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Tool and Die Design for the Prototype Fabrication of Automobile Pleated Air Filter

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Abstract— Air filter is one of the important components of internal combustion engine driving system. In this study tool, die and fixtures that can be designed and assembled for the fabrication of air filter is presented. Dies were further heat treated for better hardness property so that it can press sheet metal. Then sheet metal was sandwiched in between these two dies and pressed together using flywheel press to fabricate pleat base. Effect of dry pressing, clearance, lubrication and removal of shearing angle for achieving quality finishing were thoroughly presented. Dry pressing result provided distorted pleat shape as shearing and wrinkles were obtained in the bending portion of pleat base. Due to this reason dies were redesigned and lubrication was introduced during pressing. Similarly, clearance and shearing angle were modified to achieve pleat base. After that perforated support and pleated air filter were fabricated and assembled together to fabricate an air filter.

Keywords — Pleat air filter, die, pressing, clearance, lubrication

I. Introduction

Air filter is a part of an internal combustion engine, which blocks the ingoing aerosol particles along with the intake air into the combustion chamber. General type of air filter used is pleated paper air filter which is manufactured by sandwiching the resin-impregnated cellulose filter paper between two pleat bases made from sheet metal and is supported by perforated support in the inner circumference of the pleat base. Air filter product has huge market in automobile business sector in Nepal. Every year huge quantity of air filters is imported to Nepal from our neighbor country India and China. Import is easy solution for trading business as compared to production or setting up factories in Nepal. Therefore, there is no any industry established in Nepal which is involved in production of air filter. According to the Ministry of Finance, Custom Department, the import rate of air filter are sequential increasing of 40 percent as compared to the year 2024 [1]. Despite of being cheap and easy to manufacture the product, huge amount of money is spent in importing it. So, these circumstances lead us to find out solutions for the manufacturing of the air filter in Nepal. Thus, in this study, tools and die that are required for design and fabrication of pleat automobile air filter is initiated with an aim of devising a process to manufacture.

I. Material Selection

Material selection was necessary mainly for die design, sheet metal pressing forces, perforated support and adhesive.

A. Die

For the fabrication of die, pressure plate of automobile vehicle is initially selected as a suitable material as shown in figure 1 (a). But the material that is used to manufacture pressure plate was pearlitic gray iron [2]. It has a property being hard material with higher brittleness and non-machinability. So, machining it to impart desired die shape was impossible. Thus, another softer material with better machinability property was obtained.

B. Sheet Metal

Sheet metal used in air filter is required to support the filter paper latched to it by adhesives. Originally used sheet metal was made of density 7373.9 kg/m^3, which was close to that of tin. The original metal used in the filter paper has the ultimate tensile strength of 175.4 MPa. While making the prototype, first selection was of aluminum (Density 3313.5 kg/m^3) because of its easy availability and also because of its low ultimate tensile strength which requires less force to shear the sheet metal.

C. Perforated Support

Perforated support should be strong enough to avoid the

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compression of pleat, thermally stable for engine inlet condition and porous enough to allow the smooth flow of air. Aftermarket product contain sheet metal which contained punched holes. This require extra operation that need to be carried out in the sheet metal. So instead, we intended to replace its use by using metal wire net, that in readily available in our market as shown in figure 1 (b) and figure 1 (c). Also selected material do not pose any threat in compromising the air flow through the filter as total surface available for the passage of air in selected sample is greater than that in original sample.

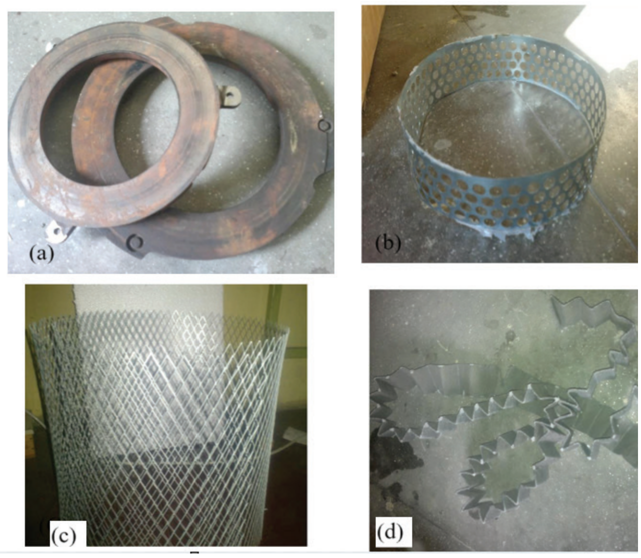

Fig 1. (a) Pressure plate (b) Initially used perforated support (c) substitute of perforated support (d) filter paper

