"DESIGN AND MANUFACTURING OF PROTECTION CAP FOR STUB SHAFT USING PLASTIC INJECTION MOULDING"

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ABSTRACT

In most industries, the product is manufactured at one place while assembled at another location. So, during transportation and handling, from manufacturing to assembly plant the part might get damaged, due to which it will not fit to assemble, leading to a big loss for the company. To avoid this, the part needs to be protected. By manufacturing of product using Plastic Injection Moulding (PIM), it will protect the part during transportation and handling. Considering strength as one of the important properties of the part, injection moulding is best suited for the mass production of plastic parts. Hence, injection moulding is most widely used in the local industries. This paper gives an insight into the Plastic Injection Moulding process from designing to manufacturing of the product, with certain process parameters that need to consider while designing for the selection of optimum material for the product.

Keywords: Plastic Injection moulding, Mass Production, Optimum Material.

INTRODUCTION:

The most common methods of manufacturing plastic parts include Extrusion, Injection moulding, Blow moulding, Casting, etc. However, injection moulding is most widely used in the local industry as it is suitable for mass production. In the plastic injection moulding process, plastic products are produced by forcing the resins made of plastic materials by application of high pressure into a mould (hollowed-out block cavity) where it is cooled, allowed to solidify, and after that taken out from the mould by opening cope and drag part of the mould. The solidified material ejected from the mould results in the final product. Objects having complicated shapes and geometries can be easily manufactured by using a plastic injection moulding process with great dimensional accuracy.[1] The cooling process in plastic injection moulding is of great importance as it plays a crucial role in determining both the production rate and part quality.[2]

In this project, a protection cap is being manufactured to protect the base of the stub shaft. Stub shaft is used in power transmission systems. It is a small rotating shaft that helps to transmit power from its place of generation to a location where it is applied to perform useful work. It allows side-load to the back of an engine while simultaneously preventing any load transmission back to the crankshaft. Considering the dimensions of the stub shaft a protection cap is manufactured by using plastic injection moulding. The main purpose of the cap is to protect the edges of the stub shaft during transportation from one location to another.

Another important parameter that needs to be considered is costing of the process. Higher cost of material will result in an expensive product. Hence, the selection of material should be considered to fulfil the requirements of the customer.[3] Fig. (1) shows a vertical plastic injection moulding machine.

Fig. 1 – Injection Moulding Machine

LITERATURE SURVEY

R. M. Khan et al.[1] , In this paper author studied and identified the factors which are considered to manufacture a product with minimum defects. It is concluded that to control defects in manufactured product selection of proper geometry and process parameters are important.

Y. C. Lam et al.[2] **,** This paper states the importance of a cooling system in plastic injection moulding. CAE (Computer - Aided Engineering) technology is adopted for the optimization of the cooling systems in plastic injection moulding. From a case study, the authors have concluded that the genetic algorithm and CAE stimulation is efficient in a cooling system. It results in a high production rate and good production quality.

P. K. Mulge et al.[3] , This paper gives a brief review on optimization of process parameters used in plastic injection moulding by using Taguchi's methodology. Taguchi's techniques are most widely used in industry to save cost, reduce experimental time, and improve the quality of the manufactured products.

G. Singh et al.[4] , In this paper author reviewed and concluded that controlling process parameters leads to improve quality of the product. The two most commonly occurring defects in plastic injection moulding are warpage and shrinkage. The use of recyclable and eco-friendly raw materials is highly beneficial for the environment and society.

K. Jain et al.[5] , This paper highlights the causes of defects in plastic injection moulding components. The product quality of components mainly depends on the selection of material, mould design, setting process parameters, and cooling system. In plastic injection moulding, residual stresses lead to the formation of shrinkage in components. By using Taguchi's approach shrinkage defects can be minimized which helps to reduce the warpage of components.

