Failure analysis of polymer and rubber

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Polymeric materials, like rubbers, cure or harden (set) into a given shape, generally through the application of heat. Curing, also known as vulcanizing, is an irreversible chemical reaction in which permanent connections known as crosslinks are made between the material's molecular chains. These intra-molecular crosslinks give the cured rubber material a solid three-dimensional structure.

Rubber products are designed using engineering principles of loads and deflections applied to a certain volume of material. The use of engineering principles in the development of rubber products provides an application envelope in which the products are expected to perform. Most of the products do provide the required services for satisfactory lifetimes; however, failures do occur. Failures occurring under field service conditions are expensive, and it becomes imperative to identify the cause and rectify it as soon as possible. The failure mode of polymers sets limits to engineering design.

Understanding the actual reason for failures is absolutely required to avoid recurrence and prevent failure in similar components, systems, structures or products. The analysis should also help with the understanding and improvement of design, materials selection and manufacturing techniques.

Failure analysis consists of investigations to find out how and why parts and components failed.

The four major reasons for engineering failures are:

1) Poor and improper design features,
2) Incorrect use of material,
3) Defects introduced during manufacturing, and
4) Service conditions.

Traditionally, failure analysis methods have focused on laboratory testing and chemical analysis of components to fully understand why components fail. The evolution of faster computers, as well as the growth of available material information, have made computer-based failure analysis using techniques like finite element analysis (FEA) and computational fluid dynamics (CFD) more feasible and accessible.

Figure 1 shows the flow chart of a systematic approach to a typical failure analysis study. The process of failure study invariably starts with observing the working of the component under service conditions, and gathering the facts about the conditions. One can identify patterns in the behavior of the material or component under service conditions and develop a technical hypothesis based on the observations. Once all the observations have been recorded, a failure hypothesis is generated that fits all the observations. This failure hypothesis is now tested to make sure that all the facts and observations fit into the failure narrative. Upon verification and validation of the tested hypothesis, the conclusions are formed and finalized.

The failure analysis procedure calls for defining the function and operating condition of the elastomer component and establishing a failure criterion clearly quantifying under what performance and service conditions the component can be declared as having failed. The failure criterion may be an unacceptable change in a property, and this change may cause a particular failure. Abnormal changes in the values of properties like stress relaxation, tear resistance, stiffness and modulus change, dynamic properties, etc., can be defined. The next step is to characterize and identify the underlining physics and mechanisms involved in causing these changes. Establish the rate of change by accelerated laboratory testing at different levels of severity and different time intervals. It is important to keep the accelerated test conditions similar to the service conditions and perform the test at at least four temperatures higher than the average service temperature. These four conditions can be suitably used for life predictions using the Arrhenius technique.

Any investigation in failure analysis results in a large amount of data regarding the sample history, test data, analysis and discussion of results. ASTM E860-2013 specifies a protocol for the examination of forensic evidence pertaining to failure analysis. This well developed method can be taken as a template to follow and carry out the failure analysis pro-

