Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan *Vol. 27 No. 2-2022*
ISSN:1813-1786 (Print) 2313-7770 (Online)

Additive Manufacturing of Plastic Tools for Sheet Metal Forming

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Abstract- Due to higher manufacturing costs and significant time required for the manufacturing of conventional punch and dies for sheet metal forming, manufacturing industry is working to take a shift to manufacture plastic tools additively manufactured by using 3D printing techniques. Therefore, the objective of this research work is to additively manufacture U & V shape punch and dies using plastic material and evaluate its applicability. For the said purpose, 3D design model of U & V shape punch and dies were made using CATIA (a CAD software) followed by static structure analysis performed in ANSYS. Later, STL file of CAD was prepared and after setting the parameters on G-codes, tools were prepared using 3D printer. The research work also focusses on finding the suitability of plastic tools for sheet forming and compared the findings with traditional bending dies. It was found that using this technique fixed time required for the manufacturing of punch and dies along with the money being spent on the shaping process of tooling were reduced. Furthermore, it is recommended to improve the overall efficiency of plastic tools by using reinforcement techniques.

Keywords- Sheet Metal Forming, Conventional Tools vs Plastic Tools, Plastic Tools for Sheet Metal Forming, Additive Manufacturing, Fusion Deposition Modeling (FDM)

I. Introduction and Literature Review

Metal forming are those manufacturing processes which are accomplished by the plastic deformation (permanent deformation) of metal to change the shape of metal workpieces. Deformation is produced by applying mostly the compressive or sometimes tensile, shear and bending stresses as well. One of the broad categories of metal forming is the sheet metalworking processes which are performed on metal sheets, strips, and coils. This class is characterized by high surface area-to-volume ratio. Pressworking is the term often applied to sheet metal operations because the machines used to perform these operations are presses. Sheet metal operations are always performed as cold working processes and the conventional tolling used in these processes are often punch and die which are also made of metal. The punch is the positive portion which penetrates and the die is the negative portion of the tool set which is the receiver [1].

Forming, metal forming, is the process usually known as process of fashioning metal parts and objects through mechanical deformation; the work piece is reshaped without adding or removing material, and its mass remains unchanged. Very high loads and stresses required, between 50 and 2500 MPa. Also large, heavy and expensive machinery is required to accommodate such high stresses and loads. The production runs with many parts to maximize the economy of production and compensate for the expense of the machine tools [2]. This modern era is a time of inventions and replacing the traditional technologies by smart technology to get better results and save cost as well as time [3, 4]. Usually, sheet metal forming takes place by using dies and punches; these tools are commonly manufactured from metals with the help of heavy and costly machinery which not only takes a lot of time but skilled labor is also required to get accurate results [5]. This manufacturing structure and processing is not easy and simple. Another factor of concern is a lot of money required to install this setup and also to run this structure to get the required results [6]. Due to these circumstances, we need to move to some alternative tooling design methods, techniques, processes and solutions.

Using advanced methods of 3D printing e.g., selective laser melting and fused deposition modelling, various mechanical components can be directly manufactured without the involvement of traditional tooling [5,7-8]. These advanced processes are, on one side, characterized by better surface finish and good dimensional accuracy and, on the other side, are also characterized by relatively expensive raw material and significantly longer times required for the manufacturing of the parts. This is why they are not currently being used for large production. One of the significant applications of additive manufacturing techniques is known as Rapid Tooling (RT) [9-10] which is used not for the manufacturing of the parts but for the manufacturing of tools used for the manufacturing of parts. As the traditional tools are already much expensive, therefore the problems of higher cost and longer time are not actually the problems when compared with traditional manufacturing of the parts [2, 11].Laser additive manufacturing and selective laser melting processes have been applied and reviewed by [2] and [12] respectively. The use of fused deposition modelling for metal forming is also studied and presented in [13-17]

So far different grades of metal punch & dies have long been manufactured for sheet metal forming purposes with machining and traditional methods. One of the advanced versions of manufacturing punch and dies is the Rapid Tooling which is an additively manufacturing processes [18]. As compared to the traditional tooling techniques which are usually costly and time-consuming, RT manufacture tools using CAD data without any skilled workers [19]. Researchers found out that the overall strength of manufactured dies is also increased by this step-by-step layer forming (which is the base of additive manufacturing). However, issues related to reseal workforce have been risen on additively manufacturing techniques for sheet metal forming. Therefore, different types of non-metal materials are under process these days [20].

