Clearance effect on the sheared edge characteristics of key chain cranioplasty plate in the punching process

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Abstract. Punching process is a process to cut sheet metal by pressing the workpiece until it exceeds the elastic limit of the material. In this study, the researcher used the finite element method as a solution to a problem during the manufacturing process. This research simulated the punching process, particularly hole-making, in keychain cranioplasty product to obtain smoothest sheared edge characteristics by optimising the clearance amount variations. The product had 1.53 mm diameter and 0.6 mm thickness of titanium alloy plate. The analysis was performed using the finite element method with the support of ANSYS Explicit Dynamic software. During the punching process, the punching speed was 2600 mm/min. The results showed that reductions in clearance, below 2.5% clearance, produced rougher sheared edge. The higher clearance produce rougher sheared edge. The 2.5% clearance was the standard for a right sheared edge to make a hole in the keychain cranioplasty plate with 0.6 mm thickness.

Keywords: punching, keychain, clearance, sheared edge characteristic, finite element method

1. Introduction
Punching process is a cutting process by pressing the workpiece until it exceeds the elastic limit of the material [1]. Punching process produces coin, bone grafting implant plate, ring, and small and large engineering components. Keychain cranioplasty plate is an implant that is generally used to graft the skull.

The product from the punching process has two smooth surfaces to be called perfect. The sheared edge surface from the blanking and punching has four category areas: rollover, shear zone, fracture, and burr, as seen in Figure 1 [2]. Important parameter that must be considered to obtain smooth surfaces are blanking die design, blanking punch design, material selection for dies and punch process, suitable clearance following the correct calculation to avoid burr on the product, and material type, thickness, and dimension for the punching process [3].
2. Methods and materials

2.1 Materials and finite element setup

The model that was analysed using the finite element method was the punching results in the form of sheared edge surface characteristics. The products were compared to find the optimum characteristics based on their clearance variation. The analysed products were the simulation results of the keychain cranioplasty plate hole during the punching process. Since the product geometries were small, the dimension measurement was performed using a Dino-lite microscope. Figure 2 shows the product dimensions.

Figure 2. (a) Keychain cranioplasty plate, (b) Actual dimensions of keychain cranioplasty plate

The sheet metal on the blanking process was simulated using a three-dimensional axisymmetric FEs model (ANSYS software) by dynamic explicit method. The blank is modelled as a deformable body exhibiting elastic-plastic material behavior, whereas the tools are alleged to be

Previous research had successfully created a Micro Punch CNC machine that could produce a pierce in 790 µm diameter with 500 µm thickness on copper sheet material [4]. From that research, the best product was found in the sample with 2.5% clearance. Meanwhile, the study of [5] had the best clearance, with a value of 1.67%, to make a product with 19.95 mm dimension and 1.5 mm thickness. The best sheared edge characteristics using 0.08 mm clearance to produce a pierce in 20 mm diameter and 1 mm thickness [6].

Software technology development is helpful for manufacturing process because it simulates the numerical calculation and visualises the possible occurrence during the process [7,8]. Numerical simulation software that is often used is the finite element method, which is software can simplify the numerical iteration process. Studied fine blanking process on DP 600 steel with 5 mm thickness using the finite element method obtained accurate results [9]. Based on the above description, the main discussion in this research is an analysis simulation on the clearance variations on commercially pure titanium sheet with 600 µm thickness to be applied in keychain cranioplasty plate. Thus, there needed a simulation using the finite element method with a dynamic analysis method to obtain the best clearance recommendations which contain a sheared edge dominated by shear zone shape.
rigid. Figure 3 depicts the punching process model in this research. There were several parts related to the punching process, namely punch, workpiece, and die. The parameter settings used in this study are punch speed with 2600 mm min\(^{-1}\) and 40000 N pressure force. During the punching process, the punch tool pressed the workpiece, created the opposite force between the punch tool and the workpiece, which causes the object to experience shear intersection. Table 1 displays the material properties for the punching process.

![Figure 3. Punching process model using the finite element method](image)

### Table 1. Material properties of the simulation Model

| Properties                  | Titanium Alloy (Ti-6Al-4V) | Punch and Die |
|-----------------------------|----------------------------|---------------|
| Density (kg cm\(^{-3}\))    | 4510                       | 7580          |
| Elongation (%)              | 15                         | 25            |
| Poisson’s Ratio             | 0.37                       | 0.30          |
| Modulus Young (GPa)         | 105                        | 200           |
| Yield Strength (MPa)        | 480                        | 550           |
| Tensile Strength (MPa)      | 550                        | 880           |

#### 2.2 Clearance calculation

In the case of making circle products, clearance variations of 0.5, 1.5, 2.5, 3.5, and 4.5% with a punch diameter value of 1.53 mm have been used. Distance calculation between the punch and die (clearance) was determined using the equation 1 [10].

\[
C = \frac{d_d - d_p}{2t} \times 100\% \tag{1}
\]

Where \(d_d\) was the die diameter (mm), \(d_p\) was the punch diameter (mm), and \(t\) was the material thickness (mm). Table 2 presents summarize the clearance variations that were analyzed.

### Table 2. Clearance calculation results in the punching process

| Clearance | Punch diameter \((d_p)\) | Die diameter \((d_d)\) | Distance between the punch and die |
|-----------|--------------------------|------------------------|-----------------------------------|
| 0.5 %     | 1.53                     | 1.536                  | 0.003                             |
| 1.5 %     | 1.53                     | 1.548                  | 0.009                             |
| 2.5 %     | 1.53                     | 1.56                   | 0.015                             |
| 3.5 %     | 1.53                     | 1.572                  | 0.021                             |
| 4.5 %     | 1.53                     | 1.584                  | 0.026                             |
3. Result and discussion

Sheared edge characteristics are rollover, shear zone, fracture, and burr, presented in Figure 4a. In order to calculate the sheared edge characteristics used Image J software and were divided into three areas, as seen in Figure 4b.

