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A case study: Comparative examination of active punch adjustment and relative fixation in multi-point forming for 3d free-form shape

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Abstract

Multi-point sheet metal forming (MPF) is one of the versatile methods for shaping sheet metal. Mostly utilized in prototypes for automotive and aerospace products, MPF saves time and money. In this study, active punch modifications and relative fixation were applied to examine how different forming types affect multi-point forming. By using the finite element program, three-dimensional shape of multi-point forming (MPF) were modeled and examined. This form is made of 1 mm thick aluminum 1100 sheet metal. Based on the models' needed load and effective stress distributions for sheet metal, three different diameters, 10 mm, 12 mm, and 14 mm, were examined. Based on the results, active punch adjustment for all pins was a more appropriate forming type for this shape.

Keyword: Multi-Point Forming; Sheet Metal; Finite Element; Punch.

1. Introduction

The manufacture of small batches and prototypes is better suited to flexible forming processes, such as the one known as multi-point forming (MPF). A set of opposing changeable equipment with pin matrices can take the place of traditional solid forming tools. The two industries that employ sheet metal components with 3D shapes the most are the automotive and aviation industries. This kind of sheet metal is produced using the sheet metal forming technique. The research on the techniques and theories of multi-point forming for sheet metal were performed in [1]. Multi-point die forming, and multi-point press forming were the main categories that were referred to as MPF in multi-point forming principles. Then, the MPF's ability to form was investigated. The apparatus section includes a description of the process's components and operating ideas. The hydraulic press, the upper and lower element groups, the computer control subsystem (CCS), the CAD integrated software subsystem (CADS), and CMM are all parts of the multi-point die forming process. Design ideas and adjustment modes were presented in the conclusion. The use of ABAQUS finite element software to simulate the multi-point forming of the front panel of the rail has been studied in [2]. In order to complete their multi-point forming process, they use digital control and die systems. Use of MatLab was made of the MPF control system and orientation regulating system models. Finite element analysis reveals that this approach is appropriate for sheet metal objects having 3D forms as a result.

Some defects, dimpling and wrinkling, are encountered in multi-point forming process. By adjusting factors such punch speed, punch pressure, and elastic pad thickness, dimple formation and wrinkling were reduced using multi-objective optimization in [3]. The evaluation of dimpling and wrinkling under alteration in these three MPF parameters benefits from the computational efficiency of traditional Kriging. A genetic algorithm for multi-objective optimization is used to determine the Pareto fronts for the dimpling and wrinkling measures, and the TOPSIS method for ranking desires according to how close they are to the ideal solution is used to identify the optimal choice among the Pareto optima. The

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TOPSIS solution is then numerically compared to the results of a complete model simulation, and it is empirically proven by its application to a finished product. As a consequence, the TOPSIS solution lacks the appearance of wrinkles and dimpling.

Additionally, some 3D shaped parts forming have studied in several studied. The process of hull structures and offshore structures forming has been studied in [4]. Such curved plates have traditionally been produced using flame bending. However, because of the uncertain process and lingering distortion, it is challenging to obtain the required shape precisely. The production of 3D ship hull plates using the multi-point forming mechanism with square press heads is a novel process. However, the main issues with the cold-forming process are residual stress and springback. This study uses theoretical derivation methods and numerical analysis to investigate the residual stress distribution in the multi-point formation. The theoretical model's predictions for maximum residual stresses agree quite well with the outcomes of the computations. In [5], the morphology of relationship between the objective surface and the multi-point punch components in the multi-point warm press forming process was examined. The multi-point CAD/CAM application was used to calculate the punch height and modify the punch location. The effect of the process temperature, elastic pad, and load on the precision of the forming was examined in a series of multi-point warm press forming studies. Then, using a multi-point hot press forming method, Corian sheets were shaped to 3D spherical and saddle-shaped parts utilizing the best forming parameters. Both saddle-shaped and spherical components produced at 165 °C and 100 kN of forming force showed best surface quality and form accuracy. It shows that the MPWP forming technique can successfully produce 3D Corian sheets parts. In [6], theoretical investigation, finite element analysis, and experiments were used to study the springback phenomenon of the hyperbolic component. The study includes the recently created springback compensation technique, the resulting surface curvature-based springback compensation formula, as well as further die surface correction and fitting. The results demonstrate that the multi-point forming technique for corrosion-resistant aluminium alloy hyperbolic components may effectively reduce springback error when combined with the springback compensating method established in the study.