S. Kitiyama et al.[6] , This paper states various process parameters of the plastic injection moulding process to minimize the weld lines and the importance of clamping force to improve the quality of the moulded product. By using numerical simulation, factors such as mould temperature, melt temperature, injection time, etc. were optimized for the smooth manufacturing process.

M. Kroon et al.[7] , In this paper author investigated fracture mechanical properties of Low-Density Poly-ethylene (LDPE) using both analytical and experimental methods. The Author also discussed various grades of polyethylene (PE) according to their mechanical behaviour.

P. K. Bharati et al.[8] , This paper focuses on various process parameters and approaches used for plastic injection moulding. Various approaches used are mathematical models, Taguchi method, fuzzy logic, case-based reasoning (CBR), finite element method (FEM), non-linear modelling, etc. These approaches help to optimize the process in the best possible way.

P. D. Kale et al.[9] , This paper gives a brief review of, how the runner system affects the quality of the product and the complete injection moulding process in detail. From this paper, author observed that improper runner system causes burn mark, warpage, weld lines in the product. From this paper, author concluded that replacing the cold runner system with a hot runner system reduces the defects in the product also helps in scrap reduction.
R. A. Yadav et al.[10] , In this paper methods of optimization in the plastic injection moulding process and various process parameters are reviewed. The Strength and weakness of various approaches such as Taguchi method, Artificial Neuron Networks (ANN), Case-Based Reasoning (CBR), Genetic Algorithms (GA), etc. are addressed in this paper. By adopting these approaches various factors in manufacturing such as cost, quality, and time can be controlled.
Dr, A. R. Ahamed et al.[11] , In this paper author focused on critical factors involved in the plastic injection moulding process. Some critical factors include melt temperature, injection pressure, cooling time. Taguchi and ANOVA techniques were used to find the effects of melt temperature, injection pressure, and cooling time of plastic materials.
X. P. Dang et al.[12] , In this paper author discussed basic steps for optimization of plastic injection moulding process parameters. The author mainly focuses on simulation based optimization and introduced two robust techniques for optimizing mould parameters, which include direct numerical optimization and metamodel based optimization. The author concluded that the direct GA optimization method is the best choice for low non-linear problem.
S. J. Liu et al.[13] , In this paper author gives a brief review on the manufacturing of thermoplastic components by novel water-assisted injection moulding technology. To optimize various process parameters during manufacturing such as melt temperature, mould temperature, etc. The author used Taguchi orthogonal array design method for the precise manufacturing of component. The author concluded that the parts produced by assisted injection moulding method have shortened cycle time as compared to other assisted injection moulding processes.

PROBLEM STATEMENT

Design and manufacturing of protection cap for stub shaft using injection moulding methodology. The major challenge is to come up with an optimum design to match customer requirements in a cost efficient way and to select the best supplier for rawmaterials and ensure smooth manufacturing to match customer demand.

