Finding Fault

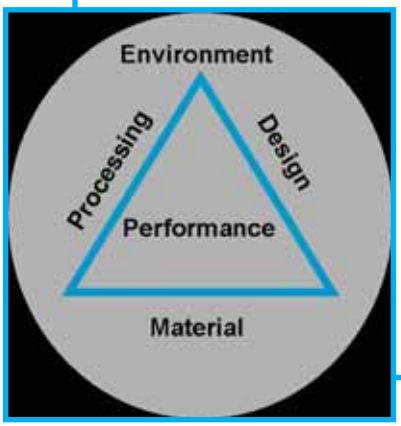

Fig. 1. Graphic illustration of the four factors that affect plastic part performance.

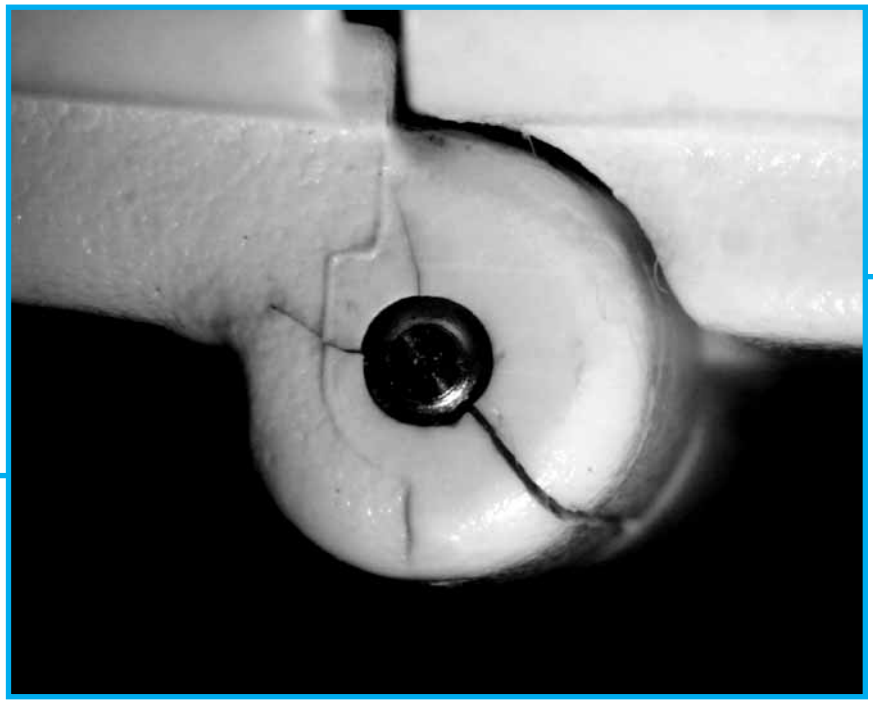

Fig. 2. Photomicrograph showing cracking within a typical monitor case hinge.

Impartial failure analysis needed to solve part problems.

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When a component failure occurs in service, the negative effects can extend well beyond the cost of replacing the piece of equipment. This is particularly true when user safety may be at risk. When a failure takes place, it is extremely important to approach the situation scientifically to elucidate the situation. The goal of a failure investigation is quite basic — to determine the nature and cause of the failure, to identify how and why the part failed.

Assessing the cause of the failure includes ascertaining both primary factors and contributing influences. Factors affecting product performance can be placed into four categories: material, component design, part processing/assembly, and service conditions in which the part is used. This is illustrated schematically in ***Fig. 1***. It is rare that a failure can be attributed to a single factor; instead, it is often the consequence of two or more contributing elements combining to create the failure. The key to the analysis, and the ultimate solution, is properly identifying all of the factors that played a role in the failure.

Failure analysis is the application of analytical observation and testing, guided by engineering practices, to the investigation of a failure within a part or assembly. A failure analysis provides information that assists in improving products through the revision of part design, material selection, fabrication/assembly techniques, and inspection and evaluation procedures. This is achieved by identifying systematic defects or flaws within a manufactured component. Conducting a failure analysis is like putting together a jigsaw puzzle. When the individual pieces are assembled, the picture becomes quite clear. The expression, "If you don't know how it broke, you don't know how to fix it," accurately and succinctly states the importance of conducting a failure analysis.

