FINITE ELEMENT SIMULATION OF NEEDLE PEEN FORMING PROCESS FOR SHEET METAL

Guldane KAHRAMAN
Master Student, Gaziantep University, Faculty of Engineering, Mechanical Engineering Department
(Responsible Author)

Omer EYERCIOGLU
Prof. Dr. , Gaziantep University, Faculty of Engineering, Mechanical Engineering Department,

Mahmut TANDOGAN
Research Assistant, Adiyaman University, Faculty of Engineering, Mechanical Engineering Department

Abstract

Peen forming is a stretchy sheet metal forming method and its usage area is increasing and the application method is developing gradually. Process procedure constitutes dimple on the surface to attain intended free form shaped plate. The basic principle of the peen forming process is to obtain a free-formed sheet metal by utilizing residual stress on the material after impact. In this study, needle peen forming is analyzed by using finite element method. Owing to the workpiece is fixed and the impacting needle is movable, the process can obtain any desired free form. In FE simulation, the needle is controlled to form dimples' indentation that causes bending on sheet metal. The study guideline is to adjust the indentation of punch to form sheet metal as the concave and convex with improving an existing random dynamic model. A 1,6mm AA2024-T351 strip is used as the workpiece and a carbon tungsten punch to create dimples is simulated. The concavity effect of the indentation of the needle peen forming process is discussed.

Keyword: Forming, Peen, Needle, Residual Stress, Finite Element, Sheet Metal, Dimple, Concavity

1. Introduction

Peen Forming is a versatile and flexible manufacturing process commonly used in the aerospace industry to shape wing skins and rocket panels [1]. In addition of the general areas of usage of the aerospace industry, peen forming is a cold manufacturing process which used for the automotive industry, shipbuilding industry, biomedical devices, microelectronics and micro-electromechanical systems (MEMS). The increasing tendency in applications of peen forming process to obtain specially shaped forms of plates challenges the traditional methods. Peening is very useful process for extending the service life of a large of metallic components [2]. Also, the peening process is less costly than other sheet metal forming methods. No die required. According to C. F. Barrett being a dieless process, peen forming requires minimal lead time. The costly development and manufacturing time required to make hard dies is eliminated, reducing start-up cost. The process permits design changes and reworking of the part to improve fit when necessary [3]. As it is a cold-forming method, it provides the material to be shaped by preserving the basic chemical properties of the material. It can be adapted to different application areas. In these aspects, it is an improvable cold forming method.

Peening procedure is performed by projecting numerous small particles, laser beams or striking with a punch at high velocity onto the surface of metallic components. Each impacting shot, laser beam or striking a punch plastically deforms the surface of the part. These plastic deformations induce an isotropic residual stress distribution in the component and a convex curvature of the component towards the peening direction [4]. H. Y. Miao 's convex notify is possible to change in this study as this bend varies depending on indentation. This study is modeled and demonstrated the indentation-related concavity change as a 3D simulation in Ansys workbench dynamic model.

In order to deform permanently the surface of the work-piece, the material must be yielded in tension, producing elastic stretching of the upper surface and local plastic deformation that manifests itself as residual compressive stress. Upon unloading, fibers placed below the indentation, try to restore their position to their original shape, but the surrounding material does not allow this to occur. Therefore, a region of compressive stresses is generated [5]. Due to being constituted the residual stress after the peening process, the plane shapes as requested form. This is all to say, residual stresses are stresses that remain in a solid material after the original causes of the stresses have been removed.

Several theoretical and numerical works have been performed to study the residual stress distribution and the deformation of a component after conventional peen forming. Al-Hassani used the assumption that the residual stress profile is the sum of an equivalent stretching stress and equivalent bending stress acting in a manner to balance the induces stress [6]. Meo and Vignjevic employed an axisymmetric finite element (FE) model to obtain the induce stress profile by simulating the impact of a single rigid sphere on an elastic-plastic work-piece [5]. Most of the investigations of stress peen forming are based on experiments and empirical relationships. Baughman introduced the principles of elastic stress peen forming with the pre-bending moment or pre-stretching force [7].

According Hong et al. shot peening is a very complex process to model numerically, involving dynamic analysis of fast moving shot impacting on a metallic target which can often has complex geometry. Therefore, they simulated the shot peening process as an FE model. About shot peening, they discovered an increasing mass flow causes a higher amount of energy dissipation and hence to a reduction of the average impact velocity of the shots in the stream. In addition, it was shown that shots rebound from the target surface and interact with incoming shots causes an additional reduction of the average impact velocity [8]. Kopp et. al presents that in the case of a convex curvature the neutral fibre lies inside the cross-section, whereas an entirely plastically deformed cross-section consists only of elongated fibres. Starting from a low kinetic energy of the shot particles the curvature will emerge convex and increase to a maximum. Proceeding by increasing the system pressure the curvature will decrease and turn into a concave form, again reaching a maximum at a certain operating point. In light of this information, they hit the plate with balls of different diameters in two directions to obtain free form. They focuses on changes in kinetic energy to achieve concave and convex results in the shot peening process [9].

