FAILURE ANALYSIS OF PLASTIC PRODUCTS

Introduction

Failure analysis (FA) of products and materials always requires careful observation of the general circumstances involved. The product failure analyst should never overlook external causes or environmental effects. All failure analyses also require a healthy dose of common sense and a 'Sherlock Holmes' investigatory sense.

However, specialized material and product tests are also essential components of successful failure analyses including: material mechanical properties, tests for composition and uniformity, residual stress tests, tests for contamination, identification and quantification of residual solvents, microstructural examination, and many more.

In this article we will present an overview of general failure analysis techniques, followed by specific examples of plastic failure analyses.

In today's current manufacturing environment, where products typically progress from the design stage through manufacturing and to the market at a very rapid pace, some companies are overlooking the need for failure analysis and the economic benefits to be derived from performing failure analysis in the early stages. *It is usually far cheaper* to *perform adequate failure analysis in the early stages of* a *product's life than it is* to *deal with product at a later date.* Failure analysis is the science of understanding how materials and products fail.

Whenever a component no longer performs its intended function, it is valuable to understand how and why the component has failed. Failure analysis is a critical part of understanding what went wrong.

Reasons for Failure

Plastic failures generally fall into four broad categories: Environmental considerations, Design considerations, Polymer processing errors and Polymer Selection. Mismatching any one of these can easily result in a failure.

Environment Considerations - These range from straightforward issues such as UV exposure, operating temperature and loaded stress to much more subtle problems like a secondary supplier making what they consider a minor process change. This type of failure is one of the more difficult to solve.

Design Considerations - As part design safety factors are reduced due to cost pressures and plastics are used in broader and more unusual applications, material design limits are met, and on occasion, exceeded.

Polymer Processing - Common errors that can and do occur during processing include insufficient drying of the material prior to processing and actual process temperatures either above or below those recommended by the plastic manufacturer.

Polymer Selection – This can be caused by a lack of proper research or by material substitution. In the first case a manufacturer simply uses the most easily available material they happen to have on the factory floor, it appears to work and goes into production. Sometimes there is no problem at all and sometimes the parts all fail within six months. Material substitutions most commonly occur when the customer is unable to enforce quality procurement specifications; the result is that a molder simply substitutes a cheaper or more readily available material. As additional manufacturing is shifted to remote

© Microbac Laboratories, Inc., 2005.

parts of the world, it becomes more and more costly to conduct on-site audits. In some cases it may even be impossible to conduct surprise audits and thereby ensure that proper procedures are being followed on a day-to-day basis.

Any one of these factors can be the root cause of failure in a plastic part. The goal of failure analysis is to determine conclusively which one is at fault.

Analysis Techniques

A complete failure analysis starts with the collection of background information and the selection and preservation of samples. Background information will include any and all aspects of the failure including service and manufacturing history, photographic records of the sample in service and during or after failure, and any abnormalities with the samples and its environment. It is also valuable to inventory the samples available for inspection and testing at this stage.

Other information regarding the component should be obtained such as material and product specifications, in-process manufacturing specifications, test specifications and methods, and installation and handling specifications. This information should be obtained from National code and specification groups such as ASTM, ISO, ANSI, UL, NSF, etc. or from product and retail groups. Also, the best example of what a component should look like is an un-failed exemplar. For testing purposes, the best exemplar would be from the same production lot and mold, but other lots sometimes offer significant data.

Near the beginning of any failure analysis, if possible, make observations of the failed component in the actual failure environment. Although this is not always possible due to uncontrollable factors, it is best because valuable information may be lost during removal or replacement of the failed component. What is the geometry and physical location of the components involved? What is normal regarding these locations and what has changed? This stage is sometimes merged with laboratory observations of the failed component if the failure site is altered or unavailable for observation. Clues noted during observation would include overall appearance, as well as any contributing factors such as mechanical damage and environmental concerns like heat, light, and chemicals. Photographic recording of this portion of the analysis is critical, since some information which may be critical at a later time in the investigation may only be present in the photographic record.

During the course of a failure analysis, it is best to perform as much non-destructive testing as possible prior to performing any destructive tests. Non-destructive testing of samples includes observation and documentation, liquid penetrant inspection, electromagnetic and or ultrasonic inspection, and residual stress analysis using photoelastic techniques.

