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Analytical and Experimental Investigation of Product Geometry and Dimensional Accuracy in the Punching Process of AA 1050 and AA 1070 Sheets

Abdullah YETGIN[1], Bilge DEMIR[1], Hakan GURUN[2,*], Khalil Belras ALI[1]

[1]*Karabuk University, Engineering Faculty, Department of Mechanical Engineering, Karabuk, Türkiye*
[2]*Gazi University, Faculty of Technology, Department of Manufacturing Engineering, Ankara, Türkiye*

Highlights

- This paper focuses on part geometry and dimensional accuracy in the punching process.
- Finite Element Analysis and Experimental studies were carried out and the results were compared.
- The required cutting force can be significantly reduced by changing the punch geometry.

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Product geometry
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Abstract

Punching is a widely used and economical manufacturing method. The forces that occurred during punching and the dimensional accuracies of the parts obtained from punching are significant in manufacturing processes. This study aimed to examine the cutting forces that occur in the punching process and the dimensional accuracy of the parts. AA 1050 and AA 1070 sheet materials were used in the experimental studies. Five punches with various cutting-edge geometries were employed in the punching processes. Punching operations were carried out at a constant clearance value and press speed. The geometries of the specimens obtained from the experimental studies were examined using stereo and shuttle-pix microscopes. In addition, the finite element method was used to study punching processes. The consistency of the finite element model was analyzed by comparing experimental and numerical studies. When the flat punch geometry was used, the cutting force was at its greatest. Using the largest angled punch geometry resulted in the lowest cutting force. It has been determined that the dimensional accuracy of the blank and the falling part is better when using the flat punch geometry compared to the other punches used. In addition, it was observed that experimental and theoretical studies are compatible with each other. It is thought that finite element software can provide time and cost savings in determining the cutting force of materials.

1. INTRODUCTION

Because of its high strength-to-weight ratio, aluminum alloys have found a place in the automotive industry. However, several technological obstacles need to be cleared to reach their full potential [1]. After steel, the most used metals as engineering materials are aluminum alloys. As it is known, the specific density of aluminum alloys compared to steel materials is approximately 1/3. In addition, although its mechanical properties are low as a pure metal, it can gain mechanical properties at a level that can be used instead of steel materials with strength mechanisms such as alloying, aging, and cold deformation [1, 2]. Therefore, it can be used instead of steel materials in some applications. It is common to use aluminum alloys in the industry as sheet material. As in every process, the understanding and analysis of the punching process are essential both for the optimization of the process and for the examination and correct orientation of the effects of the process on the products. In general, the cutting force and surface quality that occurs with the punching process are accepted as two critical factors that determine the optimization of the process and the quality of the product [1–4]. The aluminum alloy 1000 series shows excellent weldability, has excellent resistance to atmospheric corrosion, and is highly suitable for decorative anodizing. Aluminum 1050 and 1070 commercial grades are two of several common aluminum alloys and are low strength. They can be obtained commercially as 98-99% pure.

*Corresponding author, e-mail: hgurun@gazi.edu.tr

To date, many investigations have been done about sheet metals, especially steel sheets, and punching process parameters, for example, clearance [5, 6], tool wear and type [4, 7, 8], punching velocity[9, 10], hole quality [11–14], punch angles and cutting force [15, 16] and simulation [4, 17, 18]. Tekiner et al. [16] found a high correlation between the clearance value and punch geometry, burr size, sheared area, and cutting force. Çavuşoğlu and Gurun [1] investigated the effects of clearance value on burr height and blanking force for AA 5754 alloy. Apart from these few studies, research on punching-cutting aluminum alloys has been limited. A study on the dimensional conditions of parts has not been found in the open literature. It is known that the quality of a part's cutting surface is significantly impacted by clearance. On the other hand, Gurun et al. enforced that punch angles and types affect cutting force more than clearance [15].

The geometric tool parameters are related to the edge and the dimensions of the part being sheared, the radius of the cutting edge, the clearance, the complex material behavior of the sheet, the sheet thickness, and lubrication [15, 18–22]. However, empirical knowledge is generally used due to the complexity of the cutting process. Therefore, using an accurate numerical tool to improve the cutting process's setting is highly desirable. Thus, it is possible to meet the requirements of high-quality products, and dimensions can be precisely adjusted.

Significant challenges in the punching process include work hardening, increasing the sheared surface, and decreasing punch force. However, these difficulties can be overcome with the appropriate punch geometry. Kurniawan et al. investigated the punching of titanium sheets with three different punch geometries: double and single shear angles and flat. The findings demonstrate that, compared to a flat punch, the punching process using single shear angle and double shear angle punch geometries reduces the punch force. The rollover height, however, has increased by almost 48%, and the sheared surface quality has worsened [23]. Besides, the flying behavior of a cut scrap and noise level are influenced by sheet strength, press velocity, and punch geometries. The sound level also increases as the sheet strength and press velocity increase. In addition, using angled punches is also beneficial to reducing the cutting flying speed and sound level [24]. The effects of cutting polymer composite belts with piercing punches that have a spherical bowl have been investigated. It has been seen that the maximal cutting force, tool life, and cut-hole quality are significantly impacted by the geometrical characteristics of the punch [25].