It is established from the literature survey that conventional tooling used for the metal forming carries significant costs as well a lot of time is required to manufacture conventional tooling (from metallic materials). Moreover, those tools, once manufactured, cannot easily be modified to some other shapes. Therefore, the recent trend in the manufacturing industry is to take a shift to manufacture plastic tools additively manufactured using 3D printing techniques. Therefore, the objective of this research work is to additively manufacture U & V shape punch and dies using plastic material and evaluate its applicability for low volume metal sheets' bending operations.

II. Materials and Methods

The complete methodology is described as follows:

1. Designing of U & V Shape Punch & Die

By using CATIA software, 3D designs of U shape die, as shown in Figure 1, was made. For this purpose, the dimensions were set as 25mm height, 75 mm length and 50 mm width. The other dimensions are also shown in Figure 1. After designing the U shape die as shown in figure 1, U shape punch was designed as shown in Figure 2. The length of the punch was set as 75 mm, width as 15mm and height as 25mm. the radius at end corner was set as 7.5 mm.

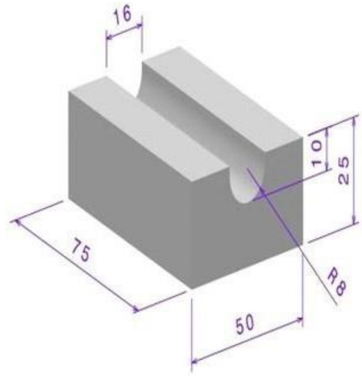


Figure 1. 3D model of U shape die

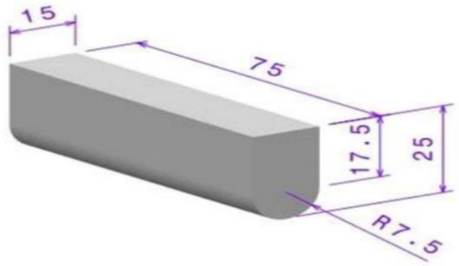


Figure 2. 3D model of U shape punch

Similar to the design of U shape punch and die, V-shape die and punch were designed. V-shape die was designed, as shown in Figure 3. Length of the V-shaped die was kept as 75mm, height as 25 mm and width as 50 mm with centerized 16 mm V shape 90-degree depth with 0.5 mm radius end edges. After designing the V shape die, V shape punch was designed as shown in Figure 4. Length of the V shaped punch was kept as 75 mm (same as the length of V shape die), the depth as 15.29 mm.

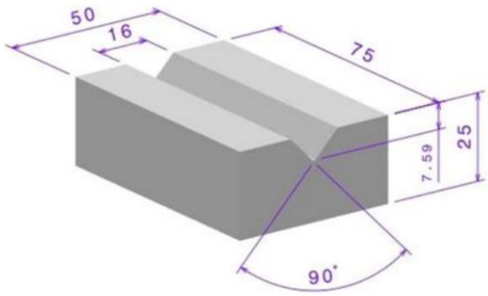


Figure. 3D model of V shape die

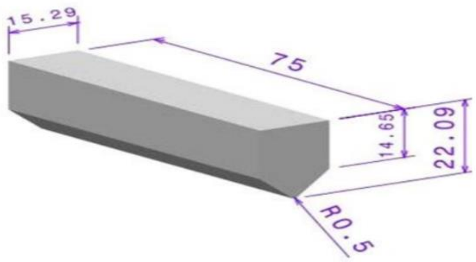


Figure 3. 3D model of V shape punch

Analysis of U Shape Punch and Die

After developing punch and die of U and V shape, CAD STL file, as shown in Figure 5, was imported to ANSYS workbench and static structural analysis was performed to find out the elongation or deformation of designed part.

