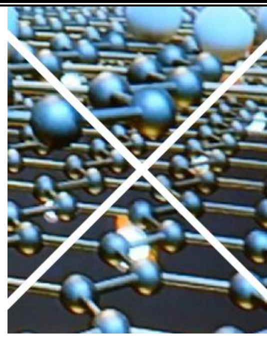
TIJMET, Vol. 003 (2020) 120-130

The International Journal of

Materials and Engineering Technology

ISSN: 2667-4033
TIJMET ID: 200302007 (11 pages)
Type of the Paper: Article
Received 27.02.2020 Revised: 09.11.2020 Accepted: 10.12.2020 Published (Online): 30.12.2020
Journal homepage: http://dergipark.gov.tr/tijmet



PRINCIPLES AND FINITE ELEMENT SIMULATION OF MULTI-POINT FORMING TECHNOLOGY FOR SHEET METAL

MAHMUT TANDOGAN [*1], OMER EYERCIOGLU [2], MUSTAFA DULGER[3]

[1] Adiyaman University, Engineering Faculty, Mechanical Engineering Department, Adiyaman, TURKEY.
[2] Gaziantep University, Engineering Faculty, Mechanical Engineering Department, Gaziantep, TURKEY.
[3] Istanbul Cerrahpasa University, Engineering Faculty, Mechanical Engineering Department, Istanbul, TURKEY.

Abstract

Multi-point sheet metal forming is a relatively new and developing flexible sheet metal forming technology. In this type of forming, the die is separated into small discrete pins which can be arranged in height. So, this reconfigurable die meets the customer requirements mainly used in prototyping of sheet metal parts. Dies in the conventional forming process are replaced with these pairs of matrices of pins. In this study, the fundamental principles of multi-point forming (MPF) are examined and the main parameters of this process are determined with numerical analysis. In FE modeling each pin is actively controlled to form the sheet part. Aluminum 1100 H14 with a 1 mm sheet is used as workpiece material for sheet metal part and finite element simulations are employed then, differences between solid die forming and multi-point forming are indicated. Tearing and dimple formation are investigated and compared with the conventional methods. The results of the numerical analysis show that multi-point forming is very suitable for forming sheet metal with complex shapes.

Keyword:, Multi-point Forming, Finite Element, Sheet Metal.

1. Introduction

Three-dimensionally formed sheet metal parts are widely used in aerospace, aircraft, automobile, and architectural industry. These parts are produced by using metal forming dies. During the design and development of them, prototypes are prepared. Conventional prototyping methods are time-consuming and so as results in high production costs.

Many dies must be manufactured and small changes of the part geometry require new die components. These problems can be overcome by using a multi-point forming (MPF) technique, also called reconfigurable die forming. Solid dies in conventional forming methods are divided into many discrete pins, utilizing punch elements to form the sheet metal instead of solid dies. This means that MPF dies are used to shape different geometries using one die set by adjusting the pins in the dies. The first idea was introduced by Nakajima; discrete pins are mounted on the headstock of NC milling machine then all pins pressed to sheet metal [1]. Discrete pin dies were arranged to the desired shape, fixed into a rigid tool that behaves as a solid die set by using the NC system [2, 3]. Reconfigurable discrete die forming design and analysis for sheet metal was examined in Walczyk's study [4]. A matrix of densely closed packed pins was used to construct a rigid tool. Frictions between pins and pin-side clamping were investigated. Also, improvement of carrying forming load capacity was studied [4]. Deformation characteristics, fundamental principles, and some defects were investigated by describing four main types of multi-point forming. Non-spingback forming was obtained due to step-by-step forming and that is used to shape for large parts with small apparatus [5].

The main problems related to control of the multi-point forming process were discussed and suitable numerical solutions were also investigated. Positons of each punch for multi-point die to form three dimensional sheet part must be computed. These computations require the calculation of analytical derivatives of objective shape. 18 DOF high precision triangular finite element technique was used for a solution to this problem [6]. Numerical analysis for multi-point forming was described on the basis of updated Lagrangian formulation and elastic-plastic material model. Contact points between sheet and pins are discontinuous and were modeled based on the penalty method and on the Coulomb non-classical friction law of elastic-plastic formalism. The finite element package code was newly developed for analyzing the multi-point sheet metal forming. Applicability of the algorithm was shown as a result and numerical examples stated good general coincidence with experiments reported in the literature [7]. Multi-step and sectional forming of MPF were applied for dish head to obtain principles and characteristics of these methods. Numerical simulations were investigated for both methods. Multi-step forming deformed the sheet more equably. It can restrain wrinkles effectively and improve the deformation capacity by optimizing the deformation path [8].

