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Application of CAD/CAM/CAE in modelling of Die for Hot Forging of Stainless Steel Valve

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Abstract**—** *The study aims to present and analyze the correlation between tools such as the durability of the tool, and the quality of the output product of the valve when stamping the 3-sided valve, the expected result of each case approved by the simulation. The results of the analysis and simulation process will give the advantages and disadvantages of each case, from which to conclude and choose methods of optimal and efficient machining for practical application. The research was carried out with the help of QForm software, that allows finding the optimal interference value that provides a state of compressive stress in complex but fragile particles under actual stamping loads. It can predict defects in the actual hot forging process based on simulation, thereby minimizing defects by many different options such as changing the stopping distance of the pestle, velocity, and embryo*.

Keywords**—** *QForm, Hot forging, FE Simulation, Stainless Steel Forging, Valve Forging*.

I. INTRODUCTION

Hot forging is a method of processing metal by pressure in the hot state, it is widely applied in the processing of motorcycle engine products[1], and gears[3] thanks to its outstanding advantages such as less scrap, achieving higher strength than other methods. The design process for a SUS 304 steel hot forging die is based on forging standards and manuals, such as GOST 7075-89; IN EN 10243-1; DIN EN 10243-2;... First, when designing a forging mold for each type of mold, it is necessary to look up and determine the parameters by the standards recorded in the forging documents and manuals. Then, based on those parameters, proceed to the manufacture of the forging die. Finally, after the mold is completely manufactured, carry out detailed forging and then evaluate the quality, confirm the defects, find the cause, and then repair the mold or workpiece shape. This process is repeated until the final product meets the set technical requirements. This design method has the advantage of a clear and transparent design process, the resulting product meets technical requirements. However, this method also has many significant disadvantages. Firstly, the actual mold set must be test-run, then modified many times before applying to the actual production process. Second, the number of tests can be huge to complete a set of molds. This means wasting workpiece materials, wasting time on practical testing, increasing production costs, and reducing economics. For these reasons, simulation software is often the most accurate choice for optimizing forging dies and designing workpieces to reduce design time and improve product economics[4].

To overcome the above problems and difficulties when forging valve parts made from sus 304 material, the article presents an evaluation of the optimal method for the production process of the SUS 304 steel valve billet by simulation. Finite element simulation (FE) allows for finding the right mold design and optimal workpiece shape. The simulation also produces the profile shape of the mold to compensate for the elastic deformation of the mold and produce the geometric precision of forging products. Plastic cracks in forging objects can be predicted and minimized by simulation[5]. The presentation model is realized in QForm 10 metal forming simulation software. The software will automatically apply theories to the analysis process, including plastic deformation and finite element method described in Figure 1. The results of this work make it possible to predict loops, and locate incomplete defects and forging forces required for the actual process. From there, find the most optimal mold.

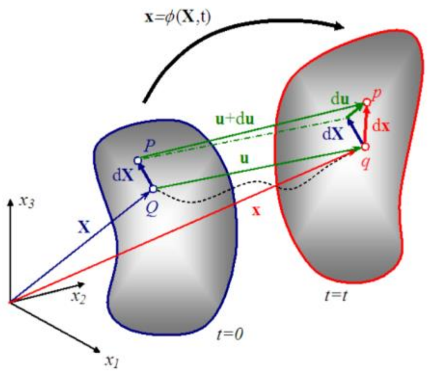

Figure 1. Description of geometric plastic deformation.

The applied formula of the finite element method:

$$f(x) = \sum_{m=1}^{M} \varphi_m(x);\ \varphi_m(x) = \frac{f_{n+1} - f_n}{x_{n+1} - x_n}(x - x_n)$$

In addition, there are several other related scientific theories such as friction in the process of plastic deformation, and metal flow pressure.