The effects of forming types on 3D free-form surface multi-point forming was investigated in this paper. Two kinds of types, relative fixation and active punch adjustment, were used to compare with each other. Al 1100 sheet metal was employed as workpiece material by using 10 mm, 12 mm and 14 mm pins for multi-point forming dies. Relative fixation and active punch adjustment were modelled and simulated in finite element analysis. Experiments were carried out only by using 12 mm pin with relative fixation manner to verify the simulations.

2. Experimental Setup and Finite Element Modelling

2.1. Workpiece Material and Experimental Setup

In the experiment and finite element modelling, sheets of the aluminium alloy 1100 H14, also known as ASTM B209, with a thickness of 1 mm, were employed. Al 1100 is often used as shaped components in the automotive and aerospace sectors due to its low density, high strength to weight ratio, toughness, excellent ductile behaviour, and fatigue resistance [7].

Tensile tests were used to determine the tensile characteristics of Al 1100 aluminium alloy sheet. Tensile tests were carried out using the Shimadzu AG-X machine and the ASTM E8 standard. The 1 mm/min test speed was chosen. Following tensile testing, the specimen is shown in Figure 1. The longitudinal yield strength of 105 MPa was calculated using the offset yield technique, and the tensile strength of 112 MPa was obtained in Figure 2[7].

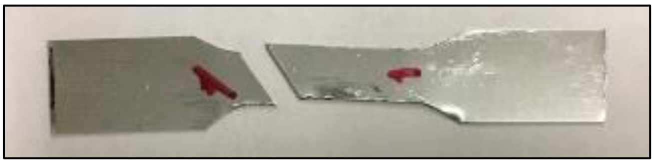


Figure 1 Tensile test specimen

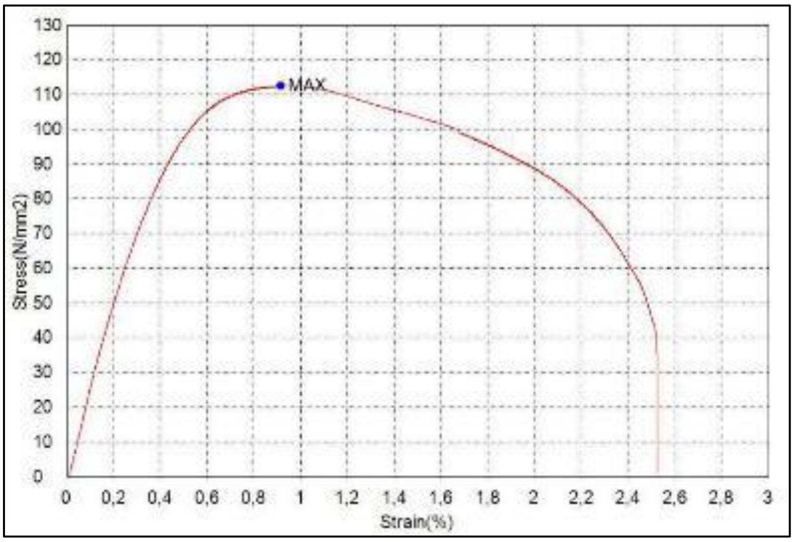


Figure 2 Tensile test result [7]

Experimental investigations for multi-point forming were conducted in order to specify some boundary conditions of finite element modelling and validate finite element results produced in DEFORM-3D Ver 6.1. As indicated schematically in Figure 3, experimental work was done utilizing a die set for multi-point formation with matrices of 7-row by 7-column. Die setup was built as a method of relative fixation.

