

# Plastics Product Design

# Designing for Success

**The market trends indicate India becoming a major supplier of plastic components and it is imperative that we design the plastic components successfully. If proper care is not taken in the design stage, it takes a long before the problem is fixed and results in delayed product launch.**



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## Introduction

The article is written to serve as a reference guide to designers who are not very well versed with plastics. The market trends indicate India becoming a major supplier of plastic components and it is imperative that we design the plastic components successfully. If proper care is not taken in the design stage, it takes a long before the problem is fixed and results in delayed product launch.

## Why Plastics

To compete in today's very competitive environment, product differentiation is a key element for maintaining good margins and low cost. This differentiation is done by design, vi-

sual appearance or by development of new functionalities. A very important feature of plastics is its ability to integrate various components into one, thereby minimising number of operations needed to manufacture a product. Plastics is gaining importance to replace metal and other traditional materials with new resins being developed and the technological advances in decorating and welding techniques. This trend is expanding rapidly due to the multiple benefits provided by plastics compared to metal. All of them lead to significant productivity improvements and/or product differentiation.

Designing successful plastic component involves:

- Product design
- Material selection
- Process selection
- Tool design
- Studying post processing/secondary operations

Ideally, plastic part designer needs to have knowledge on plastic material, mould design and processing to successfully design plastic parts. A successful plastic product is like a tripod; if one leg is product design, the other two

are mould design and processing. If any of these, is not correct, the product will fail. The other way is to engage mould designer and processor in the design process.

Almost 80% of industrial components are manufactured by injection moulding that needs tight dimension tolerances. Injection moulding is the most prevalent process used to manufacture components in large quantities. In this paper, we will discuss the use of thermoplastics for product development using injection molding techniques.

### Product Design

Product design phase starts once the concept design phase is over with necessary ideation. Product design includes product engineering and product detailing. In product engineering, the functionality requirements are studied and accordingly a design is developed which is then taken for product detailing. A designer should upfront have all the information readily available about where the product will be used, the functionalities demanded by the product and the environmental conditions under which it has to be used.

When detailing a plastic product, design guidelines should be used which are different for each polymer. Increasing thickness beyond certain point does not add to the strength of the component. Section thickness has to be uniform as far as possible. Gusseted ribs give more strength to a product than thick ribs. The part thickness has to be optimised for performance as well as for minimising production costs. As a guideline, the thickness for plastic components is in the range of 0.8 - 5.0 mm.

Lesser the thickness, greater the difficulty to fill the cavity and greater will be the injection pressure requirements. The part thickness also has an impact on productivity. Doubling a 2 mm part thickness, the cooling time increases four times. To improve on strength, the product can be designed with ribs. One has to be careful in designing ribs; a wrong rib design will not meet the performance expectations and may lead to stress, warpage and premature failure of parts. Plastics are notch sensitive and sharp corners should be avoided; atleast a minimum radius of 0.3 mm is essential. For highly notch sensitive materials like polycarbonate, the radius has to be more. Drastic change in thickness will lead to warpage. The material in thicker section will remain hot and will try to pull the material from thinner sections to compensate for shrinkage. This will induce stresses in the components which tend to buckle the part. In case of glass reinforced polymers, if there is too much of shearing happening in the flow path, the glass fibers break and do not yield the necessary strength. The strength of glass reinforced polymers is based on the length of glass fibers.

Basic mould design knowledge is also essential for a plastic product designer. Parting lines and mould opening faces have to be understood for successful ejection of component from the mould. Sometimes a good product design can be marred by a bad mould design.

Product design of only component is not just enough. One has to consider the total effect in an assembly. The design has to be validated for plastics flow, structural performance and value engineering studies like DFX. A product feature in one component can have impact on others in an assembly.

Once the product design is finalized, value engineering and DFX concepts need to be applied by studying the effect of features on tool cost and processing. If the component needs to be fitted with other components, the production requirements should be studied. Cost of providing snap fits or other assembly techniques have to be looked into details. While designing snap fits, one has to really think on the assembly requirements. Snaps need undercuts which increases the cost of tooling. Also, the cycle time increases as the cores have to move out slowly without breakage. A snap fit will significantly add to the tool cost. Even the type of snap fit has to be studied based on the functional requirements.

While considering material properties for FEA, consider the secant modulus or the slope of stress strain curve below yield point. One has to be careful in applying the factor of safety. The tensile properties of plastics can vary drastically as temperature increases. Fig 1 indicates

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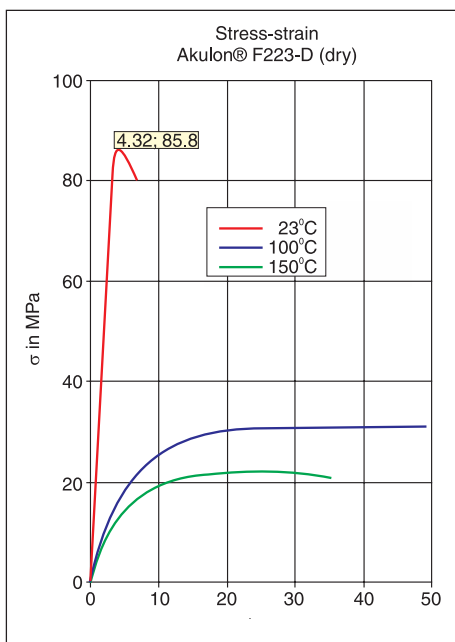