Needle peen forming (NPF) is mainly focused in this paper. The needle forming tool consists of hard spike/spikes called 'needle' which is made of a stronger material than the workpiece. The aim is to prevent the tool damage during shaping the workpiece. The tool motion is powered by a hydraulic, pneumatic or electric source in order to impact the surface of a ductile workpiece. As the powered tool is impacted against and moved vertically to the component's surface, the impacting needles make dimples at the workpiece's surface, creating indentations. This indentation is one of the major controlling parameters of the NPF process. The bulk of the substrate surrounding the deformed material opposes to indentation, as a result a region of compressive or tensile stresses encountered depending on the amount of indentation. The near-surface compressive layer is protected the workpiece from crack propagation under cyclic loading and therefore increases the material's fatigue life. In addition, the indentation is directly affects the concavity, so, the final form of the workpiece.

The authors which were studied about peen forming method were focused on the control of concavity with the indentation parameter. In the laser peen forming studies focused on energy effect to different thickness plates to affect concavity. Hua Ding et al. Applied 0.4 J laser pulse energy to T = 0.4, 0.6, 1.5 and 1.75 mm thick plates in the laser peen forming process. As a result of simulation; the transition from the concave to the convex occurred when the specimen thickness was increased to 0.9 mm and 1.75 mm thick samples [10].

J.Alberto worked about needle peening process includes a 1.6 mm AA2024-T351 material Almen strip target and needle peening tool which includes 4 needles under it. They 2D simulated the process and selected mesh type of Almen strip is SOLID164 and mesh type of needles is SHELL163. At their experimental results and finite element simulation with Ansys workbench results are compared to optimise the process. The needle velocities adjusted with pressure P1=68,95 kPa , P2=103,42kPa , P3=137,89kPa , P4=172,37kPa , P5=206,84 kPa. Depends on these pressures, respectively, v1:1.3mm/s, v2:1.42m/s, v3:1.57m/s, v4:1.62m/s, v5:1.70m/s velocities occurred. Needles' material was selected as Carbon Tungsten and radius R=0.4mm. Based on the ratio Eneedle/Estrip = 8.96, it was assumed that the needles did not experience significant plastic deformation and were therefore considered as rigid bodies (plastic deformationis expected for Eneedle/Estrip < 2). The results confirmed the experimental data of needle peen forming with simulation and outlined the external framework for further studies of needle peen forming processes. It made different speeds and multiple strokes, compared the saturation-related experimental data with the 2D model he obtained in the Ansys workbench. The saturation curve of the experiment and simulation which created at different speeds was drawn. The experimental results and the simulation results confirmed each other [11].

The needle, which is modeled as a 4-pin needle, was a controlled upper prototype of uncontrolled balls of shot peening. Isotropic hardening allows an enlargement of the yield surface with increasing plastic strain, initial residual stresses were assumed to be negligible and linear isotropic hardening was assumed, based on the work of Alexandre Gariepy [12]. Figure 1 shows a typical residual stress field produced after peening demonstrates that where negative residual stresses represent compressive stresses whereas positive residual stresses represent tensile stresses [13].

In this study, an aluminum sheet metal as a workpiece and a carbon tungsten rod as a needle were used. A needle peen forming model was simulated by using ANSYS Workbench explicit dynamics module. In the finite element model, an actively controlled rod was used. The effect of rod indentation on workpiece concavity was investigated. To examine the effect of indentation on the concavity, the indentation of the dimples was compared with each other.

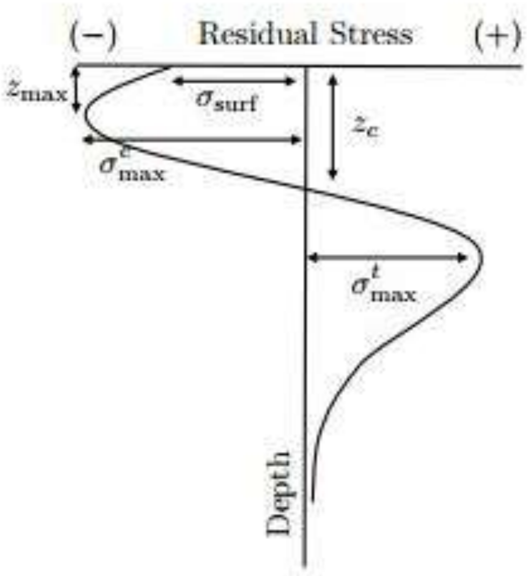


Figure 1. Typical induced stress profile after peening [13]

2. Finite Element Model

This article aims to investigate the form (convex or concave) of the sheet metal workpiece with respect to various amount of needle peen indentation. A 1.6 mm thick plate was used and instead of shot mass or shot velocity, the depth of indentation was chosen as the variable to obtain concave or convex forms. The speed of the needle rod was simulated with respect to this definition. So, the displacement of the rod and the time changed accordingly to have different indentations with the same velocity for each sample.

2.1 The 3D FE Model

The prepared 3D model for simulation uses AA2024-T351 material strip having the dimension of 76.2x19.0x1.6 mm as a workpiece. The workpiece was fixed from both short faces of strip, so as, no bottom holder was used. The peening was applied to the midpoint of the strip using a single carbon tungsten needle with 0.8 mm radius as in figure 2. The simulations were carried out using various indentations as given in Table 1.