METHODOLOGY

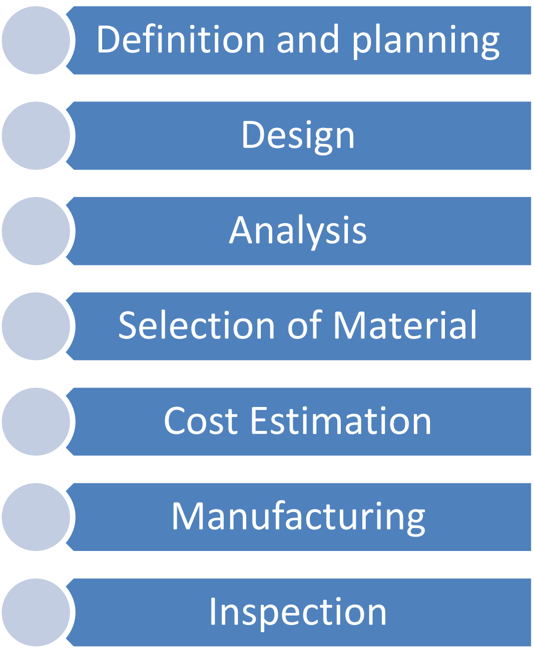


Fig. 2 – Methodology

- **Definition and Planning:** Discussion of the problem statement and further planning.
- **Design:** To design the part as per the dimensions of the stub shaft.
- **Analysis:** To carry out analysis to select best suited material.
- **Selection of material:** Based on the analysis result, selection of precise material.
- **Cost Estimation**: To predict the cost of the resources required to complete the product within the project scope.
- **Manufacturing**: To manufacture the product by using an automatic machine.
- **Inspection**: To inspect the final product by considering good quality, accuracy and precision to fulfil customer's requirements.

EXPERIMENTAL WORK

Design of Stub shaft

- A stub shaft is a small rotating shaft made of mild steel (M.S) used in power transmission systems.
- The main purpose of the protection cap is to protect the edges at the base of the stub shaft.
- From the sketch below it is observed that:
- The maximum diameter of the base of the shaft – 89.7mm
  The width of the shaft – 26.5mm
  The length of the shaft – 144.5mm
- From the fig. (3) the 3-D sketch of the stub shaft is shown which helps in determining the centre of gravity of the stub shaft.

Fig. 3 – 3D Model of the stub shaft

DESIGN OF PROTECTION CAP

- Design for manufacture (DFM) is a process in which the product is designed by the design engineer to achieve the best possible results to meet customer's requirements.
- The product which is being designed is a protective cap that is used to protect the base of the stub shaft.
- In the fig. (4), a 2-D sketch of the Protection cap is shown which is designed on solid works as per the dimensions of the stub shaft.
- The internal diameter of the cap is equal to the maximum diameter of the base of the stub shaft.
- While designing, a flange of 97 mm is provided for easy fitting and removal of the cap from the base of the stub shaft.
- For cost optimization, the minimum required thickness and width of the cap should be taken under consideration.
- As per the calculations, the thickness and width of the cap were 1.5 mm and 16 mm respectively.

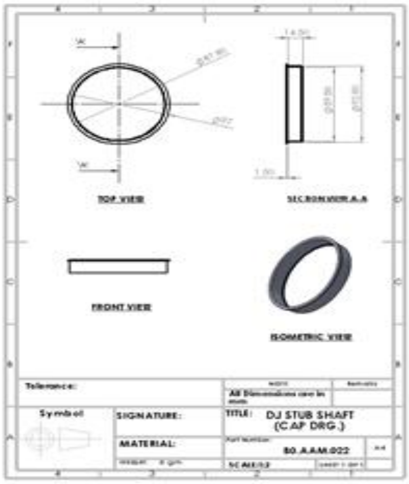


Fig. 4 – Design of the cap

PROPERTIES OF MATERIALS

The common materials used in plastic injection moulding are:
Nylon-6, Polyvinyl Chloride, Polypropylene, Low-Density Polyethylene, etc.
Few properties of the above materials need to be considered while the selection of material is given in the table below-
Table (1) shows the mechanical properties of different materials. By considering these properties, an analysis will be carried out to select the best suited material for the cap.

Table – 1 Mechanical Properties of material

PARAMETER		**MATERIAL**		
	NYLON-6	PVC	PP	LDPE
Modulus of Elasticity (N/mm^2)	3500	3230	1450	449
Tensile strength, yield (N/mm$^{2)}$	186	50	369	64.8
Hardness	82	83	83	56.0
Mould Temperature (°C)	95	70	91	65.66
Tangent Modulus (N/mm$^{2)}$	792.52	729.05	947.62	305.5

RESULT AND DISCUSSION

Modelling

Modelling is the first step towards analysis. It acts as a link between designer and manufacturer to create a 3D prototype of the product that is to be manufactured. The fig. (5) shows the 3D model of the protection cap which is modelled on ANSYS Workbench. The cap is designed on software as per the dimensions of the base of the stub shaft.