Testing that could be performed which would be predominantly destructive in nature consists of physical and mechanical properties testing of materials, chemical composition of materials, product performance and life tests performed on exemplar components, and microscopy of products performed on failed components, tested exemplar components, and un-failed components for comparison.

General mechanical testing could consist of tensile, shear, and compressive tests, and impact, creep, fatigue, and fracture mechanics testing. Most of these tests could also be performed in static, dynamic, and cyclic test protocols; also in various environmental conditions with various pre-test exposures, depending upon possible failure modes.

General physical properties testing could consist of density, hardness, residual stress, oxidative stability, and thermal properties such as melting point, crystallinity and glass transition using DSC, TGA and TMA.

© Microbac Laboratories, Inc., 2005.

General chemical property testing is valuable to determine the chemical composition of the base material, and any additives, fillers, and possible contaminants. Various techniques employed could include FTIR, chromatographic techniques such as GPC, HPLC, GC, etc., and other spectroscopic techniques such as MS, NMR and UV-VIS.

For high power microscopic examination of fracture surfaces, scanning electron microscopy (SEM) is by far the best technique. Light microscopes have a very limited depth of focus, and transmission electron microscopes require tedious sample preparation and or replication techniques. SEM has the ability to magnify to approximately 20,000X, with a large depth of focus at any magnification.

Summary

With the results of the above described testing and analyses in hand, the failure analyst can then put together the larger picture of why the component failed. Some test results may indicate that an initial understanding of failure mode is not correct, and additional testing may be needed. In this instance, initial photographic records and in-process notes are usually critical to developing and testing additional specimens to confirm a different failure mode.

The testing performed should be chosen to confirm, or exclude, the hypothesized failure mode, as well as gain an understanding of what can be altered and improved to prevent failures in the future. This is the ultimate goal of any failure analysis. The following are a series of failure analyses performed by Microbac’s Hauser Laboratories Division, which should demonstrate the practical application of the above-described failure analysis techniques.

Case Study #1: Product Misuse

Hauser received three samples of 12-inch nominal ABS Truss pipe from a State’s Utility District which used the pipe in a sanitary sewer application. ABS truss pipe consists of a coextruded ABS shell that is filled with Portland cement. Upon receipt the samples were inspected and found to contain an axially oriented area of damaged ABS, such that under ring compression the pipe had buckled. This buckling reportedly occurred at the 6 o'clock position in the sewer system, which is consistent with a gravity flow system. The ABS appeared to be damaged due to chemical attack, and displayed evidence of softening, possibly due to exposure to solvents. The softened ABS had subsequently altered shape and dimensions. A main component of the failure analysis was heated headspace gas chromatography (mass spectroscopy) HHGC-MS. The HHGC-MS test results indicated the presence of Perchloroethylene in quantities greater than 1000 ppm in the wall of the ABS at the 6 and 12 o'clock positions. Trichloroethene was also found. It is known that Perchloroethylene is used for dry-cleaning, and the damage to the sewer system was isolated to an area directly downstream from a commercial dry-cleaning operation. Subsequent testing by the municipality confirmed that the dry cleaner was discharging solvents directly to the sanitary sewer system and was found liable for repairs.

Case Study #2: Poor Fabrication

The client submitted numerous samples of solvent cemented 4-inch nominal schedule 40 bell/spigot joints In PVC pipe. The joints were from a system that was used to transport a sodium hypochlorite solution. The system owner and user reported that the joints had leaked in service at an ambient system pressure of approximately 80 psi. The joints were sectioned and inspected. The inspection results were then compared to the requirements of an ASTM specification, which describes how to correctly assemble PVC solvent cement joints. Numerous deficiencies were found, notably lack of complete insertion, inadequate fusion (possibly due to lack of primer use), incomplete coverage, and possible contamination of the glue (sand/dirt/debris). The system installer was required to return to the jobsite and make repairs without additional cost to the owner/user.

© Microbac Laboratories, Inc., 2005.

