Design*

Proper material selection alone will not prevent a product from failing. While designing a plastic product, the designer must use the basic rules and guidelines provided by the material supplier for designing a particular part in that material. One must remember that with the exception of a few basic rules in designing plastic parts, the design criteria changes from material to material as well as from application to application. Today, designers are challenged with multiple requirements while designing plastic parts. Major emphasis is on economics, functionality, manufacturability, and aesthetic appeal. Some compromise during the design process is inevitable and in some cases trade-offs like these lead to premature failures.

The most common mistakes made by designers when working in plastics are related to wall thickness, sharp corners, creep, draft, environmental compatibility, and placement of ribs. Failure arising from designing parts with sharp corners (insufficient radius) by far exceeds all other reasons for part failures. Maintaining uniform wall thickness is essential in keeping sink marks, voids, warpage and more importantly areas of molded-in stresses to minimum. Viscoelastic nature of plastics materials as opposed to metals, require designer to pay special attention to creep and stress relaxation data. Plastics parts will deform under load over time depending upon type of material, amount of load, length of time and temperature. Design guides for proper plastic part design are readily available from material suppliers. Table 15-2 shows a typical part design checklist.

Earlier in the chapter, we discussed the importance of concurrent engineering practices for a successful part design. Robust product development process that incorporates sound engineering is critical. This can be achieved by incorporating a systematic approach to developing a new product. This logical and scientific approach requires step-by-step progression in a definite order. Designers are cautioned not to skip any of the steps for economics reasons or time constraints.

Steps for Robust Part design Process

Basic part design
Material selection
Structural analysis
Moldflow simulation and analysis
Rapid prototyping
Design review I
Single cavity prototype
Design review II and tolerance analysis
Tooling protocol and mold cooling analysis
Mold construction phase with regular follow-ups
Sampling, pilot run, and establishing process parameter
Final part Evaluation and acceptance

Proto typing aspect of part design process is often overlooked due to cost and time constraints. Regardless of the medium chosen, prototyping technique generate physical models that act as a primary means of communication between marketing, engineering,

tooling, and manufacturing groups. The use of the prototype to describe the function, size, shape, feel, and look of a part inevitably leads to a major productive environment and a higher degree of interaction between the members of the product design team (6). Equally important is the use of structural analysis tools commonly known as finite element analysis (FEA) and process simulation techniques such as Moldflow® analysis. Computer simulations give designers early indication of the weak areas and potential problems. Addressing these concerns prior to mold construction designers can avoid costly rework and untimely product failures. Oversimplification could be a real danger in such situations as it may sway the results too far from the true picture. Often, the significant factors that affect failures are incorrectly considered or ignored. Proper differentiation between primary, secondary, and peak stresses must be made, since each has a separate failure mode that should be considered differently (7).
Many reasons for early product failures are attributed to poor part design. However, following five reasons are the most prominent of all.

A. Lack of Radius
B. Excessive wall thickness variations
C. Incorrect rib placement
D. Environmental compatibility
E. Lack of understanding Creep phenomenon

All plastics are notch sensitive. Stress concentration resulting from sharp corners and lack of adequate radius tops the list of causes that contributes to the plastic part failures. Designers are constantly reminded to avoid sharp corners at all costs. Sharp corners introduce two fold problems in plastic parts. First, it increases stress concentration in terms of molded-in stresses which tend to reduce mechanical properties and even cause catastrophic failures. Second, it impedes the flow of material and ejection of parts from the mold. This fact is illustrated in figure 15-10 which shows the combined effect of stress concentration and molded-in stress due to the sharp corner at the base of two ribs. Residual tensile stresses are the highest at the base of the ribs due to the restricted shrinkage created by the metal core between the ribs which does not allow the part to shrink until ejected from the mold. Differential cooling of the thick sections at the intersection of the ribs with the nominal wall also contribute to the stresses. The addition of the high stress concentration factor at these sharp corners makes them vulnerable to even a small bending moment, resulting in failure at either point A or point B (8).

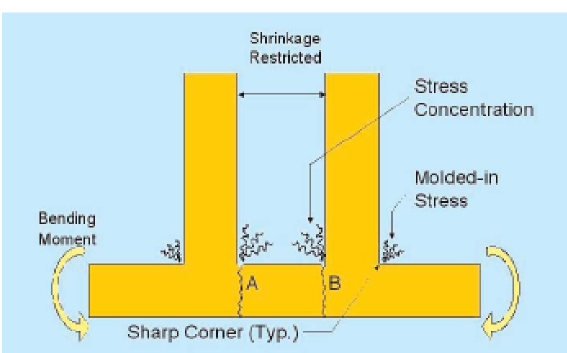


Figure 15-10

Stresses build rapidly in internal sharp corners of the part as shown in figure 15-11 which illustrates the influence of fillet radius on stress concentration. At a constant wall thickness, as radius increases, R/T also increases proportionally and thereby decreasing the stress concentration factor. Even a slight increase in radius can reduce the stress concentration factor drastically. Conversely, not specifying enough fillet radius can be disastrous.