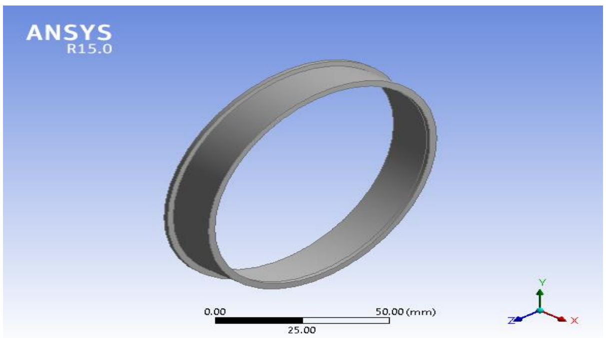


Fig. 5 – 3-D Model of Cap

NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY
[IJIERT] ISSN: 2394-3696 Website: ijiert.org
VOLUME 8, ISSUE 6, June. -2021

Analysis

The analysis of the 3D model of a protection cap was carried out on ANSYS Workbench R15.0. The material properties like young's modulus, Poisson's ratio, tangent modulus and other mechanical properties were defined for all the materials. After meshing of the cap, boundary conditions were applied to carry out the analysis.

Meshing

Meshing or discretization is defined as dividing the body into a finite number of smaller elements to increase the accuracy up to the maximum possible extent. For the protection cap, fine meshing was done which created 15555 nodes and 7405 elements.

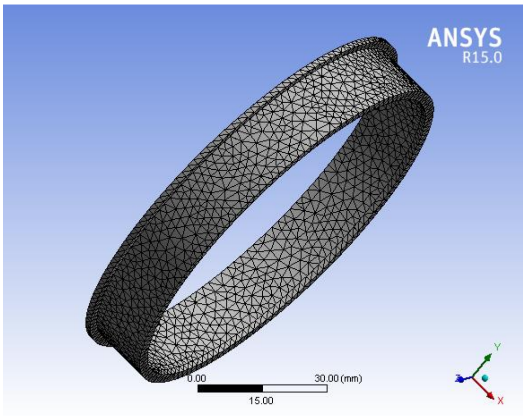


Fig. 6 – Fine meshing of cap

Boundary Condition

The value of variables such as force, displacement, temperature, etc. specified on the boundaries of the body or structure is called boundary conditions. The Boundary condition is an important factor of mathematical modelling. They help in determining the flow of the problem which leads to a unique solution. As the cap is resting on its base, the fixed support is applied at the base. A Remote point is a point in which boundary conditions can be applied from outside of the body. The significance of remote point is, the force that is applied on the point is equally distributed over the surface of the body. To apply the remote force, it is necessary to calculate the C.G of the body. Fig. (7) shows a web projected from a remote point to the targeted surface.