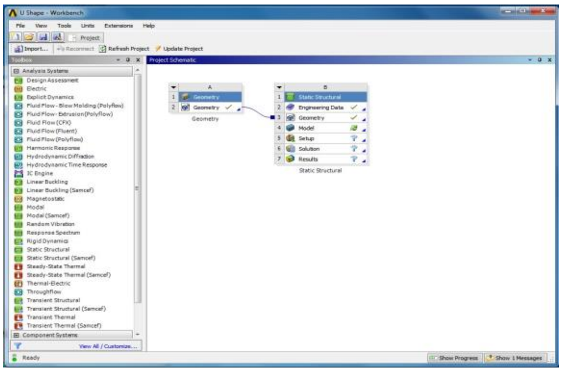
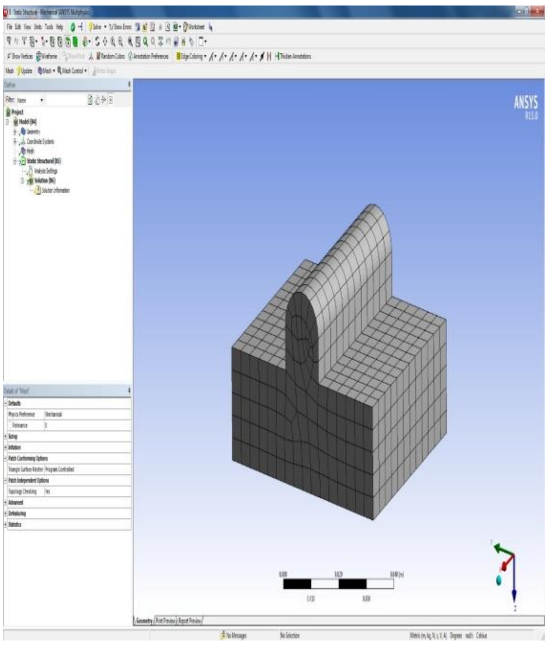


Figure 4. CAD Import File in ANSYS

Meshing

Before performing the static structural analysis in ANSYS, meshing was done to get most reliable end results and converting irregular shape volume into the best useable shape which is also known as element. The meshing of U shape punch and dies is shown in Figure 6 and their relevant numerical results are shown in Figure 7. Similarly, the meshing of V shape punch and die is shown in Figure 8.



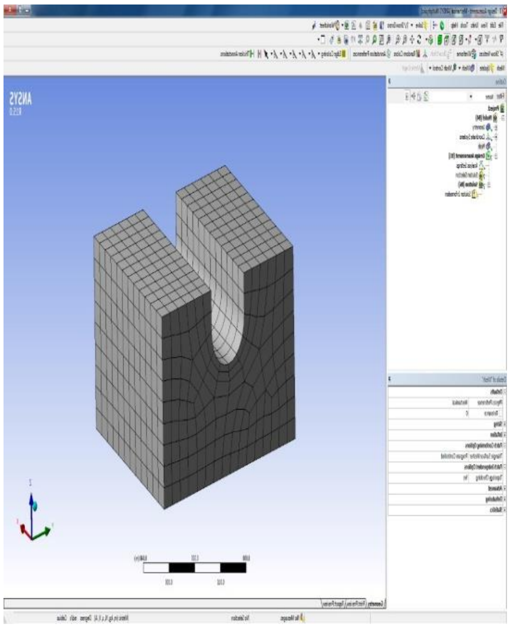
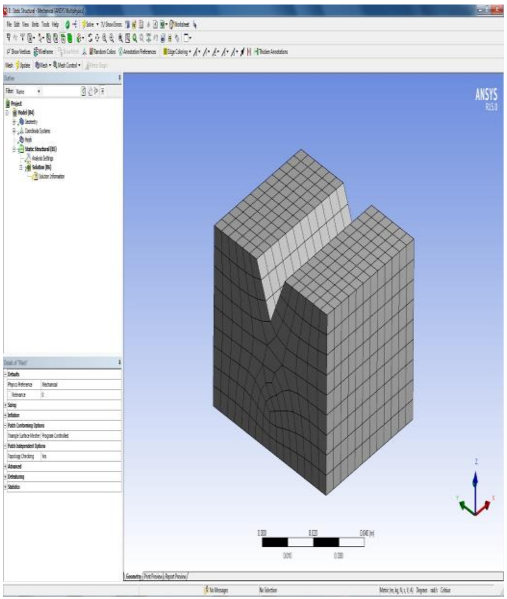


