Why do Plastics parts fail…and what can be done about it?*

Plastics part failure is generally related to one of four key factors.

Material Selection
Design
Process
Service Conditions

Material Selection

Failures arising from hasty material selection are not uncommon in plastics or any other industry. In an application that demands high-impact resistance, a high-impact material must be specified. If the material is to be used outdoors for a long period, a UV-resistant material must be specified. For proper material selection, careful planning, a thorough understanding of plastic materials, and reasonable prototype testing are required. The material selection should not be solely based on cost. A systematic approach to material selection process is necessary in order to select the best material for any application. The proper material selection technique involves carefully defining the application requirement in terms of mechanical, thermal, environmental, electrical and chemical properties. In many instances, it makes sense to design a thinner wall part taking advantage of the stiffness-to-weight ratio offered by higher-priced, fast cycling engineering materials. Many companies, including material suppliers, have developed software to assist in material selection simply by selecting application requirement in the order of importance.

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, design-related failures are by far the most common type of failure.

Process

After proper material selection and design, the responsibility shifts from the designer to the plastic processor. The most innovative design and a very careful material selection cannot make up for poor processing practices. Molded-in stresses, voids, weak weld lines, and moisture in the material are some of the most common causes for premature product failures. The latest advancement in process control technology allow the processors to control the process with a high degree of reliability and also help in record keeping should a product fail at a later date. Such records of processing parameters are invaluable to a person conducting failure analysis. Any assembly or secondary operation on processed part must be evaluated carefully to avoid premature failures. Failures arising from stress cracking around metal inserts, drilled holes and welded joints are quite common.

Service Conditions

In spite of the built-in safety factor warning labels, and user's instructions, failures arising from service conditions are common in the plastics industry. Five categories of unintentional service conditions are as follows.

1. Reasonable misuse.
2. Use of product beyond its intended lifetime.
3. Failure of product due to unstable service conditions.
4. Failure due to service condition beyond reasonable misuse.
5. Simultaneous application of two stresses operating synergistically.

Most of the stresses imposed on plastics products in service can be grouped under the heading of thermal, chemical, physical, biological, mechanical, and electrical.

TYPES OF FAILURES

Mechanical Failure

Mechanical failure arises from the applied external forces which, when they exceed the yield strength of the material cause the product to deform, crack, or break into pieces. The force may have been applied in tension, compression, and impact for a short or a long period of time at varying temperatures and humidity conditions.

Thermal Failure

Thermal failures occur from exposing products to an extremely hot or extremely cold environment. At abnormally high temperatures the product may warp, twist, melt, or even burn. Plastics tend to get brittle at low temperatures. Even the slightest amount of load may cause the product to crack or even shatter.

Chemical Failure

Very few plastics are totally impervious to all chemicals. Failure occurring from exposing the products to certain chemicals is quite common. Residual or molded-in stress, high temperatures, and external loading tend to aggravate the problem.

Environmental Failure

Plastics exposed to outdoor environments are susceptible to many types of detrimental factors. Ultraviolet rays, humidity, microorganisms, ozone, heat, and pollution are major environmental factors that seriously affect plastics. The effect can be anywhere from a mere loss of color, slight crazing and cracking, to a complete breakdown of the polymer structure.

ANALYZING FAILURES

The first step in analyzing any type of failure is to determine the cause of the failure. Before proceeding with any elaborate tests, some basic information regarding the product must be gathered. If the product is returned from the field, have the district manager or consumer give you basic information, such as the date of purchase, date of installation, date when the first failure encountered, geographic location, types of chemicals used with or around the product, whether the product was used indoors or outdoors. All this information is very vital if one is to analyze the defective product proficiently. For example, if the report from the field, and the defective product, indicate a certain type of chemical was used with the product, one can easily check the chemical compatibility of the product or go one step further and simulate the actual use condition using the same chemical. Recordkeeping also simplifies the task of failure analysis. A simple date code or cavity identification number will certainly enhance the traceability. Many types and styles of checklists to help analyze the failures have been developed. Seven basic methods are employed to analyze product failure.