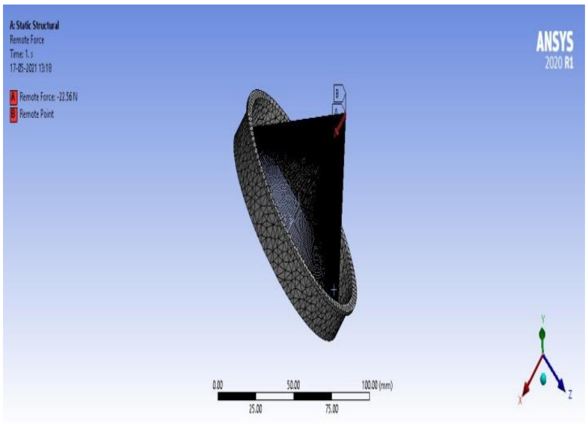


Fig. 7 – Remote force applied on the cap

Results and selection of material

LDPE

A. Deformation

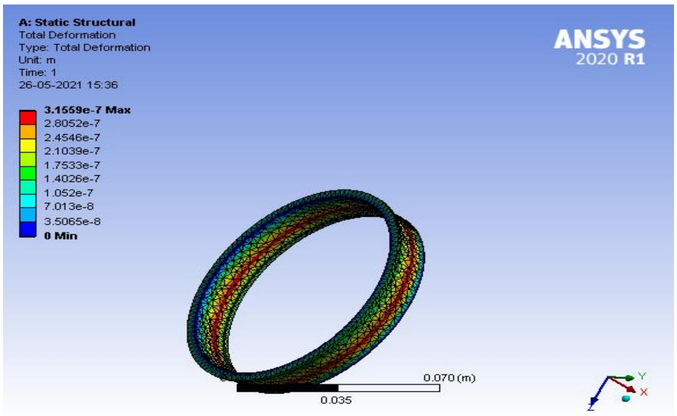


Fig. 8 – Total Deformation of LDPE

B. Stress

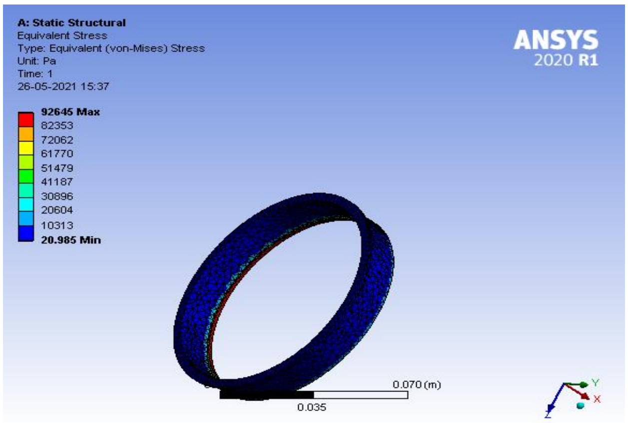


Fig. 9 – Equivalent Stress of LDPE

- From the above figures, the deformation of the cap under a certain load and stress induced on the cap is shown.
- Table (2) shows a comparison of various materials concerning to different parameters.

Table 2 – Comparison of Materials

Parameters	LDPE	PVC (FLEXIBLE)	PP	NYLON-6
Stress (N/m^2)	92645	83495	83096	83561
Cost (Rs)	120	115	140	260
Mould Temperature (°C)	65	70	91	95
Young's Modulus (N/mm^2)	449	3230	1450	3500
Ultimate Compressive strength (N/m^2)	$6.5*10^7$	$2.5*10^7$	$4*10^7$	$5.5*10^7$

Analytical Calculation of Stress:

$\sigma = F/A$

where,

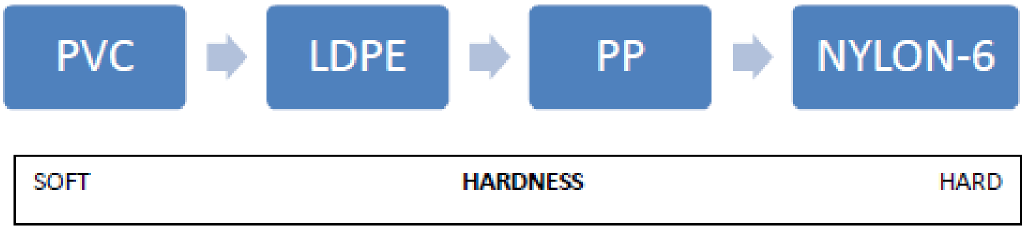
F = Load acting on the body in Newton.