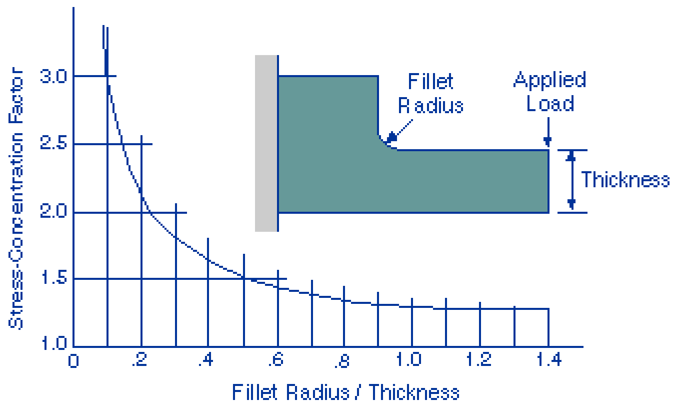


Figure 15-11

As a rule, inside corner radii should be 30 to 50 percent of the nominal wall thickness with a 0.020 inch radius as bare minimum. Outside corners should have radius equal to the inside corner plus the wall thickness. This practice allows wall thickness to be uniform at corners and reduces stress concentration. It is important to note that as the curve flattens out beyond R/T ratio of 1.0 further increase in fillet radius does not contribute significantly towards the improvement in stress concentration factor. In fact, too generous a radius can create a very thick wall section and possibility of increased molded-in stresses and voids. Effect of notch sensitivity on a very tough material like Polycarbonate is shown in Figure 15-12. There is a drastic reduction in the izod impact strength in a sample with a sharper notch (9). Figures 15-13 and 15-14 illustrate a typical part failure arising from lack of radius in the key areas of the part.

Figure 15-13

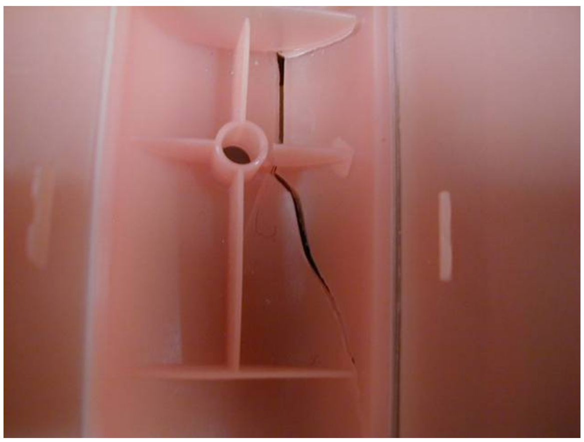


Figure 15-14

The fundamental rule for designing plastic parts is to maintain uniform wall thickness throughout the part. However, for most applications complexity of the design requirements makes maintaining uniform wall thickness impractical. Designer must use well established part designed principles such as gradual transition between thick and thin walls to improve stress distribution, gating from thick to thin area, generous radius at intersections to promote flow, originating inner and outer radius from the same point to ensure uniform wall thickness through the corner etc. Excessive wall thickness separation is perhaps the single largest cause of warpage, voids, and sink marks in thicker sections. Such variations lead to high level of residual stresses. Residual stresses develop due to differential cooling and results in shrinkage differences between thick and thin sections. These internal stresses gradually lead to reduce mechanical performance and stress parts are also more susceptible to chemical attacks. Warped parts present only and aesthetic and minor functional issues in some cases. However, this problem is more severe in the case of assembled parts. Plastic parts are somewhat more ductile in nature and tend to give a little making assembly of slightly warped parts possible. The constrained parts that are extremely stressed deform under load over time and eventually crack. The combination of internal stresses created by non uniform wall thickness and external stresses from assembly accelerate the part failure process exponentially. Figure 15-15 shows failure resulting from excessive wall thickness variations.

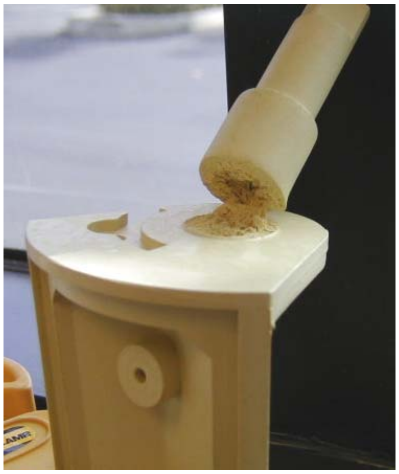
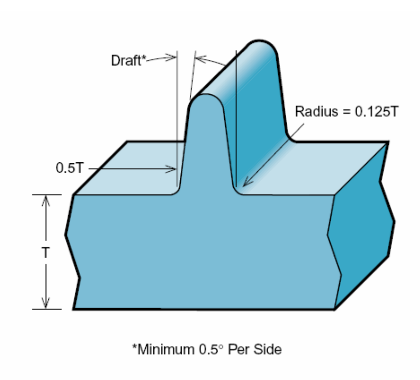