The impacts of the punch cutting edge forms in the cutting of aluminum alloy sheets, particularly the AA 1050 and AA 1070 series alloys, were not studied in the literature. However, although the piercing of sheet materials is an easy process, it depends on multiple parameters, making it difficult to get quality results. A high-quality piercing process can be realized depending on parameters such as clearance, cutting force, press speed, punch tip geometry, and material punched. Cutting force, part geometry, and dimensional accuracy are the most complex of these parameters [15, 16]. The punch cutting edge shape significantly impacts the cutting force and part quality [1, 14, 16]. In this study, the punching-cutting force, part dimensional accuracy, and failures that occur due to different punch tip geometries were investigated experimentally and theoretically. As a result, information with a focus on academic and sectoral applications was created.

2. MATERIAL METHOD

The chemical compositions of the commercial AA 1050 and AA 1070 aluminum sheet materials used in this study are given in Table 1. Sheet thicknesses are 1.5 mm. Sheet materials were cut into small strip pieces of 130x27 mm for punching.

Table 1. *The chemical compositions of the Al sheets*

Material	Si	Fe	Cu	Mn	Mg	Zn	P	Al
AA 1050	0.35	0.55	0.04	0.03	0.09	0.035		99.055
AA 1070	0.6	0.35	0.6	0.02	0.015	0.025	0.01	98.38

Tensile tests of the specimens were conducted for the ISO 6892-1 standard using a Zwick/Roell 600 kN device at a tensile speed of 1 mm.min^{-1} (Figure 1). The engineering stress-strain data were obtained from the tensile tests and the results were used to compute the true stress-strain curves. The data obtained from these curves has been employed to determine material properties in the numerical modeling.

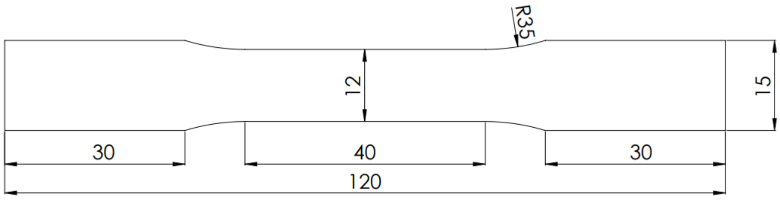


Figure 1. *Technical drawing of the tensile test samples*

Tensile test results for AA 1050 and AA 1070 sheet materials are shown in Figures 2 and 3, respectively. AA 1070 Aluminium material shows high strength and low elongation values compared to AA 1050. These materials exhibit lower yield strength, tensile strength, and strain hardening than steel materials [12].

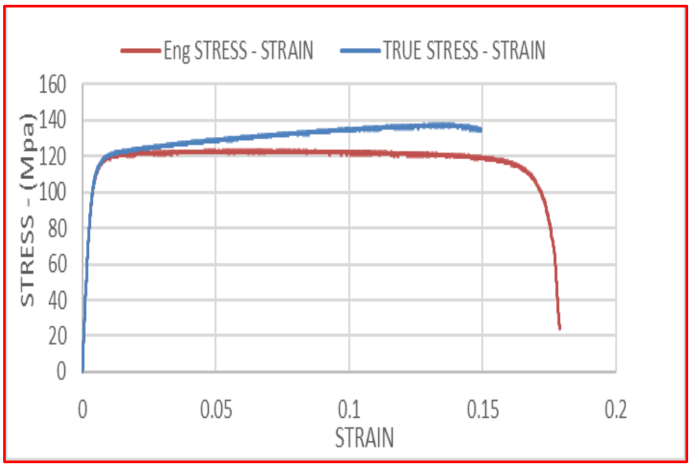


Figure 2. *The tensile test result of the AA 1050 sheet*

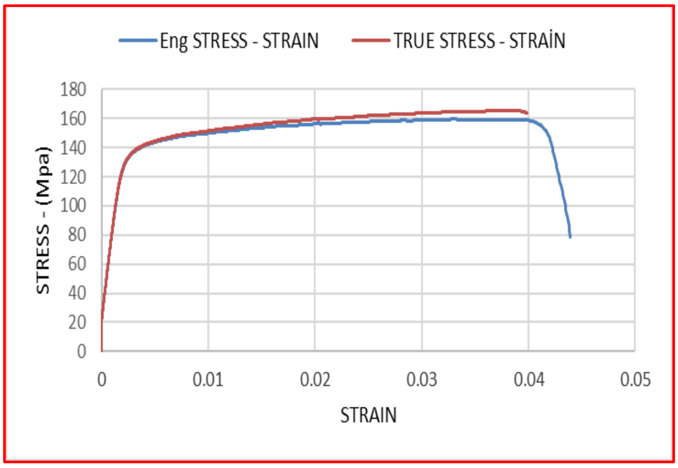


Figure 3. *The tensile test results of the AA 1070 sheet*

The system, which consists of the press, die, load cell, and computer, in which punching experiments are carried out, is shown schematically in Figure 4. A modular cutting die was manufactured to be used in the experimental studies. A 120 kN load cell was mounted on the die. Although the load cell utilized in this study has 10000 data per second measurement capability, only 2000 data measurements per second were sufficient to get the results. The data obtained from the load cell was transferred to the computer environment using a data acquision card, an amplifier, and a computer software. The test system was calibrated on the accuracy of the force-time data before punching experiments. This experimental setup obtained the forces during the cutting experiments. The forces emerging in the punching experiments were taken as time-dependent data using the experimental setup and graphed by Excel software. According to the literature, the clearance value used in cutting and piercing operations significantly affects the cutting force. Therefore, the 0.4% clearance value suggested for aluminum materials in the literature was applied to get the best results from the experimental studies.