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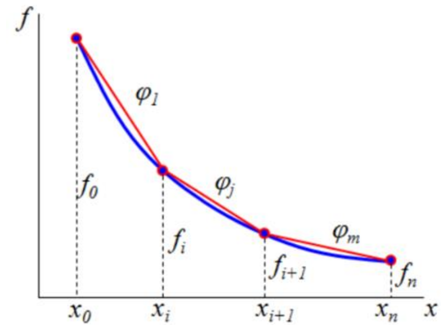

Figure 2. Diagram depicting finite element method

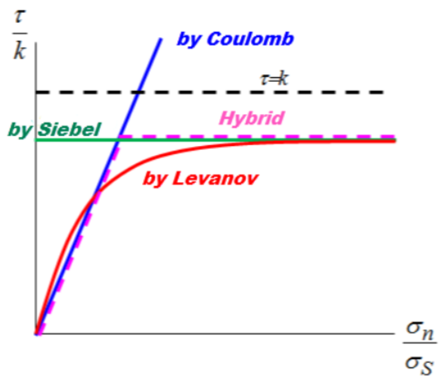

Figure 3. Charts the crossover between friction theories.

II. MATERIALS AND METHODS

FE-QForm simulation software was applied to predict the results of the stamping process, simulating the hot stamping process in this study. First, create stamping models with some CAD/CAE software such as Inventor, and Solidworks,... Next, use software with mold-forming functions based on the stamping object model, e.g. NX to create the upper and lower molds. Depending on the stamping structure, it is possible to create other tools to coordinate shaping during the stamping process, in the study valve details are stamped 3 holes with the most optimal depth. Finally, put the data of the stamping object model, dies, remaining tools, and QForm software, set the parameters, and then proceed to simulate the stamping process. The tissue results of two different methods will be analyzed and compared to find the solution that brings the most optimal effect.

Materials of workpieces and dies

The workpiece material is SUS 304(JIS) stainless steel with chemical percentage composition according to Table 1.

Table 1. The chemical composition of JIS stainless steel 1 SUS 304 in percent

C	Yes	Mn	P	S	N	Cr	Ni
< 0.07	< 1	< 2	< 0.045	<0.015	<0.11	17.5÷19.5	8÷10.5

The mold material is H13(JIS) alloy steel with chemical percentage composition according to Table 2

In this study, the forging process was carried out at 1200°C of workpiece, so that the state within the fastest plastic deformation range could be achieved within the permissible temperature range. The parameters used in the hot forging process are based on the recommendations of experts, who have long experience in the stamping industry and according to the parameters of the stamping machine in the actual workshop. All parameters are summarized in Table 2.

Table 2. The chemical composition of AISI/SAE H13 in percent

C	Si	Mn	P	S	Cr	Mo	V
0.35÷0.45	0.9÷1.2	0.25÷0.55	< 0.03	<0.03	4.5÷5.5	1.2÷1.7	0.85÷1.15

Table 2. Forging process parameters

	Raw-Forging
Workpiece material	SUS304
Workpiece temperature	1200°C
The material	H13
Workpiece temperature	300°
Machine	Mechanical Press C63-KJ
Below the	Fixed
Lubrication	Graphite + water
Stop condition: Tool 2 to tool1	25.5 mm
Stop condition: Tool 2 to tool1	12 mm
Tool 3 to plan1	18 mm

Simulation process in QForm

The four main steps of a simulation process in QForm 10 are shown in Figure 2.