= 22.56 N

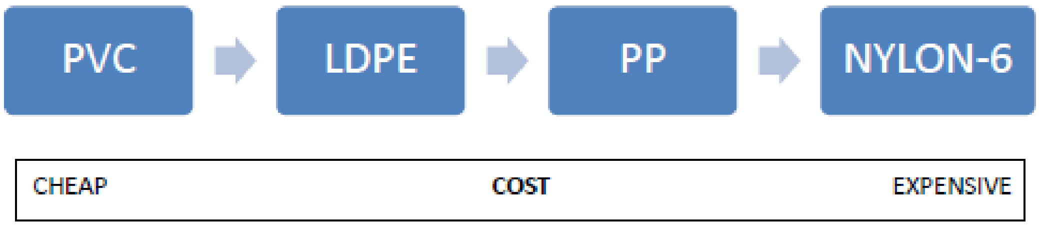
A= Cross sectional area in mm2
=278.973 mm2
σ = Stress acting on body.
= 80.868 KN/m^2

The following scale shows variation in property of different materials for selection of optimum material.

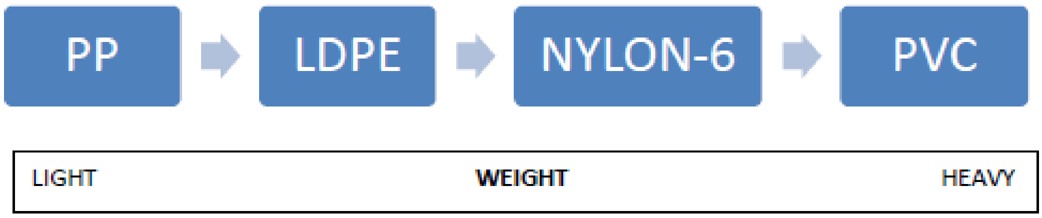
HARDNESS



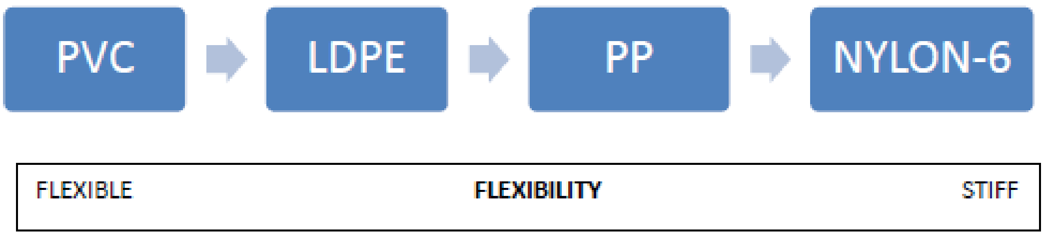
COSTING



WEIGHT



FLEXIBILITY



From charts, a comparison of different materials concerning various parameters is shown. To select the optimum material for the cap all the parameters must meet the customer requirement. The cap material must withstand the stress induced due to the force acting on the cap and at the same time, it must be cost-effective.

1. STRESS: Analytical value of stress-induced in the cap is calculated in the analytical stress calculation section. So, by comparing the actual value and the experimental value the best-suited material can be selected for the cap. The actual value of stress-induced in the cap due to force is 80.868 KN/m^2. This is the minimum value of stress the cap should withstand.

2. DEFORMATION: The deformation values of all compared materials are almost equal. Therefore, these values will not be considered as the main comparing parameter for the selection of material.

3. MOULD TEMPERATURE: Mould temperature has a profound effect on the final properties of the product. The actual surface temperature of the mould is called the mould temperature. Perfect mould temperature results in the reduced unit cost of plastic product and improves the quality of the moulded product. The higher the mould temperature, the higher will be the cooling time which will indirectly increase the cycle time of the product. Therefore, the mould temperature should be as low as possible.

4. COST: Cost is one of the important parameters that need to be considered while the selection of material. The increasing cost of material gradually increases the final cost of the product. Failing to control the cost of the product results in less demand for the product in a competitive market. Hence the selected material should be cost-efficient and should have good mechanical properties which match the requirements of the product.

Considering the above parameters, the mould temperature of LDPE is lowest as compared to other materials which reduce the product ejection time resulting in an increased production rate. Similarly, in costing the price of PVC is lowest as compared with other materials but it does not fulfil the demands of some mechanical properties required for the cap. Hence the second-best cost-efficient material i.e., LDPE is considered. From table (2) the experimental values of stresses of all materials meet the maximum value of stress-induced. Therefore, by considering all the above parameters LDPE is the best-suited material for manufacturing of Protection cap.