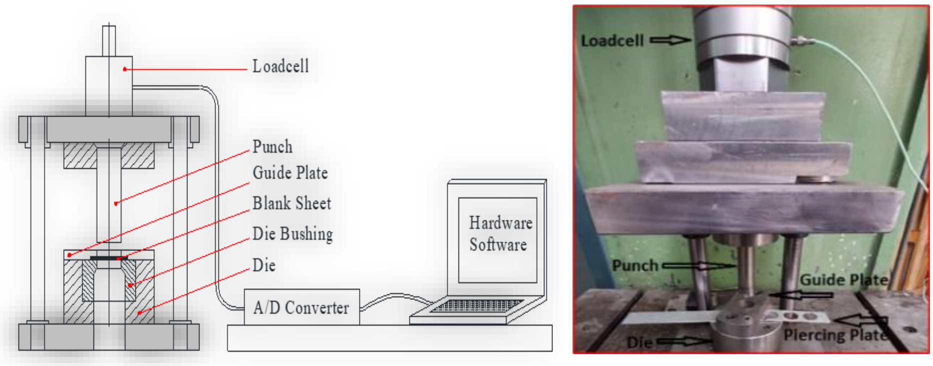


Figure 4. *Experimental setup of the punching process*

Punches were manufactured from DIN 1.2379 grade tool steel 20 mm in diameter. Cutting/piercing processes were complated using five different punches. The punches have various geometries named P-0°, P-16°, P-R1, P-R2, and P-V16 (Figure 5).

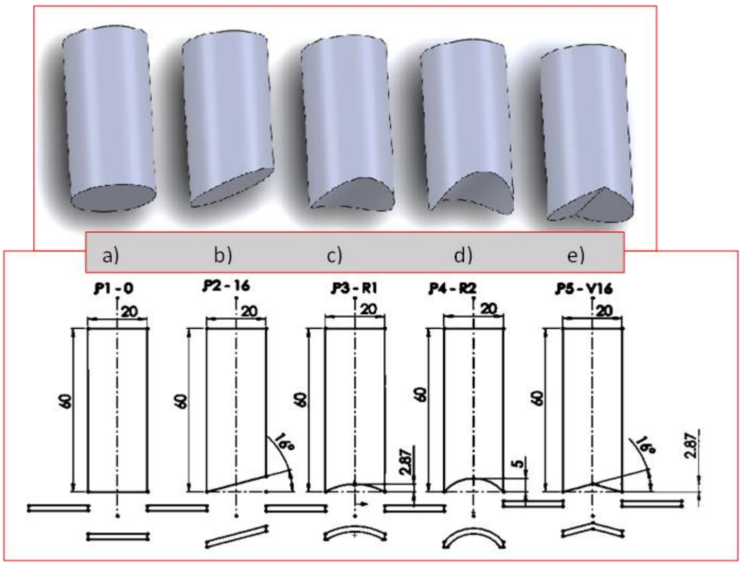
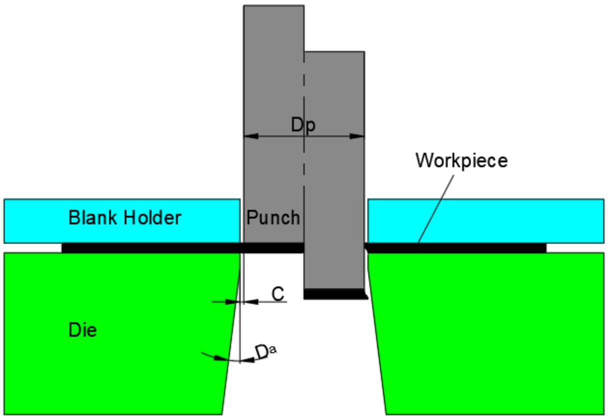


Figure 5. *Punch geometries used in the studies*

The measurements of the blank on the sheet and falling parts were performed using the help of stereo and shuttle-pix microscopes equipped with measurement software.

An approximate solution to boundary value problems is identified in engineering by using the FEM. The material properties (AA 1050 and AA 1070) were determined from the tensile test results. These properties were used for material identifications in FEM analyses. SolidWorks was used to create the geometric model, and the model prepared was transferred into Deform software. The schematic of the experimental setup is given in Figure 6. A friction factor representative of the materials employed was determined by the correlations to contact between tangential and normal surfaces. Only the sheet material had a determined mesh structure. It was assumed that the cutting punch, blank holder plate, and die were all rigid bodies. The mesh density has 3000 tetragonal elements for the sheet material. The nonlinear static analysis method, which excludes the effects of inertia forces, was used to investigate the numerical model. The boundary conditions were defined as fully fixed for the die.