While common sense and historical insight are essential parts of a failure analysis, pet theories and conjecture must not be allowed to cloud the judgment of the investigator. It is very important that a failure analysis be approached with an open mind, without prejudice or predisposition. Such impartiality is sometimes best accomplished by utilizing the services of a neutral third party, which has no stake in the results. No matter who performs the failure analysis, it is imperative that it is based on a deliberate methodology, using

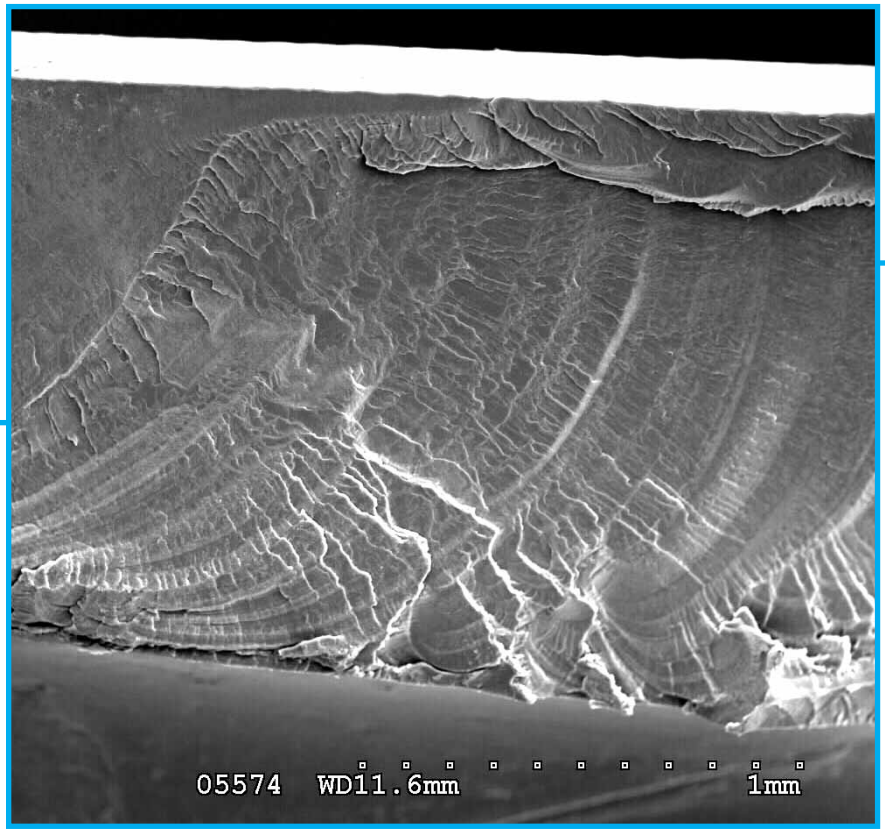

Fig. 3. Scanning electron micrograph showing a crack origin and adjacent surface on a hinge fracture.

sound engineering practices and analytical data. It must be remembered that the goal of the failure analysis is to solve a problem, not conduct a research study or generate data. The following case study illustrates the value and methodology used in performing a failure analysis.

A group of cases used in a portable personal medical monitor was received for failure analysis, as the parts had cracked while in service. A comprehensive failure analysis should begin by collecting the relevant background information. In this investigation, the submitted parts represented a limited release design modification within the 9 V battery door hinge. The cases were designed using an interference fit between the hinge pin and the hinge holes. Specifically, a 0.0495 in. hinge pin was used in conjunction with a 0.0480 in. diameter hole.

The individual components making up the monitor case were injection molded from an unfilled flame-retardant grade of polycarbonate/polyethylene terephthalate blend. In addition to the failed monitor cases, a typical sample of molding resin was also received for comparison purposes. Speculation surrounding the failure suggested that aggressive cleaning agents had been used on the parts that had resulted in chemical attack of the plastic resin and subsequent cracking.