D. Filter Paper

In case of filter paper to be used, actually there was no availability of raw resin impregnated cellulose filter paper in Nepali market, thus we have reused the filter paper from an aftermarket air filter for the prototype fabrication as shown in figure 1 (d). But for the manufacturing of actual air filter, we have to procure this type of filter paper from international market. Some of the technical information about generally available filter paper are listed in table 1.

Table 1

Technical data of generally used air filter [3]

S. N.	Properties	Unit	Numeric Values
1	Basic Weight	Gm/m^2	100-140
2	Thickness	Mm	0.35-0.65
3	Air Permeability	L/m^2. s	200-800
4	Corrugation Depth	Mm	0.2-0.3
5	Pore Size	µm	40-100

E. Adhesive

For the portion of adhesives, commonly used adhesives for air filter manufacturing are Polyurethane, a thermosetting adhesive. Polyurethane adhesives are available in various colors, curing rates, viscosities and hardness levels as well as in one-part formulation or two-part formulation. Two-part polyurethanes are better suited for filter application as they can be cured at room temperature in three to five minutes or can be heat accelerated [4].

II. Design and Fabrication

In this section, the design of tool and die and fabrication of air filter is studied in detail. Performance of tool in service depends on proper tool design, accuracy with which tool is made, selection of proper tool steel and heat treatment employed [5-7].

A. Die Design

Sheet metal operation for creating the pleat base requires two operations. One being cutting and another being forging. Cutting operation simply cuts the two concentric holes on the sheet metal and forging operation as shown figure 2 (a) creates flanges on the edge of thus cut sheet metal. Two step operations can be applied for the purpose, but for the ease and efficiency of production compound die is designed and used. Compound die is the one which can perform multi operations simultaneously. In this case, the operations are cutting and bending. Accordingly, during the sheet metal operation, at first the die combination cuts the sheet metal and again the cut part is forged by second step operation giving the required shape to the sheet metal, as shown in figure 2 (b). This not only helps in easing the process but also the force required for forging will be provided by the force applied during cutting.

B. Filter Paper

Filter paper need to be closely packed for better filtering but while doing so air flow may be largely obstructed resulting in poor air flow in cylinder. Thus, pleat density around 25-35 pleats per 100mm is suitable for optimization of filtering efficiency while trading off with the total pressure drop during filtration [8]. The pleat height will be of 40mm.

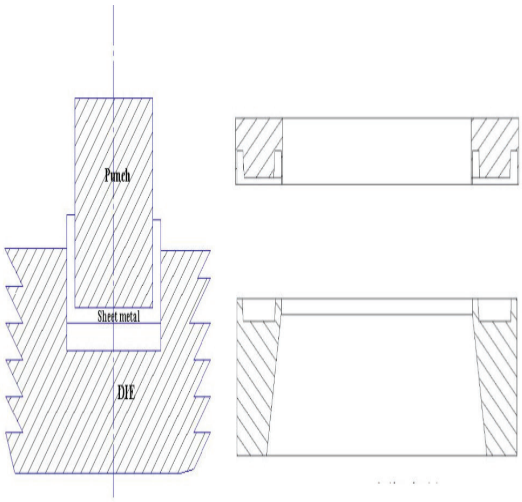

Fig 2. (a) Forging of sheet metal

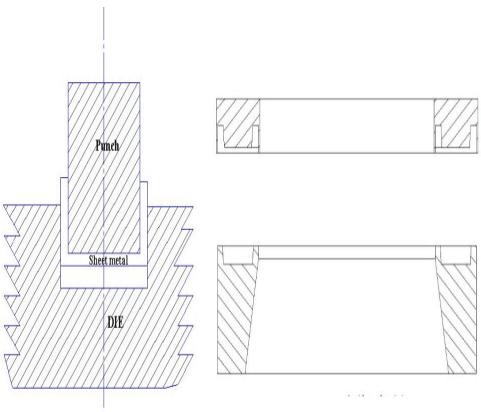

Fig 2. (b) Design of compound die

C. Design Calculation

While designing the tool/die for fabricating the pleat base, the most important parameters to consider are blank clearance, blanking, piercing and total shearing force. Clearance should be precise in order to produce a product of required dimension.