On the other hand, the punch movement in the vertical axis caused the sheet material to be cut symmetrically. The analyses were repeated for all the punch types. The punch velocity was adjusted to 1.5 m/min in all analyses. The process parameters used in punching operations are also given in Figure 6.



PARAMETERS	VALUE
Blank material/Thickness	AA 1050/1.5 mm
	AA 1070/1.5 mm
Punch diameter (D_p)	20mm
Die cutting angle (D_a)	2°
Clearance (C)	0.06 mm
Punch velocity (V)	1.5 m/min
Mesh density	3000 tetragonal elements
Coefficient of friction	0.1

Figure 6. *Schematic of the experimental setup*

In order to confirm compliance with the experiments and evaluate the software's capacity to simulate cutting processes, 3D models were utilized in the analyses (Figure 7).

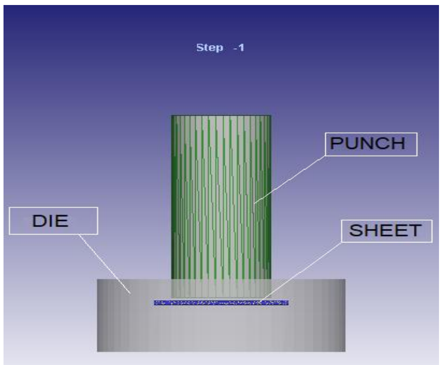


Figure 7. *Experimental setup modeled in FEM software*

The cutting operations were performed for the five different punch shapes under the same boundary conditions after the piercing process was modeled in the deform program. As a result, the graphs of cutting force versus time values were obtained.

3. RESULTS AND DISCUSSION

3.1. Cutting Forces

The force-time graphs obtained from the experiments and FEM analyses using various punch shapes for the AA 1050 sheet were compared in Figure 8. In addition, Figure 9 illustrates how the different punch types affect the cutting/piercing force.

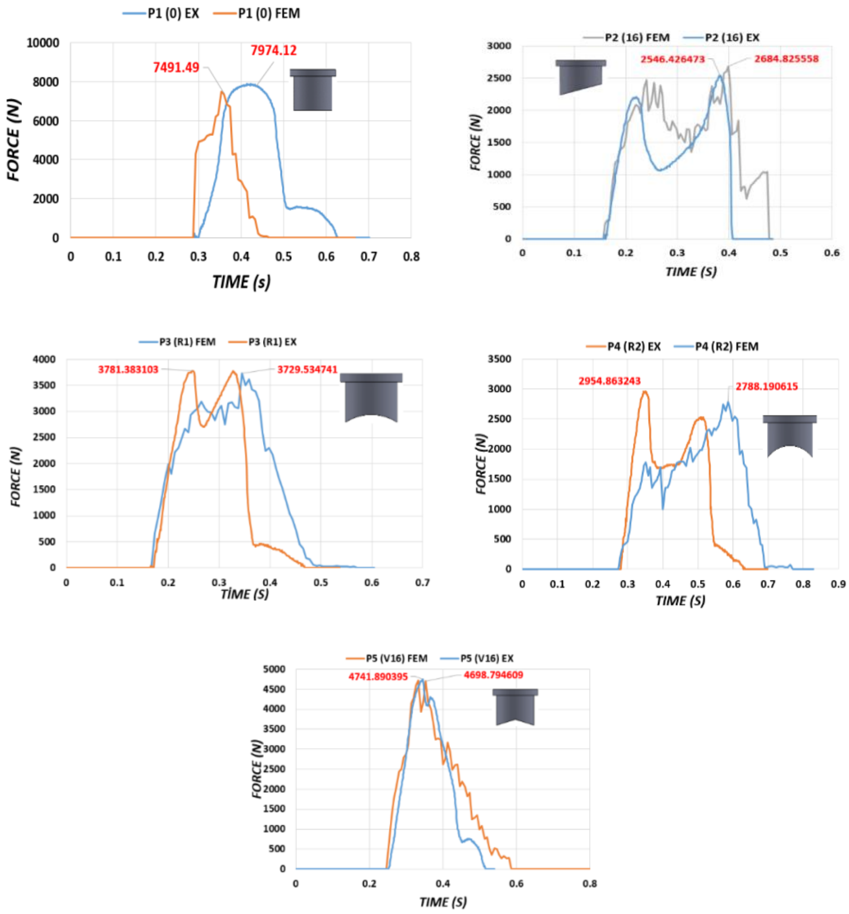


Figure 8. *The comparison of the force-time graphs for the AA 1050 sheet*

The biggest cutting force was obtained using the P1 (0°) flat-ended punch shape in the cutting experiments by different punch geometries. The lowest cutting force was measured in the use of the P2 (16°) angled punch. It is due to a higher cutting area during cutting by flat-ended (0) punch. The cutting edges of the punches except P1 are not flat, so they reduced the cutting area. Dimensional accuracy and ovality are the most significant factors affecting the quality of parts. The experimental results and FEM analyses were compatible and very close to each other in terms of dimensions of accuracy and ovality.

