in the raw forging process, the maximum forging force was 106.1MN at simulation number 1 (workpiece 1), while in finish forging process, the maximum forging force was 372.1MN at simulation number 2 (workpiece 2). Besides, the maximum forging forces in finish forging were many times larger than that ones in raw forging. However, in all these cases, the maximum forging force was still much smaller than the machine's maximum forging force (3150MN).



Forging force

(Workpiece 1 - raw forging)



Forging force

(Workpiece 2 - finish forging)

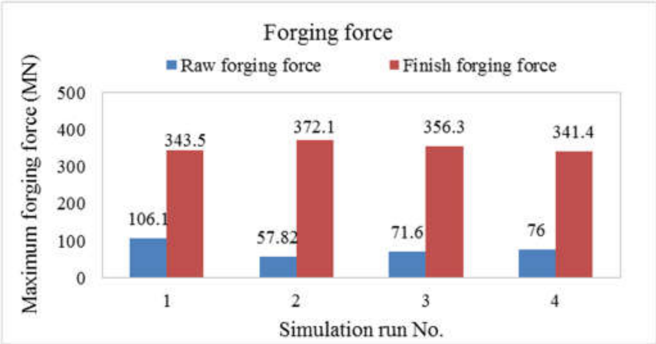


Fig. 6. Evaluation of forging force in raw and finish forging

3.2. Evaluation of the filling ability and the prediction of the laps

The evaluated results of the filling in finish forging process was shown in Fig. 7. The simulation results showed that, in all four simulation cases, the die cavity (the part containing the product) is completely filled. The unfilled regions are all out of the boundary region. These regions usually do not affect on the product quality. Besides, the simulation results also showed that, among four simulations, the simulation number 1 (workpiece 1) has the smallest number of laps. Therefore, the number of generated defects in the hot forging process for simulation case 1 will also be the smallest. So, when using the workpiece type 1 in hot forging, the generated defects will be limited during plastic deformation.