Figure 6. Meshing of U Shape Punch and Die in ANSYS

Object Name	Mesh
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	7.5e-003 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5

Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	7617
Elements	1536
Mesh Metric	None

Figure 5 ANSYS Automatic Generated Mesh Report



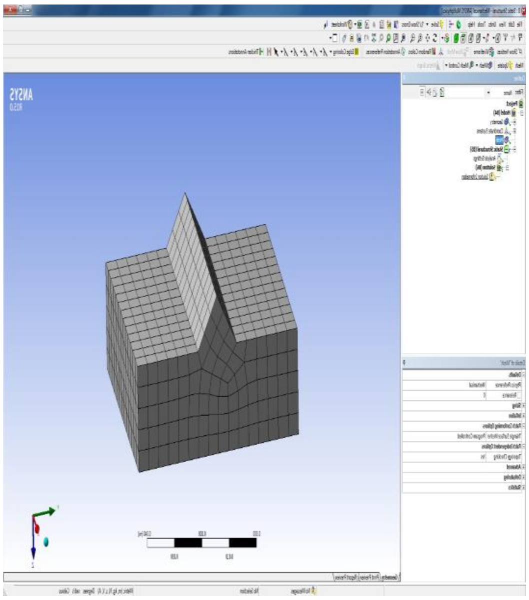


Figure 8. Meshing of V Shape Punch and Die in ANSYS

Static Structure Analysis of U shape Punch and Die

After getting the numerical meshing results of U and V shape punch and die, static structural analysis was performed to check out the total deformation. The results of static structural analysis performed on U shape die and punch are shown in Figure 9 and 10 respectively.

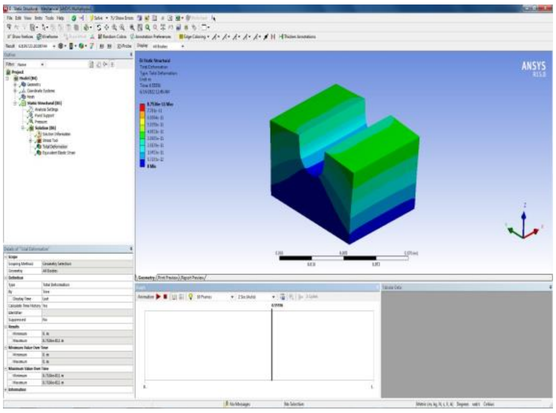


Figure 9. ANSYS Result of U shape Die

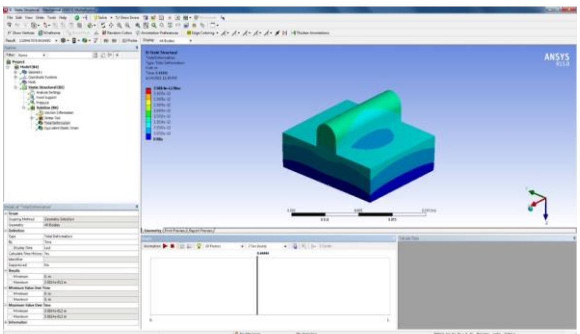


Figure 10. ANSYS Result of U shape Punch

Analysis of V Shape Punch and Die

Just like the static structural analysis of U shape punch and die, static structure analysis of V shape punch and dies was performed and the results are shown in Figure 11 and 12 respectively.