Table 1. FE simulations

Simulation No	Indentation (mm)	% indentation wrt thickness
1	0.2	12.50
2	0.4	25.00
3	0.5	31.25
4	0.6	37.50
5	0.7	43.75
6	0.8	50.00
7	1.0	62.50
8	1.1	68.75

The strip meshed with quadratic 60348 elements with 73709 nodes and fixed from both two short sides' surfaces. The material was considered as homogeneous and free from initial residual stresses. The initial distance between the rod and the top surface of the strip was 2.72 mm and the time was adjusted accordingly to obtain a constant velocity of 11.07 m/s during simulations.

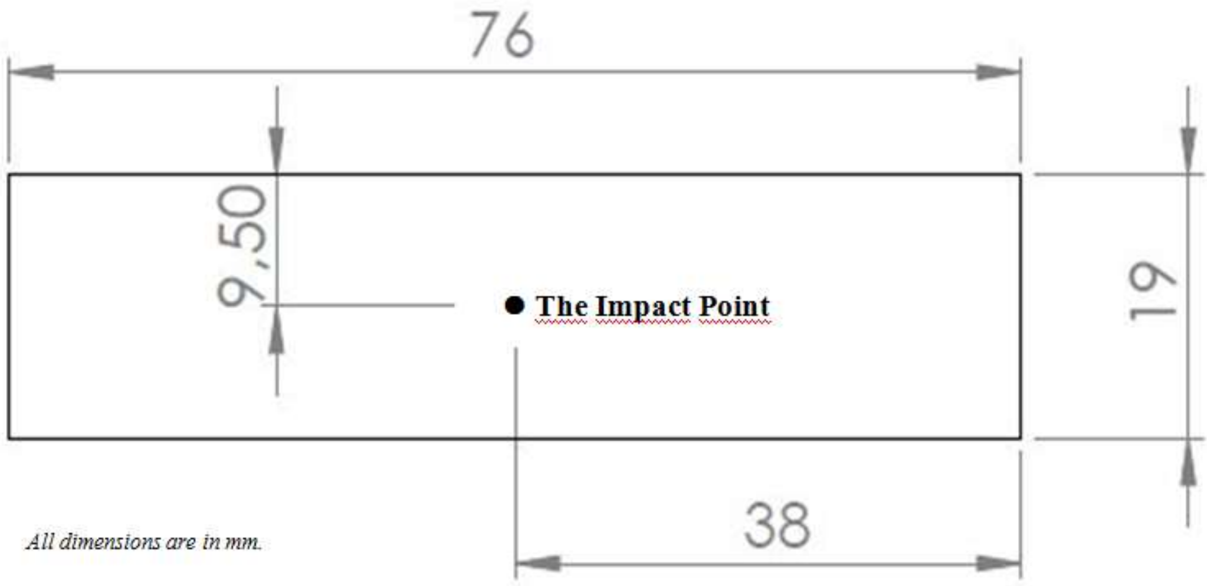


Figure 2. The impact point of needle peen

2.2 Workpiece Material

AA2024-T351 was used as the workpiece material which is a high-strength, age-hardenable aluminum alloy. The material compositions are given in Table 2.

Table 2. Workpiece Material Compositions

Cu	Mg	Mn	Si	Zn	Ti	Cr	Ni	Pb	Bi	Al
4.4 %	1.5%	0.6%	0.5%	0.25%	0.15%	0.1%	0.05%	0.05%	0.05%	Remaning

T351 designation indicates that the material was solution heat-treated, cold worked, naturally aged and finally stress relieved by stretching [1].

The mechanical properties of workpiece material and needle material are given in Table 3 and Table 4, respectively.

Table 3. Mechanical Properties of Workpiece Material

Young's modulus, E_{strip}	71.7 MPa
Poisson's ratio , ν	0.33
Density, ρ	2810 kg/m^3
Strain hardening coefficient, H	810 MPa
Initial yield strength	379 MPa
Maximum stress	1189 MPa

Table 4. Mechanical Properties of Needle Material

Young's modulus, E_{strip}	643 GPa
Poisson's ratio , ν	0.21
Density, ρ	15630 kg/m^3

Also, the punch radius is 0.8 mm. The needle assumed that it did not experience significant plastic deformation and was therefore considered as a rigid body.

3. Results and Discussion

3.1 The stress distribution on the strip

Convex and concave shape changes with respect to residual stress in workpiece. Normal stresses for indentations I_1, I_2, I_3, I_4, I_5 and I_8 after unloading is given in Figure 3. Indentation 1 and 2 causes the convex shape due to compressive type of residual stress. After indentation 4, concave shape has begun to be seen because of residual stresses became tensile type of stresses.

The equal, normal and shear stress distribution of sheet metal underload and load released condition, which is formed in the simulations made at I_2 and I_8 depths, illustrated as in Figure 5 and Figure 6. It is seen that different stress distribution occurs in these indentations and different residual stresses occurred on Al plates. Indentation levels that are caused to different stress distributions on the material are produced different residual stresses on the material and consequently take on concave or convex shapes.