The principles of multi-point die forming (MPDF) and multi-point press forming (MPPF) are described. Two groups of forming pins are changed with continuous male and female dies. For any shape changes in the sheet metal part, all elements' position was set by computer control. CAD software, two-element arrangements, computer control system, press, and CMM are the components of MPDF. The results show that three-dimensional sheet metal parts were formed without tearing [9]. Reconfigurable bottom die and a rubber top die were utilized in multi-point sandwich forming (MPSF). The effect of workpiece and tool dimensions and workpiece properties were investigated. Two types of elastic material and three types of sheet metal were used in experiments. The results show that increasing thickness reduces the dimple formation and increases the forming load. Also, rubber pad stiffness has an effect on the geometry of the final product [10].

Elastic pads with different thicknesses were investigated to obtain cylindrical surfaces in finite element analysis by applying a multi-point bending process as a specified shape. Plastic dissipation energy, stress components, shape error, and maximum ductile damage are the main parameters.

To find the suitable thickness of the elastic cushion, these parameters were introduced and analyzed in finite element simulations. As the result, each value of four evaluating indicators is decreased, and their distributions become more uniform on the deformed blank by adopting the elastic cushion [11]. The dimpling and wrinkling by adjusting parameters such as the punch speed, punch pressure (cushion compressive strain ratio), and elastic cushion thickness were aimed to eliminate through multi-objective optimization [12]. Elastic pad thickness, coefficient of friction, pin size, and pin-head radius of curvature on quality of formed part in multi-point forming was investigated. Optimum values for these parameters were defined as the aim of this article. A hemispherical workpiece was used in finite element modeling. The pin size and pin-head radius of curvature have a higher effect on wrinkling formation and final shape geometry [13].

In this study, two types of MPF of sheet metal arrangement are used. Forming operations are simulated numerically by using DEFORM 2D finite element package. In finite element modeling, each pin is actively controlled. The effect of pins geometry on final geometry is investigated. Tearing or damage factor, dimple formation is compared with each other and conventional forming method.

2. Finite Element Simulations

DEFORM™ 2D finite element package is used in this study. This software is mainly adapted to forming operations. Pre-Processor (modeling or input data section), Simulator, and Post Processor (results section) are the three levels of the finite element package. Plane strain condition is used and cold forming is applied for simulations. The die and pins were modeled as a rigid body because the stress and strain of the die were not analyzed. Due to this, any material is not attached and the mesh was not created in DEFORM for rigid bodies. This is a usable application to reduce the running time in simulations. The Newson-Rapson Method and the Langrangian incremental type were used for the iteration method and the solver, respectively. In numerical analysis, Newton–Raphson method, named after Isaac Newton and Joseph Raphson, is a root-finding algorithm which produces successively better approximations to the roots (or zeroes) of a real-valued function [14]. Langrangian incremental type is used for finding approximate solutions of partial differential equations for finite element method. It is based on an expansion of the dependent variable(s) into a linear combination of polynomial trial functions defined over subvolumes [15].

2.1 Multi-Point Forming Arrangements

The MPF dies are include the bottom or female die sheet part and forming pins. Sheet metal part and bottom die geometries are shown in Figure 1 and Figure 2, respectively. Two types of multi-forming dies were used in simulations. Arrangement 1 includes 13 pins with a 10 mm diameter. Another arrangement has 25 pins with a 5 mm diameter tip. The distances between the pins are 1 mm for both arrangements. Pin geometries are shown in Figure 3. Both arrangement simulations are shown in Figure 4 and Figure 5, respectively.