![Image 1](image1.png)

**Figure 4.** a) Sheared edge characteristic from the punching process simulation, b) Area grouping on the sheared edge characteristics

### 3.1 Fracture growth simulation in the punching process

![Image 2](image2.png)

**Figure 5.** Fracture growth in the punching process simulation at 2.5% clearance

During the punching process, the punch tool pressed the workpiece, creating the opposite force between the punch tool and the workpiece. Where the maximal equivalent stress is obtained on the equivalent plastic strain point, the material loses its strength completely. A material particle
that's deformed at some stage of the blanking process to its ultimate loading state. Therefore material is no longer homogeneous but is divided into two subdomains. Figure 5 shows the fracture from the punching process simulation using the finite element method with ANSYS Explicit Dynamic software.

In Figure 5a, when the punch tool reach the sheet metal, or at punch pressing distance of 0 mm, this is called the initial step of the punching fracture process. The formation of cracks on both the highest and bottom edges of the workpiece. Second image (b), plastic deformation occurred in the workpiece with a punch force distance of 0.004 mm. Third image (c), at punch force distance of 0.009 mm, the workpiece has yet to experience a fracture, but the shear stress is getting larger. In the fourth image (d), at the punch force distance of 0.049 mm, the material is at maximum shear stress so that the fracture is initiated. Fifth image (e), at 0.069 mm punch pressing distance, the crack grows and the shear stress decreases, the cracks finally meet each other and there is a complete separation. Lastly, in the sixth image (f), the workpiece is split due to continuous punch pressing at 0.093 mm. Shear stress growth of punching process curves, plotted in Figure 6.

[Image of shear stress growth chart]

**Figure 6.** Chart of shear stress growth of punching process at 2.5% clearance variation

3.2 Clearance variation of the punching process

Figure 7 presents the sheared edge characteristics from the punching process. The analysis results showed that the largest rollover value was in the sample with 4.5% clearance during the punching process, the workpiece run into quite long plastic deformation that created larger rollover, this result is in accordance with [11,12].

The rollover value increased except for the sample with 3.5% clearance where the rollover decreased, as seen in Figure 8a. Generally, the rollover area increases with higher clearance. Figure 8b is the shear zone comparison, the highest shear zone was in the sample with 2.5% clearance. From the analysis, it can be concluded that lower clearance created smaller shear zone as proven by the shear zone from the 0.5% to 2.5% clearance. Meanwhile, higher clearance generated smaller shear zone and can be seen from the shear zone at the 2.5% to 4.5% clearance. The high shear zone requires the correct clearance following the dimensional form in the punching process. Edge quality is often improved with an increasing punch speed of about 100000 to 700000 mm min⁻¹. Sheared edge can undergo severe cold working in consequence of the high shear strains involved. Hardening the edges reduces the ductility of the material and thus affects the formability of the sheet metal during subsequent operations.
Figure 7. Sheared edge characteristic of the punching process simulation with clearance variations

Figure 8. Comparison chart of characteristics of fracture and burr in the sheared edge results in each region of punching process simulation with clearance variations

4. Conclusion
Based on the discussion, it can be concluded that during the punching process, the clearance value influenced the sheared edge characteristics. The punching process simulation in hole-making the keychain cranioplasty plate obtained the amount of 2.5% clearance as the best clearance value that produced the best sheared edge characteristics.
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6. **References**
[1] Suchy I, 1998 Hand book of die design,(New York: Mc Graw-Hill, Inc)
[2] Chatterjee S, Mahapatra S S, Abhishek K, 2016 Simulation and optimization of machining parameters in drilling of titanium alloys, *Simulation Modelling Practice and Theory* 62 31–48
[3] Lange K, 1985 Hand Book Of Metal Forming, (Printed and Bond bu R.R. Donnelley & Son Company. McGraw-Hill Book Company)
[4] Lubis D Z, & Ristiawan I, 2017 Blanking clearance and punch velocity effects on the sheared edge characteristic in micro-blanking of commercially pure copper sheet. *Journal of Mechanical Engineering Science and Technology* 1 pp. 53-60
[5] Fang, Gang, 2002 Finite element simulation of the effect of clearance on the forming quality in the blanking process. (China: Tsinghua University)
[6] Cavosoglu O. 2014 Investigation and fuzzi logic prediction of the effects of clearance on the blanking process of cuzn30 sheet metal,*Kovove Mater* 54 125–131
[7] Kwak T, 2002 Finite element analysis on the effect of die clearance on shear planes in fine blanking, (South Korea: Pusan National University)
[8] Efendi S and Andoko 2019 Design and Simulation of Cracks in A Four-Cylinder Engine Crankshaft Using Finite Element Method, *IOP Conf. Series: Materials Science and Engineering*, 494 012004
[9] Zhao P, 2016Experimental and numerical analysis of micromechanical damage for DP600 steel in fine-blanking process,(China: University of Science and Technology Beijing)
[10] Boljanovic V, 2004 Sheet metal forming processes and die design (New York: Industrial Press)
[11] Sirvin Q, Velay V, Bonnaire R, Penazzi L 2019 Mechanical behaviour modelling and finite element simulation of simple part of Ti-6Al-4V sheet under hot/warm stamping conditions, *Journal of Manufacturing Processes* 38 472–482
[12] Lubis D Z & Mahardika M 2016 Influence of Clearance and Punch Velocity on the Quality of Pure Thin Copper Sheets Blanked Parts. *IOP Conf. Series: Materials Science and Engineering* 157 012012