i. Clearance, blanking and piercing

Clearance, blanking and piercing are given by following expression [9].

$$c = \frac{k \times T \times \sqrt{\tau_m}}{6.32} = \frac{k \times T \times \sqrt{0.7 \times UTS}}{6.32} \quad \text{for } T \leq 3 \text{ mm} \qquad (1)$$

Where T is a thickness of material (mm), k coefficient depending on the type of die, that is k = 0.005 to 0.035 (most frequently used k = 0.01), UTS is ultimate tensile strength and τ_m is shear strength of a material.

Blanking and piercing are given by

i) Blank die opening size (D_c) = part size – elastic recovery

ii) Blank punch size (D_d) = die opening size – 2 x c

iii) Piercing punch size (d_c) = part hole size + elastic recovery

iv) Piercing die opening size (d_d) = punch size + 2 x c

D. Working Die

The dimension refers to table 2 are the one to produce pleat-base of original size. But due to the limit in chuck size of the lathe machine available, our design was scaled down to a much favorable dimension which limits the maximum diameter of work-piece to 150 mm. and accordingly the new scaled dimension of die becomes to D_c = 140 mm, D_d = 139.8 mm, d_c = 80 mm and d_d = 80.2 mm. Effect of elastic recovery on dimension is neglected since the least count for the design limits to 0.1 mm and the effect of elastic recovery is lower than that. The dimension of die is supposed to produce pleat base of outer diameter 130 mm; inner diameter 90 mm and flange of height 5mm. For this, die opening profile: h = 6 mm, α = 8^0, Shear angle employed = 1.5^0 were considered.

Table 2

Sizes and Parameters For Design Calculations

Coefficient of die, k	Sheet metal thickness, T (mm)	Elastic recovery, r	UTS	Clearance, c (mm)
0.01	0.254	0.025	90 MPa [10]	0.1
Part size, mm	Die opening size, mm	Part hole size, mm	Piercing die opening size, mm	
220	219.77	150	150.225	

i. Shearing force

The shearing force required is given by equation 2,

Theoretical force required, F = length cut x thickness of material x shearing strength

$$= \pi \times D \times t \times 0.7 \times UTS \qquad (2)$$

Thus, punching force of 4021 N, blanking force of 7038 N are estimated. And net shearing force is estimated from the 1.3 times the sum of punching force and blanking force, i.e., 14.4 kN.

ii. Raising force and torque

The raising force is given by the equation 3 [10] ,

$$T_R = F \text{ x } [l + \pi \text{ x } d_m \text{ x } f \pi \text{ x} d_m - f \text{ x } l] \qquad (3)$$

where f = 0.08 (graphite grease [9]), d_m is mean diameter of square thread of fly wheel, and l is.

And the raising torque, T_R [10] is given by equation 4,

$$T_R = P_R \text{ x screw radius} \quad (4)$$

From this expression, the raising force of 5885 N and raising torque of 141 Nm are determined. And the force applied to the 50 kg mass fly wheel is 371 N. Thus, the inertial force provided by running the wheel contributes largely during sheet cutting operation. The force required for drawing is given by equation 5,

$$\text{Drawing Force } (F_d) = \pi \text{ x } d_m \text{ x T x UTS} \quad (5)$$

The value of drawing force is estimated 7890 N.