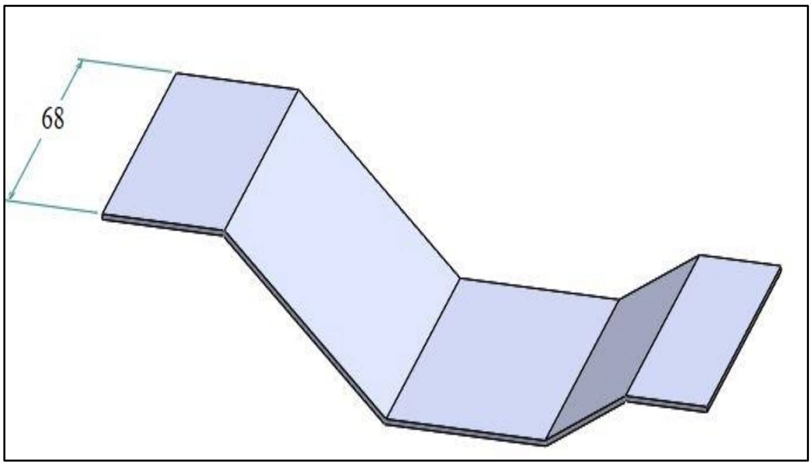


Figure 1. Sheet Final Shape

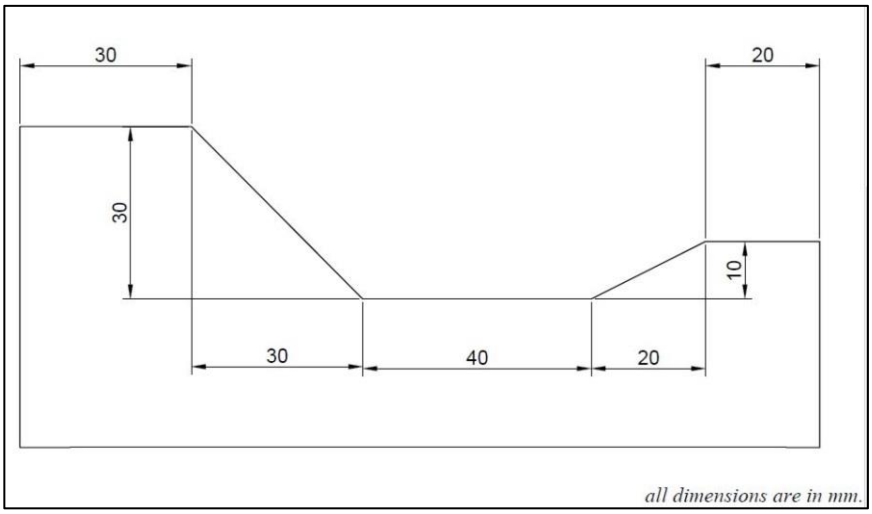


Figure 2. Bottom Die Geometry

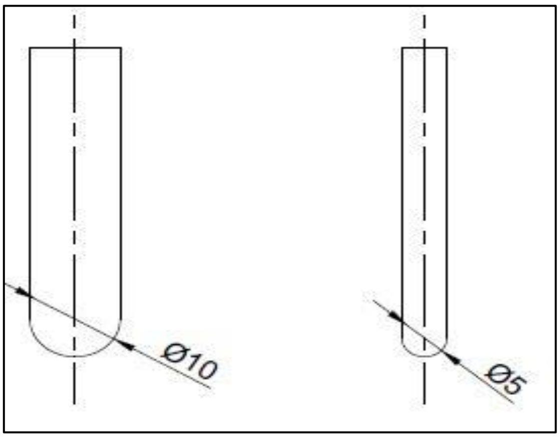


Figure 3. Pin Geometries

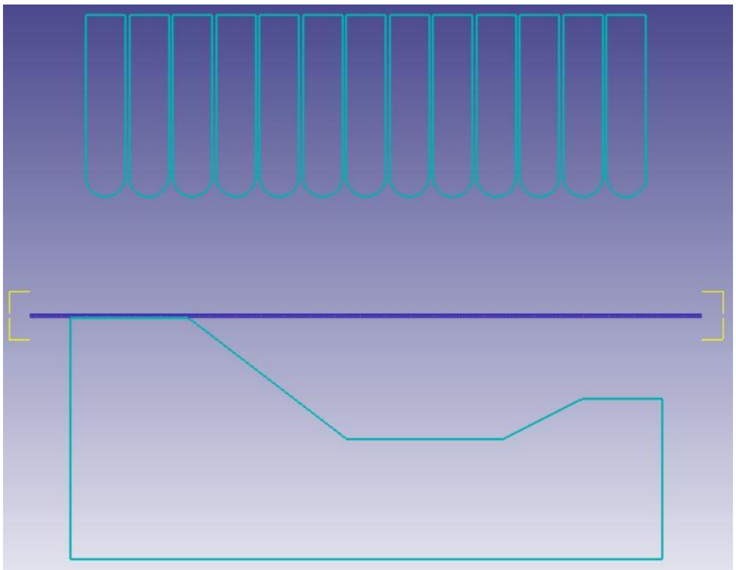


Figure 4. Arrangement 1

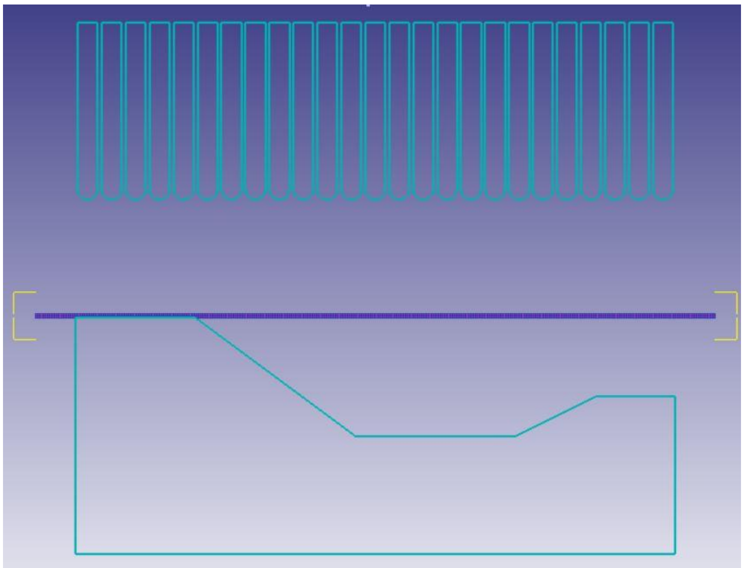


Figure 5. Arrangement 2

2.2 Workpiece Material

1 mm thick Aluminium 1100 H14 sheet is used as workpiece material. The workpiece was modeled as elasto-plastic material and 500 2D quadratic mesh elements were generated by a tool called automatic mesh generator in DEFORM. The bottom die and pins are not investigated in simulations so they were modeled as rigid bodies. This feature reduces running time in finite element simulations. The flow stress-strain curve existing in the finite element package database and the experimentally determined one from the tensile test are shown in Figure 6. These curves are very similar to each other. Fracture or tearing criteria is also an important