Cost Estimation

Cost estimation is one of the important parameters which need to be considered while manufacturing any product. It gives a brief idea about the inventory cost as well as the production cost of the product. Table (3) shows the expected final cost of the cap.

Table 3 – Cost Estimation

Sr. No.	Component	Weight	Raw Material	R/M Cost/Kg	Material Cost	Labour Cost	Over Head Cost	Profit @ 15%	Total Rate
1	Dia 87.8 Cap	200 Grams.	LDPE	Rs. 120/-	2.60	0.55	0.20	0.50	3.85

By calculating the weight of the material per Kg required for the production, the material cost can be calculated. The Production cost primarily involves Labour cost and Cycle time. The complex design of the part tends to increase the production cost, which can be minimized by advanced mould designs. By using a recycled form of material, the cost of the product can be minimized. It possesses the same plasticity as that of the virgin material and the cost is 30% less than the raw material which is one of the main advantages of using recycled material. Whereas the cost of the cap can also be reduced by reducing the cycle time of the process, which can be done either by using automatic machines which will indirectly reduce the labour cost or by improving the process parameters. Apart from the production and material cost, the profit parameter is included for the growth of the company. By combining all the discussed parameters, the final cost of the cap is estimated.

Manufacturing

Plastic injection moulding process manufacture's products that have good dimensional accuracy, high quality and better dimensional stability. Factors that affect the quality of the moulded product depend on Design of product, Mould design, Machine performance and efficiency. The basic requirements of injection moulding are plasticization, injection and moulding. Plasticization is a prerequisite which ensures the quality of moulded product and helps to meet the requirements of moulding. Sufficient speed and pressure must be maintained while injecting the molten material into the mould. At the same time to sustain the high pressure generated inside the cavity, there must be sufficient clamping force. Thus, the clamping device and injection device play a major role in the injection moulding machine.

Basic steps of manufacturing

In the following figure, the basic steps of the plastic injection moulding process are shown:

Step 1 – **Mould Closing:** Mould cavity consists of two parts: Cope and Drag. For the product to be manufactured, both parts of the mould are in a closed position to avoid the spillage of material during the injection.

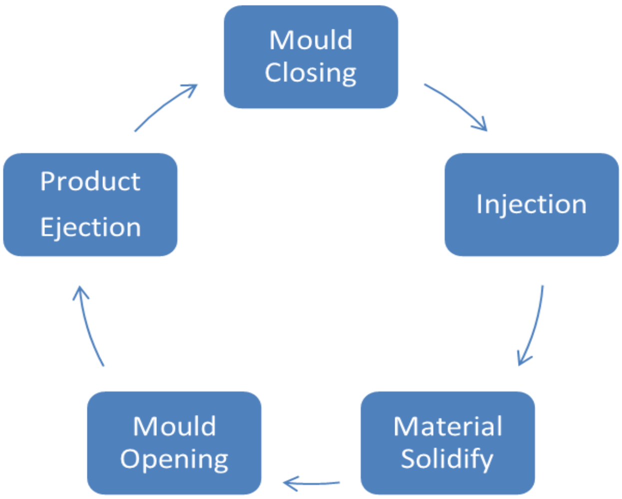


Fig. 10 – Manufacturing Process

Step 2 – **Injection:** The resins are fed into the hopper which passes through the barrel in which heating coils are located. This results in the melting of material and the molten resins are dosed through a nozzle at high pressure into the mould cavity.
Step 3 – **Material Solidify:** The injected material is kept inside the mould for a certain period of time to solidify. Also, water cooling channels are provided for effective solidification of the material.
Step 4 – **Mould Opening**: After the Solidification of material inside the cavity, the mould is opened for ejection.
Step 5 – **Product Ejection:** After ejection of product from the cavity, post-processing is done to get the final-product.