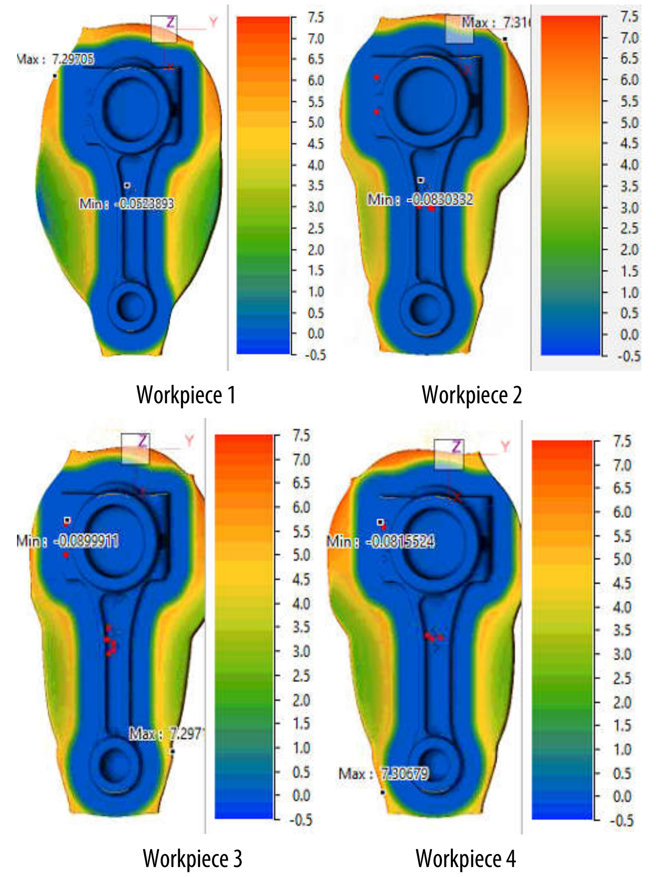


Fig. 7. Evaluation of filling ability in finish forging process

3.3. Evaluation of the forging temperature contribution

The evaluated results of the the temperature distribution in the finish forging process was shown in Fig. 8. The analyzed results showed that, in all simulations, the temperature of the product zone was usually lower than the temperature of the out boundary zone. In the product zone, the temperature was usually greater than 800 Celsius degrees and less than 1200 Celsius degrees. This helps the plastic deformation process to be more uniform throughout the product. In addition, the analyzed results also showed that the simulation No. 1 has a more uniform temperature distribution on the product than other simulations (maximum temperature was 1214.28 Celsius degrees and minimum temperature was 887.635 Celsius degrees). So, the simulated results also showed that, using workpiece type 1, the finished product will have the most uniform temperature distribution, and therefore, the product quality in this case will also be better than that one of other simulations.

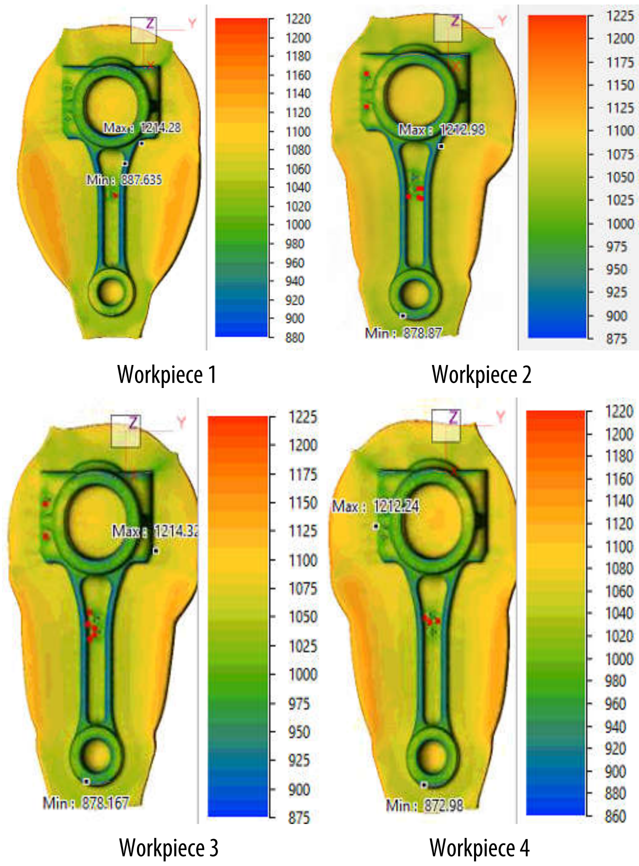


Fig. 8. Evaluation of temperature contribution in finish forging process

3.4. Evaluation of the plasticity stress contribution

The analyzed results also showed that, in the product region, the plastic deformation stress was usually low and fairly uniformly distributed, while in the out of product region, the plastic deformation stress was usually larger. In four performed simulations, the simulation number 1 (using workpiece 1) has lower plastic deformation stress and has a more uniform distribution than other cases.

