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An experimental and numerical study of forming parameters affection on multi-point deep drawing process

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ABSTRACT

Multi-point forming is a modern flexible manufacturing technology, which has been used in many industries successfully. In order to provide a flexible method for forming a metal, multi-point forming is used to form aluminum alloy 2024 with an initial size of 300 × 300 mm sheet. Finite elements were simulated through ABAQUS/EXPLICIT 6.14.1. Through, increasing of elastic layer hardness, the minimum required a thickness of elastic layer proliferates. Furthermore, blank holder force increment has a direct relation with the enhancement in polyurethane layer hardness. The multi-point forming experiments of aluminum sheet are done, and the comparisons of a forming process between experimental parts and simulation functions are conducted, which establish that the aluminum products have good surface accuracy and shape accuracy.

1. Introduction

At the present time, the tendency is towards procedures which deliver the maximum efficiency in the shortest time. Significant reductions in manufacturing costs are assumed to make structural material attractive for mass production applications such as automotive components. Deep drawing is the most common method of shell piece formation. Due to producing various pieces with high quality and speed and low costs, this method has been increasingly applied. In this process, many parameters such as friction, drawing ratio, quality, and type of die and sheet, blank holder force, drawing speed, mandrel head radius, and matrix edge is involved. Among sheets formation methods, new formation methods that use a flexible die and do not need multiple rigid dies, have recently drawn the attention of researchers. The multi-point formation is a flexible technique to produce metal sheets with 3-d geometry. In multi-point formation process, the pins have been designed in a way that is independent of each other and are adjusted easily. So, controlling pin height may create a continuous working surface. In multi-point formation, the curved surface of the die has been created by a large number of pins. In this method, independent pins are utilized instead of traditional dies (Li et al., 1999). The multipoint forming concept was first introduced in Japan. Nakajima (1969) presented adjustable discrete surface die concept for the foremost time. Nishioka (1973) manufactured Universal pressure test kit which was indeed an adjustable separate die. The universal pressure test kit is comprised of upper and lower flexible dies controlled by a computer. Walczyk and Hardt (1998) and Hardt et al. (1982) carried out extensive research regarding multipoint forming in the United States. They offered the closed-loop control system for a continuous die of discrete pieces and manufactured test equipment controlled by a computer. Finckenstein and Kleiner (1991) in Germany controlled flexibility developments and tool system for deep drawing and stretch numerically. They referred to a tool system which includes a matrix comprising 1089 rods and stretches die was formed by adjusting them separately. Rao and Dhande (2002) in India provided a continuous surface in tools discrete surface by flexible sheet-like rubber materials and called it flexible surface tool. The computational simulation was carried out on the flexible surface and revealed that optional flexible surface for sheet forming process in general and for such processes as composite layers in specific. Li et al. (1999) studied the basic theory and practical technology of multipoint forming in China. For basic theory, they offered four main methods for multipoint forming and replicated forming method that can control effectively the bouncy return. Sun et al. (2007)

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offered a new method named as continuous multipoint forming, which is a combination of multipoint forming and continuous forming (rolling). They have developed experimental equipment and have carried out some experiments. The experiment results reveal that 3-d surface can be shaped by the continuous forming method. Wong et al. (2003) investigated principles and development of spinning. They depicted that pinning has a potential in the development of complicated forms manufacturing, which is demanded in the increased number of productions by global industries. Music et al. (2010) studies the most practical work in analyzing and using spinning mechanics. They demonstrated that the existing work represents multiple gaps in the current science of spinning mechanics, and studying spinning process features reflects that there is a great potential for innovation in spinning (Gong et al., 2012). In this inquiry, the tenderness of the parameters such as polyurethane layer thickness, blank holder force and type of polyurethane on multipoint deep drawing process will be looked into.

2. Material and methods

In this research, equipment applied in the test and geometrical features of the final workpiece will be introduced. Then different stages, die components, sample preparation, used materials, and the manner of obtaining mechanical features will be elaborated.

2.1. Equipment

To implement experiments, a dual-purpose hydraulic press T.S.S. with a capacity of 200 KN has been applied, Fig. 1 shows a picture of this press and also assembled multi-point die.

2.2. Multipoint forming dies

To manufacture this die, 200 hemispherical head pins have been applied. These pins are independent of each other and have been designed in a manner that their heights are easily adjustable. So adjusting pin height properly may create surfaces with different curvatures. The blank holder force required in the forming process is supplied by the lower jack of the press kit. In order to an acquaintance of multi-point die, a schematic diagram of multi-point dies components is pictured in Fig. 2.