Figure 15-15

As discusses earlier designer has the option to maintain wall thickness and still maintain the desired rigidity, strength, and structural integrity by incorporating ribs in the part design. The proper use of the ribs and correct rib placement makes the difference between a structurally strong part with uniform wall thickness and an extremely weak part prone to premature failures. Inadequate rib design generally result in high internal warpage, sink marks, voids, stresses, and molding and tooling issues. Rules for the proper rib design as follows:

a. Make the rib thickness at its base equal to fifty percent of the adjacent wall thickness
b. Height of the rib should be less than three-hundred percent of the wall thickness.
c. Radius of the base of the rib must be a minimum of twenty-five percent of the nominal wall thickness to avoid high stress concentration.
d. Distance between the ribs should be two-hundred percent of the nominal wall thickness
e. All ribs should have a draft of 0.5 to 1.5 degrees
f. Avoid free standing ribs to minimize air trapping in blind hole and resulting burn marks and short shot.

Guideline for basic rib design is showed in Figure 15-16. Typical issues related to due improper rib design is shown in Figure 15-17.



Rib design guidelines.

Figure 15-16

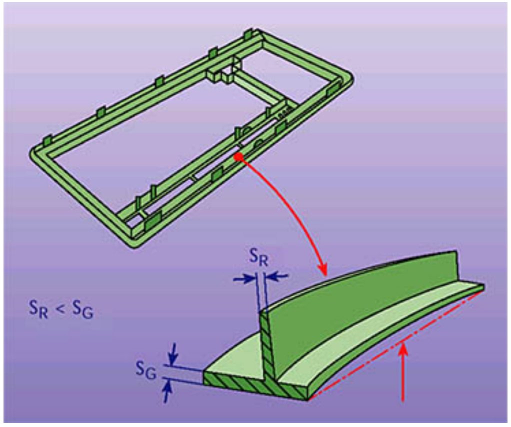


Figure 15-17

Statistics show that almost fifty percent of the failures of engineering plastics result from environmental degradation (10). Designers must take into account the effect of various environmental factors such as exposure to chemicals, ultraviolet rays, weather extreme, pollution, acid rain, moisture, and microorganisms on the end product. The major challenge is to predict long term behavior from short term laboratory or field exposures. The steps in the degradation process involves stress enhanced absorption and concentration of the chemical molecules at acceptable micro structural sites. Localized plasticization then ensues leading to crazing and subsequent crack development (11). For most part, designers are well aware of the limitations of plastic material in terms of chemical compatibility and generally do a thorough job of investigating the effect of well known solvents and other aggressive chemicals. The problem arises when the least suspected solids, o-rings, seals, gaskets, and trapped vapors from glues, adhesives, and solvents used in assembly, come in contact with the end product. A good example is the incompatibility of well known PVC plasticizer dioctyl phthalate (DOP) with polycarbonate (12). Figure 15-18 shows crazing induced in polycarbonate barb by PVC tube containing one such plasticizer.

One of the major problems facing designers is the lack of chemical compatibility data along with the misinterpretation of published data. Published data are generally derived from immersion of plastics specimen in chemical environment for twenty-four hours suspended in a glass beaker. ASTM D543 Immersion Test is discussed in chapter nine in further detail. Most polymers will undergo stress cracking when exposed to certain chemical environment under high stress under a given period of time. Such cracking will occur even though some chemicals have no effect on unstressed part, and therefore the simple immersion of test specimen is an inadequate measure of chemical resistance of polymers. The combined effect of the molded-in or internal stresses, chemical concentration, temperature, exposure time, and external stresses can be devastating and usually bring about a catastrophic failure. Designers must also pay extra attention to the parts molded with metal inserts since they tend to become stressed at the interface due to the coefficient of thermal expansion differences and poor molding practices. Cracking of the plastic around metal insert due to chemical exposure is a common problem and is well illustrated in Figure 15-19. All metal inserts must be preheated to the same as the mold temperature prior to loading them into the mold to minimize molded-in stresses around the inserts.

figure 15-19

Detrimental effects of environmental factors on appearance and properties are discussed in chapter 5 on Weathering Properties.

Creep is one of the most misunderstood and highly neglected phenomenon by designers contributing to premature failure of plastic parts. This is discussed thoroughly in section 15.1.1 on material selection.

* From ***Handbook of Testing and Failure Analysis***, 3rd edition by Vishu Shah, John Wiley & Sons.