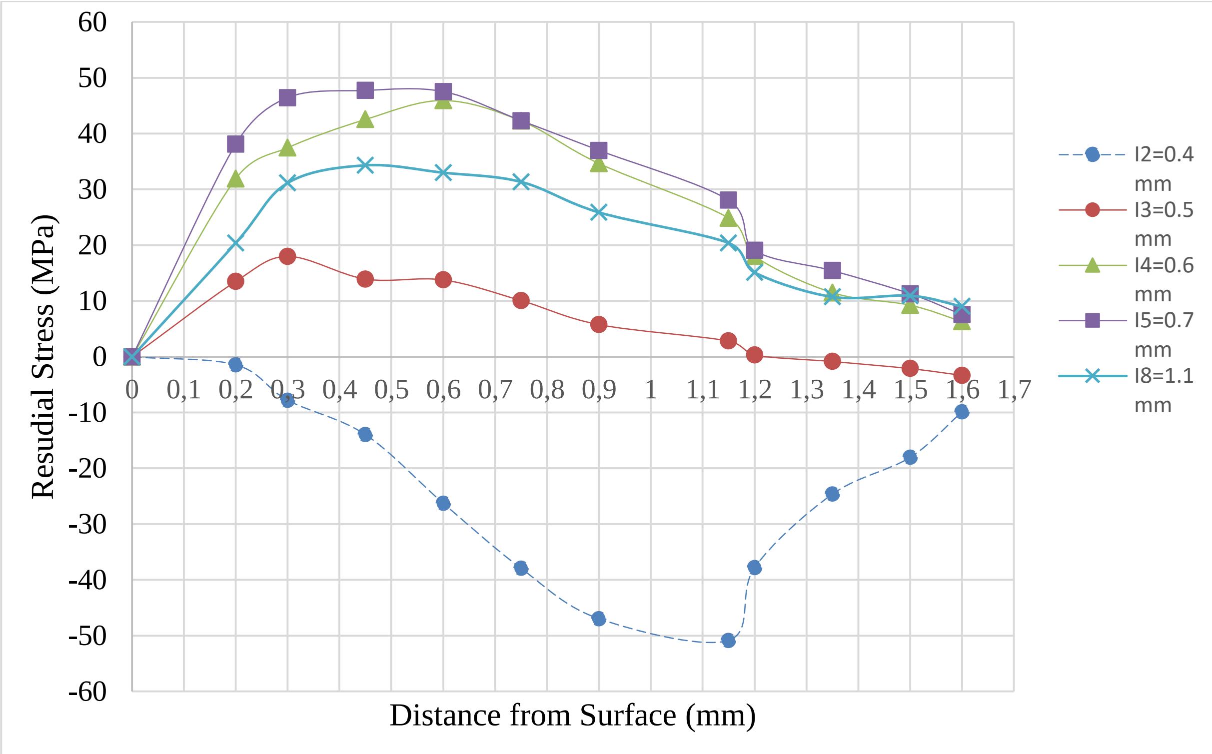
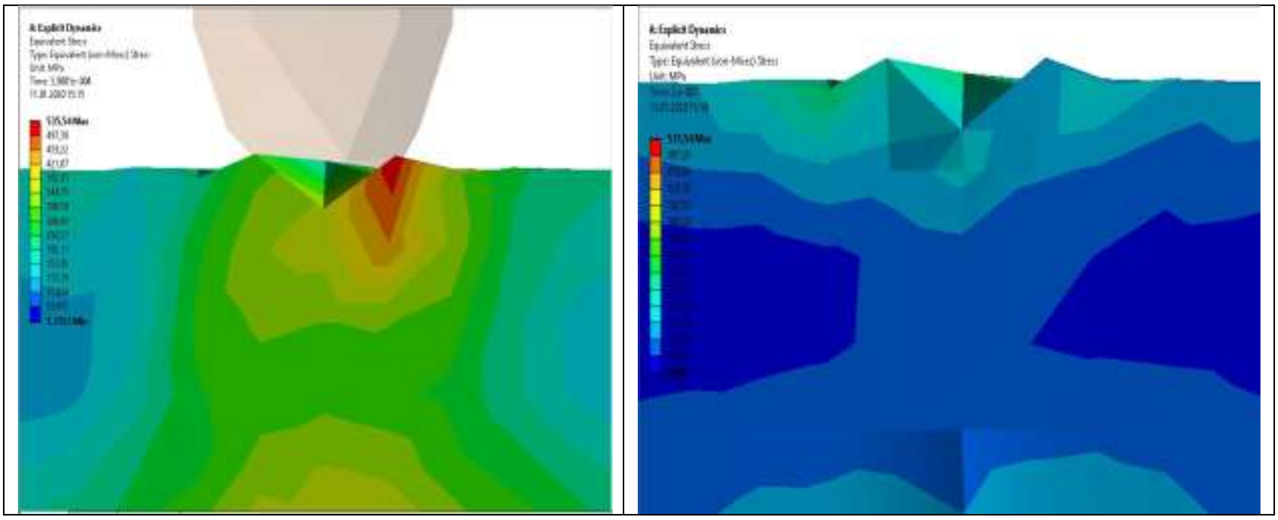


Figure 3. Normal stresses for indentations I_2, I_3, I_4, I_5 and I_8 after unloading

(A) (B)



