Fabrication of punch and die of micro-blanking tool

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Abstract. The difficulties of tool fabrication in micro level provide an enormous challenge due to the dimension limitation. Reducing the difficulty and tool cost fabrication should always be considered by determining the simplicity of tool geometry, precision tolerance, and an appropriate material selection. This paper study about the manufacturing of micro-blanking punch-die. The mechanical material removal method was chosen to fabricate punch-die since this is a single piece production and intended for small-scale production of micro parts. The manufacturing process consists of punch-die design and fabrication, tool assembly, and clearance measurement. The stress analysis is also conducted to ensure the strength of the punch-die. A micro-blanking experiment was held to observe the tool performance. The result showed that micro-blanking tool can be manufactured successfully and used well to conduct the micro-blanking experiment.

Keywords: Micro-blanking tool, punch-die, tool fabrication

1. Introduction
To date, the growing needs of micro-parts still indicate an increase. Therefore, the manufacturing process of micro-parts still required to meet the demand. Micro-sheet metal forming is one of the popular micro manufacturing processes to produce the micro-parts. In this technology, the tool is an aspect that holds a very important role since it directly affects the geometry and the quality of the micro-part. The difficulties of manufacturing process is an enormous challenge since the size of the tool is very small. A simple geometry of tool, a required tighter tolerances, a material selection, and a simple assembly must be determined very carefully in order to reduce the difficulty level and the cost of the tool component fabrication.

The most likely manufacturing method to produce the micro-tool components are additive, subtractive, and mechanical material removal. In this study, the main components of micro-blanking tool is fabricated by mechanical material removal method. This is suitable to be applied on a single tool piece production and intended for small-scale production of micro parts [1]. In the tool components machining process, the entire machining system requirements must be met well, such as machine tool itself, environment, sub-system, and reliable data management.

Some previous researches have been held in micro-tool manufacturing, such as Yi et al. [2] fabricated a punch piercing for 15μm hole using micro-EDM and Chern et al. [3] who introduced a technique to produce a variation of clearance of micro-blanking tool by controlling the spark gap in micro-EDM. Further, Jie Xu et al.[4] developed a micro-forming system for micro-punching process in high production volume. Meanwhile, in bending process, Fujimoto et al. [5] investigated a surface
treatment of the punch with an ion beam irradiation and diamond-like carbon (DLC) coating. Another die manufacturing was also explained by Gau et al. [6] in micro-deep drawing tool.

This paper study about the manufacturing process of the main components of the micro-blanking tool, i.e. the punch and die. The study consists of tool design process, stress analysis, tool manufacturing, tool measurement, and micro-blanking experiment. The results showed that the manufacturing processes have been successfully performed and produce a reliable tool to be used in micro-blanking experiment.

2. Micro-blanking
Blanking process is a cutting process of the sheet material (strip material/foil material) by applying shear forces on the material being cut. The cuts would occur if the shear stress on the material beyond the limits of the shear strength. Therefore, this process is also called shearing process. Other similar shearing process is the piercing. The difference between both of them is shown in Fig. 1.

![Figure 1. Shearing process: blanking and piercing [1]](image)

In general, the micro tool components are divided into two groups, namely the main components and support components, as shown in Fig. 2. The manufacturing of main components, i.e. punch and die, will be discussed further in this study. A gap between punch and die is called clearance, which are designed to facilitate the occurrence of fracture on the material to be cut. In micro level, the behavior of micro-blanking deformation is influenced by the ratio of clearance and the grain size, c/d [7].

![Figure 2. Micro-forming tool components](image)

Material that can be used for the main component and has a good machinability is from the tool steel group, while the other components can use the material from the machinery steel group. In this research, the SKD11 (AISI D2) was used for the punch and die. Whereas, the S45C (AISI 1045) was chosen from machinery steel for the rest non-standard components of micro blanking tool. The mechanical properties for SKD11 and S45C are shown in table 1.
Table 1. Mechanical properties of S45C dan SKD11

|                         | Machinery Steel | Cold Work ToolSteel |
|-------------------------|-----------------|---------------------|
| **S45C (AISI 1045)**   |                 |                     |
| Ultimate tensile strength MPa | 569             |                     |
| Yield Strength MPa       | 343             | 1650                |
| Elongation %             |                 |                     |
| Modulus of Elasticity GPa | 205             | 209.9               |
| Poissons Ratio           | 0.29            |                     |
| Machinability %          | 55              |                     |
| Shear Modulus GPa        | 80              |                     |