The monitor cases were initially examined visually and at low magnification with the aid of an optical stereomicroscope. This type of inspection is essential in the characterization of the failure mode and the selection of samples for further evaluation. The visual and microscopic examinations revealed generally similar features on all of the submitted cases. Numerous cracks were evident on the battery door hinge, within both the bosses on the case body and the door bosses. This is illustrated in ***Fig. 2***. The cracks lacked substantial macroductility, as would be apparent in the form of stress whitening or permanent deformation. Conversely, brittle fracture features were observed. Specifically, no evidence was found to suggest yielding of the material, indicating that the fractures were associated with stresses below the yield strength of the material.

Handling of the parts clearly showed that the cracks corresponded to areas of high stress. This was indicated in that hairline cracks widened considerably upon closing the battery door and securing the corresponding latch. The microscopic examination of the submitted parts showed that a high number of the cracks were present within knit lines. Knit lines represent areas of incomplete fusion formed during the molding operation.

A typical fracture surface was further evaluated via scanning electron microscopy (SEM). This allows examination at high magnification with great depth of field providing characterization of the fracture surface regarding both crack origin and failure mode. The inspection of the failed hinge fracture surface revealed two distinct types of surface morphologies. The fracture surface exhibited an area of crack initiation along the inner diameter. The observed features included a relatively smooth surface, corresponding to slow crack growth, suggestive of creep rupture. A second distinct area of crack extension was evident along the outer diameter of the hole. The features within this region included alternating arrest markings and at higher magnification substantial micro ductility in the form of stretched fibrils. The arrest markings and the nested pattern of fibril formation were indicative of crack extension through low cycle fatigue. Thus, the fracture surface exhibited distinct modes of crack initiation and subsequent extension, as illustrated in ***Fig. 3***.

In order to more comprehensively examine the hinge failures, a cross section was prepared through a typical failed part. The cross section, as presented in ***Fig. 4***, revealed a significantly higher number of cracks than was apparent from the exterior examination. The cracks lacked features associated with apparent macro or micro ductility, and appeared to originate within mid-wall areas and at the inner diameter immediately adjacent to the hinge pin. The general appearance of the fractures was consistent with cracks initiating through the exertion of stresses below the yield point for an extended period of time, via a creep mechanism.

In order to confirm material identity and assess possible degradation and contamination,

the monitor case samples were analyzed using micro-Fourier transform infrared spectroscopy. Analysis of the reference molding resin produced results characteristic of a PC/PET resin. A similar analysis performed on the cracked case material produced consistent results, as shown in ***Fig. 5***. Thus, no evidence was found to suggest contamination of the failed parts.

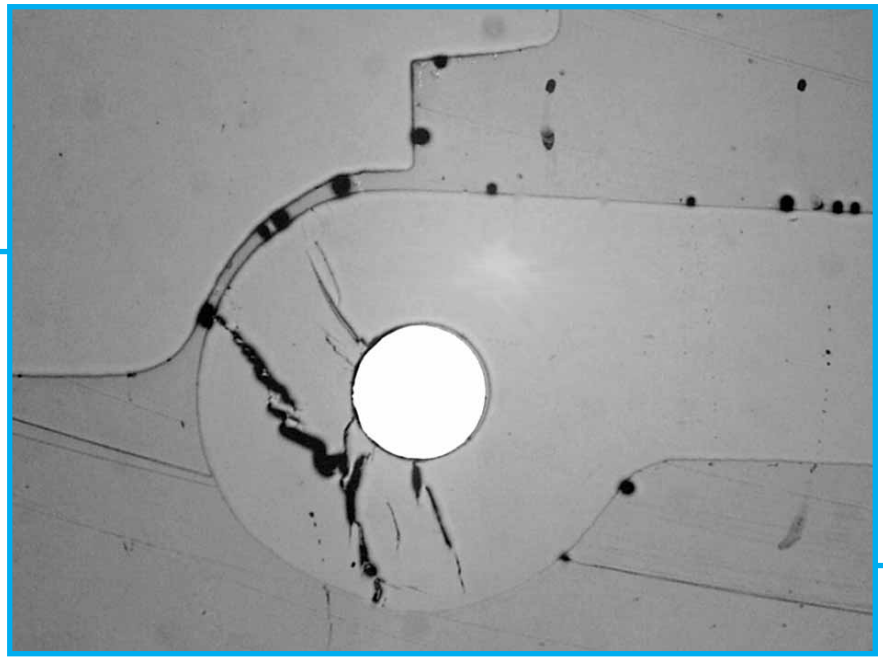

Fig. 4. Photomicrograph showing a cross section prepared through a cracked hinge.