Figure 1 - systematic approach to failure analysis

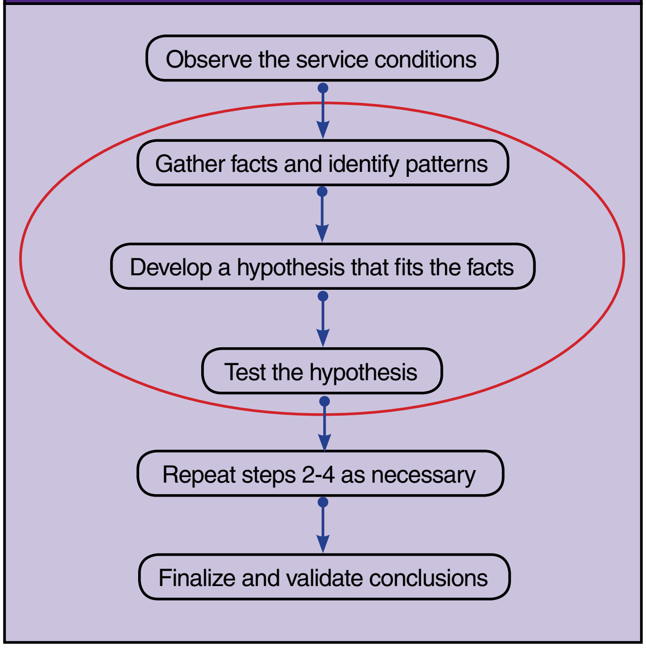
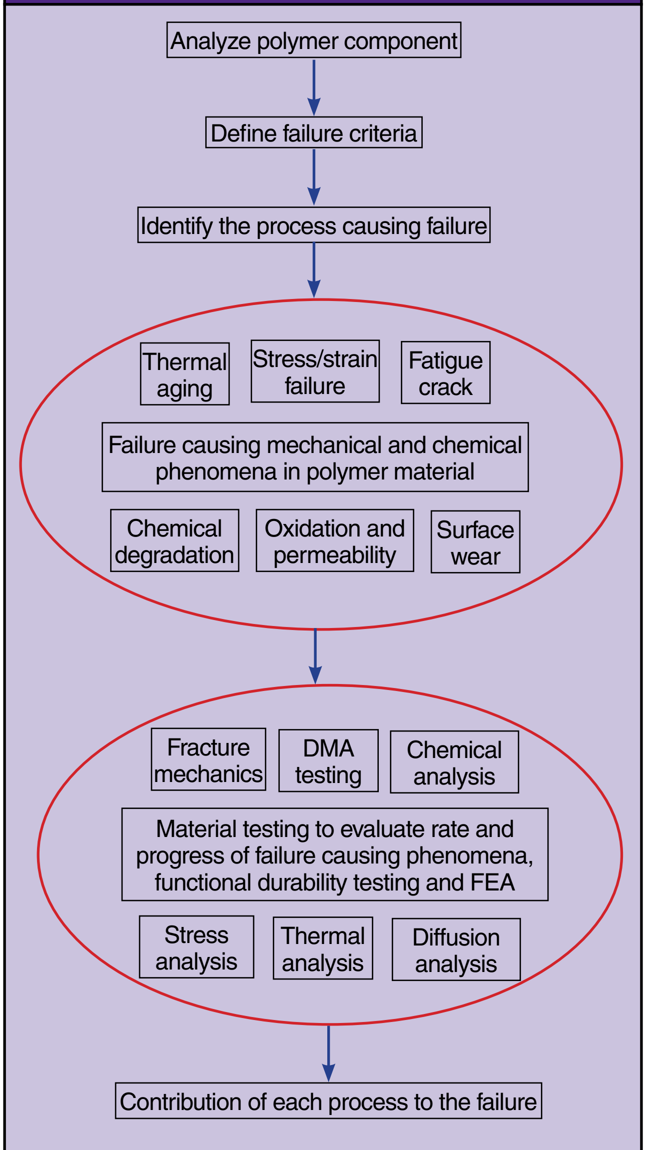


Figure 2 - failure analysis



cedure as described. This establishes a well-defined protocol showing the steps followed to collect, document, study and analyze, and present the results for failure analysis on material samples and components.

The following shows in brief the information from ASTM E860-2013 specifications;

1) Chain of custody documentation
   - Copies of receiving and shipping documentation
   - Pictures of materials as received
2) Physical evidence documentation
   - Labelings
   - Samples with benchmarks
   - Steps in dissection
   - Steps in testing
   - Test equipment number, calibration, etc.
3) Photo documentation
   - Digital
   - SEM, TEM, etc.

The approaches discussed in flowcharts 1 and 2 can be applied to determine failure analysis of polymer components used in engineering applications. It is important to define failure modes and failure mechanisms for parts under service conditions. It is also critical to establish validations between field and laboratory samples using different physical and chemical analysis techniques. The primary rate determining the mechanism of component failure can be used to predict failures using the accelerated functional tests.

The failure mode analysis effort conducted on polymer materials provides a good materials and process database for design and FEA engineers who can optimize the product without the need for expensive trial and errors, thus reducing cost and time to market.

References

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