Fig 1:

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### Typical Design Checklist

(courtesy: Ticona www.ticona.com)

- What is the part geometry? Are there undercuts? Are there combined sections that are too thick or thin? What is the thinnest and thickest section?
- What is the function of the part?
- What agency approvals are required? (UL, FDA, USDA, NSF, USP, SAE, MIL)
- What electrical characteristics are required and at what temperatures?
- What temperature will the part have to withstand and how long?
- What loading and resulting stress will the part undergo? And, at what temperature and environment?
- What chemicals will the part be exposed to?
- How the part is to be assembled? Is it by fasteners or molded in threads or snap fit or by welding or by bonding?
- Will the part be insert molded or have a metal piece press fit in the plastic part?
- Is the assembly going to be permanent or one time only?
- Will the part be subjected to impact? If so, what type of loads will be acting?
- Is surface appearance important?
- Is the part likely to be decorated by Colour, printing, painting, plating, special treatments
- Is weathering or UV exposure a factor?
- Can the required tolerances be relaxed to make molding more economical?
- Is wear resistance required?
- Does the part need to be sterilized? With what methods (chemical, steam, radiation)?
- Is there a living hinge to be designed in the part?
- Will the part be loaded continuously or intermittently? Will permanent deformation or creep be an issue? What deflections are acceptable?
- Will the part be machined?
- What is the worst possible situation the part will be in?
- What is the expected lifetime of the part?

Once these requirements are captured, it will be easier to select materials. Accordingly, a plastic component can be designed taking into account all these requirements. When very high investments are committed at the design stage, it is very essential that we take all the precautions in designing a part to introduce a product in the required time frame

the tensile properties of Nylon 6 at three different temperatures. The properties also change with change in strain rate. Thus the best way to consider properties for finite element analysis is to use following guideline. For intermittent loading, take the 25 -50% value of published data; if the loads are critical, one has to consider only 10-25% value of published data. Applications demanding continuous loading, take the 10 - 25% value of published data while for critical failures with continuous loading, one has to consider only 5 -10% value of published data. There are no fixed rules for safety factor. It depends on case to case basis. Before finalizing a design, one has to actually produce a part and put it to extreme working conditions. Plastics perform badly at sub zero temperature impact loads. Impact loading is to be tested at lowest operating or transportation temperatures.

Plastic product design should be validated by using FEA and flow simulation software. Designers can get an idea of any abnormality in design and can take immediate corrective actions.

### Raw Material

While selecting a raw material, functional, thermal and chemical requirements need to be

considered. One cannot change the chemical resistance and continuous service temperature resistance by design changes. There are many materials that can be used for the same application. In such cases, one should not just consider raw material costs but should also consider the processing related costs and the costs needed for secondary operations. The best practice is to short list group of materials as it meets the requirements. While selecting the materials one needs to have absolute values like chemical resistance to 60% H2SO4 or tensile modulus of 1200 MPa etc. There are over 65000 grades of plastics available with data; however a designer needs to know about 20 different polymers which are most commonly

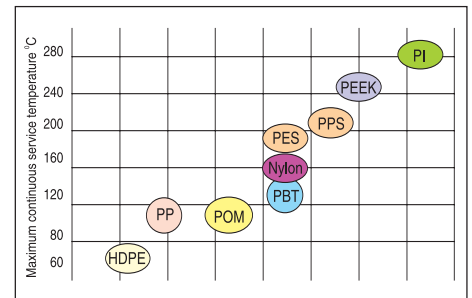


Fig 2: Heat distortion temperature of various

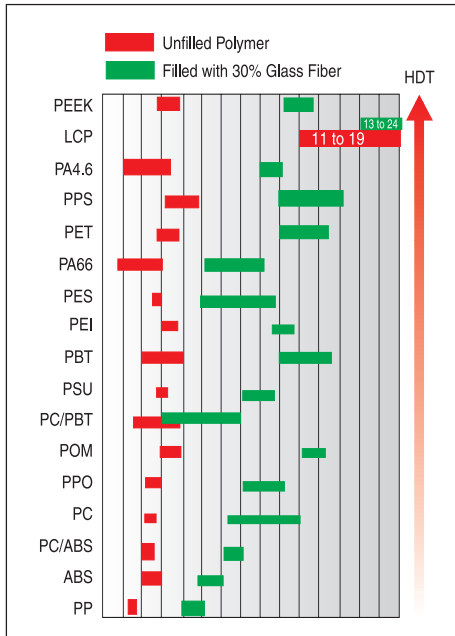


Fig 3: Flexural modulus of various polymers

used. At the lowest scale are polymers like LDPE, EVA etc, it moves up to styrenics, acetals, nylons and on higher scales are polycarbonate, polysulphones, polyethers etc.