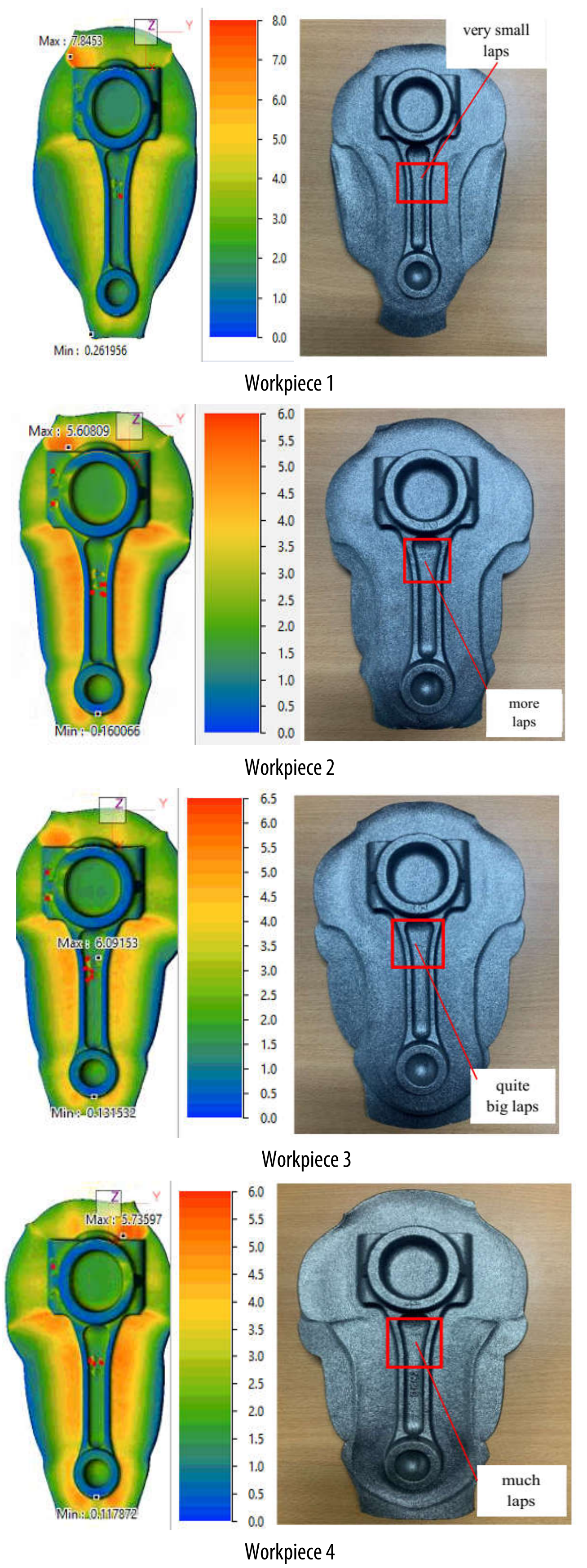


Fig. 9. Evaluation of plasticity stress contribution and actual connecting rods in finish forging process

So, the analyzed results of plastic deformation stress have also shown that using workpiece type 1 in the hot forging process also gives the best quality product. The compared results between simulation and experimental process were also shown in Fig. 9. Once again, these results were also shown that in the actual hot forging process, using workpiece type 1 will be obtained the product with the best quality.

Thus, in this study, applying the FEM (simulated by Qform software), of the four types of the workpiece, the first type that is the one can be used to obtain the product with the best quality in hot forging process. Qform software can be applied to optimize the hot forging process and the die structure to improve the product quality, reduce energy costs, material costs, etc. and these issues will be the futher directions of this study.

4. CONCLUSION

This study was performed by used QForm and experimental method to analyze several properties in hot forging process of a connecting rod. The conclusions were drawn as follow:

- The maximum forging forces in finish forging were many times larger than that ones in raw forging. For all simulation cases, the maximum forging force was still much smaller than the machine's maximum forging force (3150 MN).

- The simulation number 1 (workpiece 1) has the smallest number of laps. When using the workpiece type 1 in hot forging process, the generated defects will be limited during plastic deformation.

- Using workpiece type 1, the finished product will have the most uniform temperature distribution. The quality of the connecting rod in this case will also be better than that one of other simulations.

- Using workpiece type 1 in the hot forging process also gives the best quality of the connecting rod. In the actual hot forging process, using workpiece type 1 will be obtained the connecting rod with the best quality.

- Qform software can be applied to optimize the hot forging process and the die structure to improve the product quality, reduce energy costs, material costs, etc. and these issues will be the futher directions of this study.

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THÔNG TIN TÁC GIẢ

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