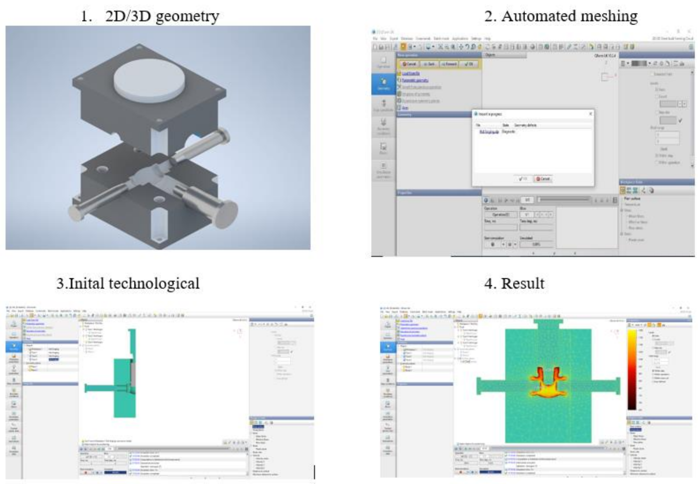

Figure 4. Simulation process in QForm software

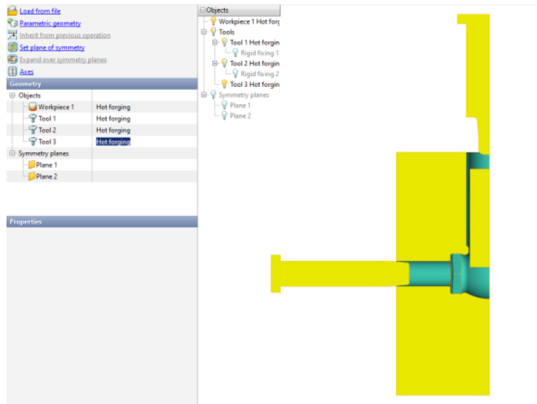

Figure 5. Initial geometric data of workpieces and dies.

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In the first step, the geometric data of the workpiece and mold are prepared and imported then auto matic meshing and simulation conduction. This is an important step because the accuracy of the imported geometric data will directly affect on the results of the simulator.

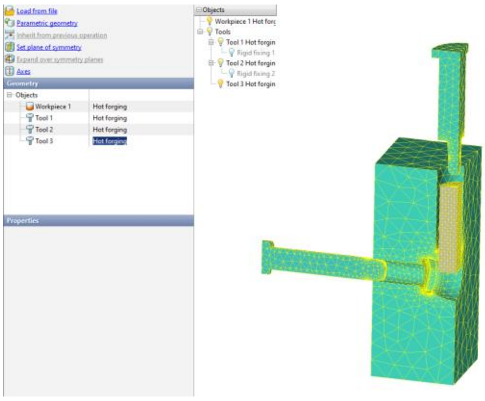

Figure 6. Meshing initial geometrical data using the adaptive meshing tool.

In the second step, the imported geometry data of workpiece and dies will be used for meshing by QForm's adaptive meshing tool.

After meshing the initial geometry data, QForm's adaptive meshing tool outputs the mesh properties of the workpiece and mold before shaping shown in Table 3.

In the next step, the initial parameters are set and filled in the position corresponding to the parameters required by the software. Which, include material parameters, temperature, stopping conditions of workpieces and molds

The workpiece used for processing products are billets made from SUS304 steel material. Based on the material library of QForm software, the properties of SUS304 steel can be seen as shown in Figure 7.

Table 3. Mesh properties of initial geometrical data

Object	Nodes on surface	Internal Nodes	Total Nodes	Surface Elements	Volumetric Elements
Workpiece	583	187	770	1162	2768
Tool 1	3368	2745	6113	6732	27146
Tool 2	1103	361	1464	2202	5318
Tool 3	1866	789	2655	3728	10192
Total	**6920**	**4082**	**11002**	**13824**	**45424**

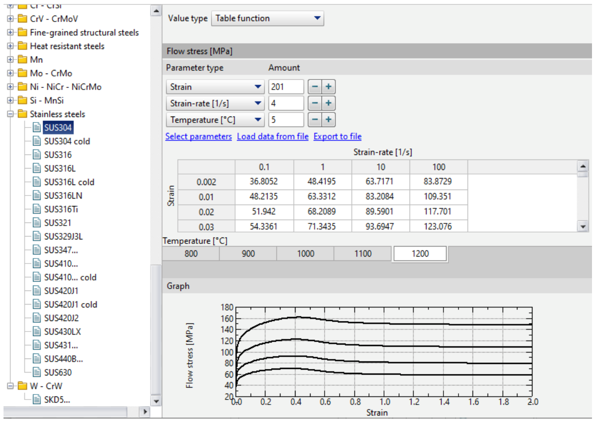

Figure 7. Embryo parameters

The upper dies, lower dies, and pestle forging material are H13. Technology parameters of temperature, forging force, material, and movement method of the instruments are shown in Figure 8. In this experiment, the two halves of a mold move in the OZ direction, the central pestle moves on the OY axis, and the two side pestles move in the OX direction. The mold is heated to a temperature of 200°C as the actual manufacturing conditions.