Fig. 1: Dual-purpose hydraulic press T.S.S and assembled multi-point die.

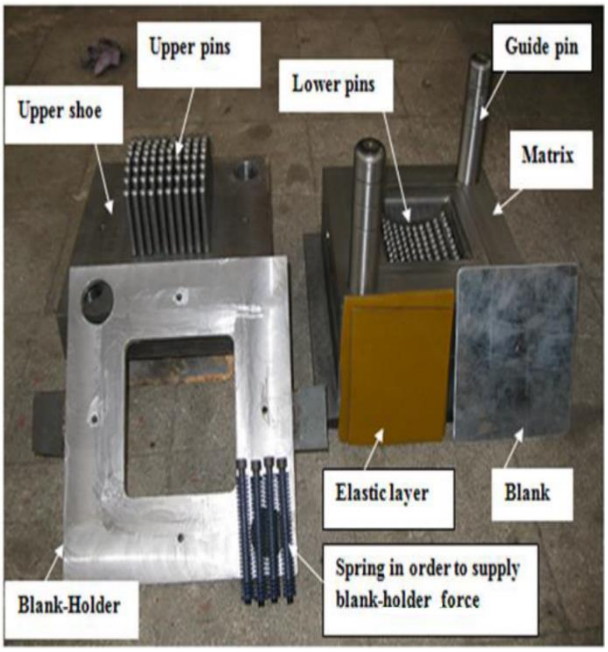


Fig. 2: Components of the multi-point die

2.3. Mechanical specifications of 2024 aluminum sheet and polyurethane

The tested material is 2024 aluminum alloy with a thickness of 1 mm. The chemical composition of this alloy is presented in Table 1.

To obtain mechanical features of the samples, the uniaxial stretch test has been applied. In so doing, as shown in Fig. 3, samples of 2024 aluminum alloy are prepared based on ASTM B557m and with a basic length of 50 mm and width of 12.5 mm.

Table 1: Chemical composition of 2024 aluminum alloy

Material	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Zn%	Ti%
AA2024	0.50	0.50	4.5-4.3	0.6-0.5	1.5-1.3	0.10	0.25	0.15

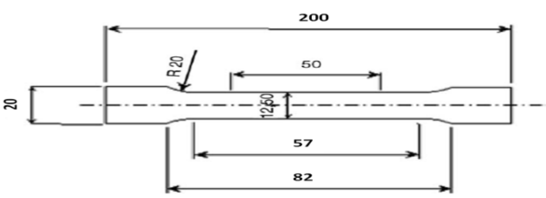


Fig. 3: The sample used for simple stretch test

To obtain such features as yield strength, final strength, and the stress-strain diagram, the standard sample was prepared in the rolling direction and was drawn by the puller to reach fracture. Having implemented the uniaxial stretch test, the real stress-strain diagram related to 2024 aluminum alloy is obtained as per Fig. 4.

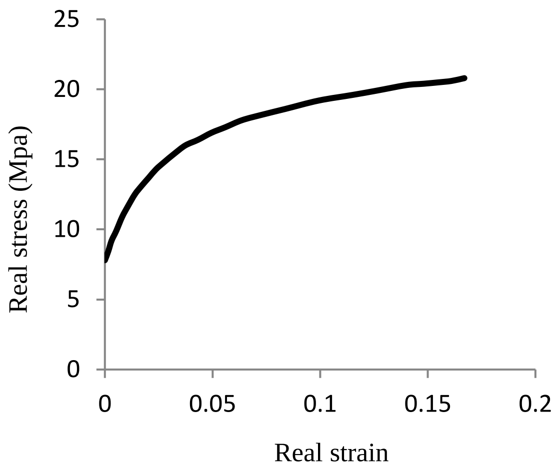


Fig. 4: Real stress – strain diagram of 2024 aluminum alloy

Thickness strain is usually obtained by measuring longitudinal and transverse strains and using the principle of constant volume as per $\varepsilon_t = \varepsilon_w + \varepsilon_l$. To obtain anisotropy coefficient, samples are prepared in the rolling direction which makes a 45degree angle with the rolling direction and in a direction perpendicular to the rolling and are put under uniaxial stretch, and longitudinal and transverse strains of all three samples are measured. Then anisotropy coefficient is obtained by below relation (Eq. 1):

$$R = \frac{d\varepsilon_w}{d\varepsilon_t} = \frac{d\varepsilon_w}{d\varepsilon_t + d\varepsilon_w} = \frac{\varepsilon_w}{\varepsilon_l + \varepsilon_w} \quad (1)$$

