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Design & Fabrication of Paper Clip and Die By CNC Milling Machine and Acquiring Prototype through Hand Injection Moulding

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Abstract: ***The present work deals with the design and fabrication of Paper-clip Die. Paper clip is a useful product in office. The paper clip is used to bind a bunch of papers. The available binders require spring and consists of two pieces. The present design is a single piece clip which doesn't requires spring mechanism. The model is generated in UNIGRAPHICS and analysis is carried out. The die required for manufacturing the clips is made up of Mild Steel and is designed using Unigraphics. The fabrication is carried out with the help of CNC Milling Machine. The prototype is acquired through hand injection moulding process. The product is optimized in terms of cost, weight and ease of manufacturing.***

Keywords: Unigraphics, Fabrication, Cnc Milling, Spring Mechanism Hand Injection Moulding, Prototype

1. Introduction

The die may be defined as the female part of a complete tool for producing work in a press. It is also referred to a complete tool consists of a pair of mating members for producing work in a press.

Injection moulding has been the most popular method for making plastic product due to high efficiency and manufacturability. The injection moulding machine includes main for stage for production of plastic parts: filling and packing Stage, cooling stage and ejection stage. Among these stage cooling stage is a very important one because it mainly the productivity, quality and total efficiency of the machine. The cooling stage taken 70% time of cycle time. The appropriate design of cooling channel reduces cooling time, increase the productivity and minimizes undesired defect such as sink marks, differential shrinkage, thermal residual stress and warpage. The cooling phase, heat transfer between the molten materials inside the cavity and the cooling fluid flow in the cooling channel inside the mould. The rate of heat exchange is very important and directly related to the time taken by the cooling phase. So it is important to understand and optimize the cooling channel design to optimize the rate of heat transfer in an injection moulding process. The optimizing convectional cooling channels and finding architecture for injection mould cooling channel. The optimize the configuration of the cooling system in the terms of shape, size and location of cooling line. The cooling layout conformal cooling channel the conform to the mould cavity surface and examines the effectiveness of the cooling system. Solid free- form fabrication or rapid prototype techniques have been proposed build this complex cooling system. The cooling quality is better than that conventional cooling channel. Along with SFF technique, milled groove conformal cooling channel. The conformal cooling channel in the plastic injection mould by using an array of baffles.

The combination of analytical method, design of experiment, finite element method, boundary element method and CAE tool especially the mould flow software were used to derive approximate equations showing the relation among cooling channel design variables, mould material process parameter for a given polymer. The design of injection mould is highly interactive and manual process involving substantial knowledge of multiple areas, such as mould design features, mould making processes, moulding equipment and part design, all of which are highly coupled to each other. The main challenge is to design and produce a mould that is straightforward to manufacture, while providing uniform filling and cooling of plastic parts. At the same time the tool has to be strong enough to withstand millions of cyclic internal loads from injection pressures and external clamp pressures, in order to assure the target part reproducibility.

2. Present Practice

The paper clips that are used in the present days are of two-piece design. There should be another spring like support to keep the two pieces combined. These clips are to be pressed to let them bind the papers. Again the spring in the clip is to be manufactured separately and to be assembled with the two pieces. The manufacturing cost of the two-piece clip is more than a single piece clip. The clips in these clips are also having a danger of getting rusted and this effects the papers.

3. Objectives of the Project

- To design the single piece clip which does not require spring mechanism.
- To prepare the die required for manufacturing the clip which consists of core plate and cavity plate by considering mild steel as material for preparation of die.
- To manufacture the single piece clip by placing the die in Injection moulding machine which is an extremely useful for mass-producing polymer parts once the parameters for its ideal operation have been ascertained.

4. Design of Paper Clip

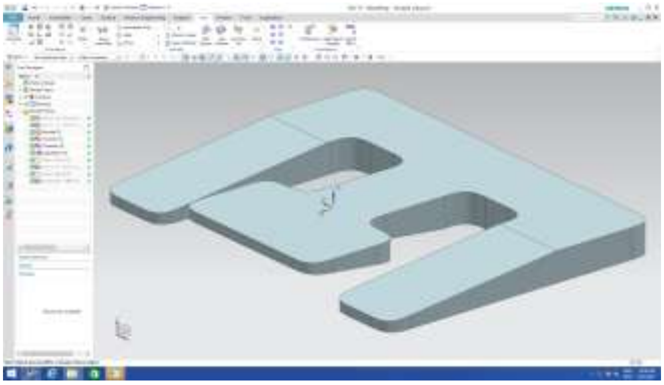


Figure 4.1: Basic Design of Clip

4.1 Dimensions of Paper Clip

1) Length=40mm
2) Width=30mm
3) Height=3mm
4) The slope at the jaws is 84 degrees.