factor for simulations. Normalized Cockroft & Latham (1968) was chosen as the fracture criterion. Normalized Cockroft & Latham criteria predict the fracture strain more precisely than the other criteria in metal forming processes [16]. So, the damage factor is defined as 0.34 taken from the tensile test.

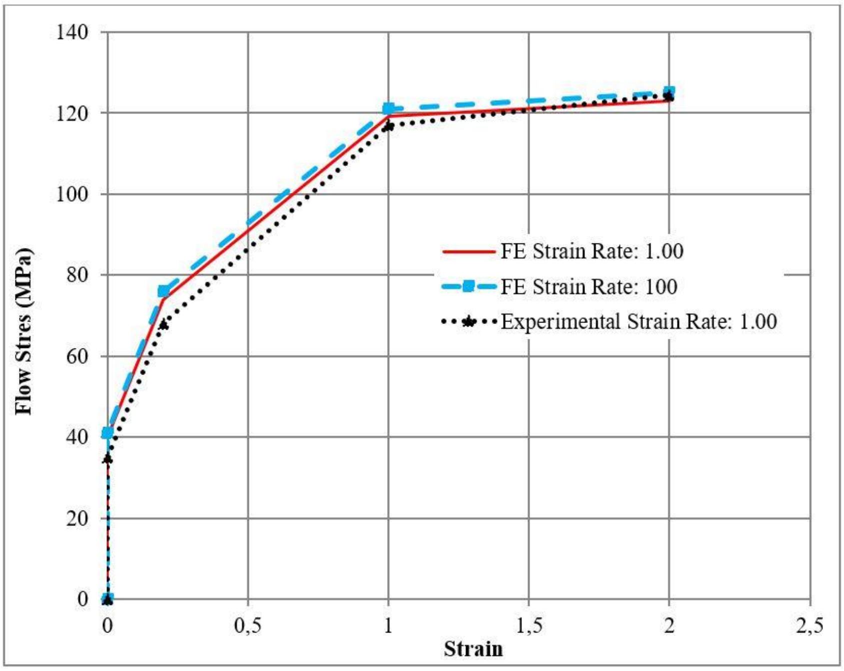


Figure 6. Flow stress – Strain Curve of Al 1100

3. Results and Discussion

In arrangement 1, left end and right end pins firstly pressed to sheet metal. This movement behaves like a blank holder. After that center pin is descended and formed the sheet metal. Then, pins correspond to the inclined area were activated and pressed to sheet metal. All forming operations for both arrangements are 0.5 mm/sec. The final shape of forming operations and pin numbers according to pressing is shown in Figure 7. The damage factor did not reach the defined value. So, there is no tearing on sheet metal. The final damage factor obtained as 0.0523 is shown in Figure 8.