With regard to the above relation, anisotropy coefficient values of 2024 aluminum alloy are presented in Table 2. In Table 2, $\bar{R}$ is obtained through Eq. 2. The mechanical properties are presented in Table 3.

$$\bar{R} = \frac{1}{4}(R_0 + 2R_{45} + R_{90} \quad (2)$$

Table 2: Anisotropy coefficient values of 2024 aluminum alloy in different directions

Alloy	R_0	R_{45}	R_{90}	$\bar{R}$
2024 Aluminum	0.73	0.75	0.77	0.75

In order to determine properties of polyurethane applied in this paper, the standard test (ASTM D575-91) has been used. According to this standard, sample have a cylindrical shape with a diameter of 27.6 mm and a height of 5.12 mm to be prepared and impact speed 12 mm per minute stay on under pressure test. Fig. 5 shows a polyurethane sample image which is preparing for the pressure test.

Table 3: Mechanical properties of AA2024-O aluminum alloy

Sheet direction relative to rolling direction	Yield strength, Mpa	Modulus of elasticity, Gpa	Strain hardening, n	Strength, Mpa	Anisotropy, R
0°	79	73	0.2662	353.08	0.73
45°	76	73	0.2565	353.02	0.75
90°	77	73	0.2427	338.04	0.77

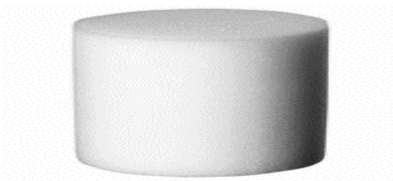


Fig. 5: Prepared polyurethane sample for testing pressure

3. Finite elements simulation

In this study, ABAQUS/EXPLICIT 6.14.1 software is used for simulation, to determine whether the shrinkage of the part and Also considers the effects of anisotropy in sheets of aluminum, three-dimensional models have been used to analyze. Also, due to the symmetry and reduced the analysis time only a quarter of the mold and the plate are modeled. Sheet mode of the shell and deformable, elastic layer of solid and definable, pin, matrix and blank-holder of discrete rigid is determined. Since mold components, including pins, blank-holder and matrix are modeled as rigid surfaces; mechanical properties are not attributed to them. Simulations of the used process have been set in a two-step. In the first step, the blank-holder force is applied to the upper surface of the plate, and the second step is to move the upper punches to create the desired shape. Contact between the sheet surfaces with polyurethane layer and the mold surfaces are selected surface to surface type. Blank-holder surface 0.1 is considered. This coefficient for the contact surface between the sheets and a layer of polyurethane, and polyurethane layer to the surface of the pins are 0.1 and 0.2, respectively. Elements used in the model of the plate are S4R. In order to model the friction of the interface of plate surfaces with die components surfaces and polyurethane layer, the Coulomb friction model is used. According to reference Liu and Hua (2010); the friction coefficient between the sheet contact surface with mold and four-node element. For meshing the layers of polyurethane, the eight-node solid element C3D8R is used. And elements used in the upper and lower matrix, pins and components of the die are R3D4. For investigation of the grain size effect, thickness changes at critical points of the work piece and also the time of the analysis process in various scenarios comparing and at the end with probing the results, 0.0015 for numeric grading is selected. Fig. 6 depicts a simulation of the multi-point die and other components.

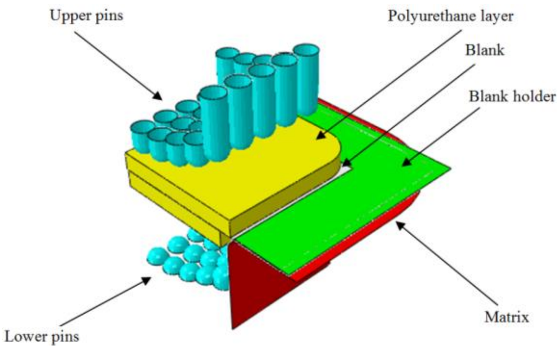


Fig. 6: Simulation of multi-point die

4. Results and discussion

Here, the results obtained from experiments and simulations are presented. In the experiments, the effect of polyurethane layer thickness and formed parts thickness distribution are studied.

4.1. Investigation of sheet thickness distribution by using elastic layer

In Fig. 7, formed metal sheets by using of elastic layer with a thickness of 2,4,6,8 and 10 mm are shown.