4.2 Dimensional Design of Clip

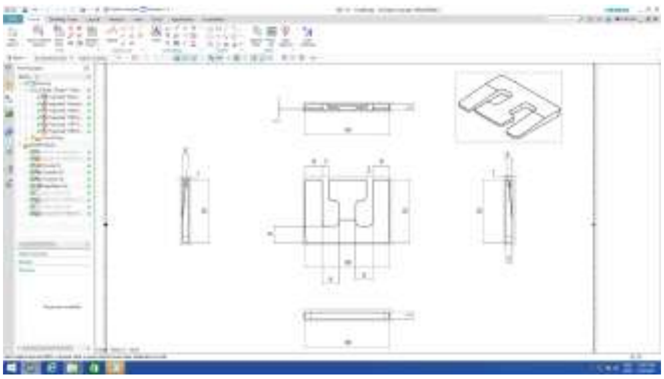


Figure 4.2: 2D Design of Clip

4.3 Description of Design

We designed the clip in a push and pull mechanism which is different to regular clip designs. The above picture shows the basic design of the clip.

Speaking, these easier-flow materials have a lower average molecular weight, which reduces the effective viscosity of the resin. While this can be done successfully, a holistic approach should be taken to see how the change in material will affect the short- and long-term performance of the product. This often requires more than just looking at a datasheet. An alternative approach to reducing the injection pressure while maintaining the desired nominal wall is either relocating the gate or adding additional gates to reduce the flow length.

5. Design Considerations for die

The design considerations are mainly classified into 2 types:

- Considerations related to maintance
- Considerations related to production

5.1 Considerations related to maintenance

The die maintenance is difficult because of easily corrosion in nature and the machining of narrow and sharp shapes on the die mould flash occurs when a thin layer of material is forced out of the mould cavity at the parting line or ejector pins or poorly fitting cavity or mould plates due to dirt , grease etc., Insufficient clamp force the machine clamp force must be greater than the pressure in cavity to sufficiently hold the mould hold the plates shut Non- optimal condition mould condition including material viscosity , injection rate and runner system .

5.2 Considerations related to production

1. Flow Lines
2. Sink Marks
3. Vacuum Voids
4. Surface Delamination
5. Short Shots
6. Warping
7. Burn Marks
8. Jetting
9. Flash