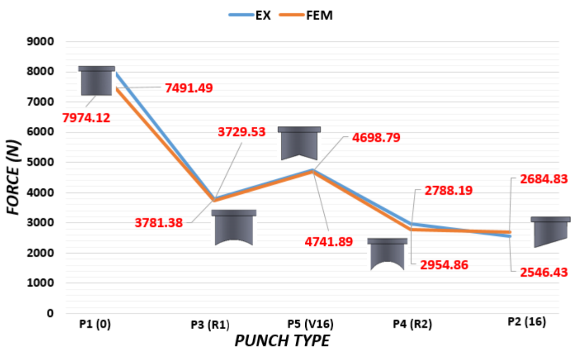


Figure 9. *Variation of the forces depending on the punch types in the cutting of AA 1050 sheet*

When Figures 8 and 9 are examined, it is seen that the cutting forces are significantly reduced in the use of the angled-inclined punches. Moreover, in the use of the P5 (V16), P3 (R1), P4 (R2), and P2 (16), cutting forces decreased by 39%, 53%, 63%, and 68%, respectively, compared to flat-ended punch (P1). On the other hand, the comparison of the force-time graphs produced from the cutting processes and FEM analyses of the AA 1070 Al sheet using different punch shapes is shown in Figure 10. The alteration of the cutting/piercing force depending on the punch types is given in Figure 11. These experimental and FEM analyses were also compatible and very close to each other.

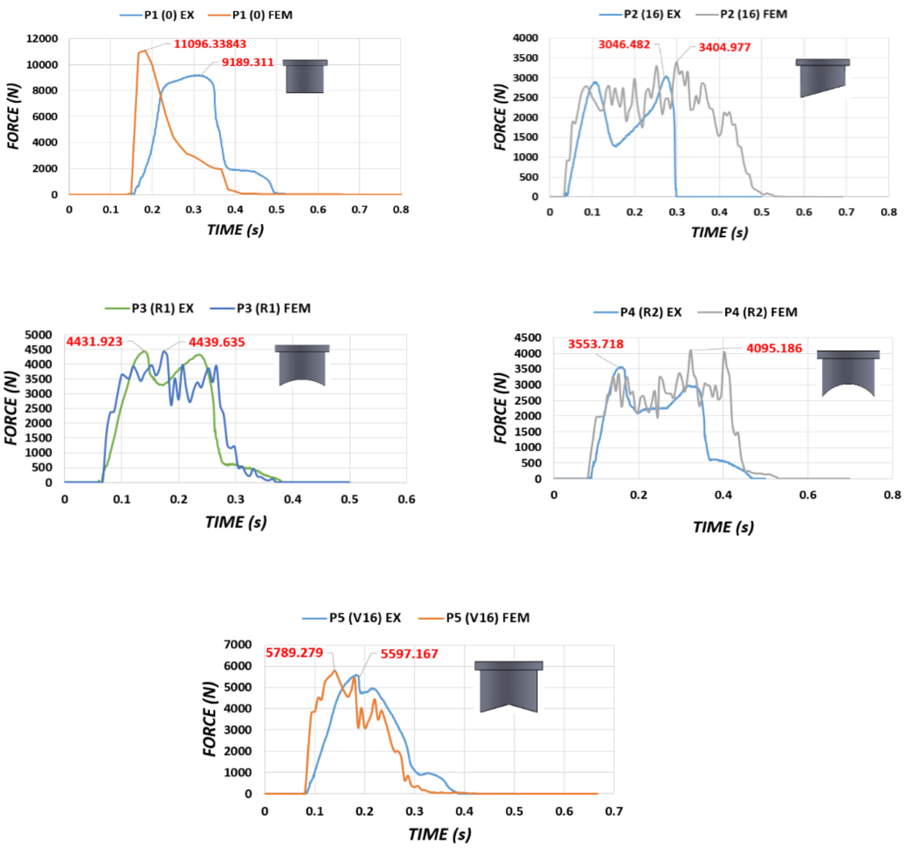


Figure 10. *The comparison of the force-time graphs for the AA 1070 sheet*

It has been previously stated that the cutting forces obtained from the analysis studies of AA 1050 and AA 1070 metal sheet material using the finite element software and the cutting forces obtained from the punching processes are very close. However, there are slight differences. The meshing density causes discrepancies, such as the inability to accurately define the material or the failure to account for any pre-existing defects.

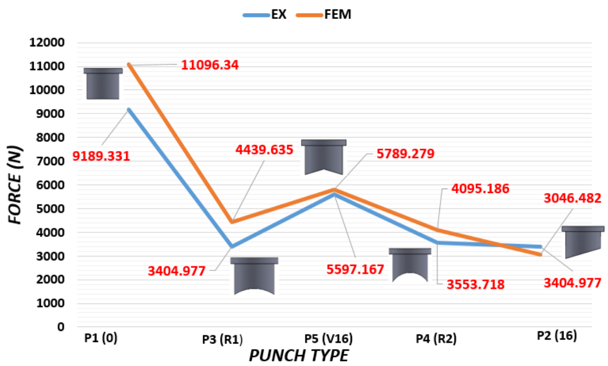


Figure 11. *Variation of the forces depending on the punch types in the cutting of AA 1050 sheet*

It was seen that the FEM analysis results can be used to determine the approximate cutting forces of metal sheets for the different punch geometries. In order to reduce the necessary shear force during the blanking/punching process, Gurun et al. [15] investigated the effects of different punch angles. They have also examined the effects of clearance on the forces for cutting processes. They used various angled punches and die matrices with different clearance values. It has been understood from these studies that cutting forces can be decreased by 80% when a 16° angled punch is used and the punch angle had a greater impact on the cutting force than the punch clearance.