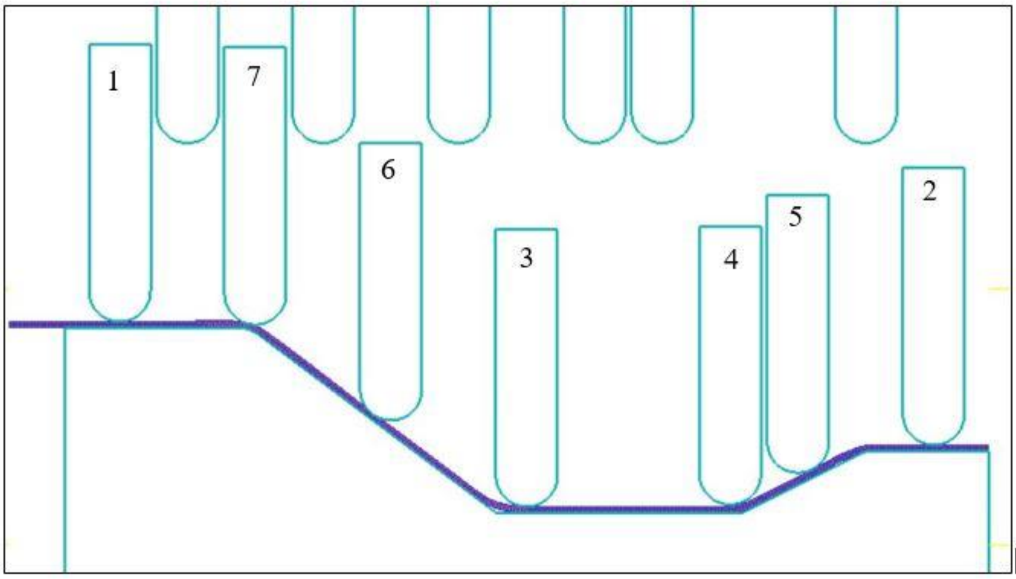


Figure 7. Final Shape in Arrangement 1

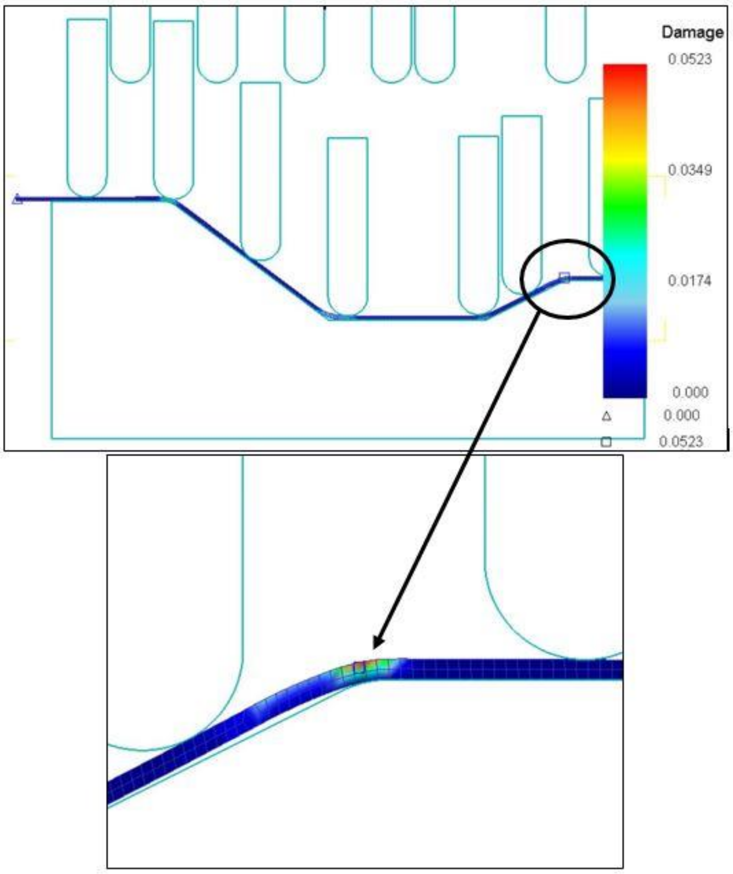


Figure 8. Highest Damage Factor Value

The same procedure was applied to arrangement 2 and also more pins were pressed to the sheet to get the final shape. Figure 9 shows the final shape in arrangement 2 and pin numbers according to the pressing.