6. Design of Die

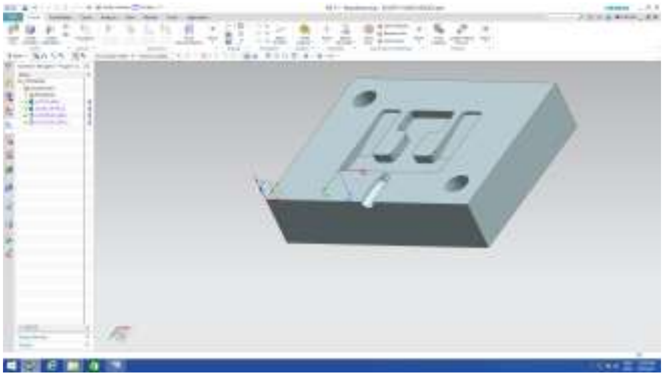


Figure 6.1: Design of Cavity Hand Mould Part

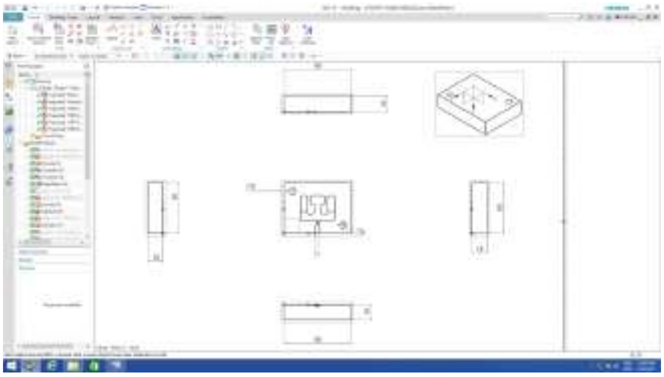


Figure 6.2: Dimensional Design of Cavity Hand Mould Part

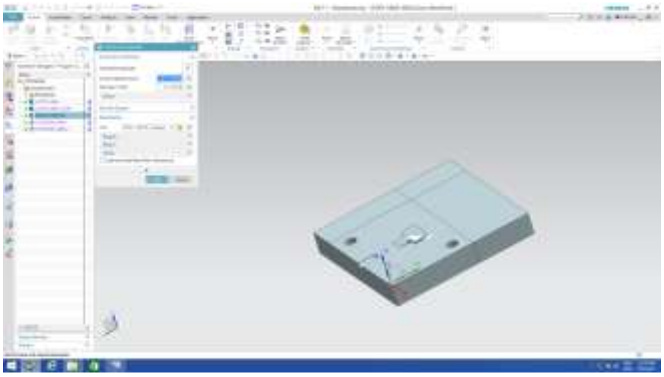


Figure 6.3: Design of Core Hand Mould Part

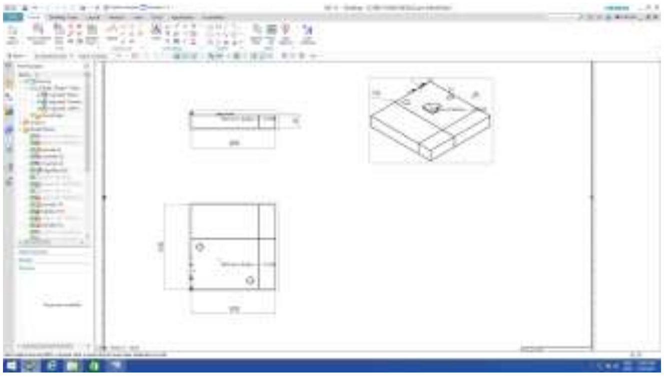


Figure 6.4 : Dimensional Design of Core Hand Mould Part

7. Design Procedure of Die

The sequence of steps followed for designing of die:

1) Computer Aided Design (CAD)
To design our product in a computer by using design software SIEMEN'S NX-11.0. The main goal is to understand how to draw our imagination into a 3D model in NX-11.0.

2) Computer Aided Manufacturing (CAM)
To create a set of operations which ensures a perfect replica of the design in real time. To perform different operations and check their output using NX-11 software. After working over it for a week the final set of programs were completed.

3) Computer Numerical Control (CNC)
To utilize the designs and codes and to make raw material into our required product. To use milling and EDM machines for the manufacturing process.

4) Manufacturing of Product
Using injection press to inject the plastic into the mould and to obtain the product. Then testing the product for any abnormalities or defects. Finalizing the material for the product, mould and manufacturing process for the product.

8. Operations Performed On Mould

The mould consists of two parts namely the cavity plate and the core plate. Various operations were performed on the cavity plate and the core plate.

8.1 The operations performed on the cavity plate are as follows :

1. Cavity Milling (6mm, mill)
2. Z-profile (2mm, mill)
3. Contour Area (3mm, ball mill)
4. Contour Area 1 (3mm, ball mill)

1) Cavity Milling:

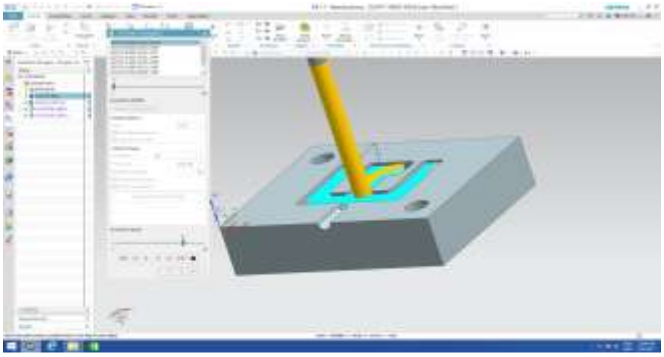


Figure 8.1.1: Cavity Milling Process on Cavity Plate

Tool: Flat mill (6mm)
Spindle speed: 3500 rpm
Feed rate: 250 mm/m
Ramp angle: 6 degrees
Surface speed(mm): 54
Engage type: Ramp on shape
Feed per tooth: 0.0357
Cut pattern: Follow periphery

2) Z-Profile

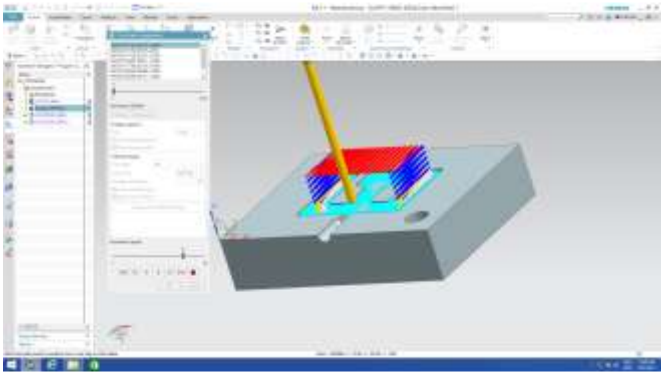


Figure 8.1.2: Formation of Z-Profile on Cavity Plate
Tool: Flat mill (2mm) Spindle speed: 6925 rpm
Feed rate: 250 rpm Ramp angle: 6 degrees
Surface speed(smm): 62 Engage type: Ramp on shape
Feed per tooth: 0.018 Cut pattern: Linear

3) Contour Area:

Figure 8.1.3: Contour Area of Cavity Plate

Tool: Ball mill (3mm) Spindle speed: 4000rpm
Feed rate: 250 rpm Engage angle: Automatic
Surface speed(smm): 62 Engage type: Linear
Feed per tooth: 0.0312 Cut pattern: Climb cut
Stock: 0.1