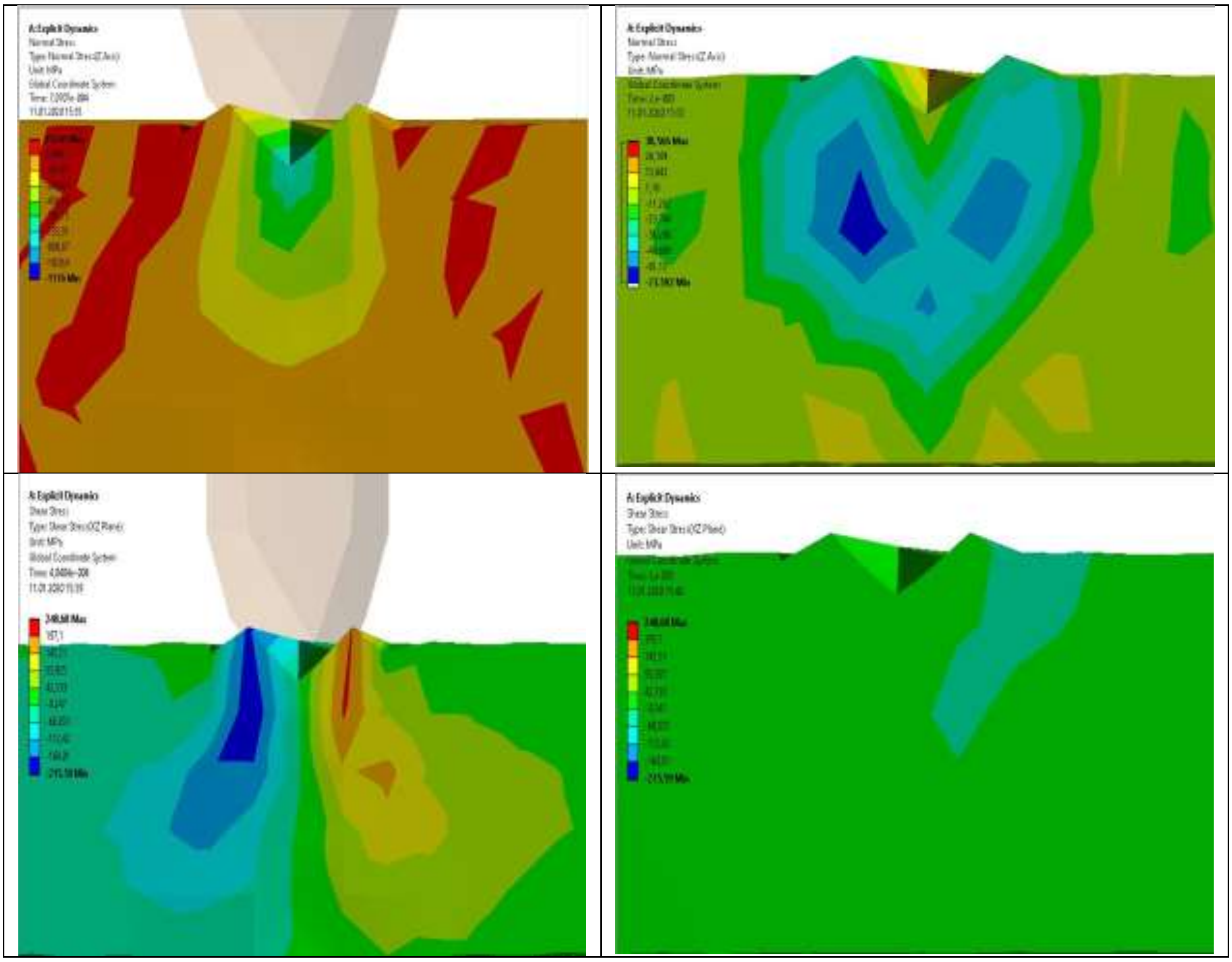
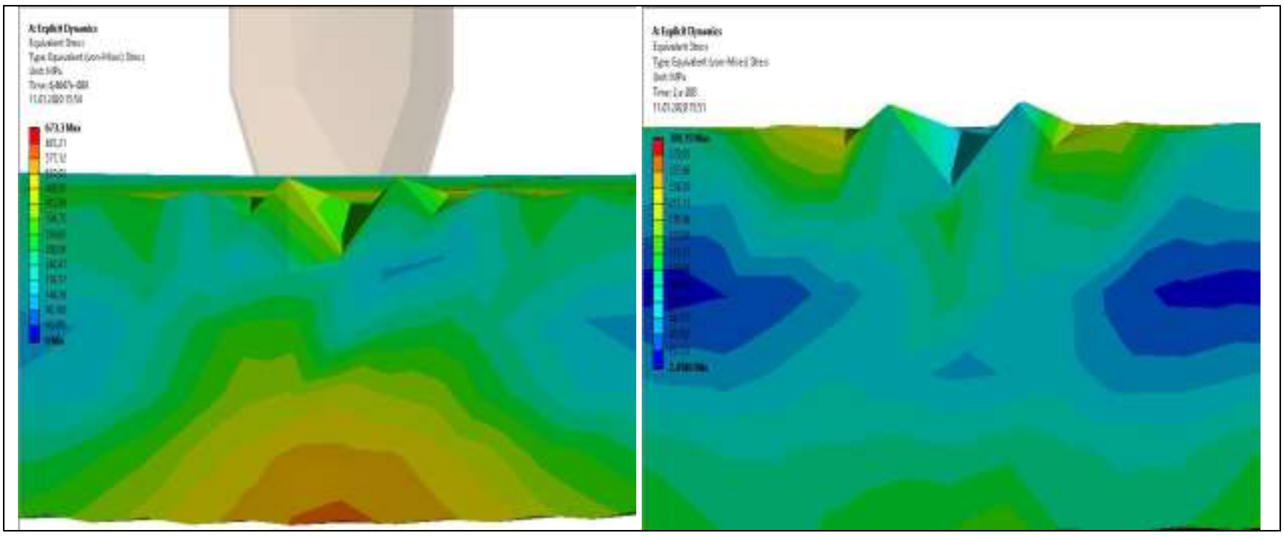


Figure 5. When I_2 = 0.4 mm
(A)The Equal, Normal and Shear Stress Distrubition of Sheet Metal Underload Condition.
(B)The Equal, Normal and Shear Stress Distrubition of Sheet Metal Loaded Relased Condition.

