Design of ironing dies with CAD/CAM topsolid7 assistance for making 20 millimeter caliber bullet case

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Abstract. One of the stages to make a bullet case is ironing process, which is the process to thinning the wall part of a cup that is place between die and punch in a press tool. Die has an inner diameter difference from a small diameter to bigger diameter along the inner hole. In the other words, the inner hole of the die is conical with a slope angle is $10^\circ$. To help design ironing dies, used a Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software TopSolid7. In this research was designed and made to make a 20 mm bullet case, from brass material CuZn30. Design process started from dimension and material strength calculation. Then the die was drawed in 3-D with CAD TopSolid 7 software. The design of die machining process is helped with TopSolid 7 CAM software. In that process design, is adding a raw material (stock), defining a reference, making toolpath, verification and G-Code making. The machining process on CNC machine become the end of design process that completed with measurement of a machining result. For example design process is designing and making an ironing die for making 20 millimeter bullet case. Ironing dies machining process is using a CNC lathe machine. The ironing die are made, measured to find out the product result spesification. From the dimension measurement of ironing die can be conclude that TopSolid 7 CAD/CAM can help the manufacture of ironing die well and can produce a precision ironing die.

1. Introduction
The manufacture of a bullet case is start with cutting a sheet material, the process is called piercing and blanking. Then, the process continue with deep drawing, which is a forming process to make cup from cutting a sheet metal (blank plate). After the cup is formed ironing process is carried out, which is the process to thinning a wall of the raw material (cup), by pressing cup with a punch when it is right in the middle of the ironing die. As a result, the cup height will be increase and the cup wall thinner equally. From several stages of ironing process on the inside diameter of dies that shrink or change gradually, will cause the height of the cup continue to increase, and at certain stages of the ironing process, a certain height of case is formed. Then the bullet case is cut off according to plan, after that one of the cup point was close, and the other point is neck case formed. According to planned of bullet caliber, then, the neck of the bullet case is cut off, therefore the final height of bullet case is obtained. The bullet case making process steps, started from forming a cup with deep drawing process, until the neck of the bullet case process (necking) and last process is cutting a case neck, as shown in Figure 1.
Fig 1. The Steps Of Bullet Case Making Process

It From several observations that have been made on the bullet case making process, problems arise in geometry uniformity and product dimensions that are not achieved. One reason is the hole geometry and diameter dimension on the die is rough and not precision, as a result of difficult hole making process with the size of inner diameter changing continuously make a tapered hole form (deep cone). The manufacturing experts look for solutions to make the manufacturing process with the help of CAD/CAM software. In addition to being able to compete in the market, the procurement of software is a necessity for industry to get precision geometry and product dimensions. Various brands of CAD/CAM software are produced by software developers to help the industry design and manufacturing products. One software that is currently being introduced in the Mechanical Engineering Department, FTI ITS is the TopSolid7 CAD/CAM software. The software is one of the results of the collaboration between KODAMA Japan and the Mechanical Engineering Department FTI ITS. Therefore, this research will try out to use of this software for design and manufacture of ironing dies to make 20 mm caliber case.

2. Research Method
Design and manufacture die is done by designing dimension and calculating the ironing force first, then drawing the ironing die with TopSolid 7 CAD. From the CAD image continue to design the machining process with TopSolid 7 CAM. The machining process design on TopSolid 7 software then continue to verification. The verification result become a reference to component dimension that will be produce, then the G-Code is built with CAM software assistance. The G-Code result will be entered to CNC machine for running test. To evaluate the design result, geometry measurement and workpieces dimension were carried out (ironing die) with proper measurement tool. Systematically the steps for designing 20 mm ironing die are as follow: 1) Designing ironing die, 2) Drawing ironing die, 3) Designing manufacture process of ironing die, and 4) Measuring dimension of manufactured ironing die.