iii. Sizing of sheet metal

If the sheet metal is cut haphazardly, without proper analysis, the amount of sheet metal wasted to make small amount of pleat base will be high. So, to lower the wastage, an appropriate dimension of sheet metal has to be used. Since a single set of die to blank out the pleat base, so the consideration is for single file cutting in present case, Blank Width (D) = 220 mm, Thickness of material (T) = 0.257 mm, Distance from edge of blank to side of strip, (m) = T + 0.015D = 3.557 mm. Thus, the total left over at each edge of blank = 7.114 mm. And hence the width of strip for economical use of sheet metal is = D + 2 x m = 227.114 mm.

iv. Perforated support calculation

Calculation for area available for airflow:

Total length of support = π x diameter = π x 90 = 282.7mm

Total width of support = 40mm

Total surface area = 282.7 × 40 = 11308 mm^2

For original support: 4 arrays of circular holes of 5 mm diameter with each array being 8 mm apart and circles of each array being 10 mm apart, was present. Thus, total area available for airflow = 5642.9 mm^2. For wireframe support: Angular stripe of wires 1 mm wide with spacing of 6 mm was present. Total area of wires only = 3458.14 mm^2. Thus, total area available for airflow was calculated to be = 11308 – 3458.14 = 7851.46 mm^2.

E. Machinery Equipment and Hand Tools

After the selection of iron blocks for die fabrication, with better machinability, it was put under process of getting into the final shape of die. It being the circular work piece, best option for machining was Lathe machine as shown in figure 3. Aside from machining from lathe, there were other processes like drilling, threading, cutting, grinding and filing that required the equipment's like pillar drill, taps and dies, hack-saw, power hack-saw, grinding machine and files.

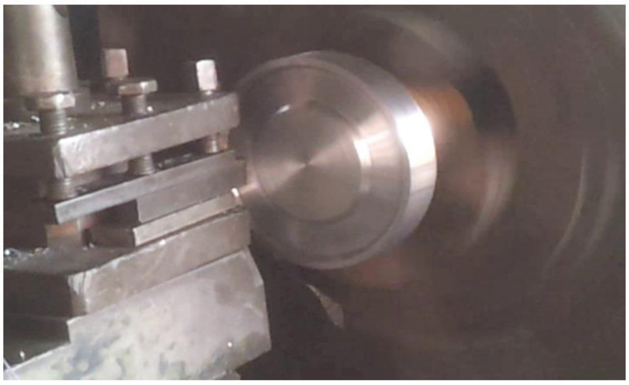

Figure 3. Punching die machining in Lathe operation.

Main portion of fabrication procedure was the lathe machine operation. Various operations like facing, boring, turning, drilling etc. were performed. Additional operation of thread cutting was also done. Machining process could also be carried out after heat-treatment of die, with the benefit of precision in dimension of the product. But in doing so, problem may occur while machining the hard and brittle part. So hardening was done after machining of the product

F. Heat Treatment

Die is subjected to extremely high loads that are applied rapidly. They must withstand these loads a great number of times without undergoing excessive wear and deformation. Thus, heat treatment (hardening) [5-7] is a crucial part of die fabrication process. The durability and effectiveness of die depend largely on the hardness of die. The dies after heat treatment as shown in figure 4.

Figure 4. Heat treatment of dies for surface hardening

III. Results

A. Dry Pressing Result

The output of the die gave the required shape as shown in figure 6, but various glitches were seen from the dry pressing as shown in figure 5 (a). Shearing of the sheet metal was smoothly carried out. There was smooth cut edge left at the sheet metal which implied the success of shearing operation. But for the case of bending, no satisfactory result was observed. In case of inner flange, bending started out quiet fine from one side of the plate but towards the other side, shearing was observed instead of bending. On the outer flange, slight shearing was seen along with few wrinkles. Also, the cut-portion got stuck on the cutting die which caused huge problem in recovery of the pleat base as shown in figure 5 (b). So, the clearance was adjusted.

Figure 5. sheared flange of pleat base and pleat base stuck in the die

B. Effect of Increasing Clearance for Bending

In order to avoid the problem of sheet metal being stuck in the punching die, two holes 180 degrees apart were bored to help recovery by pushing the stuck plate from within the punching die. To option out the possibility of insufficient clearance for bending, the gap that was employed for bending was increased.