According to the mechanical properties of AISI 4140 steel [8], all components in the multi-point forming die set were produced. M8 thread holes are produced on both the top and bottom plates. Each hole is 15 mm from the center to the center. The diameter of the pins is 12 mm, and their length is 87 mm. Additionally, an M8 internal hole was manufactured with pins that were 45 mm long. Additionally, pins have tips with a 6 mm radius. M8 bolts with a grade rating of 10.8 were used to join plates and pins together. Figure 4 (a), (b) and (c) show the pins dimensions.

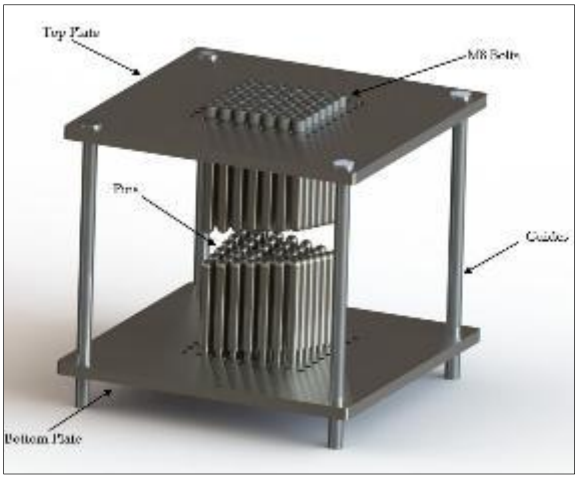
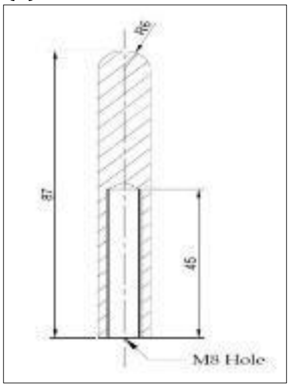


Figure 3 MPF die set

(a)

(b)



(c)

Figure 4 Pin dimensions

3D free-form surface shape was utilized in the multi-point forming process when conducting experimental works and finite element simulations. This final shape was made from a blank sheet of 150 by 150 mm. The last shape of 3D free-form surface is shown in Figure 5.

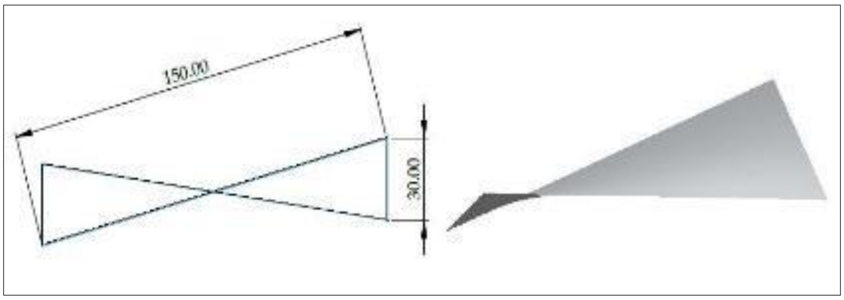


Figure 5 3D free-form surface

Using a Utest universal testing device with a 20 kN maximum load capacity, the press source was established. The press head was operating at a stroke rate of 1 mm/min, forming sheet metal at room temperature. SEA 40 oil was also used to lubricate the joint between the sheet and the pins. The die set's forming areas' geometry was created by separately changing the pin height. The needed pin heights were calculated using CAD data in Solidworks after the sheet metal's forming area was divided into seven 7 by 7 matrices. Figure 6 shows the die and sheet during the forming process.

Figure 6 The die and sheet during the forming process

2.2. Finite Element Modelling

In this work, finite element software DEFORM-3D Ver. 6.1 was employed. Both relative fixation and active punch adjustment models were built. Analysis was done using the pin diameter effect for each model. In FEM, pins of 10 mm, 12 mm, and 14 mm are used. Comparisons are made between effective stress distribution, and maximum needed loads.