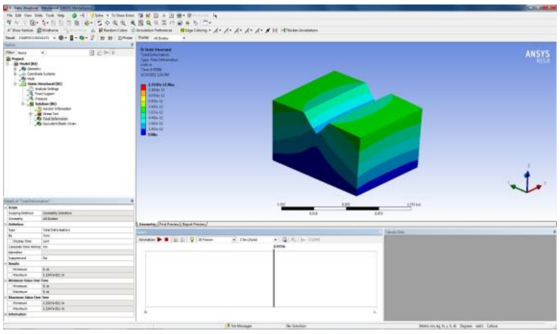


Figure 11. ANSYS Result of V Shape Die

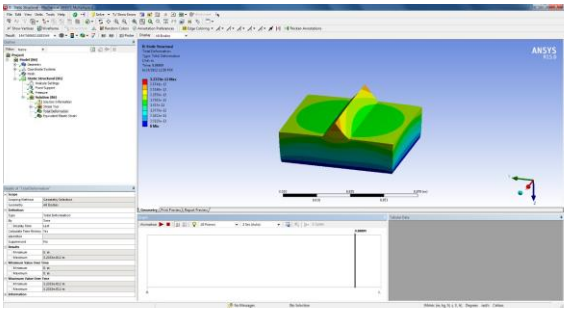


Figure 12. ANSYS Result of V Shape Punch

STLs File & G-CODES of CAD file

After getting the satisfaction results from static structural analysis, STLs files of CAD file by using Cura Software were made as shown in Figure 14 and the G-codes thus obtained are shown in Figure 15 which are the numerical data of CAD files, required as input data to 3D printer for automatic setting of their axis and further processing.

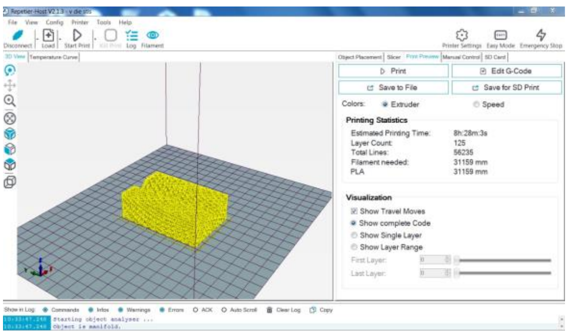
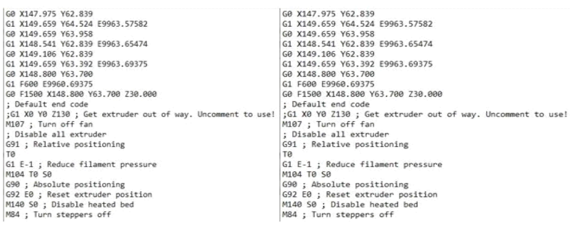


Figure 6. STL File of Die Before Printing



```
G0 X147.975 Y62.839
G1 X149.659 Y64.524 E9963.57582
G0 X149.659 Y63.958
G1 X148.541 Y62.839 E9963.65474
G0 X149.106 Y62.839
G1 X149.659 Y63.392 E9963.69375
G0 X148.800 Y63.700
G1 F600 E9960.69375
G0 F1500 X148.800 Y63.700 Z30.000
; Default end code
;G1 X0 Y0 Z130 ; Get extruder out of way. Uncomment to use!
M107 ; Turn off fan
; Disable all extruder
G91 ; Relative positioning
T0
G1 E-1 ; Reduce filament pressure
M104 T0 S0
G90 ; Absolute positioning
G92 E0 ; Reset extruder position
M140 S0 ; Disable heated bed
M84 ; Turn steppers off
```

Figure 7. G-Codes of CAD File

Fused Deposition Modeling Process

For the manufacturing of punch and dies, after making G-Codes of CAD files, we give the command to 3D printer, as shown in Figure 16 where we also attached PLA material as per our selection. In Fused deposition modeling process, printer works in both way where an extrusion nozzle moves over a built platform. The process involves the use of thermoplastic material which reaches melting point and is then forced out to create a 3D object layer by layer. As the design takes shape, it is clear to see each layer as a horizontal cross section. Following the completion of one layer, the nozzle of the printer is lowered in order for the next layer of plastic to be added to the design.