The samples were also analyzed via differential scanning calorimetry. DSC is used to characterize materials for thermal transitions. Analysis of the failed case material generated a thermogram showing that the material underwent an endothermic transition at 251 DegC, associated with the melting point of the PET resin. The initial heating run results also showed an exothermic transition centered at approximately 123 DegC. This transition is characteristic of low-temperature crystallization of the PET resin and represents under-crystallization of the material in the as-molded condition. Under-crystallization is often the result of molding in a relatively cold tool, which produces frozen-in amorphous regions within the preferentially crystalline structure of the PET.

In general, under-crystallization can reduce tensile strength, creep resistance, and fatigue resistance of the molded component. A review of the second heating results obtained on the failed sample material showed the glass transitions associated with the PET and PC resins. The result lacked the low-temperature crystallization exotherm as the sample material had been cooled slowly between the two individual heating runs. The obtained DSC results are presented in ***Fig. 6***.

The resin and failed case sample were analyzed using thermogravimetric analysis. TGA is a thermal analysis technique which provides information regarding the quantitative composition of the plastic material. The obtained TGA thermograms representing the two samples were very consistent. Both results showed a minor weight loss at relatively low temperatures resulting from the evolution of volatile materials. At higher temperatures under a dynamic nitrogen purge, the results exhibited the primary weight loss step corresponding to the thermal decomposition of the polymer. The form of the polymer weight loss step was suggestive of the presence of a flame retardant.

Upon conversion to an air atmosphere, a third weight loss occurred. This transition represented the combustion of char formed during the initial polymer decomposition. Upon completion of the TGA testing, a non-combusted residue content of approximately 3 percent remained. The overall TGA results obtained on the samples were consistent with those expected for a flame retardant grade of PC/PET resin.

The residue remaining after the TGA evaluation was analyzed using energy dispersive X-ray spectroscopy. EDS tests results present an elemental profile of the material and are effective for characterizing inorganic materials. The EDS results showed that the TGA residue contained primarily titanium and oxygen, consistent with titanium oxide, a common white pigment used in plastics compounding. The presence of this material, however, is significant, given that PC resins are known to be degraded in the presence of titanium dioxide.

The melt flow rates of the resin and failed monitor case samples were determined. Melt flow rate is used as an indication of melt viscosity and provides information regarding the average molecular weight of plastic resins. Prior to testing, all of the samples were dried to a moisture content below 0.019 percent. The obtained test results showed that the submitted molding resin produced an average value of 15.6 g/10 min. This was in excellent agreement with the nominal value of 16 g/10 min. and the corresponding specification of 10 g/10 min. to 20 g/10 min. indicated by the resin supplier. Analysis of several failed cases produced values that were significantly higher. The monitor case results ranged from 32.2 g/10 min. to 76.2 g/10 min. min., representing melt flow rate changes of 107 percent to 389 percent.

These results showed an unsatisfactory increase in melt flow rate associated with severe molecular degradation. The observed level of increase in melt flow rate and the corresponding molecular weight reduction of the failed parts are consistent with the apparent brittle behavior of the monitor cases. As molecular weight is reduced through degradation, all material properties, including strength, impact resistance, creep resistance and fatigue resistance are reduced. The relatively wide spread of results obtained on the failed parts is suggestive of a molding process that is not under control and may have been adjusted during individual molding runs.