AL 1100 is a weaker material than AISI 4140 steel during the forming process. Plates, bolts, and pins are simulated as rigid bodies due to this and to shorten simulation run times. Modelling the workpiece included using elasto-plastic material. The DEFORM-3D database for cold forming contains information about the elasto-plastic material properties of AL 1100. Figure 7 shows the consistency between the database flow stress-strain curve for Al 1100 and the calculated flow stress-strain curve from the tensile test [7]. The elastic modulus is 70 GPa, and the Poisson's ratio is 0.33 [7].

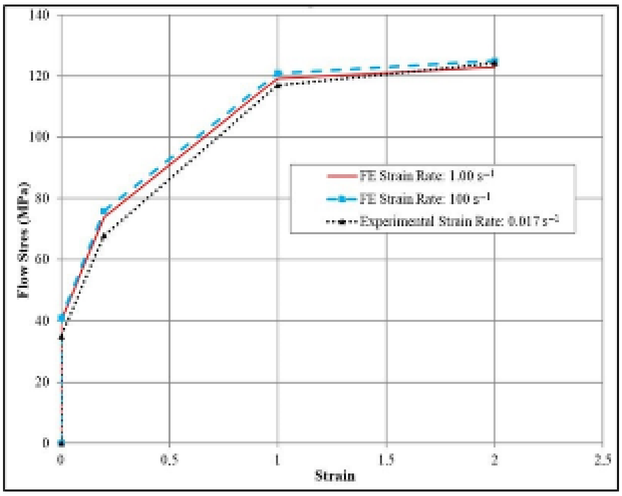


Figure 7 Flow stress-strain curve [7]

Table 1 displays the total number of sheet metal nodes and components for form of relative fixation and active punch adjustment.

Table 1 Elements and Nodes number

Pin Diameter	Elements Number	Nodes Number
10 mm	31138	12018
12 mm	31138	12018
14 mm	31138	12018

3. Results and Discussion

3.1. Finite Element Simulation Result

For the form, the relative fixation (RF) adjustment was made. Pins were set up in this adjustment before the forming process, and the sheet metal was then loaded. Pins moved throughout the forming process in active punch adjustment (AP) to create sheet metal. Pin heights and movement ranges were derived using shape-specific CAD data.