(A) (B)



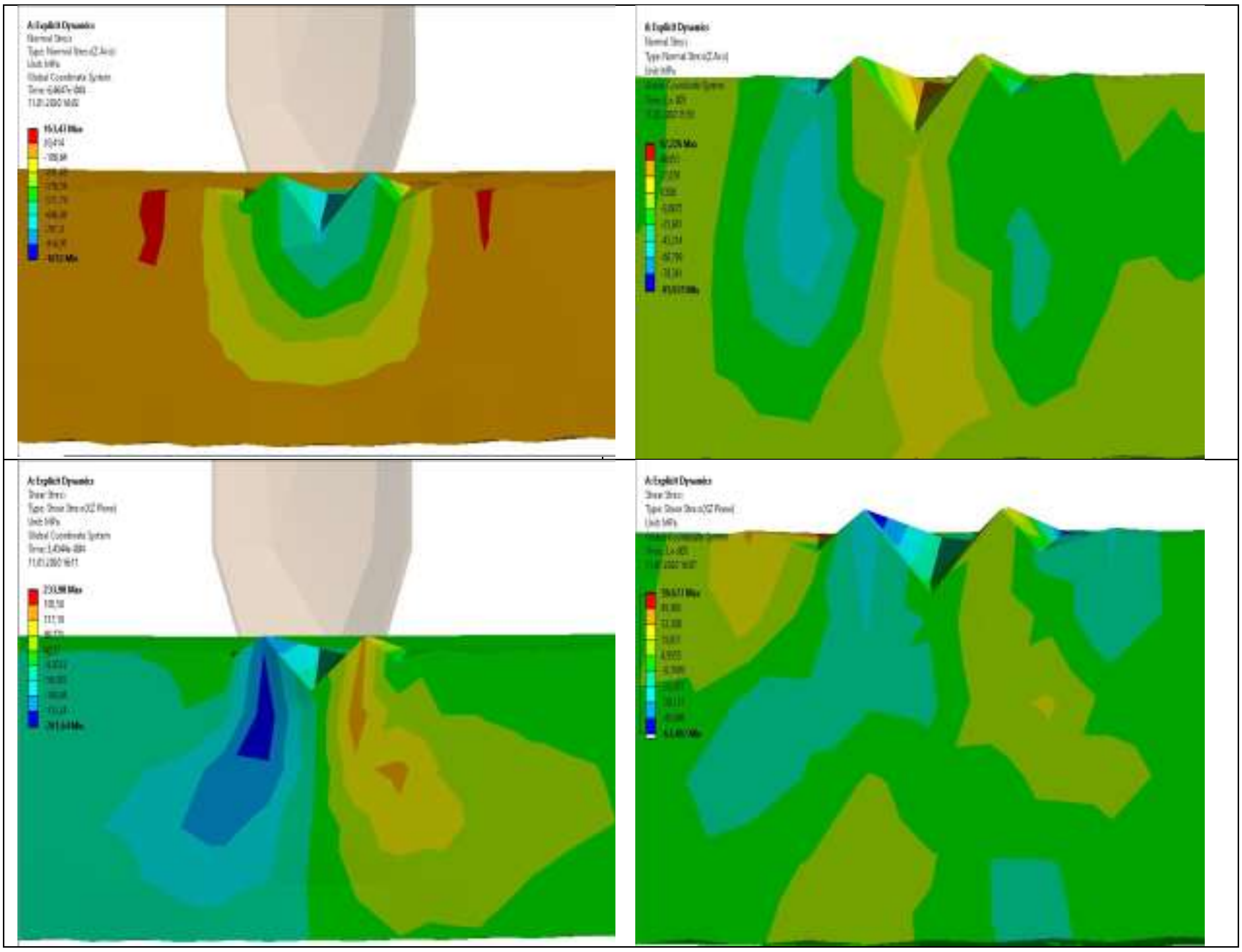


Figure 6. When $I_8 = 1.1$ mm
(A)The Equal, Normal and Shear Stress Distrubition of Sheet Metal Underload Condition.
(B)The Equal, Normal and Shear Stress Distrubition of Sheet Metal Loaded Relased Condition.

3.2 The concavity (arc height)

The left and right short edge surfaces of workpiece are fixed for each sample. A 0.8 mm radius carbon tungsten needle impacts the workpiece surface with a velocity of 11.07 m/s and makes a dimple in the middle of the sample as shown in Figure 2. This movement angle is 90 degree to the workpiece surface. Owing to different indentations the surfaces take the result shapes as concave and convex. This paper gives some parametric information and it includes a guide simulation about free-formed sheet metal with NPF process. I_2=0.4 mm I_8=1.1 mm depths were compared. The concavity graph of I_2 and I_8 in Figure 7 shows the convex and concave results.