1. Visual examination.
2. Identification analysis.
3. Stress analysis.
4. Microtoming.
5. Mechanical testing.
6. Thermal analysis.
7. Nondestructive Testing (NDT) Techniques

By zeroing in on the type of failure, one can easily select the appropriate method of failure analysis.

Visual Examination

A careful visual examination of the returned part can reveal many things. Excessive splay marks indicate that the materials were not adequately dried before processing. The failure to remove moisture from hydroscopic materials can lower the overall physical properties of the molded article and in some cases even cause them to become brittle. The presence of foreign material and other contaminants is also detrimental and could have caused the part to fail. Burn marks on molded articles are easy to detect. They are usually brown streaks and black spots. These marks indicate the possibility of material degradation during processing causing the breakdown of molecular structure leading to overall reduction in the physical properties. Sink marks and weak weld lines, readily visible on molded parts, represent poor processing practices and may contribute to part failure.

A careful visual examination will also reveal the extent of consumer abuse. The presence of unusual chemicals, grease, pipe dope, and other substances may give some clues. Heavy marks and gouges could be the sign of excessively applied external force.

The defective part should also be cut in half using a sharp saw blade. The object here is to look for voids caused by trapped gas and excessive shrinkage, especially in thick sections during molding. A reduction in wall thickness caused by such voids could be less than adequate for supporting compressive or tensile force or withstanding impact load and may cause part to fail. Last, if the product has failed because of exposure to UV rays and other environmental factors, a slight chalking, microscopic cracks, large readily visible cracks, or loss of color will be evident.

Identification Analysis

One of the main reasons for product failure is simply use of the wrong material. When a defective product is returned from the field, material identification tests must be carried out to verify that the material used in the defective product is, in fact, the material specified on the product drawing. However, identifying the type of material is simply not enough. Since all plastic materials are supplied in a variety of grades with a broad range of properties, the grade of material must also be determined. A simple technique such as the melt index test can be carried out to confirm the grade of a particular type of material. The percentage of regrind material mixed with virgin material has a significant effect on the physical properties. Generally, the higher the level of regrind material mixed with virgin, the lower the physical properties. If during processing, higher than recommended temperature and long residence time is used, chances are that the material is degraded. This degraded material, when reground and mixed with virgin material, can cause a significant reduction in overall properties.

Part failures due to impurities and contamination of virgin material are common. Material contamination usually occurs during processing. A variety of purging materials are used to purge the previous material from the extruder barrel before using the new material. Not all of these purging materials are compatible. Such incompatibility can cause the loss of properties, brittleness, and delamination. In the vinyl compounding operation, failure to add key ingredients, such as an impact modifier, can result in premature part failure. Simple laboratory techniques cannot identify such impurities, contamination, or the absence of a key ingredient. More sophisticated techniques; such as Fourier Transform infrared (FT-IR) analysis and gel permeation chromatography (GPC) must be employed. These methods can not only positively identify the basic material, but also point out the type and level of impurities in most cases.

Stress Analysis

Once the part failure resulting from poor molding practices or improper material usage through visual examination and material identification is ruled out, the next logical step is to carry out an experimental stress analysis. Experimental stress analysis is one of the most versatile methods for analyzing parts for possible failure. The part can be externally stressed or can have residual or molded-in stresses. External stresses or molded-in stresses or a combination of both can cause a part to fail prematurely. Stress analysis is an important part of failure identification. Detection of residual stresses has a different meaning than evaluation of stresses due to applied forces. It is possible of course to see failure due to poor design, or underestimating of forces. These failures are usually detected in proof testing, or in early production. Residual stresses are altogether different: A molding process can generate residual stress just about anywhere, anytime. Here, ongoing photoelastic inspection can prove extremely helpful, allowing detection of defective molded parts or identification of failures in clear plastic products. Experimental stress analysis can be conducted to determine the actual levels of stress in the part. Five basic methods are used to conduct stress analysis.