3.2. Dimensional Measurements and Failures of the Blanks

Figures 12 and 13 show changes in hole sizes after the cutting/piercing processes of AA 1050 and AA 1070 sheet materials for all punch geometries. When these figures are evaluated together, it is seen that a minor variance has occurred in the use of the P1 (0°) flat-ended punch geometry in piercing operations of both AA 1050 and AA 1070 sheet metal materials.

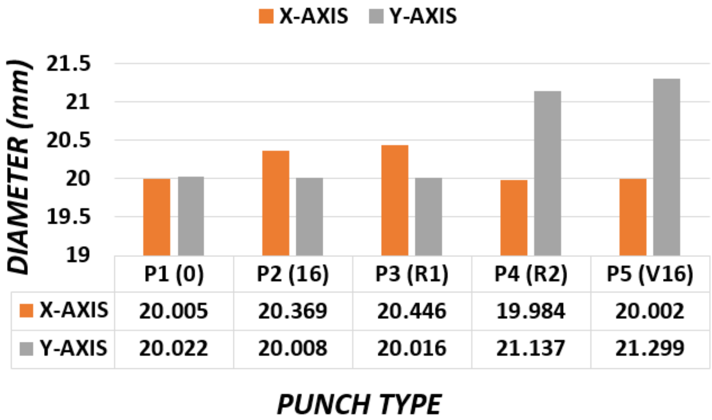


Figure 12. *The hole diameters on the blank in the cutting of AA 1050 using different punches*

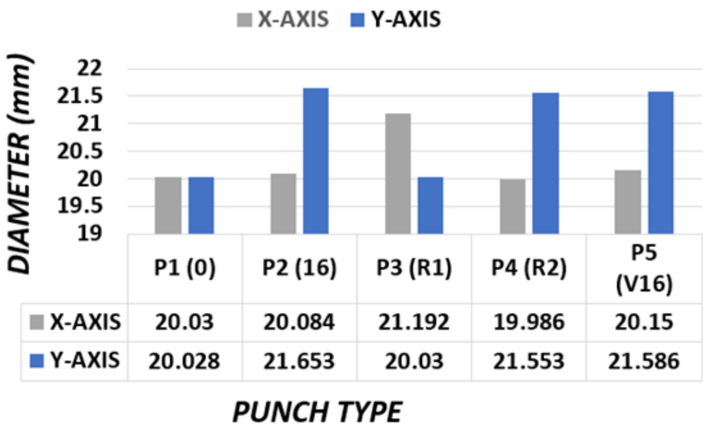


Figure 13. *The hole diameters on the blank in the cutting of AA 1070 using different punches*

The highest deviations for sheet metal material were obtained in the use of the P5 (V16), P4 (R2) concave, P3 (R1) concave, and P2 (16°) angled punches, respectively. Due to the cutting-edge geometries of the punches, there were significant dimensional variances in the sizes of the holes. Therefore, it can be stated that the punch edge geometry significantly impacts the dimensional accuracy of the blanked hole.

Top views of the AA 1050 and AA 1070 sheet materials cut with various punch geometries are shown in Figures 14 and 15, respectively. The images show damaged regions that occurred during the cutting-piercing processes. It can be seen that the damaged areas are formed at the places where the workpiece and punch make their initial contact.