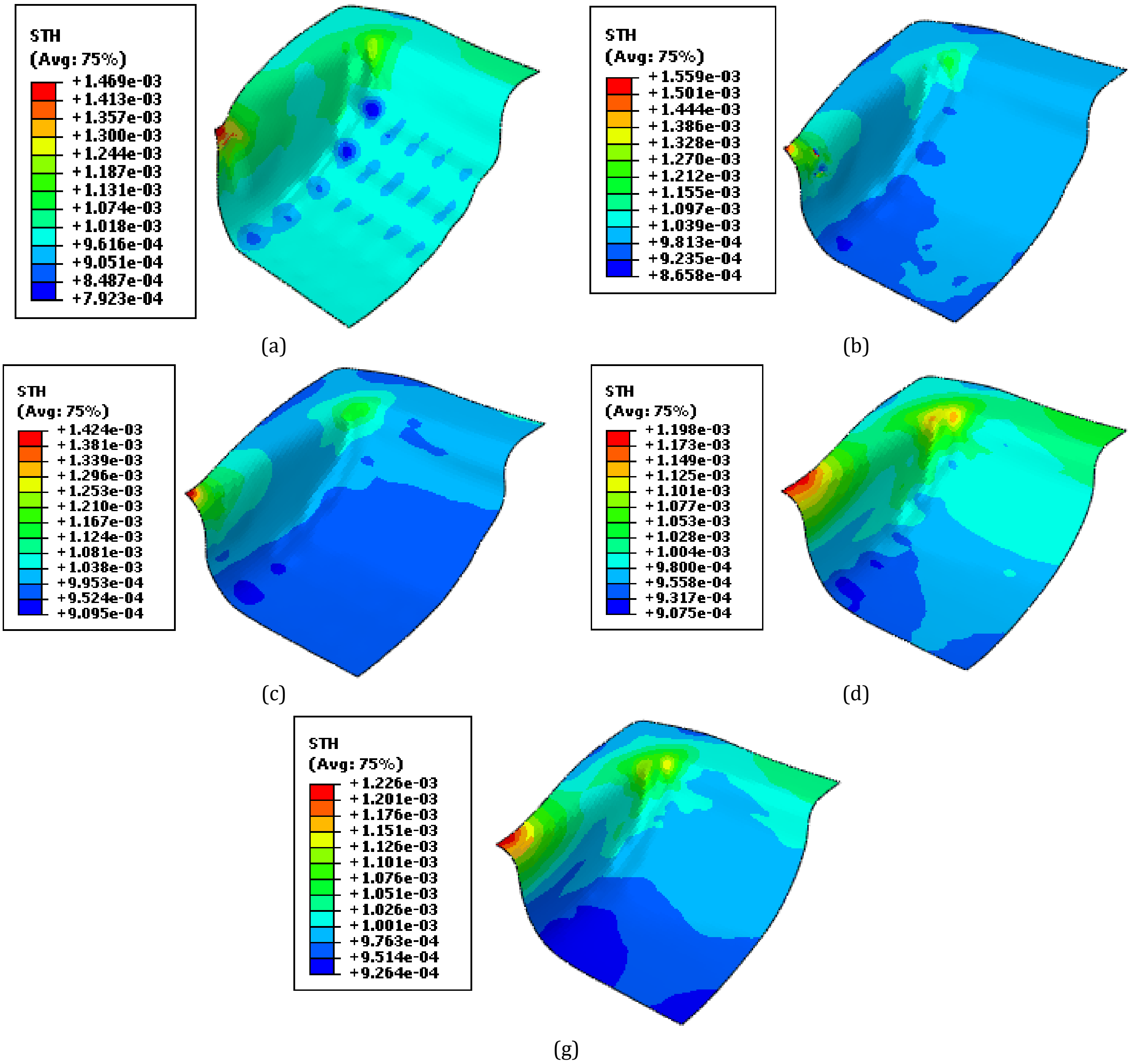
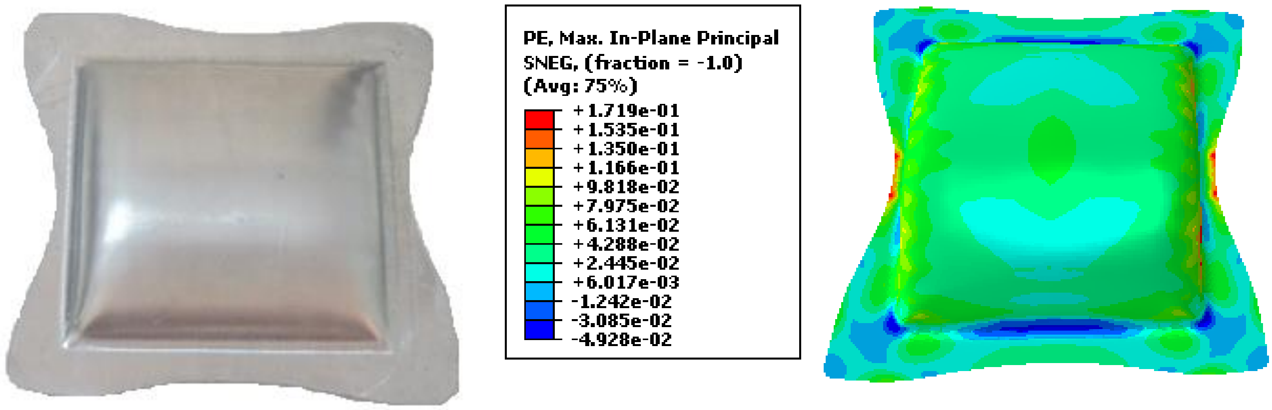