1. Photoelastic
2. Brittle coatings
3. Strain gauge
4. Chemical
5. Heat reversion

Photoelastic Method

The photoelastic method for experimental stress analysis is quite popular among design engineers and has proved to be an extremely versatile, yet simple technique.

If the parts to be analyzed are made out of one of the transparent materials, stress analysis is simple. All transparent plastics, being birefringent, lend themselves to photoelastic stress analysis. The transparent part is placed between two polarizing mediums and viewed from the opposite side of the light source. The fringe patterns are observed without applying external stress. This allows the observer to study the molded-in or residual stresses in the part. High fringe order indicates the area of high stress level whereas low fringe order represents an unstressed area. Also, close spacing of fringes represents a high stress gradient. A uniform color indicates uniform stress in the part. Next, the part should be stressed by applying external force and simulating actual-use conditions. The areas of high stress concentration can be easily pinpointed by observing changes in fringe patterns brought forth by external stress.

Another technique known as the photoelastic coating technique can be used to photoelastically stress-analyze opaque plastic parts. The part to be analyzed is coated with a photoelastic coating, service loads are applied to the part, and coating is illuminated by polarized light from the reflection polariscope. Molded-in or residual stresses cannot be observed with this technique. However, the same part can be fabricated using one of the transparent plastic materials. In summary, photoelastic techniques can be used successfully for failure analysis of a defective product.

Brittle-Coating Method

The brittle-coating method is yet another technique of conveniently measuring the localized stresses in a part. Brittle coatings are specially prepared lacquers that are usually applied by spraying on the actual part. The part is subjected to stress after air drying the coating. The location of maximum strain and the direction of the principle strain is indicated by the small cracks that appear on the surface of the part as a result of external loading. Thus, the technique offers valuable information regarding the overall picture of the stress distribution over the surface of the part. The data obtained from the brittle coating method can be used to determine the exact areas for strain gauge location and orientation, allowing precise measurement of the strain magnitude at points of maximum interest. They are also useful for the determination of stresses at stress concentration points that are too small or inconveniently located for installation of strain gauges. The brittle-coating technique, however, is not suitable for detailed quantitative analysis like photoelasticity. Sometimes it is necessary to apply an undercoating prior to the brittle coating to promote adhesion and to minimize compatibility problems. Further discussion on this subject is found in the literature.

Strain Gauge Method

The electrical resistance strain gauge method is the most popular and widely accepted method for strain measurements. The strain gauge consists of a grid of strain-sensitive metal foil bonded to a plastic backing material. When a conductor is subjected to a mechanical deformation, its electrical resistance changes proportionally. This principle is applied in the operation of a strain gauge. For strain measurements, the strain gauge is bonded to the surface of a part with a special adhesive and then connected electrically to a measuring instrument. When the test part is subjected to a load, the resulting strain produced on the surface of the part is transmitted to the foil grid. The strain in the grid causes a change in its length and cross section, and produces a change in the resistivity of the grid material. This change in grid resistance, which is proportional to the strain, is then measured with a strain gauge recording instrument. In using strain gauges for failure analysis, care must be taken to test the adhesives for compatibility with particular plastics to avoid stress-cracking problems.

Residual or molded-in stresses can be directly measured with strain gauges using the hole drilling method. This method involves measuring a stress at a particular location, drilling a hole through the part to relieve the frozen-in stresses, and then remeasuring the stress. The difference between the two measurements is calculated as residual stress.

Chemical Method

Most plastics, when exposed to certain chemicals while under stress, show stress cracking. This phenomenon is used in stress analysis of molded parts. The level of molded-in or residual stress can be determined by this method. The part is immersed in a mixture of glacial acetic acid and water for 2 min at 73°F and later inspected for cracks that occur where tensile stress at the surface is greater than the critical stress. The part may also be externally stressed to a predetermined level and sprayed on with the chemical to determine critical stresses. Stress cracking curves for many types of plastics have been developed by material suppliers. If a defective product returned from the field appears to have stress-cracked, similar tests should be carried out to determine molded-in stresses as well as the effect of external loading by simulating end-use conditions. Failures of such types are quite common in parts where metal inserts are molded-in or inserted after molding. Three other tests, the stain-resistance test, solvent stress-cracking resistance, and environmental stress-cracking resistance (ESCR), are also employed to analyze failed parts.