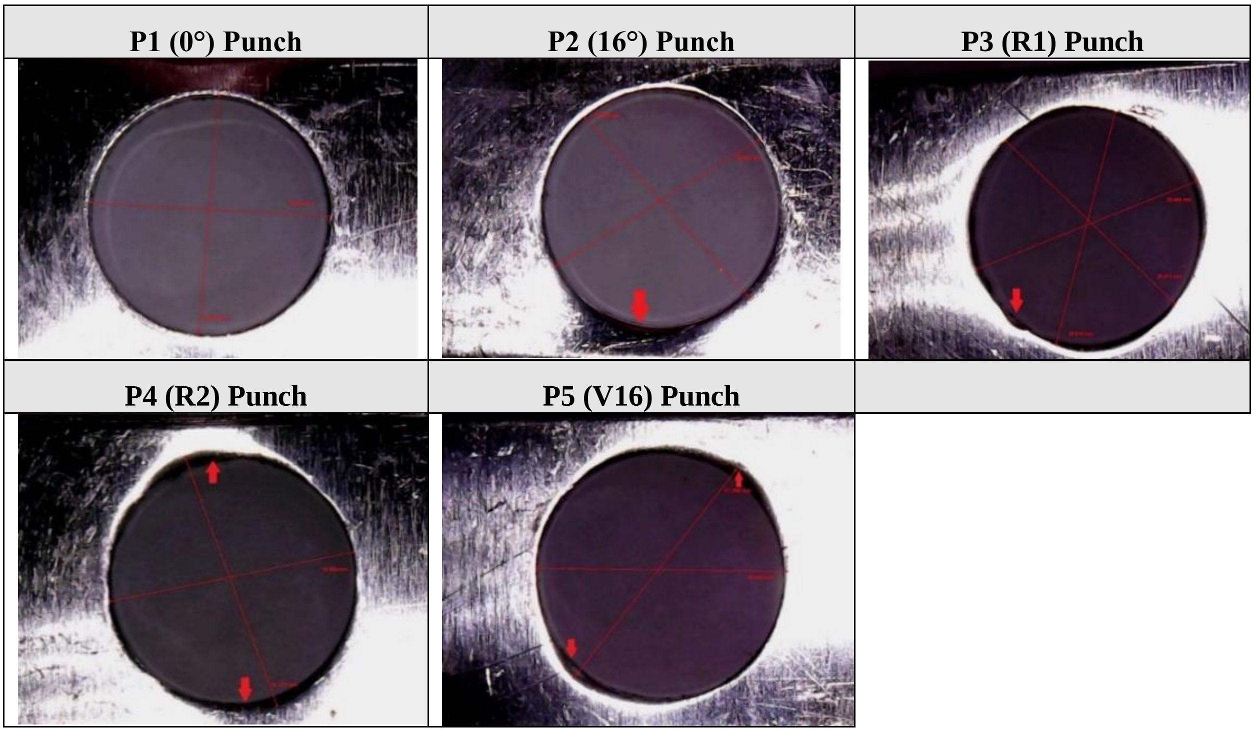


Figure 14. *Dimensional measurements and failures of the blank of AA 1050*

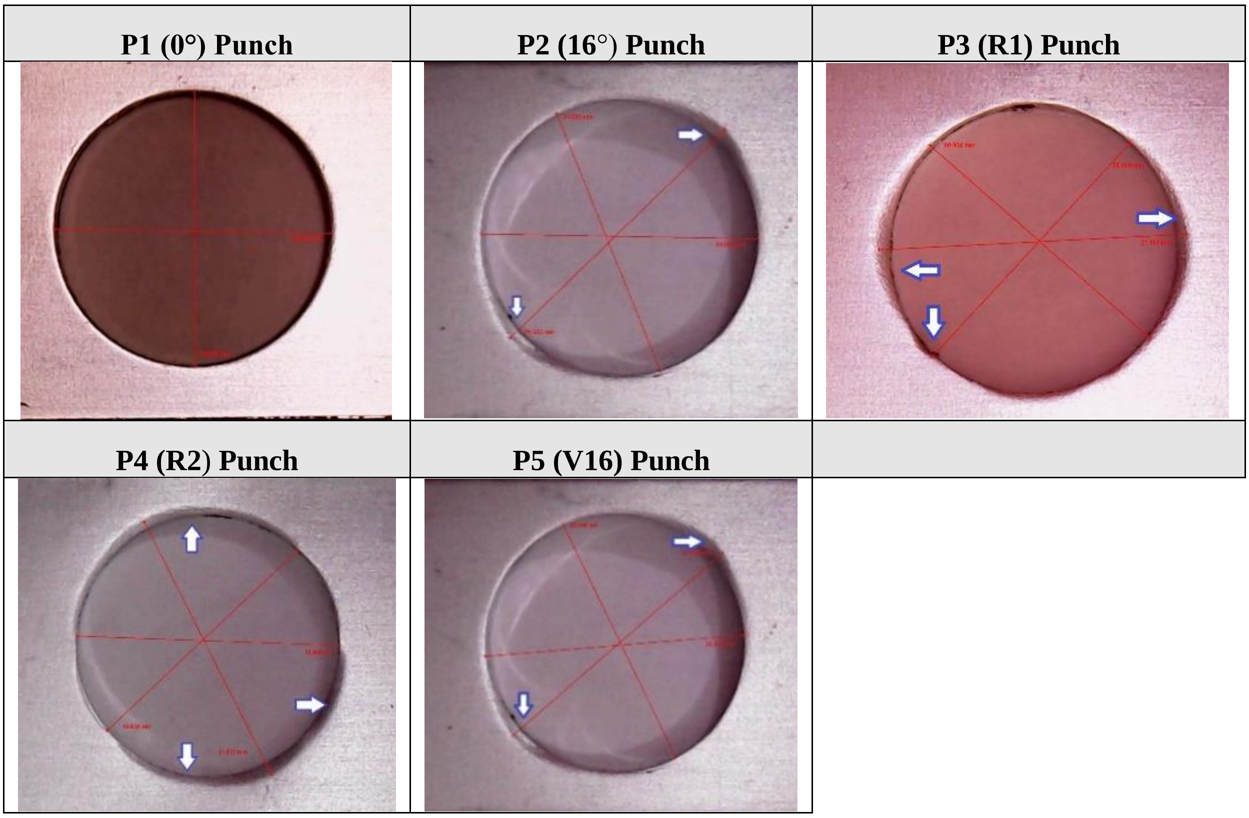


Figure 15. *Dimensional measurements and failures of the blank of AA 1070*

3.3. Diameter and Circularity Deviations

Getting the perfect cut-diameter hole during punching operations is the primary objective. Many variables influence the dimension of the holes produced in the punching operation, including punch geometry, clearance, cutting speed, and material strength. This study examined how the punch geometry affects the diameter deviation in punching operations. Figures 16 and 17, respectively, show the deviation values that occur during the piercing of AA 1050 and AA 1070 sheet materials. In the hole-cut diameter measurements, the deviation values from the diameter ranged between 0.005-1.299 mm for AA 1050 sheet material and 0.028-1.586 mm for AA 1070 sheet material.