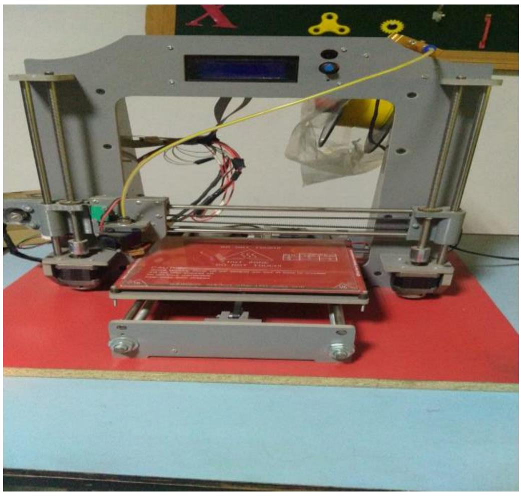


Figure 8. Experimental 3D Printer

III. RESULTS AND DISCUSSIONS

After designing the U & V shapes punch and die with designing software solid works the CAD file is generated and then decoded using repitier software for purpose of attaching the file with 3D printer for the additive manufacturing of tools.

Manufacturing and Use of U Shape Punch & Die

After 10 hours we get results of designed punch and die of U shape which is shown in Figure 17. The shape accuracy of manufactured punch and die of U shape is as per our requirement and results of printed die & punch edges is very good. Now the designed punch and die is ready to bend the thin sheet metals. As an experiment, the manufactured U shape punch and die were used to bend different gauges' sheets to ensure that our designed U shape punch and die is purely able to perform the required work. The bending of sheets is shown in Figure 18.

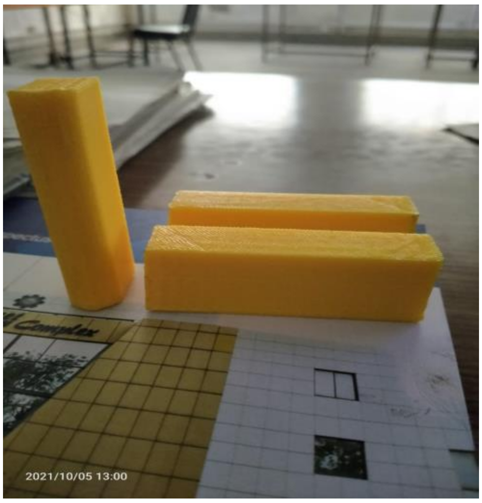
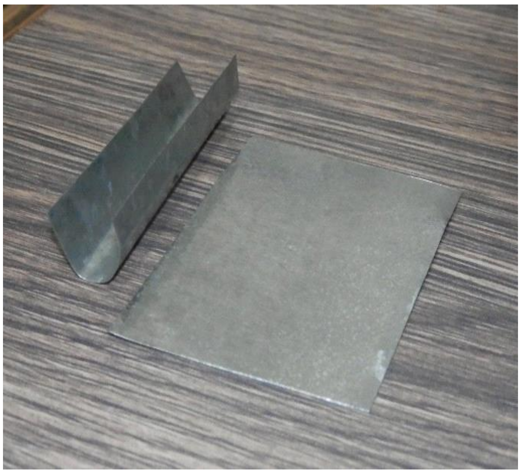


Figure 17. 3D print of U shape punch and die

Figure 18. U Shape Bending Sheet Results

We examined the PLA material based developed punch and die of U shape for low volume sheet metal bending as per our requirement and performing explained procedure we get results of U shape low volume sheet bending shown in Figure 19. The results obtained are very good and no scratches were found on U shape bended sheet and the temperature of punch and die is also found to be normal thus normal no need of lubricants is required for punch and die cooling purpose.