For blanking process, the necessary force to shear the sheet material, i.e. $F_{blanking}$ is estimated with the following equation [8]

$$F_{blanking} = L \cdot T \cdot \tau_m = 0.7 \cdot L \cdot T \cdot UTS$$  \hspace{1cm} (1)

where:

\begin{align*}
L & = \text{the total length sheared (perimeter) [mm]} \\
T & = \text{thickness of the material [mm]} \\
UTS & = \text{the ultimate tensile strength of the material [MPa]}
\end{align*}

3. **Punch-die design and fabrication**

This sub-section discuss about punch-die design and fabrication, tool assembly, and clearance measurement. The stress analysis is also conducted to ensure the strength of the punch-die.

3.1. **Design of punch-die**

It was determined that in one blanking stroke, four specimen materials should be produced. So, the blanking lay-out was designed (Fig. 3b.) based on the blanking part geometry (Fig. 3a). Thus, the geometry of raw material for blanking process was obtained (Fig. 3c). Clearance between the punch and die was set at a maximum of 0.05mm / side.

![Initial design](image)

**Figure 3.** Initial design (a). Blanking part geometry, (b). Blanking lay-out, (c). Raw material dimension

Hereafter, the punch and die was designed based on the blanking lay-out. The detailed drawing of the punch and the die are showed in Fig. 4 and 5. For ease of machining and assembly processes, the pin locator was implemented in the construction (Fig. 5c). The locator pins was set 2mm above the die surface to facilitate the raw material placing.
For stripper components, the urethane was selected since the construction becomes simple and does not damage the material foil (Figure 6c). The stripper serves as the holder of sheet material before it is cut and keep the scrap material does not stick to the punch when it is raised. The punch-stripper assembly is showed in Figure 6c.

The compressive force urethane \( F_{urethane} \) is calculated by the following equation [9]  
\[
F_{urethane} = E \cdot \frac{\Delta H \cdot S}{H} 
\]  
where,
\( E \) = the elastic modulus for urethane [kgf/cm²]
\( S \) = Load area [mm²]
\( \Delta H \) = the change in height [mm]
\( H \) = the initial height (free height) [mm]

The elastic modulus for urethane is obtained from the graphic in figure 7. Thus, with \( E = 108 \text{ kgf/cm}^2 \), \( S = 253 \text{ mm}^2 \), \( \Delta H = 2.5 \text{ mm} \), \( H = 12 \text{ mm} \), thus the \( F_{urethane} = 557.36 \text{ N} \).
3.2. Stress Analysis of punch - die

The major load that applied at punch is came from the calculated blanking force based on the Eq. 1. The sheet of material that will be used in the blanking experiment are aluminum, brass, copper, and steel with 0.1mm thickness. The mechanical properties of those materials (Table 2) are obtained from tensile test using Shimadzu Servopulser 20T tensile machine.

| Table 2. Mechanical properties of the sheet material |
|-----------------------------------------------|
|                  | Aluminum | Brass | Copper | Steel |
| Tensile Strength [MPa]  | 127      | 379   | 657    | 1338  |
| Yield Strength [MPa]    | 58       | 192   | -      | 1206  |
| Elongation [%]          | 15.8     | 23.13 | 2.11   | 5.33  |

So, the maximum blanking force is estimated reached with steel sheet as a material specimen (tensile strength = 1338 MPa), i.e.:

$$ F_{blanking} = 0.7 \cdot 16.8 \cdot 0.1 \cdot 1338 = 1573.5N $$

Based on the free body diagram of the punch (Fig. 8), the stress analysis are conducted (Fig. 9). The analysis showed that the maximum stress are 97.18 N, and the maximum displacement is 0.016mm.
3.3. Fabrication of punch-die

The technology used in the punch-die fabrication are conventional milling and drilling, CNC milling, grinding, hardening, wire EDM, and grinding for finishing. The fabrication flow-chart for punch and die are showed in Fig. 12a and 12b, respectively.

For CNC machine, it was used Vertical Machining Centre (VMC) Vista 1000 with a speed of 4500rpm and feeding tool 1500mm/minutes. To make the hole in the die, the WEDM Makino with a gap 0.01mm and 0.005mm precision was used. The diameter of the wire was 0.15mm.