4) Contour Area-1:

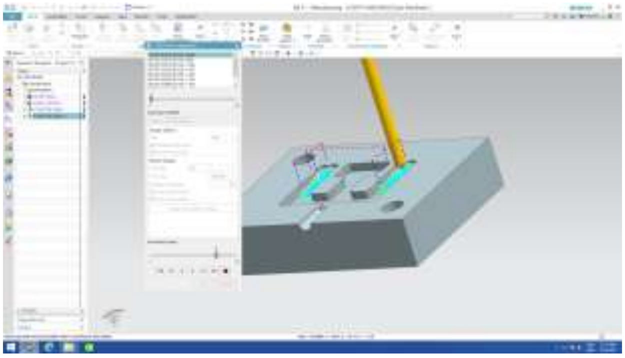


Figure 8.1.4: Contour Area-1 of Cavity Plate

Spindle speed: 4000 rpm Feed rate: 250 mmpm
Engage angle: Automatic Surface speed (smm): 62
Engage type: Linear Feed per tooth: 0.0312
Cut pattern: Linear Stock: 0

8.2 The operations performed on the core plate are as follows

1. Cavity Milling (16mm)
2. Cavity Milling (6mm)
3. Z-profile
4. Contour Area (3mm, ball mill)
5. Contour Area (6mm, mill)

1) Cavity Milling

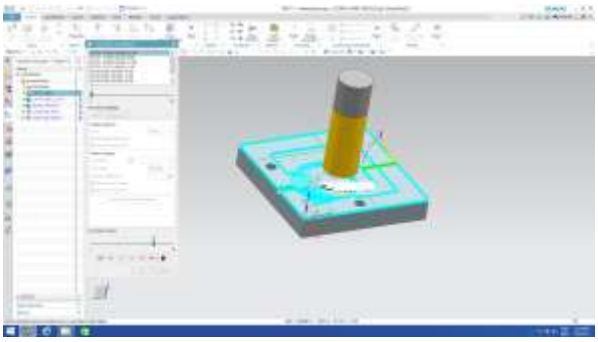


Figure 8.2.1: Cavity Milling on Core Plate

Tool: Flat mill (16mm) Spindle speed: 1800 rpm
Feed rate: 250 mmpm Ramp angle: 6 degrees
Surface speed(smm): 141 Engage type: Ramp on shape
Feed per tooth: 0.0694 Cut pattern: Follow periphery

2) Cavity Milling -1:

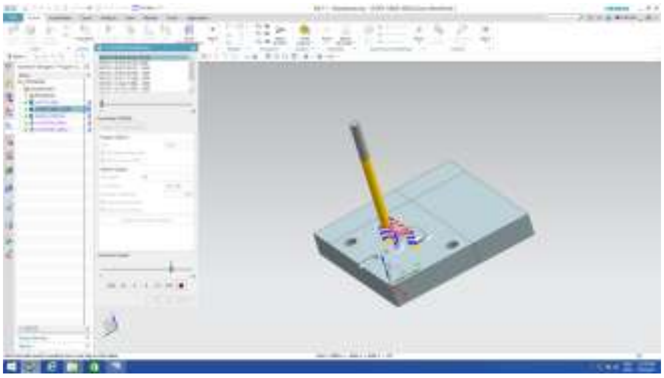


Figure 8.2.2: Cavity Milling-1 on Core Plate

Tool: Flat mill (6mm) Spindle speed: 3000rpm
Feed rate: 250 mm pm Ramp angle: 6 degrees
Surface speed (s mm): 56 Engage type: Ramp on shape

3) Z-Profile

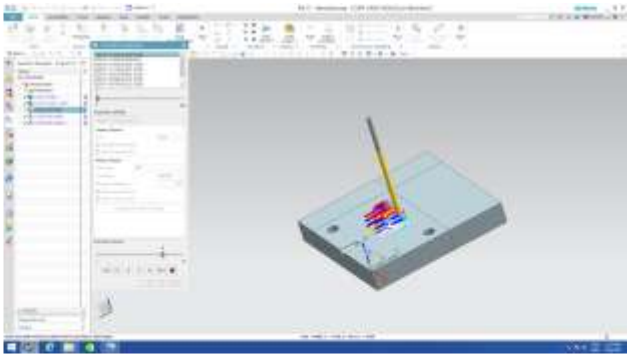


Figure 8.2.3: Formation of Z-Profile on Core Plate

Tool: Flat mill (2mm) Ramp angle: 6 degrees
Spindle speed: 3000rpm Surface speed (s mm): 37
Feed rate: 250 mm pm Engage type: Ramp on shape
Feed per tooth: 0.0312 Cut pattern: Linear