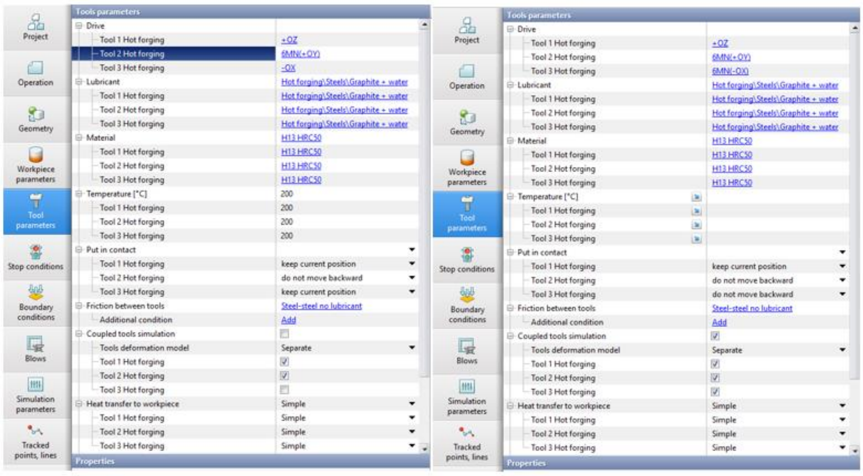

Figure 8. Die parameters

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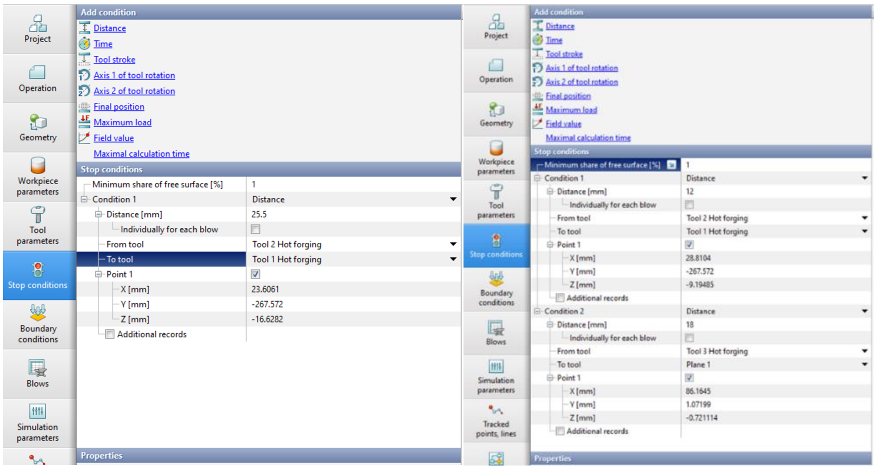

Figure 9. Stop condition.

The stop conditions of dies are set as shown in Figure 9.
In the final step, the necessary results are analyzed to survey the quality of the product in practice, thereby finding ways to change the geometry of the mold or technological parameters accordingly.
Use the software's adaptive meshing tool to check the figure data properties after finishing the forging process obtained in Table 4.

Table 4. 4 Mesh properties of geometrical data after finishing the forging step

Object	Nodes on surface	Internal Nodes	Total Nodes	Surface Elements	Volumetric Elements
Workpiece	3928	3171	7099	7852	31449
Tool 1	3368	2745	6113	6732	27146
Tool 2	1103	361	1464	2202	5318
Tool 3	1866	789	2655	3728	10192
Total	**10265**	**7066**	**17331**	**20514**	**74105**

After finishing the forging process, the simulation results are analyzed to predict product quality through many factors, then from product quality to mold modification options or assess the feasibility of the mold when forging.

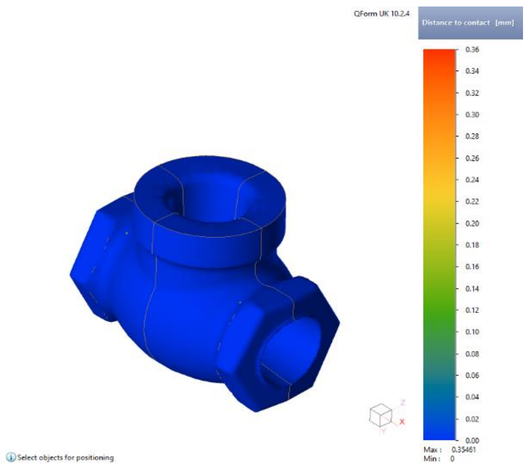

Figure 10. Distance to contact between the workpiece and the die surface in mm

III. Results and Discussion

Filling

The filling of the workpiece material in the mold is shown by the distance so that it comes into contact with the surfaces of the mold lumen as shown in Figure 11. The results show that the mold is almost 100% filled, with only a few small corner positions that are not filled represented by very small dots with a distance from the largest mold of 0.35461 mm as shown in Figure 10.