3. Cup Dimension and Material
Before the die design is done, first material specification and dimension of the workpieces are determined, especially for 20 mm bullet case. For making a 20 mm bullet case, the shapes of half-finished material is cup, made from brass (CuZn30), with 40,20 mm outer diameter, and 31,20 mm inner diameter, and 26,61 mm height, as shown as Figure 2. While the expected final height of bullet case is 110 mm. The principle, to form a expected height of bullet case is need to ironing, 4 steps ironing process is needed. This means 4 type of ironing die are needed with different dimension of die inner hole. However in this research only discussed only one ironing die, which is the first stage. Whereas die design and manufacture for the next stages is no different.
4. Ironing Dies Design

The design of ironing dies is done by calculating the thickness of cup and height of cup wall that can be achieved after ironing process. Then continue with calculating the dimension of ironing dies and ironing force is needed to carried out the ironing process. Each stages of ironing design process is described as follows. Using thickness reduction ratio ($R_t$) 26%, which is the cup has initial outer diameter (Dl0) 40,2 mm, inner diameter (Dd0) 31,2 mm, initial thickness (t0) = 4,5 mm, and height of the cup 26,61 mm, then the thickness of cup wall from the ironing process can be calculate by calculation (1), as follow:

$$R_t \% = \frac{100 \left(t_0 - t_1\right)}{t_0}$$  \hspace{1cm} (1)

$$26 \% = \frac{100 \left(4,5-t_1\right)}{4,5}$$

$$t_1 = 3,33 \text{ mm}$$

From calculation result of the wall cup thickness in ironing process, the thickness of cup wall after the ironing process ($t_1$) is 3,33 mm. Therefore, the final cup outer diameter after the ironing process is 37,86 mm (Dl1). To find out the height through the process, it is carried out with a constant volume.

In constant volume method, the initial volume of the cup before ironing process considered equal to final cup volume after the ironing process. From the cup dimension, the total cup volume ($V_{tot}$) is obtained 19766,13 mm$^3$. Based on volume constant method, the height of ironing process cup result can be calculated with equation (2):

$$V_{tot} = \left(\frac{\pi}{4} \times 40,2^2 \times L\right) - \left(\frac{\pi}{4} \times 31,2^2 \times (L - 5)\right)$$  \hspace{1cm} (2)

$$19766,13 = \left(\frac{\pi}{4} \times 40,2^2 \times L\right) - \left(\frac{\pi}{4} \times 31,2^2 \times (L - 5)\right)$$

$$19766,13 = (1125,20L) - (764,15L - 3820,75)$$
19766,13 = 1125,20L − 764,15L + 3820,75

\[ L = 44,16 \text{ mm} \]

From the calculation result, the height of cup is 44,16 mm. To get the geometry and cup dimension which is desired before, next calculate the die dimension that will be used for ironing process. The material that used for ironing die is SKD 11 steel with modulus elasticity 200000 N/mm², ultimate tensile strength 650 MPa, yield strength 350 MPa, and density 7700 kg/m³. To get a proper diameter, height and thickness of the ironing die can be calculate with equation 3,4,5 as follow:

Hole diameter of the ironing die:

\[ D_{\text{Dies}} = D_{\text{Punch}} + 2t + 0,05\text{mm} \quad (3) \]

\[ D_{\text{Dies}} = 31,24\text{ mm} + (2 \times 4,5\text{ mm}) + 0,05\text{ mm} \]

\[ D_{\text{Dies}} = 37,91\text{ mm} \]

Height of the ironing die:

\[ H = (10 + 5T + 0,7\sqrt{a + b})c \]

\[ H = (10 + (5 \times 4,5\text{mm}) + 0,7\sqrt{37,91\text{ mm} + 37,91\text{ mm}} \cdot 0,8) \]

\[ H = 30,88\text{ mm} \]

Thickness of ironing die:

\[ T = (10 + 20) + 0,8H \]

\[ T = \left(\frac{10}{20}\right) + (0,8 \times 30,8\text{ mm}) \]

\[ T = 25,20\text{ mm} \]