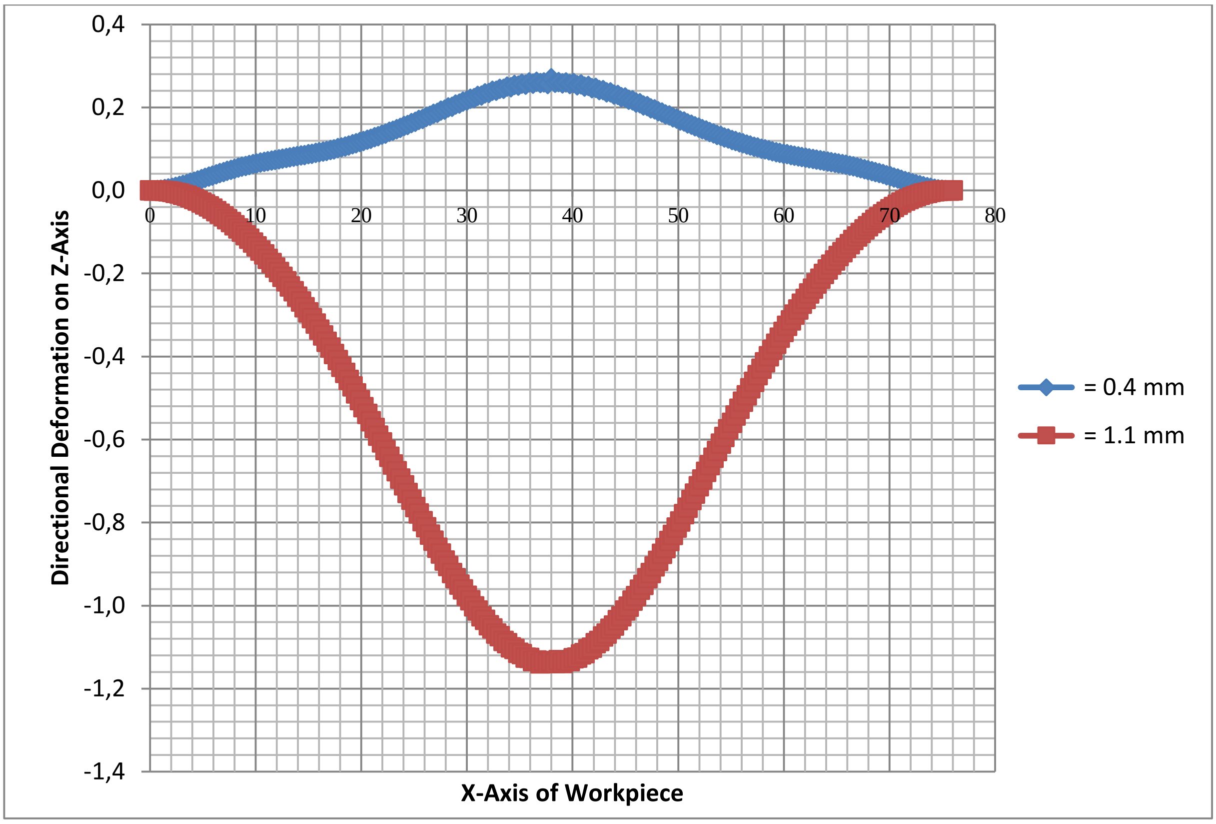


Figure 7. The Directional Deformation Graph at the Indentation Equals;
(A) I_2 = 0.4 mm, (B) I_8 = 1.1 mm

Except of indentation, all of other parameters, conditions, tool and sheet metal materials are simulated exact same. This graph declarates the indentation effect of NPF to sheet metal. Although the convex result was generated by I_2 indentation which caused by compressive type of residual stress, the I_8 has generated the concave result which caused by tensile type of residual stress.

Figure 8 shows the indentation-concavity (Arc Height, a_h) graph of all samples. This graph which created by combining the max arc heights of each sample shows the transition of the results from the convex form to the concave form. Owing to percentage indentations over the plate thickness, the results give the parametric design data required to create the desired concavity in plates of different thicknesses.