4) Contour Area

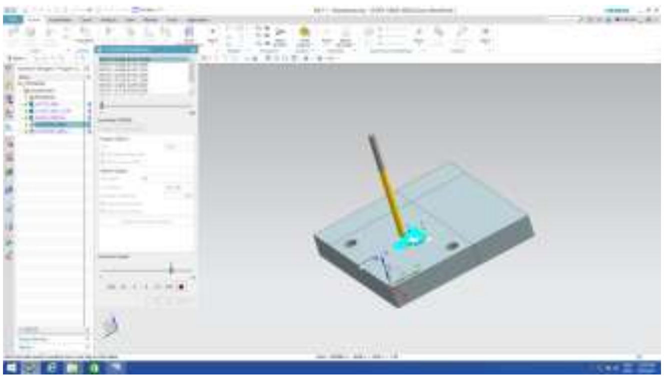


Figure 8.2.4: Contour Area of Core Plate

Tool: Ball mill (3mm) Spindle speed: 4000 rpm
Feed rate: 250 mm pm Arc angle: 90 degrees
Surface speed (s mm): 56.00 Cut pattern: Automatic
Engage type: Arc parallel to tool axis
Feed per tooth: 0.0277

5) Contour Area-1:

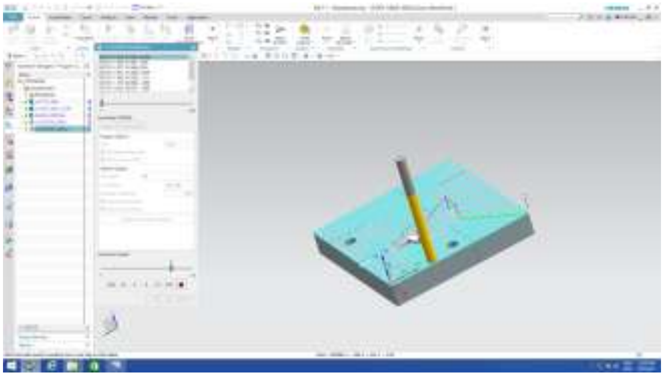
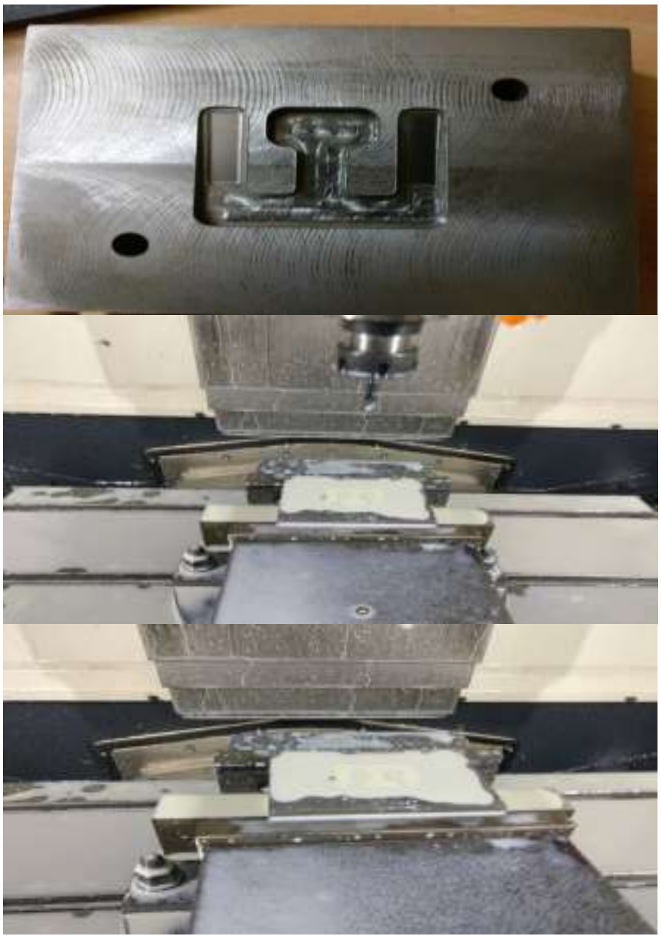
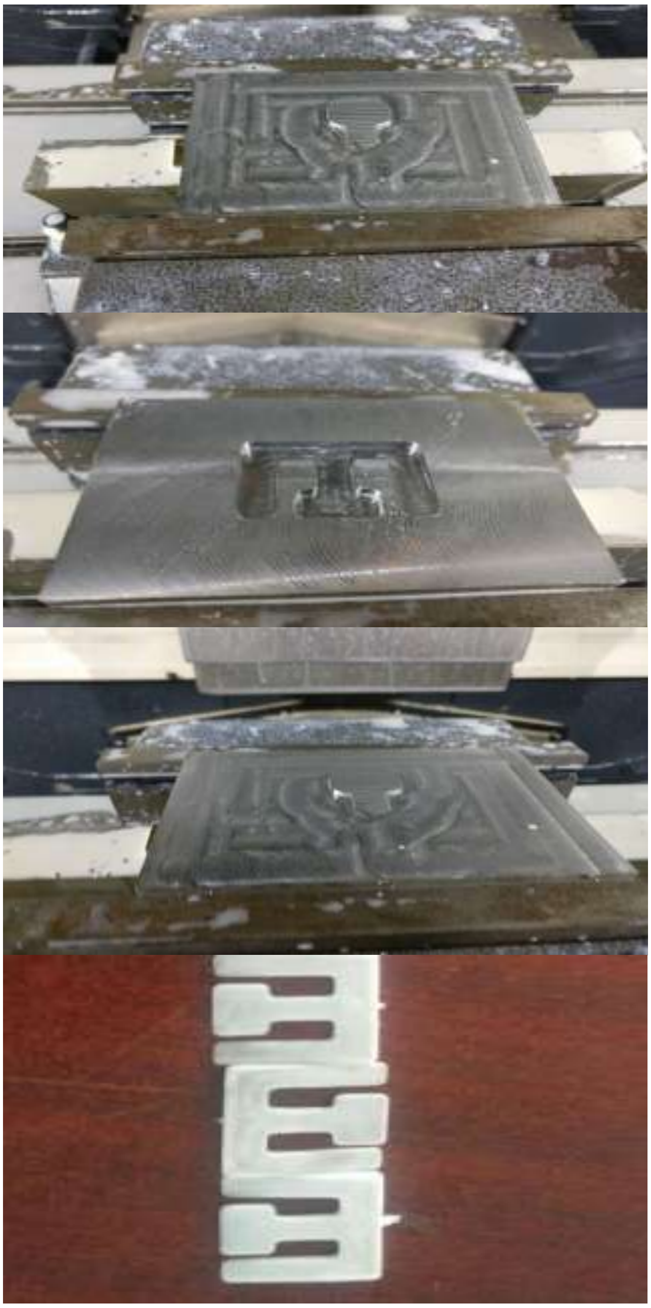