For micro-blanking tool, the final dimension of the main components are obtained from grinding process. It can also achieve a surface roughness value until 0.2μm. To achieve 63HRc hardness, punch

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**Figure 9.** Stress analysis for punch (a) Stress distribution (b) displacement distribution

The major load that applied at die is came from the calculated urethane force, \( F_{urethane} = 557.36 \) N. Based on the free body diagram of the die (Fig. 10), the stress analysis are conducted (Fig. 11). The analysis showed that the maximum stress are 13.69 N, and the maximum displacement is \( 4.16 \times 10^{-4} \).

**Figure 10.** The free body diagram for die

**Figure 11.** Stress analysis for die (a) Stress distribution (b) displacement distribution
and die were hardened at temperatures 850-1030°C, and quenching temperature was 150°C. After all components have been fabricated, the assembly process was conducted according to the guidance. The assembled micro blanking tool is showed in Fig13.

3.4. Clearance Measurement
Punch and die clearance measurements was conduct by using vision-based measuring machine TESA - VISIO 300 and CMM machines Crysta Plus M443. The determination of datum and element to be measured should be definite previously. On this measurement, the point “O” on the guide rode (Fig. 14) is determined as a datum. The measurement results are shown in Table 3, and it was obtained the clearance per side for the length direction is 0.045-0.06mm and 0.03-0.035mm for the width direction.

| No. | Die Length | Die Width | Punch Length | Punch Width | Punch-die clearance Length | Punch-die clearance Width |
|-----|------------|-----------|--------------|-------------|---------------------------|--------------------------|
| A   | 7.43       | 1.03      | 7.31         | 0.96        | 0.12                      | 0.07                     |
| B   | 7.42       | 1.03      | 7.32         | 0.96        | 0.10                      | 0.07                     |
| C   | 7.42       | 1.03      | 7.33         | 0.96        | 0.09                      | 0.07                     |
| D   | 7.42       | 1.02      | 7.32         | 0.96        | 0.10                      | 0.06                     |

Figure 12. Fabrication flow chart for (a). punch, and (b). die

Figure 13. Assembly of micro-blanking tool

Figure 14. Measurement geometry set-up
4. Experiment of micro-blanking process
The 5kN μ-Forming machine was used to conduct a micro-sheet metal forming process. The micro-blanking tool was mounted in the machine and executed some blanking processes (Fig. 15). The blanking process was held to a copper foil with a variation of punch velocity, which is 0.5 mm/s and 5 mm/s. No lubrication was implemented in the process.

![Figure 15. Micro-blanking process: (a). the mounted tool and (b). the blanked-part](image)

The blanked-parts quality was figured out by observing the shear edge on length and width orientation of material. Since the clearance on length orientation was bigger than the other one, the shear edge observation was conducted by using Dyno-Lite digital microscope PRO2 AD-4113ZT. The shear edge of the copper foil in length orientation is shown in Fig. 16.

![Figure 16. Shear edge observation of copper foil in length orientation with (a). 0.5mm/s and (b) 5mm/s punch velocity [10]](image)

However, the shear edge on width orientation was observed by using scanning electron microscope Jeol JSM-6510LA. The shear edge of the copper foil in wide orientation is shown in Fig. 17. A proportion of shear edge is occurred in micro blanking part same as in macro range, that are zone of rollover ($R_z$), shear ($S_z$), fracture ($F_z$), and burr ($B_z$).

![Figure 17. Shear edge proportion of copper foil in width orientation with (a). 0.5mm/s and (b) 5mm/s punch velocity](image)
5. Conclusions
The micro-blanking tool can be manufactured successfully and used well to conduct the micro-blanking experiment. Nevertheless, since the displacement exceeds 10% of the material thickness, it should to be controlled periodically, especially when the steel foil is used as a blanking material. A more tight clearance can be obtained if the machining method and parameters are chosen appropriately. For further works, another smaller punch-die manufacturing should be investigated. A tool wear analysis and investigation should be conduct to figure out the punch-die performance.

A urethane material can be used as a stripper, although it was stickier with the punch because it has a rough roughness and a light mass. Therefore, urethane cannot be returned to its original position by itself. However, because the simplicity of construction, the design and fabrication of urethane in micro tool should be considered to be developed.

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