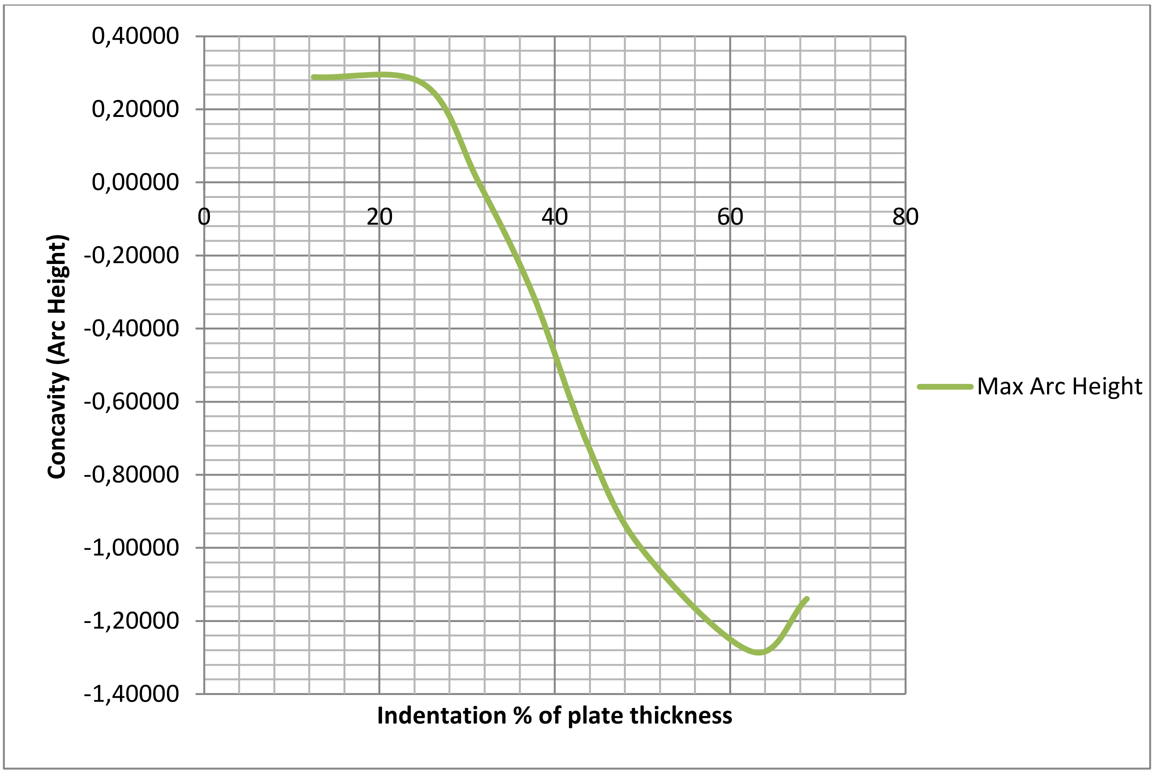


Figure 8. The Indentation-Concavity (Arc Height, a_h) Graph of All Samples (Indentations: I_{1_p}=12.5%, I_{2_p}=25%, I_{3_p}=31.25%, I_{4_p}=37.5%, I_{5_p}= 43.75%, I_{6_p}50%, I_{7_p}=62.5%, I_{8_p}=68.75% thickness of sheet metal)

When the indentation is applied up to 31.25% of the plate thickness, the workpiece is shaped as convex, concave results are obtained at deeper thicknesses from this region. Also, the concavity is unstable in 31.25% indentation region.

4. Conclusions

The rod indentation effect to the Needle Peen Forming process is presented in this paper as a finite element model. As a result of FE simulations, the followings can be concluded:

1. This method is mainly useful for free form sheet metal parts and prototyping of sheet metal products.
2. The indentation parameter directly affects the concavity of the workpiece.
3. When the indentation is applied up to 31.25% of the plate thickness, the workpiece is shaped as convex, concave results are obtained at deeper thicknesses from this region. Also, the concavity is unstable in 31.25% indentation region.
4. The needle peen forming process is suitable for the sheet metal forming process without using mold.
5. For the bring under control of the final shape of free form, the determination of the locations to the indentation on the surface of the sheet metal is one of the problems which must be overcome.

5. References:

1. Gariépy A, Cyr J, Levers A, Perron C, Bocher P, Lévesque M. Potential applications of

peen forming finite element modelling. *Adv Eng Softw*. **2012**;52:60-71.

2. Kirk D. Shot Peening. *Aircr Eng Aerosp Technol an Int J*. **1999**;77(4):349-361.

3. Barrett CF. *Peen Forming*.; **1984**.

4. Miao HY, Larose S, Perron C, Lévesque M. Numerical simulation of the stress peen forming process and experimental validation. *Adv Eng Softw*. **2011**;42(11):963-975.

5. Meo M, Vignjevic R. Finite element analysis of residual stress induced by shot peening process. *Adv Eng Softw*. **2003**;34(9):569-575.

6. Al-Hassani STS. Mechanical Aspects of Residual Stress Development in Shot Peening. **1982**:583-560.

7. D.L. Baughman. An overview of peen forming technology. *Proc 2nd Conferance Shot Peen*. **1984**:28-33.

8. Hong T, Ooi JY, Shaw B. A numerical simulation to relate the shot peening parameters to the induced residual stresses. *Eng Fail Anal*. **2008**;15(8):1097-1110.

9. Kopp R, Schulz J. Flexible sheet forming technology by double-sided simultaneous shot peen forming. *CIRP Ann - Manuf Technol*. **2002**;51(1):195-198.

10. Ding H, Shen N, Li K, Bo W, Pence CN, Ding H. Experimental and numerical analysis of laser peen forming mechanisms of sheet metal. *ASME 2014 Int Manuf Sci Eng Conf MSEC 2014 Collocated with JSME 2014 Int Conf Mater Process 42nd North Am Manuf Res Conf*. **2014**;2(June).

11. Alberto J, Romero M. Experımental And Numerıcal Study Of Needle Peenıng Effects In Alumın I Um Alloy 2024-T3 Sheets. *École Polytech Montréal Mémoıre Présenté En Vue L ' Obtentıon Du Dıplôme Maîtrıse Ès Sci Applıquées*. **2016**.

12. Gariépy A. Fınıte Element Modellıng Of Shot Peenıng And Peen Formıng Processes And Characterısatıon Of Peened Aa2024-T351 Alumınıum Alloy. *J Chem Inf Model*. **2012**;53(9).

13. Al-Obaid Y. Three-dimensional dynamic finite element analysis for shot-peening mechanics. *Comput Struct*. **1990**;36(4):681-689.