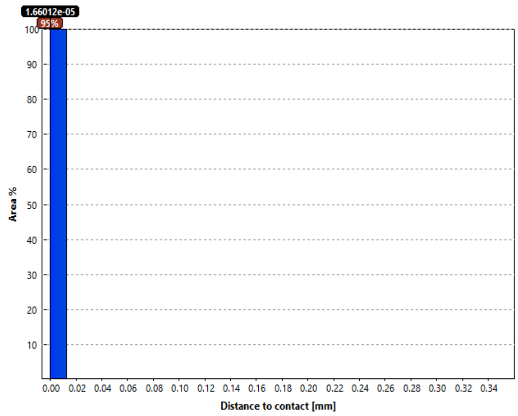

Figure 11. Distribution of the distance to contact between dies and workpiece in mm

The distribution of the filling area of the two dies demonstrated the geometric fit of the two dies during the forming process as shown in Figure 11. However, it is also necessary to further evaluate the possibility of defects in further analyses before proceeding to trial production in practice.

Die fatigue failure

The tool life of forging dies are evaluated as the forging cycle parameter per percentage of wear volume.
First, the fatigue failure of the horizontal dies can be seen in that the die begins to wear out by 0,25 % of the volume after for 1000 forging cycles. The wear is continue increased until 5% volume wear at 3432 forging cycles Figure 12.

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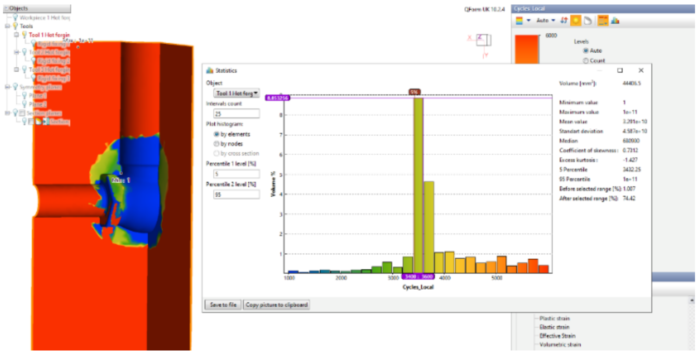

Figure 12. Wear diagram as a percentage of the volume of the die

Next, the vertical dies are pressed by greatest pressure because it is responsible for forming the main as well as the first tool that exerts the force of forging on the workpiece material. After about 500 cycles the vertical dies begins to wear at the top area and continue wear until 2370 cycles, which the won is predicted of 5% of the volume, the result as shown in Figure 13.

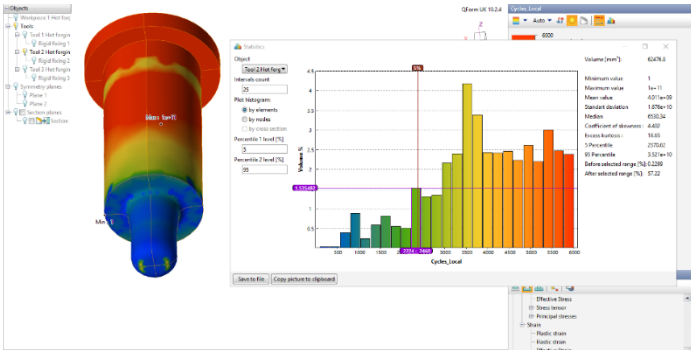

Figure 13. Wear diagram as a percentage of the volume of the tool 2

Finally, after about 1500 forging cycles, the wear was drammatic increased. The wear is continue reised to 5% at around 3400 forging cycle, Figure 14.