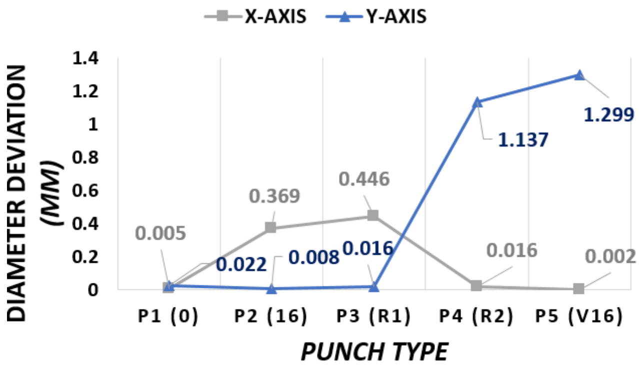


Figure 16. Diameter deviations in piercing with different punches, AA 1050

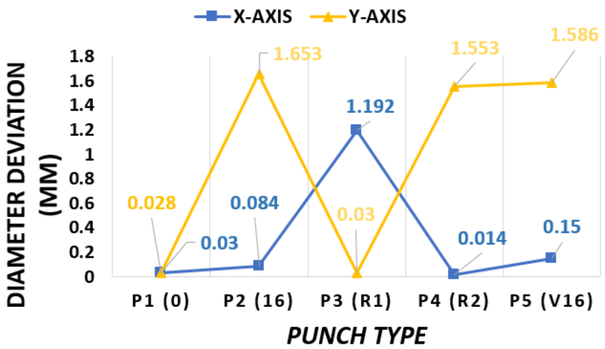


Figure 17. Diameter deviations in piercing with different punches, AA 1070

In addition, the deviation values from circularity occurring in the piercing process of AA 1050 and AA 1070 sheet metal materials are given in Figure 18.

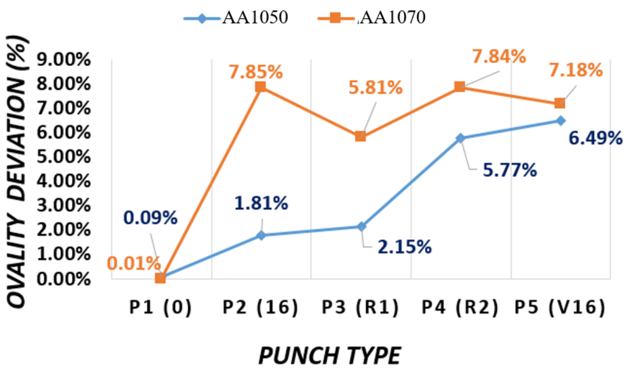


Figure 18. Circularity deviation in piercing with different punches

Figure 18 illustrates the increase of the ovality depending on the strength value of the aluminum sheet. When punch geometries are considered, it is seen that the lowest ovality was obtained using the P(0) punch and that it increased in the use of the other punches. The pressure of the punch on the cutting area can explain this situation. In the use of flat-edged punches, the punch presses on the entire cutting area, while the cutting process is spread over time in the use of the other punches. The measurements obtained from the punching processes ranged between 0.09-6.49% and 0.01-7.85% for AA 1050 and AA 1070 sheet materials, respectively.

4. CONCLUSION

Two different aluminum sheets were used as test specimens in this study. Commercially obtained AA 1050 and AA 1070 sheet materials were cut using five punches with different cutting-edge geometries. The cutting forces, dimensional accuracy of the cut holes, and ovality values were investigated. The cutting/piercing process was modeled in force-time using finite element software according to the conditions of the experiment. Consequently, the following general findings were drawn:

- The biggest cutting force was obtained using a P1 (0°) (flat-ended) punch for AA 1050 and AA 1070 sheet materials.
- The P2 (16°) punch provided the lowest cutting force.
- It has been found that the punch geometry significantly influences the cutting force. The cutting forces can be reduced by 68% for AA 1050 sheet metal and 65% for AA 1070 sheet metal using angled punches.
- Reductions in material thickness and deviations in the hole sizes occurred when the P3 (R1), P4 (R2) concave, and P5 (V16) punch geometries were utilized.
- The smoothest hole diameter was obtained using the P1 (flat) punch.
- It has been determined that the parts are deformed and cannot be obtained in the desired form when angled and inclined punches are used. For this reason, it is concluded that just P1 punch geometry should be used in the blanking processes. The other punches can be used in the cutting processes to reduce cutting forces depending on the dimensional accuracy of the parts.
- It has been observed that the cutting forces obtained from the experiments and the finite element analyses overlap substantially.
- The finite element method can save costs, speed up the production process, and save time in cutting sheet materials.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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