Figure 6. Non uniformity of flange still produced

The cut portion of sheet metal was still stuck on the punch die. By pushing the plate from the new holes bored, the pleat base was recovered. On inspecting the pleat base, it was observed that the unwanted shearing portion still persists but the amount of portion sheared was considerably decreased. Punching and blanking operations were carried out smoothly. Slight wrinkles on the outer flange were also seen while the inner flange was free from such deformation as shown in figure 6. On close observation, it can also be seen that the bending angle on two sides of inner as well as outer flange was not consistent i.e. the angle at which sheet metal was bend, differed along the circumference. The unwanted shearing of the sheet metal was due to poor alignment of dies and lack of precision of flywheel press. Wrinkles were the result of excessive gap provided for bending. The shear angle, that we had supplied to reduce the amount of force required to carry out shearing operation, was incompatible with the setup, which worked with slight low precision. And this was the major cause of the distortion seen. The variation in bending angle observed along the circumference of the flange was the outcome of modification employed. While performing machining operation during the modification of our punching die, the center alignment could be slightly different than the actual center of our die. So, the problem of varying bend angle was seen.

C. Effect of Using Lubrication and Shearing Angle

The shear angle was removed by facing the die on lathe. In case of our third trial, slight lubrication was introduced during operation process. This was done to ease the recovery of the sheet metal that remained stuck on the punching die. This time around, the result was quite satisfactory. Both punching and blanking operation was smoothly carried out. The flanges were completely intact with no shearing to be seen as shown in figure 7. Also, the most important part to be noted was, the cut portion was no more stuck inside the punch die i.e. the recovery of the pleat base was too easy. Inner flange contains no deformation while the outer flange still contain wrinkle. The cutting edge was not worn out and thus can be used for other multiple times before it is required to be replaced. Now that the problem is only on the wrinkle formation, its possible causes include die clearance, die radius and blank holding force [11, 12]. Many causes that may lead to the formation of burr, deformation/wrinkles during sheet metal cutting which includes skill of operator, handling of parts, raw material grade, punch housing, positioning of punch and punch back plate, die and punch alignment, tool alignment, clearance between punch and die, tool hardness, machine alignment etc. [13].

Figure 7. Final pleat base

D. Final Air Filter Product

Finally pleat base fabricated was fit into perforated support. Air filter paper was attached shown in figure 8. Adhesive such as dendrite was used to glue the pleat and air filter surfaces together. The final pleat air filter product was successfully fabricated.

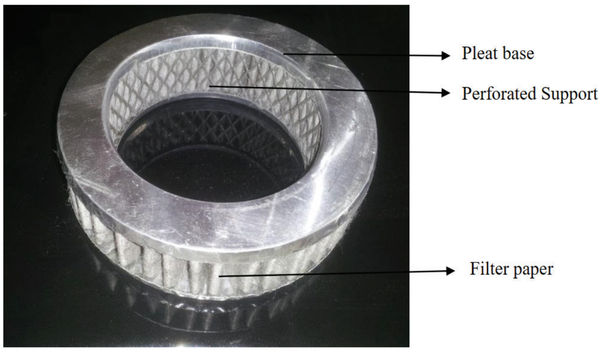

Figure 8. Pleat air filter

IV. Conclusion

Designing and fabricating of the dies were studied and machined successfully to produce the pleat base which is the crucial component of air filter. Then by assembling pleat base along with filter paper and perforated support, a final assembled air filter was thus manufactured. For the industrial manufacturing of automobile air filter, first the filter assembly is broken down into its constituent parts i.e. pleat base, pleated filter paper and perforated support. The application of power screw is used to shear and bend the pleat base of required size and shape. Pleat bases sheared at first phases of testing were not quite the expected outcomes. Excessive shearing, wavy flanges were observed but after certain experiments and trials and modification of die, like increased clearance, adjusting shearing angle and application of lubricant, brought out the required shape and size of pleat. As there is no availability of pleated filter paper in Nepal's market, it has to be imported. For the perforated support, metal wire net has to be selected and then sheared and bent using shearing and bending machines. After the fabrication of each component, these are assembled together using the adhesive. This study shows that pleat air filter product design, die design and manufacturing assembly can be manufactured in Nepal.

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