Figure 8.2.5: Contour Area-1 of Core Plate

Tool: Flat mill (6mm) Spindle speed: 3500 rpm
Feed rate: 250 mm/m Arc angle: 90 degrees
Surface speed (s mm): 65 Feed per tooth: 0.0357
Engage type: Arc parallel to axis
Cut pattern: Climb cut, inward

Therefore, the simulation of the fabrication of the Die is done using Unigraphics and the final die is fabricated in the CNC milling machine.





9. Numerical Analysis

Dimensions of Die

The mould design is made after the finalization of the product. The dimensions of the die piece are 80 X 60 X 30 mm^3. The mould is a two plate mould. One piece contains the core and the other piece has a cavity. It has a single runner and gate. The mould has been given a shrinkage allowance of 2%. The dimensions of the mould pieces are given below.

Design Parameters:

Cope:

The top plate material is Mild Steel having the dimensions is 80 X 60 X 30 mm^3. It is used to locate the runner and convey the molten plastic material.

Drag

The bottom half of horizontally parted mould.

Gate:
The size of the gate can be considered in terms of gate cross section area and gate length. This depends on

- Flow characteristics of the material to be moulded.
- The wall section of the moulding.
- The volume of material to be injected into impression.
- Temperature of mould.

Runner:
The following points must be considered for determining the size of the runner

- The wall section and volume of moulding.
- Distance of the impression from the main runner.
- Runner cooling type used.
- The range of cutter available.
- Plastic material that being used.

D= runner diameter
W= weight of moulding
L= length of moulding
D=3.1622*3.5565/3.7
D=11.24/3.7
D=3.039 ˜ 3mm

Injection moulding is capable of tolerances equivalent to an IT Grade of about 9–14. The possible tolerance of a thermoplastic or a thermoset is +/-0.008 to +/-0.002 inches. Surface finishes of two to four micro inches or better are can be obtained. Rough or pebbled surfaces are also possible.

Moulding Type	Typical	Possible
Thermoplastic	±0.008	±0.002
Thermoset	±0.008	±0.002

If the wall thickness selected requires excessive pressure to fill the mould, then either the wall thickness needs to be increased, the flow length needs to be reduced, the material needs to be changed, or a combination of these three factors. A knee-jerk reaction to excessive pressures is to use an easier-flow material. These easier-flow materials have a lower average molecular weight, which reduces the effective viscosity of the resin. While this can be done successfully, a holistic approach should be taken to see how the change in material will affect the short- and long-term performance of the product. This often requires more than just looking at a datasheet.

An alternative approach to reducing the injection pressure while maintaining the desired nominal wall is either relocating the gate or adding additional gates to reduce the flow length.