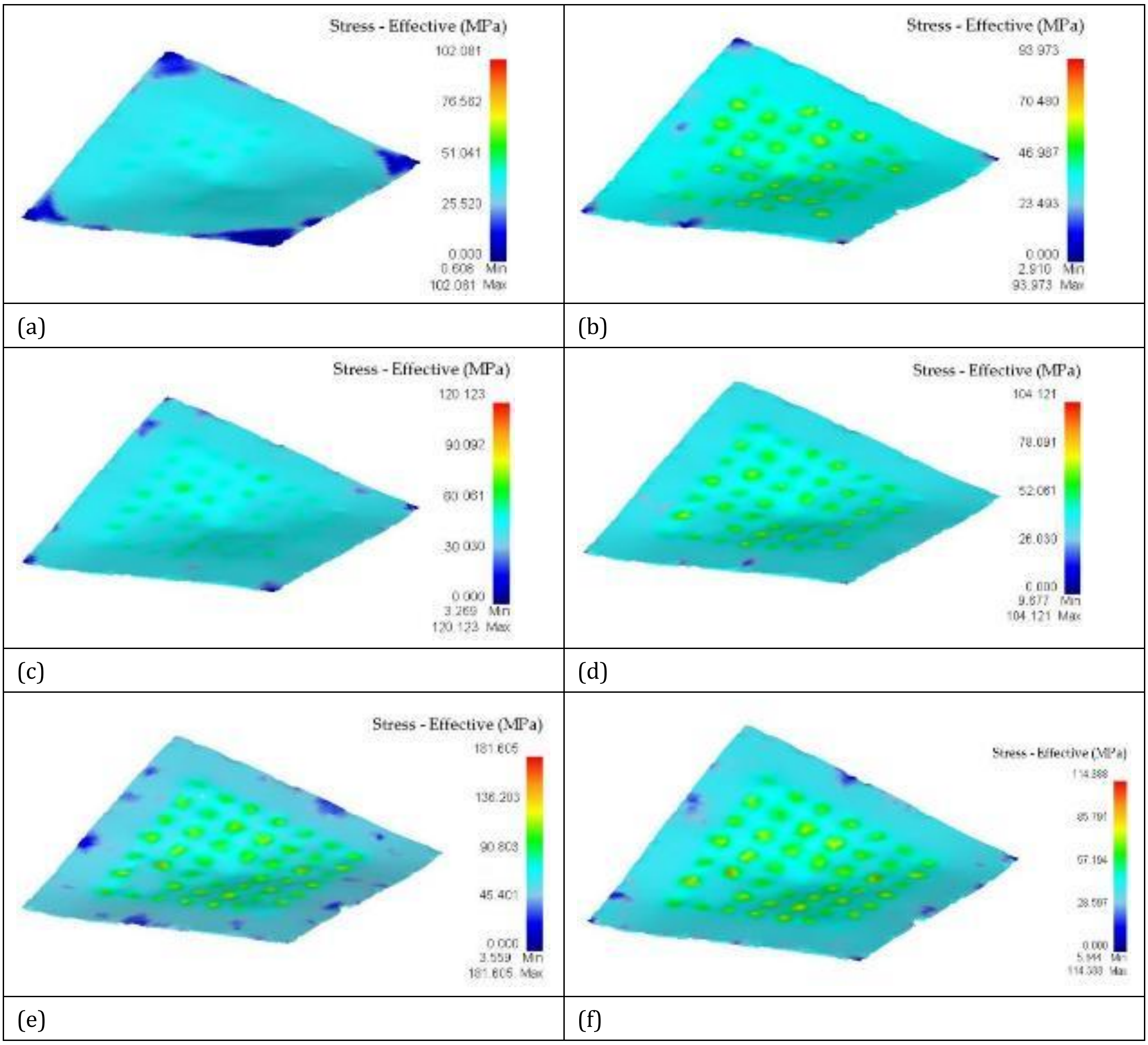


Figure 8 The effective stress distributions of (a) F3 RF 10 mm, (b) F3 AP 10 mm, (c) F3 RF 12 mm, (d) F3 AP 12 mm, (e) F3 RF 14 mm and (f) F3 AP 14 mm pin

Stress during sheet metal forming has a direct impact on the sheet metal's formability, according to [9]. The different effective stress distributions of the adjustments for all pin diameters are shown in Figure 8. For pins with diameters of 10 mm, 12 mm, and 14 mm, respectively, the variances were calculated to be 8.6%, 15.3%, and 58.7%. Additionally, for 14 mm forming operation, tearing was observed for both type of forming.

The forming loads must be compared for two forming directions. Figure 9 shows the load-stroke comparison of RF and AP adjustments. The percentage differences were calculated as almost 12.7 %, 16.5 %, and 33.8 % for 10 mm pin, 12 mm pin, and 14 mm pin forming, respectively.