The hole dimension of ironing die is 37,91 mm, the minimal height of the ironing die is 30,88 mm and the minimal thickness of ironing dies is 25,20 mm. Furthermore, the ironing force was calculated and the strength of the die material was analysed, due to the ironing force. The ironing force can be calculated with equation 6, 7, 8, 9, 10 11, and 12 as follows:

\[ A_0 = \frac{\pi}{4} \times (40,2^2 - 31,2^2) = 504,44\text{ mm}^2 \quad (6) \]

\[ A_1 = \frac{\pi}{4} \times (37,86^2 - 31,2^2) = 361,05\text{ mm}^2 \quad (7) \]

\[ \phi_{\text{max}} = \ln \frac{504,44}{361,05} = 0,334 \quad (8) \]

\[ K_{\text{Str}0} = 250 \times \frac{N}{\text{mm}^2} \]

\[ K_{\text{Str}1} = 880 \times 0,334^{0,433} = 547,652 \times \frac{N}{\text{mm}^2} \quad (9) \]

\[ \sigma_{f,m} = \frac{250 + 547,652}{2} = 398,82 \times \frac{N}{\text{mm}^2} \quad (10) \]

Therefore:

\[ F_{\text{id}} = 361,05 \times 398,82 \times 0,334 = 48156,62\text{ N} \quad (11) \]

\[ F_{\text{Shear}} = \frac{1}{2} \tan(10) \times 361,05 \times 398,82 = 12671,76\text{ N} \quad (12) \]

\[ F_{\text{Pr,S}} = \frac{2 \times 398,82 \times 0,334 \times 0,07 \times 361,05}{\sin(2 \times 10)} = 19713,24\text{ N} \quad (13) \]

\[ F_{\text{tot}} = 48156,62 + 12671,76 + 19713,24 = 80541,62\text{ N} \approx 8,2\text{ Tonf} \]
From calculation, the ironing force is 80541.62 N. While the extent of the results of the ironing process is 361.05 mm². Furthermore, the stress received by the cup material in the ironing process can be calculated by the equation (7) as follow:

\[
\sigma = \frac{F}{A} \quad (14)
\]

\[
\sigma = \frac{80541.62 \text{ N}}{361.05 \text{ mm}^2} = 223.07 \text{ N/mm}^2 = 223 \text{ MPa}
\]

From the calculation, the stress that cup received is 223 MPa, smaller than the ultimate tensile strength CuZn30 material 339 MPa. It can be concluded that CuZn30 workpieces material is safe for ironing process.

5. Ironing Die Drawing

To realize a design become a workpiece, the draw of die is done with help of TopSolid7 CAD software. The drawing process of ironing die is helped with TopSolid 7 software start from draw a die sketch in 2 dimension (2D). The result of die drawing can be shown in Figure 4. From 2D sketch that has been draw, then its give thickness to the sketch, so the 2D sketch become 3 dimension (3D). After that, the directional hole is added to the image, finally the raw material (stock) is added for machining process. The raw material which added based from actually raw material that available.

![Figure 4](image)

(a) Sketch Process (b) Giving Thickness (c) Hole Adding (d) Final 3D Design (e) Stock Dimension (f) Stock Adding

6. Design of Manufacturing Process

Toolpath is create, before design die manufacture process (machining). Toolpath making is based on the machining process planned, the toolpath result then verified to produce colours as shown in Figure 5 (b). Green colour show that the result of machining process has ± 0.1 mm dimension from planned size, while blue colour show that the result of machining process is greater than planned dimensions, therefore it means need more machining process. The stages of toolpath making process and verification process shown in Figure 5.
Figure 5. (a) Front Side Toolpath (b) Verification Result Of The Front Side (c) Back Side Toolpath (d) Verification Result Of The Back Side (e) Hole Making Toolpath (f) Verification Result

7. Design of Manufacturing Process
The design of manufacturing process is adjusted according to the toolpath design on TopSolid 7 software. CNC turning is used for manufacturing outer and inner diameters. Then, CNC milling is used to making holder holes. The used of cutting parameters are shown in Table 1.