Shrinkage Allowance
Shrinkage allowance is 2%
Amount of material should be removed from the mould

Length =40mm+2% shrinkage
=40 + (2/100) *40
=41mm

Width =30 mm +2% shrinkage
=30 + (2/100) *30
=31mm

Thickness =3mm+2% clearance
=4mm
Tolerance is 1mm in all directions

Cooling Time Calculations

Wall thickness(s) = 15mm
Cavity surface temperature (T_w)=$50^0 c$
Temperature at molten plastic (T_m)=120^0 c

The cooling time t_c required until the temperature of the moulded part become $50^0 C$is calculated using Equation

$$t_c = \frac{s^2}{\pi^2 * a} \ln\left(\frac{8}{\pi^2}\left(\frac{T_m - T_w}{T_e - T_w}\right)\right)$$

s = thickness of wall
a =heat diffusion rate of plastic at cavity surface temperature
a = $\frac{\lambda}{c*p}$

From material properties of LDPE
Specific heat =2000j/kg
=0.47769179325kcal/kg

Density =0.940g/cm^3=940 kg/m^3
Thermal conductivity = 0.36W/mk
= 0.309544KCal/m.$h^0 C$

a = λ/(c*p)
= $\frac{0.309544}{940*0.47769179325}$
= 6.89352*$10^{-4} mm^2 /sec$
= 0.0006 mm^2 /sec

Substituting all values in the above equation

$$t_c = \frac{15^2}{\pi^2 * 0.0006} \ln\left(\frac{8}{\pi^2}\left(\frac{120-50}{106.7-50}\right)\right)$$

= 26.70324722 sec ≈ 27 sec

By considering the parameters and the dimensions the die is designed in UNIGRAPHIS NX 11.1.

10. Material Used for the Preparation of Die

Mild Steel is used for the preparation of the die. It is one of the most common of all metals and one of the least expensive steels used. It is to be found in almost every product created from metal. It is weldable, very durable (although it rusts), it is relatively hard and is easily annealed. Having less than 2 % carbon it will magnetize well and being relatively inexpensive, can be used in most projects requiring a lot of steel. However, when it comes to load bearing, its structural strength is not usually sufficient to be used in structural beams and girders.

Being a softer metal it is easily welded. Its inherent properties allow electrical current to flow easily through it without upsetting its structural integrity. This is in contrast to other high carbon steels like stainless steel which require specialized welding techniques.

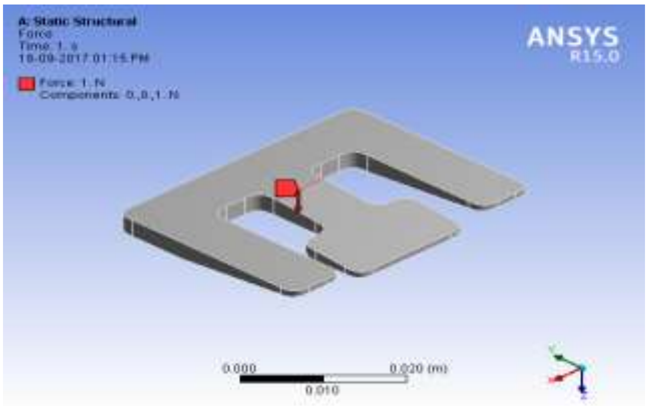
Mild steel is a type of carbon steel with a low amount of carbon – it is also known as “low carbon steel.” Although ranges vary depending on the source, the amount of carbon typically found in mild steel is 0.05% to 0.25% by weight, whereas higher carbon steels are typically described as having a carbon content from 0.30% to 2.0%.

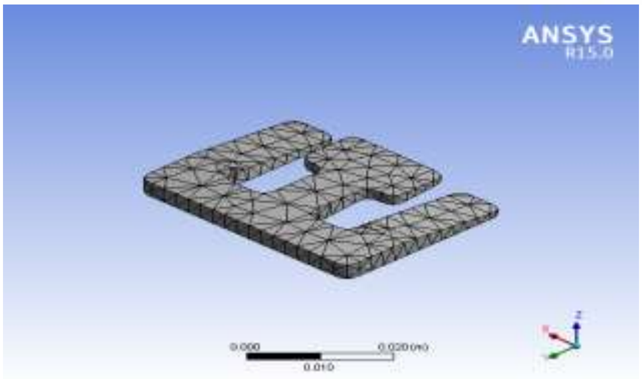
11. Materials Used in the Production of Clip

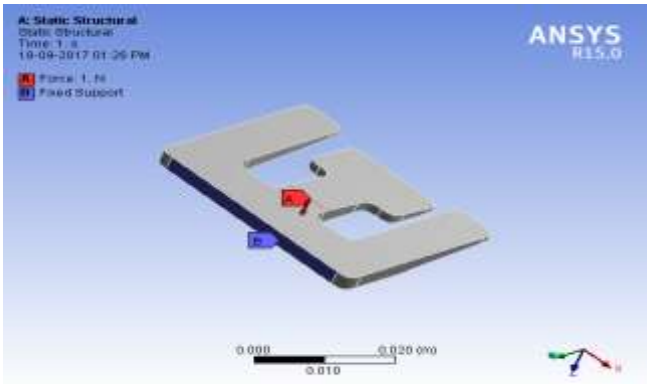
Plastics are mainly used in the production of clip. It can be either found in natural substances or may be man-made. Most of the plastics used today are man-made. Man-made plastics are known as synthetic plastics. Natural 'plastic products' occur in such things as animals' horns, animals' milk, insects, plants and trees.