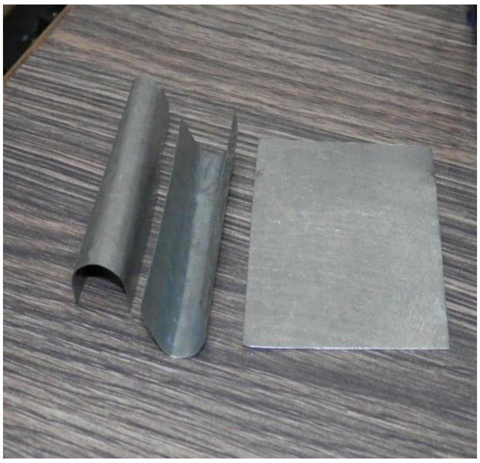


Figure 19. Different Gauges' Sheets Experimental Results

Manufacturing and Use of V Shape Punch & Die

In a timespan of about 9 hours, our 3D designed tools were manufacture additively, as shown in Figure 20. The shape accuracy of 3D punch and die are very good with smooth surface and they are able to perform the bending of low volume sheet metal products. Now we are able to perform bending low volume sheets products to check out the ability of manufactured punch and die V shaped to examine their working efficiency.

Figure 20. 3D Print of V shape punch and die

As shown in Figure 21, different gauges' low volume sheet metals were examined by using PLA based manufactured punch and die with specific method in which V Shape manufactured punch and die is used to change the shape of sheets into V shape. Different gauges ranges from 27 to 35 gauges sheets were examined and no scratches were found on punch or die as well as on bending sheets. Just like the U shape punch and die, it was observed that the temperature of V shape punch and die was found to be normal thus requiring no further lubricants for cooling purpose, in contrast to the traditional way of cutting or bending of sheets in which different lubricants are needed to be applied to maintain the temperature of punch and die.

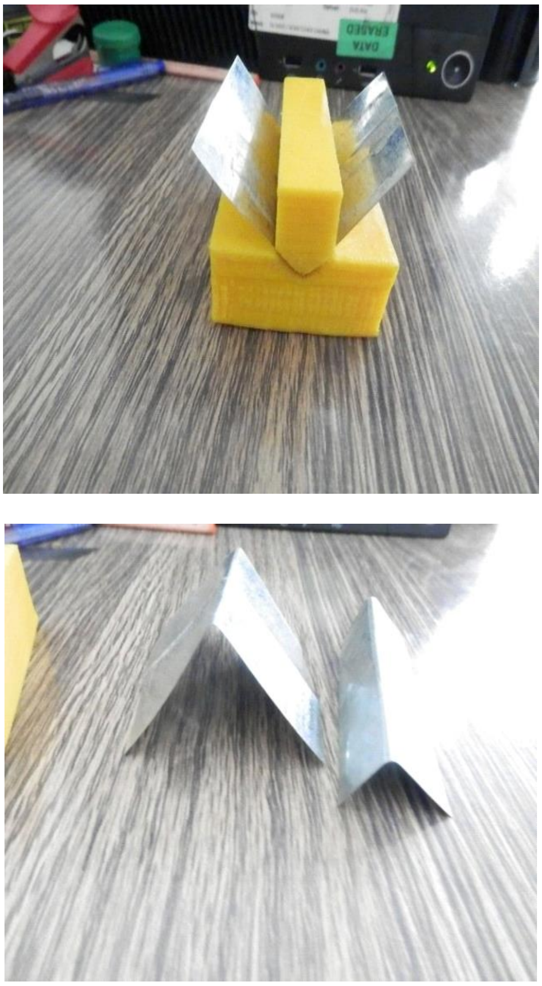


Figure 21. Bending of sheets using V shape punch and die

IV. CONCLUSIONS

During this research work, the performance of U & V shape dies and punch (of PLA material) manufactured by FDM was evaluated for different gauge's sheet metal bending. Due to manufacturing process the application of FDM process is widely spreading in Tools manufacturing industry due to low cost of manufacturing machines and easy methods. The work is helpful during making small batch size sheet metal products economically feasible. The same route can be used to manufacture customized sheet metal products at low cost with reasonable dimensional accuracy. We have evaluated the various shapes (U&V) plastic tools applicability and working performance for bending purpose and it was found that plastic tools are useful for sheet metal forming and/or bending. Moreover, raw material in this case is much cheaper and there is no or very little wastage of material. Also fixed cost of die for low volume sheet metal products is reduced. Furthermore, the shape accuracy of bending sheets is very good with no scratches found either on the sheets or on tools. Similarly, no lubricant is required for the cooling of tools.

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