Table 1. The Used of Cutting Parameters On Manufacturing Ironing Die

| No | Process       | Machine       | Vc (m/min) | N (rpm) | F (mm/rev) | Depth of cut (mm) |
|----|---------------|---------------|------------|---------|------------|-------------------|
| 1  | Facing        | CNC Turning   | 100        | -       | 0,3        | 0,5               |
| 2  | Finishing     | CNC Turning   | 200        | -       | 0,1        | 0,3               |
| 3  | Exkternal Turning | CNC Turning    | 100       | -       | 0,3        | 0,5               |
| 4  | Finishing     | CNC Turning   | 200        | -       | 0,1        | 0,3               |
| 5  | Center Drill  | CNC Turning   | 20         | 1273    | 0,08       | 3                 |
| 6  | Drill Ø10     | CNC Turning   | 20         | 636     | 0,10       | 5                 |
| 7  | Boring Ø14    | CNC Turning   | 20         | 454     | 0,15       | 5                 |
| 8  | Boring Ø23    | CNC Turning   | 20         | 276     | 0,15       | 5                 |
| 9  | Internal Turning | CNC Turning    | 100       | -       | 0,3        | 0,5               |
| 10 | Finishing     | CNC Turning   | 200        | -       | 0,1        | 0,3               |
| 11 | Facing        | CNC Turning   | 100        | -       | 0,3        | 0,5               |
| 12 | Finishing     | CNC Turning   | 200        | -       | 0,1        | 0,3               |
| 13 | Internal Turning | CNC Turning    | 100       | -       | 0,3        | 0,5               |
| 14 | Finishing     | CNC Turning   | 200        | -       | 0,1        | 0,3               |
| 15 | Center Drill  | CNC Milling   | 20         | 1273    | 0,08       | 3                 |
| 16 | Drilling Ø8,5 | CNC Milling   | 20         | 749     | 0,10       | 5                 |
| 17 | End Mill Ø14  | CNC Milling   | 100        | 1500    | 0,5        | 0,02              |
8. Inspection of Manufactured Workpieces
The component manufacturing is done by entering G-Code result form TopSolid 7 software to use CNC machine. CNC Turning is used to manufacturing ironing die and CNC milling is used to making holder holes. Ironing die that already manufactured then be measured. Figure 6 shown the dimensions that will be measured. The calipers is used for measuring process to know the compatibility of design dimension and manufacture dimension. Dimension measurement result form ironing die shown in Table 2.

Table 2. Measurement Result Of Ironing Die

| Part | Dimension | Measurement |
|------|-----------|-------------|
| ØA   | 40,20 mm  | 40,17       |
| ØB   | 37,91 mm  | 37,91       |
| C    | 30,88 mm  | 30,79       |
| ØD   | 90,60 mm  | 90,59       |
| ØE   | 40,20 mm  | 40,20       |
| F    | 10°       | 9,83°       |
| G    | 5°        | 4,91°       |

9. Conclusion
From this research can be conclude that ironing dies for 20 mm caliber bullet case making is design with die hole diameter is Ø37,91 mm with die minimal height is 30, 88 mm die minimal thickness is 25,20 mm. Ironing process for 20 mm caliber bullet case making is used to reducing an outer diameter of cup from Ø40,2 mm to Ø37,86 with height of cup result is 44,16 mm. With SKD 11 material, then ironing die was designed safe towards ironing force that will happen, and the cup material CuZn 30 can be processed properly. TopSolid 7 software can be used for help the design process and manufacturing process of 20 mm calibre bullet case. With machining process on CNC turning, the designed ironing die can be made well, and from the dimensions measurement results obtained the ironing die specifications specified in the design can be complete.
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