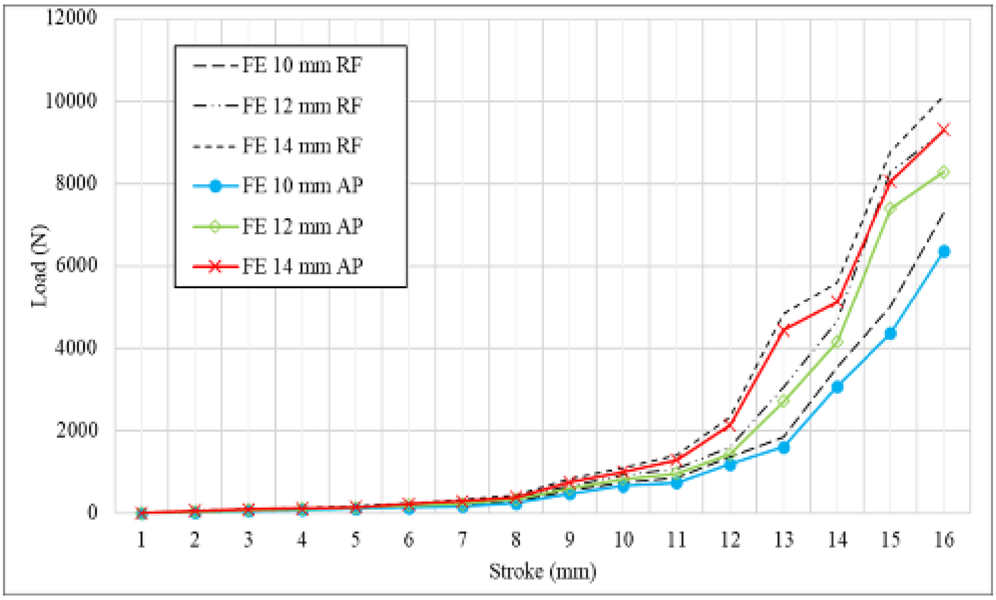


Figure 9 Load – Stroke graph

As can be seen from the figures above, active punch adjustment was considered to be a more suitable method for this shape.

3.2. Experimental Results

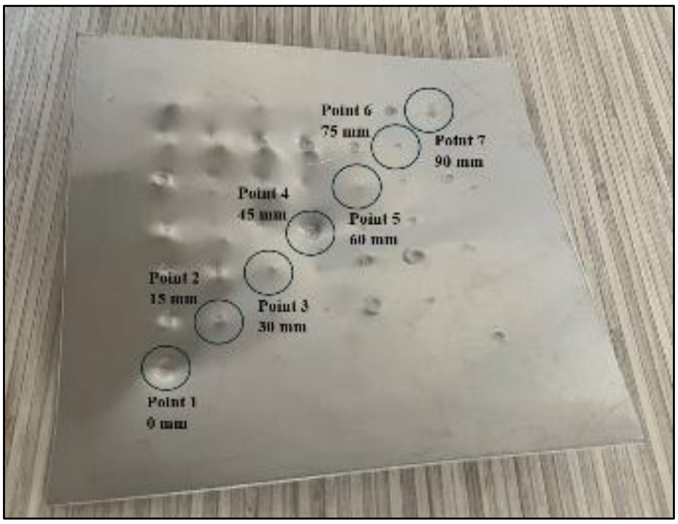


Figure 10 The Final form

By using the previously indicated relative fixation adjustment (RF) of forming for the shape, experiments were carried out using a pin with a diameter of 12 mm. Thinning of contact points and load-stroke diagrams were utilized to validate the numerical calculations. The final shape of the workpiece after the experimental works are shown in Figure 10. Also, in this Figure 10 shows the contact points where thinning was measured. The measured thickness of the experimental and FE analysis specimens of the 12 mm pin forming is shown in Figure 11. Points 1, 4, and 7 on the shape displayed the most thinning, similar trend in [7]. Points 1 and 7 had thicknesses of over 0.866 mm and 0.84 mm, respectively, while point 4 had a thickness of almost 0.83 mm. Analysing the thickness graph reveals a similar pattern. As a result, the analysis and modelling of FE's results have been validated.