Properties of crystalline polymers depend on how it crystallizes during cooling. With reduction in crystallinity, chemical resistance and tensile properties of the component gets reduced. Polymers with low coefficient of linear thermal expansion (CLTE) will have better dimensional stability. Figure 2 and 3 indicates heat distortion temperature and flexural modulus of various polymers. One can also select polymers on the web at the site <http://www.ides.com/prospector>

To select a right raw material, one should first

- Define application requirements like strength, clarity, environment temperatures
- Identify the chemical environment like grease, oil, acid, base etc.
- Identify special needs like flame retardancy, sterilization etc.
- Define economics like cost of product, recycling etc.
- Define assembly requirements like solvent, screw and fastener, snap fit, weld etc

### Material Selection Criteria

**Thermal Performance** : Heat Distortion temperature, maximum service temperature

**Mechanical Performance** : Stiffness, toughness, creep

**Electrical performance** : Conductivity, arc resistance, flame retardancy

**Dimensional stability** : Coefficient of linear

thermal expansion, shrinkage

**Environment** : Chemical, UV, etc.

**Secondary operations** : Painting, plating, welding, joining etc

As a product designer one can select a family of material like PP, HDPE, nylon, polyacetal etc and then contact the resin manufacturers to guide on specific grade for the application. Additives are added to plastics to enhance the specific properties. Always select 2-3 backup materials which meet the product requirements. A lower molecular weight material will be easy to flow but its chemical resistance will be low. While, a higher molecular material may have a very good chemical resistance but if the component thickness is too less, more injection pressure will be needed which induces more stress and the component may fail. There has to be a balance while selecting a material and CAE tools like Moldflow help in validating the product design with the short listed material.

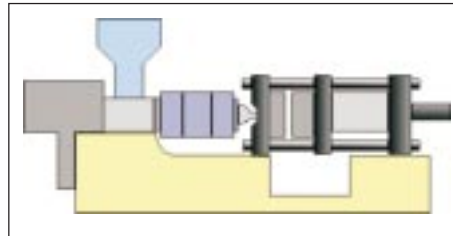
A designer should also consider the availability of material in the regions where the component is likely to be manufactured.

Almost all leading resin manufacturers provide design guides for their materials and a lot of information is readily available on the web for designing plastic components.

### Process Selection

As we are discussing the components to be manufactured by injection moulding process, there are different methods used

- Horizontal, Vertical,
- Gas assist
- Co injection



Depending on the part geometry, a method has to be selected. The horizontal injection moulding is the most common method used to produce variety of components. Co injection moulding i.e. moulding two different materials in a single mould is getting popular for manufacturing industrial components, taking advantage of properties of two different materials. Currently, we see the use in consumer items like tooth brush handle with two colour material. Automotive dashboards which have a soft touch on surface and a rigid material inside are made by co injection technique.

Moulding long or very thick components is a challenge. For long flow paths, there is an

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injection pressure drop along the flow length of a component as material fills the cavity. This leads to differential pressures and the component warps due to differential shrinkage. To overcome this problem, gas injection molding technique is used where gas is passed through small channels over the component to apply pressure across the flow length. Product design has to accommodate the gas channels as they will remain on the product. On the other hand, the thick components need to be cored to reduce sink marks and warpage. Gas is passed through to core out the material. In this case the cored section dimensions will not be consistent as it varies with the material temperature, gas pressure etc.

Once the process is selected, the position in a mould and parting line has to be decided to check if the cut out sections can be ejected.

### Tool Design

Designing a good tool is a challenge. In injection molding, about 5%-7% of the cycle time is for material injection while for the rest of the time, the material cools in the mould. The quality and productivity of the product is dependent on how the material cools. Material has to be cooled from the melt temperature to the mould temperature. It is critical to remove this heat swiftly as well as uniformly. As the material cools, it shrinks. It tries to induce stress while the polymer chains try to coil back. Ideally a product should shrink uniformly; differential shrinkage results in part warpage. Cooling needs to be uniform. The product cost calculations are made by assuming a good mold design. Increasing cycle time due to faulty mold design can significantly eat away the profit

margins of a product. Scientific tools should be used to arrive at the best cooling layout. Molded in stresses can be developed due to inappropriate gating system and hence the runner and gate dimensions are also critical. Maximum shearing action happens at a gate location. Care has to be taken that the glass fiber scission doesn't happen while the material flows through the gate.

### Post processing

Plastics might need to be decorated or welded in a secondary operation. Decoration can be done through painting, metallic foil impregnation, plating etc. The characteristics of materials decide on the post processing operations. The materials have to be selected by considering these aspects. Some materials may require surface treatments prior to the secondary operations.

### Summary

Plastic product design is a challenge and success depends on plastic materials, tool design and processing. A product can fail if any of these is incorrect. It is expected that product designers have knowledge of plastic materials, tool design and processing. If not, the best way is to form a team with tool maker and processor while designing plastic components. The properties of plastics change with temperature and loading rate and a sufficient safety factor has to be considered in designing. It is recommended that actual moulded part is tested at extreme conditions before freezing the design. Also, the product design has to be evaluated for flow, structural analysis and DFX studies.