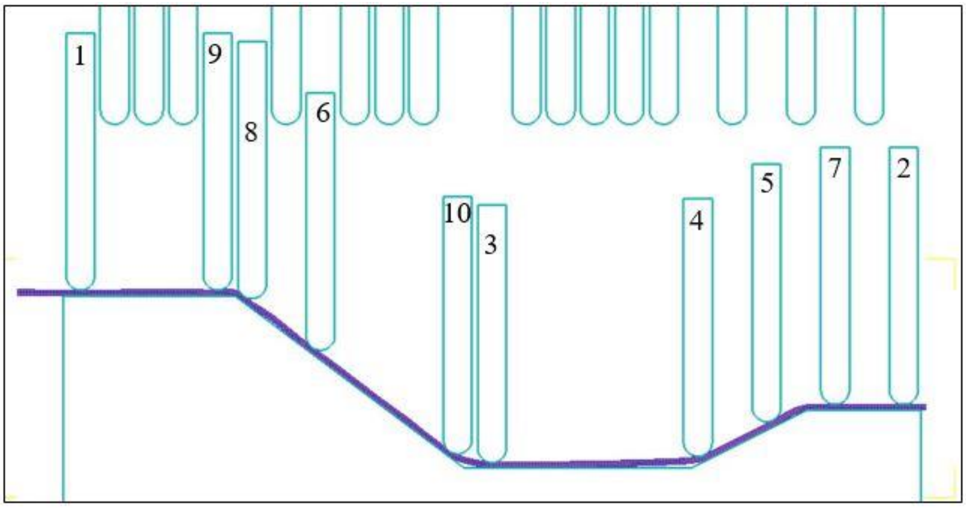


Figure 9. Final Shape in Arrangement 2

In this forming operation, the damage factor is obtained as 0.0808 (see Figure 10). Same as other arrangement tearing was not observed. But the damage value is higher than arrangement 1. Shape formation is also better than arrangement 1 due to more forming contact points.

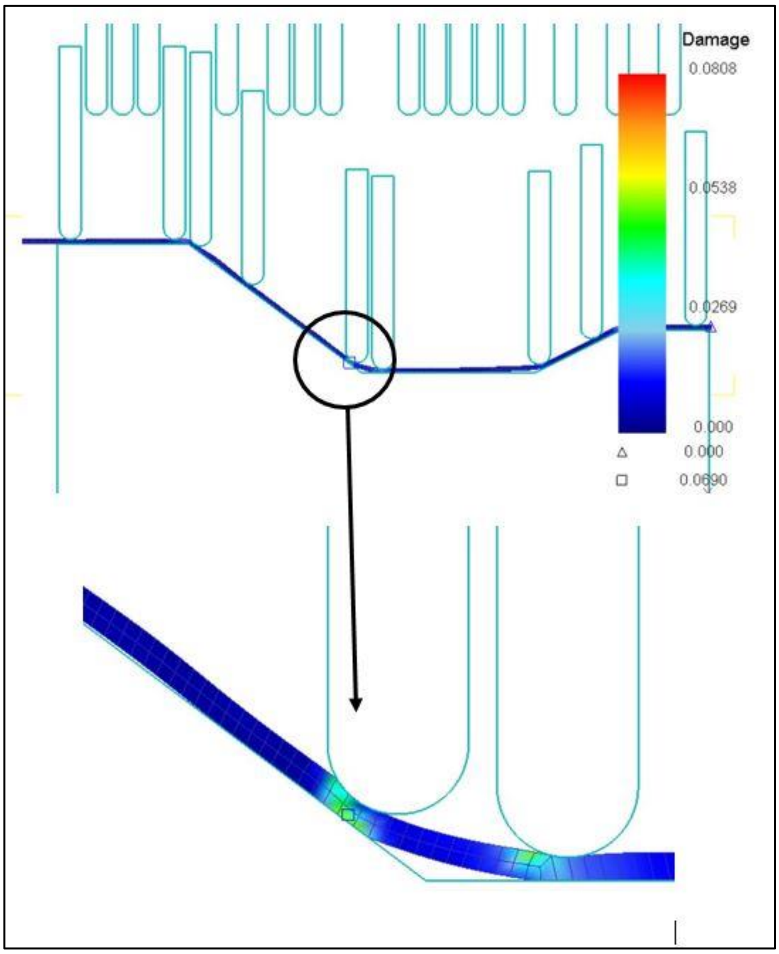


Figure 10. Highest Damage Factor Value

Dimples are one of the main problems in MPF of sheet metal [17]. Pin compresses the sheet and the crushed area was occurred due to concentrated loads. The elastic cushion can be used to overcome this problem.