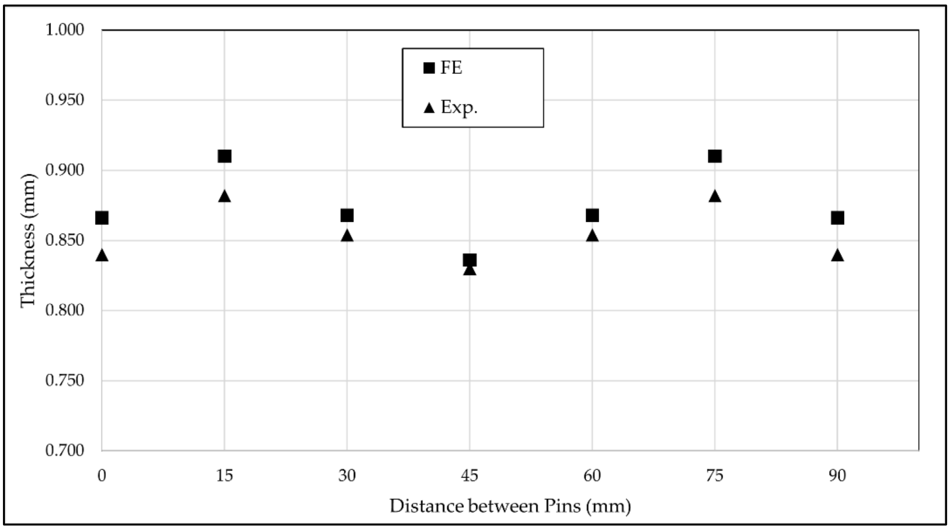


Figure 11 Thickness of the part

Both the load-stoke curves produced by the experimental investigation and the corresponding FEA results are shown in Figure 12. The maximum forming load for the shape was discovered to be about 9500 N for experiment. The calculated percentage difference between the experimental and FEA findings was 2.4%. Similar trends were visible in the thinning graphs and the load-stroke graphs accordingly in [7]. As a result, it was determined that the results of the finite element modelling and analysis seemed reliable.

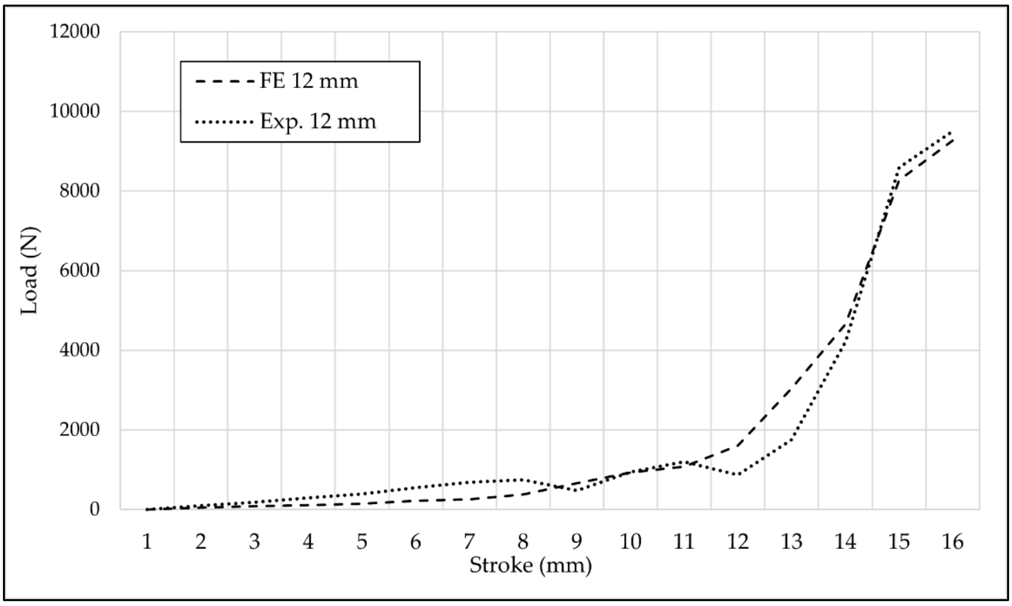


Figure 12 The Load-stroke graph

4. Conclusions

The multi-point forming technique 3D free-form surface part's finite element modeling and experimental investigations were covered in the sections before. After considering all the data from the study, it is possible to draw the following conclusions:

- The examination of the impacts of pin diameter and the variance in punch adjustments on the multi-point forming of 3D part constitutes the study's key contributions.
- The largest diameter pin (14 mm) produced the highest effective stress values, but a 10 mm diameter pin produced the lowest stress distribution values.
- For 3D free-form surface part, the active punch adjustment method was an appropriate way compared to the relative fixation method.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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