Horizontal injection moulding machine

Horizontal injection moulding machine is most widely used in plastic fabrication companies. The two main units of this machine are the clamping unit and the injection unit. Both these units lie on the same horizontal centerline.

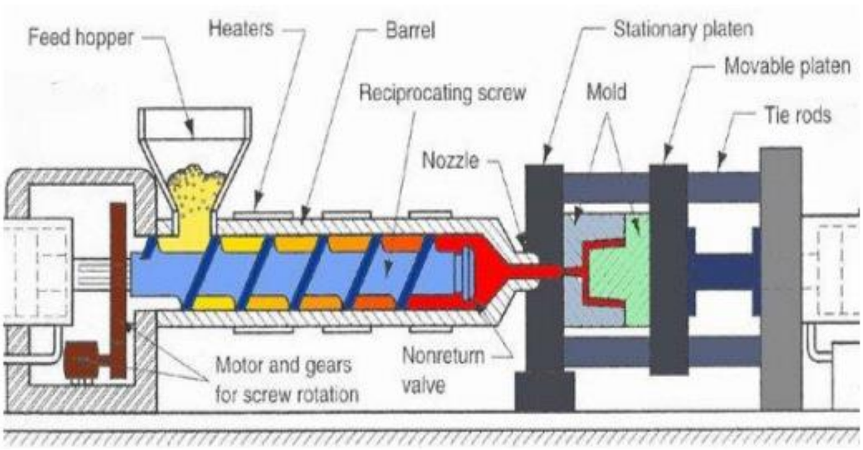


Fig. 11 Horizontal Injection Moulding Machine [3]

Fig. (11) shows a schematic diagram of a horizontal plastic injection moulding machine. The Clamping unit, injection unit and drive unit are the main units of the machine. When the molten resins are injected into the mould cavity at high pressure it results in high forces which may lead to the opening of the mould to avoid this, the clamping unit is used to keep the mould in a closed position by the use of clamping devices. Low clamping force may result in material spillage or deformed shape of the product. The function of the clamping unit is to hold, close and open the mould during the operation. The purpose of the injection unit is to inject molten granules into the mould cavity using injection nozzles. Power to perform injection and clamping operations is provided by the drive unit. Parameters considered in mould designing are runner system, gate location, sprue design, selection and location of the cooling channel.
The plastic resins are fed into the hopper either manually or by an automated system. Then the resins flow under gravity through the barrel into the heating chamber. The reciprocating screw extends from the hopper to the injection chamber. Heating bands are provided along the length of the screw which melts the plastic. Due to the reciprocating motion of the screw, the molten plastic gets injected into the mould cavity. The plastic flows into the mould cavity through the sprue, runner and gate. From the injection nozzle, the molten plastic flows through the sprue into the runner, which then directs the plastic into the mould cavity through the gate. The cooling channel is used for rapid cooling to reduce the manufacturing cycle time. When the plastic gets solidified the mould opens and the final product is ejected.

CONCLUSION

From this paper, it is concluded that a protective cap of optimum material is manufactured to satisfy customer requirements. The manufactured cap fulfils the requirement of protecting the edges of the stub shaft while transportation and handling. Considering the mechanical properties of the cap, to make the cap cost-effective and of good quality, low-density polyethylene (LDPE) is the best-suited material for the protection cap. Earlier, while transportation and handling the edges of the stub shaft were used to get damaged which led to a big loss for the company. However, the protection cap served the purpose of protecting the edges of the stub shaft, which minimizes the loss for the company. Although plastic injection moulding is a complex process, the product can be manufactured with lesser defects by controlling the process parameters.

ACKNOWLEDGEMENT

The authors acknowledge Mr. Arvind Ravetkar Akshay Firms who provided expertise and insight about the injection moulding process that greatly assisted the project work.

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