The conventional forming process (solid die) was also performed in simulation to compare with MPF. Male die and female die were used to form sheets. The same forming rate and friction value were defined as in MPF simulations. For this type of forming, the damage factor was taken as 0.118. So again tearing not observed but higher than MPF. When the complexity of the sheet metal part is increased, tearing the possibility of the sheet part is also increased. The final shape of conventional forming is shown in Figure 11.

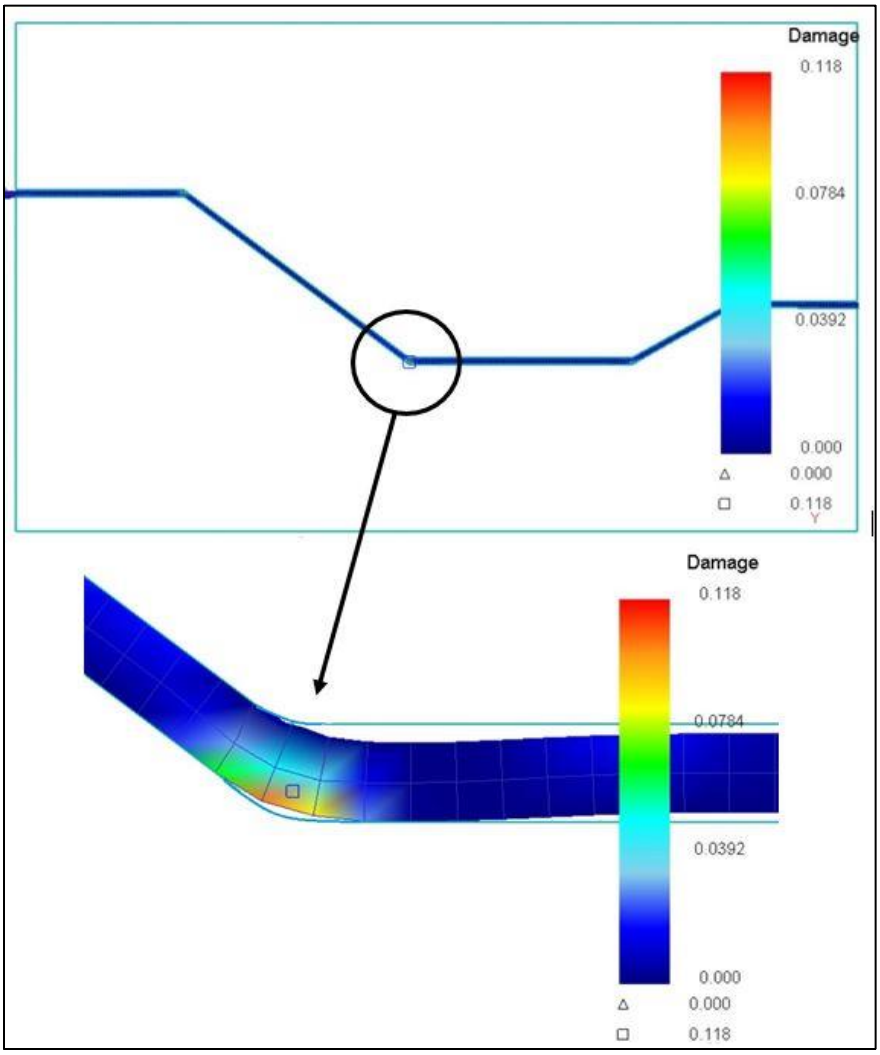


Figure 11. Final Shape of Conventional Forming

Maximum load occurring on pins are shown in Table 1 and Table 2 for arrangement 1 and arrangement 2, respectively. Higher load occurring for arrangement 1 is on pin 3 and for arrangement 2 is on pin 3. These pins apply the more deformation on sheet metal and due to this highest load occur on these pins.