Heat Reversion Technique

All plastics manufacturing process introduce some degree of stress in the finished product. The stresses in molded parts are commonly referred to as molded-in (residual) stresses. By reversing the process, by reheating the molded or extruded product, the presence of stress can be determined. The test is conducted by simply placing the entire specimen or a portion of the specimen in thermostatically controlled, circulating air oven and subjecting to a predetermined temperature for a specified time. The specimens are visually examined for a variety of attributes. The degree and severity of warpage, blistering, wall separation, fish-scaling and distortion in the gate area of molded parts indicate stress level. Stresses and molecular-orientation effects in the plastic material are relieved, and the plastic starts to revert to more stable form. The temperature at which this begins to occur is important. If changes start below the heat distortion temperature of the material, high levels of stress and flow orientation are indicated. The test has been significantly improved by new methods including the attachment of strain gages to critical regions of the part to carefully monitor initial changes in the shape. ASTM F1057 describes the standard practice for estimating the quality of extruded PVC pipe by the heat reversion technique.

Microtoming

Microtoming is a technique of slicing an ultra thin section from a molded plastic part for microscopic examination. Biologists and metallurgists have used this technique for years, but only in the last decade has this technique been used successfully as a valuable failure analysis tool.

Microtoming begins with the skillful slicing of an 8-10 m-thick section from a part and mounting the slice on a transparent glass slide. The section is then examined under a light transmission microscope equipped with a polarizer for photoelastic analysis. A high power (1000x) microscope, which will permit photographic recording of the structure in color, is preferred. By examining the microstructure of a material, much useful information can be derived. For example, microstructural examination of a finished part that is too brittle may show that the melt temperature was either nonuniform or too low. The presence of unmelted particles is usually evident in such cases. Another reason for frequent failures of the injection molded part is failure to apply sufficient time and pressure to freeze the gates. This causes the parts to be underpacked which creates center-wall shrinkage voids. Voids tend to reduce the load-bearing capabilities and toughness of a part through the concentration of stress in a weak area. Contamination, indicated by abnormality in the microstructure, almost always creates some problems.

Contamination caused by the mixing of different polymers can be detected through such analysis by carefully studying the differences in polymer structures. Quite often, poor pigment dispersion also causes parts to be brittle. This is readily observable through the microtoming technique. In order to achieve optimum properties, additives such as glass fibers and fillers must disperse properly. Microtoming a glass fiber-reinforced plastic part reveals the degree of bonding of the glass fiber to the resin matrix as well as the dispersion and orientation of glass fibers. Molded-in stresses as well as stresses resulting from external loading are readily observed under cross-polarized light because of changes in birefringence when the molecular structure is strained. Microtoming technique can also be applied to check the integrity of spin and ultrasonic or vibration welds.

Mechanical Testing

Defective product returned from the field is often subjected to a variety of mechanical tests to determine integrity of the product. Two basic methods are employed. First one involves conducting mechanical tests such as tensile, impact or compression on actual part or a small sample cut out from the part. The test results are then compared to the test results obtained from the retained samples. The second method requires grinding-up the defective parts and either compression or injection molding standard test bars and conducting mechanical tests. The test results are compared to the published data for the virgin material. The amount of material available for molding the test bars quite often precludes injection molding. The test data obtained from compression-molded samples are generally lower than injection molded samples. Fatigue failure tests such as flexural fatigue or tensile fatigue can be employed to determine premature failure from cyclic loading. Mechanical tests are discussed in detail in Chapter 2 of this book.

Thermal Analysis

Thermal Analysis techniques such as TGA, TMA, and DSC are used extensively in failure analysis.

Nondestructive Testing (NDT) Techniques

NDT techniques are useful in determining the flaws, discontinuities and joints.

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By Vishu Shah


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