Case Study #3: Inadequate Design

Hauser received two samples of two-inch nominal solvent cement PVC Tee fittings which had failed in service. The tees were portions of an amusement park ride where water jets were constantly cycled on and off. The tees branched vertically from the two-inch supply line for approximately 6 inches, where the branch then changed direction 90 degrees (from the axis of the supply line). The system operated using recycled (potable) water. Hauser performed failure analysis, and in the process determined that the fitting samples displayed adequate workmanship of manufacture and assembly, adequate material strength, and were manufactured from an appropriate material. The fractures indicated a stress field was present which caused fracture that could only have come from operation of the system. This stress field ultimately caused a fatigue type failure in the fittings due to torsional loading of the fittings through the six-inch lever arm, caused by water hammer as the water was cycled on and off repeatedly. The failures could have been eliminated by using a significantly more robust fitting and/or thrust blocking of the tee and lever arm of the pipe branch to reduce or eliminate the stress.

Case Study #4: Material Substitution

The manufacturer of a golf club bag properly designed all components on their newest product. One of the design changes was the incorporation of a plastic three-point harness. The Asian manufacturer molded and submitted prototypes for approval. These prototypes were tested and performed exceptionally well. The first production lot was received and given away to professional golfers on tour. In a matter of weeks the company received a number of complaints that the harnesses were coming apart.

The initial fix was to mold in additional washers around the rivets to prevent rivet pullout, but the field failures continued. DSC and FTIR analysis of the harnesses revealed that the prototypes were made from Acetal and the production harnesses were made from Nylon 6. The reason for this error was that the molder selected what they believed was the best material for the application during the prototyping stage and the customer assumed that they were molding Nylon. During a subsequent conversation between the two parties, the design company referred to the "Nylon" harnesses. Please note that the material type was *never* specified in writing. The part is now molded in Acetal and no additional field failures have been observed.

Case Study #5: Environmental Stress Cracking

A client manufacturing escalators with a special design was seeing field failures of a yellow polycarbonate part that was screwed into the steel of the escalator step tread to make the leading edge of the step more visible to the passengers. The edge piece was becoming brittle and cracking after three months of service. This was only happening at one installation. Analysis of the failed parts by ICP revealed a high level of Chlorine that was not present in as-manufactured samples. It was determined that a manufacturer of escalator cleaning equipment had recently introduced a new cleaner that contained a high level of chlorinated hydrocarbons. The combination of chlorinated hydrocarbons, stress at the screw holes and a fluid reservoir formed by the recess for the screw head spelled disaster for the polycarbonate. Subsequent examination revealed that the plastic part was cracking everywhere, it simply failed at the screws first. Changing the cleaner resolved the issue.

Case Study #6: Poor Design

The customer submitted a fondue pot, manufactured in China and sold in Europe, for failure analysis

© Microbac Laboratories, Inc., 2005.

after the plastic handles pulled off of the pot during use. The customer had filled the pot with vegetable oil and heated the oil to boiling, in accordance with the photograph on the front of the box that the set was packaged in. While moving the pot from the stove to the table both handles came off the pot. Hot oil spilled onto, and severely burned, one person. The handles were connected to the pot by molded-in screw-on metal inserts. These inserts had large barbs that should have held the handles in place. Visual inspection of the handles showed clear signs of melting. DSC analysis of the part revealed a glass transition at -100°C. FTIR analysis determined that the part was Styrene Butadiene copolymer. The Vicat softening temperature of the handle was measured as 103°C. The physical properties of this material were totally inappropriate for the application. While we have cited this case as poor design it may well be a material substitution failure, as it seems highly unlikely that a design engineer would make such an error.

Case Study #7: Poor Manufacturing Practices

The client submitted a sample of polyethylene (PE) natural gas pipe which had failed in service after approximately 13 years in service by slow crack growth through the wall of the pipe. The sample was documented, and the fracture opened for inspection. Upon inspection, a material was found molded into the pipe wall. Optical microscopy indicated that the molded-in contamination compromised the stress carrying capacity of the pipe wall, and also allowed a fracture to initiate and propagate. When tested by FTIR, the material was found to be cellulose. Silicone grease was also found in close proximity. A greasy shop rag had found its way into the extruder during pipe manufacture, ultimately causing failure of the pipeline.

For more information:
Dr. Kim Baughman, Director of Development
Microbac Laboratories, Inc.
kbaughman@microbac.com

© Microbac Laboratories, Inc., 2005.