Table 1. Maximum Loads for Arrangement 1

Pin Number	Max. Load(N)
F_1	97.46
F_2	88.53
F_3	179.17
F_4	157.62
F_5	101.73
F_6	118.07
F_7	51.71

Table 2. Maximum Loads for Arrangement 2

Pin Number	Max. Load(N)
F_1	117.54
F_2	109.09
F_3	257.55
F_4	214.81
F_5	157.77
F_6	182.11
F_7	91.51
F_8	161.37
F_9	103.40
F_{10}	81.45

4. Conclusions

The finite element simulation of basic MPF is presented in this paper. As a result of numerical simulations, the followings can be concluded:

1.This method is mainly useful for complex sheet metal parts and prototyping of sheet metal products.
2.Manufacturing cost of sheet metal parts is reduced due to the readjusting of discrete pins. One die set can be useful for different sheet metal geometries.
3.Pin geometry is also important to form sheet metal. Smaller forms better but increases damage factor. Also, the initial cost of press construction is higher because of controlling of each pin.
4.Dimple formation is one of the problems which must be overcome.

Acknowledgments

The authors would like to express appreciation to the organizing committee of TICMET19 for their hospitality and supports.

References

1. Nakajima N., A newly developed technique to fabricate complicated dies and electrodes with wires. J Japan Soc Mech Eng, 1969, 72(603):498–506.
2. Hardt D.E. and Gossard D.C., A variable geometry die for sheet metal forming: machine design and control. Proc Jt Autom Control Conf., 1980, USA No.2, FP7–C:1–5.
3. Webb R.D. and Hardt D.E., A Transfer Function Description of Sheet Metal Forming for Process Control. Trans ASME, J Eng Ind, 1991, 113:44–52.
4. Walczyk D.F. and Hardt D.E., Design and Analysis of Reconfigurable Discrete Dies for Sheet Metal Forming. Journal of Manufacturing Systems, 1998, 17(6):436-454.
5. Li M. and Liu Y., Multi-point forming: a flexible manufacturing method for a 3-d surface sheet. J Mater Process Technol, 1999, 87:277–280.
6. Cai Z.Y. and Li M.Z., Multi-point of Three-dimensional Sheet Metal and the Control of Forming Process, 2002, 79:289-296.
7. Cai Z.Y. and Li M.Z., Finite element simulation of multi-point sheet forming process based on implicit scheme. J Mater Process Technol, 2005, 161(3):449–455.
8. Qian Z.R., Li M.Z. and Tan F.X., The analyze on the process of multi-point forming for dish head, Journal of Materials Processing Technology, 2007, 187: 471-475.
9. Liu C., Li M. and Fu W., Principles and apparatus of multi-point forming for sheet metal, Int J Adv Manuf. Tech. 2008, 35:707-714.
10. Zhang Q., Wang Z. R. and Dean T. A., The Mechanics of Multi-Point Sandwich Forming. Int. J. Mach. Tools Manuf., 2008, 48:1495–1503.
11. Quan G.Z., KU T.W. and Kang B.S., Improvement of Formability for Multi-point Bending Process of AZ31B Sheet Material Using Elastic Cushion, International Journal of Precision Engineering and Manufacturing, 2011, 12(6):1023-1030.
12. Abebe M., Lee K. and Kang B.S., Surrogate-Based Multi-Point Forming Process Optimization for Dimpling and Wrinkling Reduction, Int J Adv Manuf. Techol., 2016, 85:391-403.
13. Abosaf M., Essa K., Alghawail A., Tolipov A., Su S., and Pham D., Optimisation of Multi-point Forming Process Parameters, Int J Adv Manuf. Tech. 2017, 92:1849-1859.
14. Süli E., Mayers D. An Introduction to Numerical Analysis. Cambridge University Press. 2003. ISBN 0-521-00794-1.

15. Hughes J.R. T. The Finite Element Method: Linear Static and Dynamic Finite Element Analysis. Dover Publication, Inc. 2000. ISBN-13: 978-0-486-41181-1.
16. Engin K. E. and Eyercioglu O. Investigation of the Process Parameters of Sheet Metal Blanking Process by Using Finite Element Method, International Conference on Advanced Technology & Sciences (ICAT'16), 2016, v4:1141-1145.
17. Cai, Z. Y., Wang, S. H., Xu, X. D. and Li, M. Z., Numerical Simulation for the Multi-Point Stretch Forming Process of Sheet Metal. J. Mater. Process. Technol., 2009, 209: 396–407.