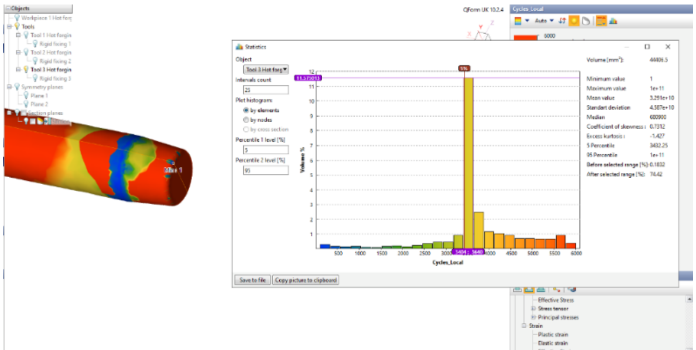

Figure 14. Wear diagram as a percentage of the volume of the tool 3

After the fatigue failure of the dies are predicted and determined, it is possible to consider the degree of damage to assess the suitability in the mold structure, thereby adjusting reasonably to improve the tool's life cycle and plan a schudule for maintainnent.

Lap defect

Product defects are one of the major concerns when calculating and designing dies in the past because it is difficult to identify all the factors that cause defects, only experiments can be carried out and then adjusted little by little. However, once simulation software is available, it is unnecessary because it can clearly show even the smallest defects in Figure 15.

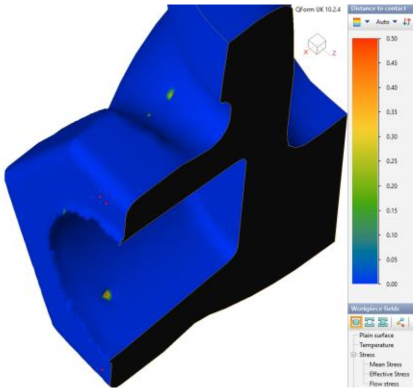

Figure 15. Material filling after the forging process

After much time of development, the day simulation software is trusted due to its accuracy and convenience of simulation software. FE simulation is highly efficient, easy to perform, fast, and costs significantly less than experimental, so simulation software is essential.

The forging force load

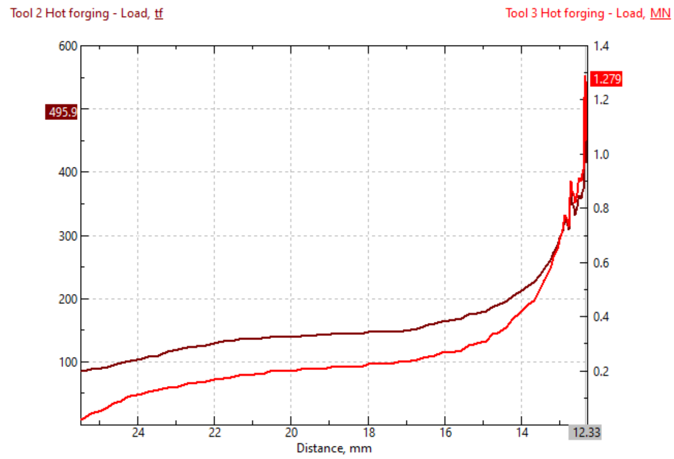

Figure 16. The relationship between forging force and the distance of 3 die's parting surface

The loads are inversely proportional to the different surface ways between the two dies and between the pestles. The maximum load achieved has a value of fewer than 600 tons of force when the two faces of the die come into contact and also when the pestles in the last position have been pre-set Figure 16. From here, it is seen that the load in this experiment is smaller than the forging machine load of 3150 tons, which shows that the structure of the die and pestle is reasonable.

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IV. CONCLUSION

The purpose of this study was to investigate the feasibility of hot forging of valve parts using stainless steel SUS304 material. The CAE software namely QForm was utilized to conduct analysis and simulation, which helped to predict the quality of hot products as closely as possible to actual quality. The following findings and recommendations were made as a result of this study:

1. The research demonstrated that hot forging valve parts using SUS304 material is a feasible method as the hot forging dies set can complete approximately 2500 cycles before requiring replacement.
2. The research process also revealed the superiority of QForm software's FE simulation tool in predicting results, which can offer increased accuracy, time-saving, and cost benefits over conducting experiments.
3. The parameters provided in this study can assist manufacturers in calculating, planning maintenance, and ensuring high-quality products.
4. This highly practical research can serve as a foundation for future studies.

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