Fig. 7: Formed metal sheets in the multi-point forming die with elastic layer with a hardness of 80 SA with a thickness of (a) 2mm, (b) 4mm, (c) 6mm, (d) 8mm, (e) 10mm

By reviewing these results, we observe that by increasing of thickness of the elastic layer, the amount of dimple defect decreases and the optimum thickness of polyurethane layer for this case are 10 mm. Elastic layers with a thickness of 10 mm, is the minimum thickness which is required for avoiding of dimple defect. The important thing is observed from these pictures, is reducing the thickness distribution of the sheet by increasing the thickness of polyurethane, the polyurethane with a thickness of 2 mm has the maximum thickness distribution and the polyurethane with a thickness of 10 mm has the lowest one. Here, Fig. 8 shows the formed sample in the simulation and experimental using polyurethane layer with a thickness of 10 mm. It can be seen that formed sample has very good surface quality and any dimple defect is not visible in the shaped sample in the simulation and experimental testing.



(a) (b)

Fig. 8: Formed metal sheets with an elastic layer with a hardness of 80 SA and thickness of 10 mm, (a) experimental, (b) simulation

4.2. Effect of polyurethane layer hardness on minimum required blank-holder force

Examination of blank holder forces for polyurethane with different hardness shows that increasing of blank-holder force has a direct relationship with increasing of polyurethane layer hardness. The survey of different hardness of polyurethane, as shown in Fig. 9, it can be seen that the minimum blank-holder force for polyurethane with a hardness of 65 S.A, 2000 Newton, polyurethane with a hardness of 80 S.A, 2300 Newton and polyurethane with a hardness of 85 SA, is 2700 Newton.

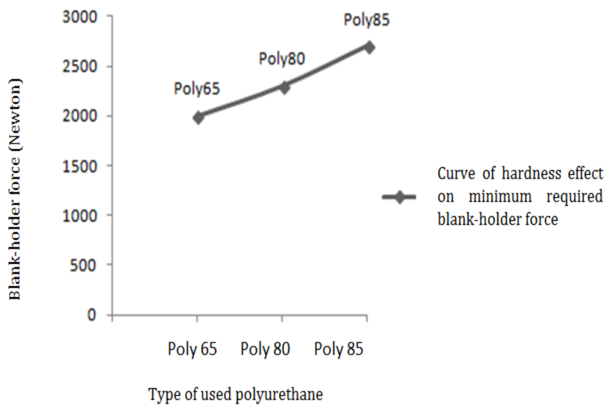


Fig. 9: Minimum required blank-holder force for different hardness of polyurethane

The results show that when the hardness of polyurethane layer proliferates consequently the blank-holder force will be increased in order to control sheet.

5. Conclusions

The influence on different polyurethane thicknesses, different hardness of polyurethane, and blank holder force are studied by forming AA2024 sheet in this paper. We can summarize several conclusions:

1. The multipoint deep drawing process is an advanced method of manufacturing complex profiles of sheet metal products.
2. The results of simulation reflect that by increasing the thickness of polyurethane layer, products will have a good surface accuracy and shape accuracy.
3. Investigation of blank holder forces for polyurethane layers with different hardness reveals that there is a direct relation between both blank holder force and polyurethane hardness increase.

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