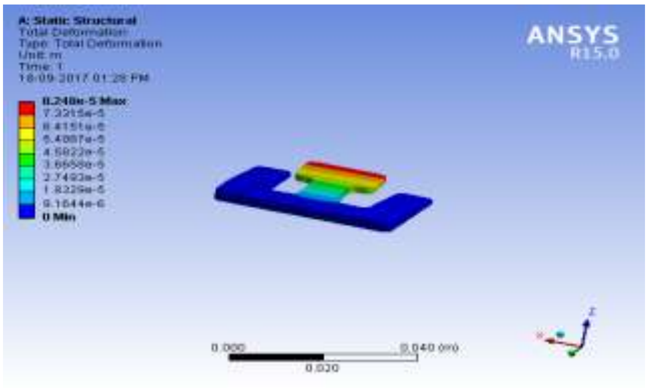
12. Analysis of Clip

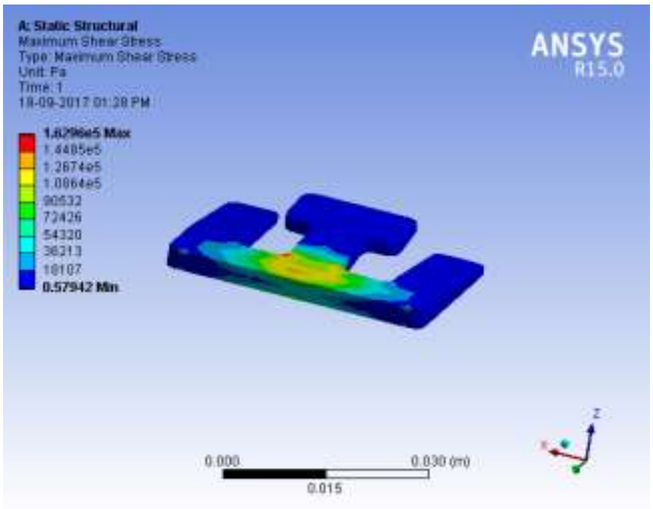
Analysis is done with the help of Ansys R15.0.

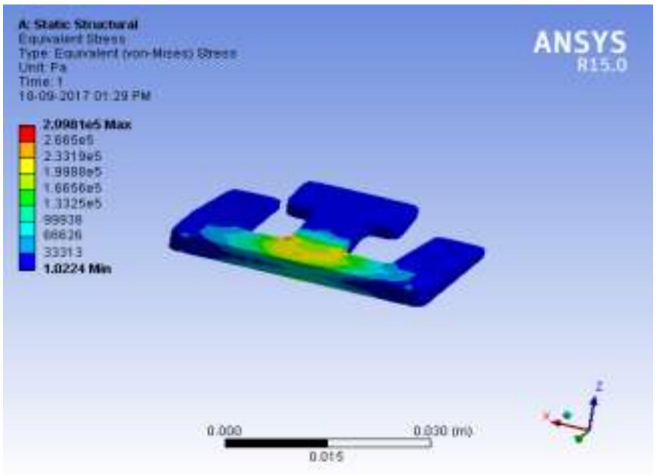












13. Conclusion

Injection moulding is an extremely useful tool for mass-producing polymer parts once the parameters for its ideal operation have been ascertained. For actual manufacturing profit and product quality are main factors. If the temperature is too hot or cold, we will either see a short shot or thermal degradation. If the pressure is too high, flashing will occur, and if it is too low, we will have too much shrinkage and the parts will not be within specified tolerances. The product must be within certain process parameters to ensure product quality. The most profitable process is performed at the lowest acceptable temperature and from our data, the highest quality part is made using a higher pressure.

14. Acknowledgement

We take this opportunity to thank all those magnanimous persons who rendered their full co-operation for completion of this project.

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Gali Sai Swaroop pursuing B-Tech in the stream of mechanical engineering from Jawaharlal Nehru Technological University Kakinada. He has an enthusiastic approach over every concept that is related to research & development activities.

Attaluri Maheedhar pursuing B. TECH final year in Mechanical Engineering from JNTUK University. He is very much interested in doing design and research projects. He has good overview on concepts related to numerical analysis.