It was the conclusion of the investigation that the cracking and failures observed within the monitor case hinges initiated in the hinge bosses through the exertion of relatively low stresses, below the yield point of the material, for an extended period of time. This failure mechanism is commonly known as creep, or alternatively, static fatigue. The features present during the visual, microscopic and SEM examinations indicated slow crack initiation. The stresses responsible for the cracking were associated with the inter-

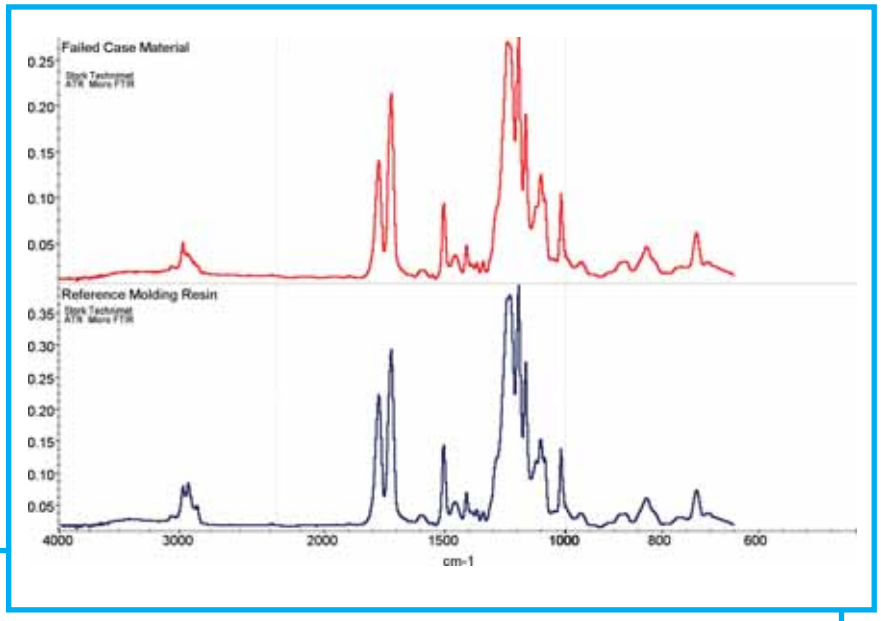

Fig. 5. FTIR spectral comparison showing a good match between the failed case material and the reference molding resin.

ference between the hinge pin and the hinge boss. The overall rigidity of the assembly, particularly in the latched condition, transferred all of the stresses to the hinges. The cracking originated at both the inner diameter of the hinge boss hole adjacent to the hinge pin and within the mid-wall. The crack origin site is determined by areas that are under the highest level of localized stress, or the areas which are inherently weaker.

In general, the fracture locations corresponded to areas of knit lines within the components. Knit lines are often associated with areas of poor fusion during mold filling and are commonly the weakest location on the molded part. While the knit line areas exhibited catastrophic failure, the cross sectional examination indicated massive cracking within the boss caused by the exertion of stresses over an extended period. The fracture surface outside of the initiation area displayed features corresponding to dynamic fatigue. It is not uncommon that an active crack can extend through dynamic fatigue after initiating through a different mechanism.

The analysis of the submitted samples, including the resin and the molded cases, produced results characteristic of an unfilled, flame retardant grade of PC/PET resin, consistent with the stated description. No evidence was found to suggest contamination of the material. However, the melt flow rate test results showed massive molecular degradation of failed monitor case material, thought to be associated with the molding operation. Specifically, three aspects of production could generate such degradation; overheating during drying, exposure of the molding resin to elevated temperatures for an extended period of time in the melt state in the injection molding barrel, and inadequate drying of the resin prior to molding.

In either case, the molding resin had been severely degraded and the high level of scatter suggested a process that was not in control. The DSC testing also showed that the part had been under-crystallized during molding. While not as severe as the molecular degradation, under-crystallization can reduce the mechanical integrity of the formed part. A third factor identified during the analytical testing which could adversely affect the part performance was the presence of titanium dioxide in the resin. Titanium dioxide in known to facilitate molecular degradation in PC resins

By conducting a failure analysis on the cracked monitor cases that failed in service, it was possible to identify the nature and cause of the problem. The evaluation identified the mode of the failure as creep associated with the interference between the hinge pin and hinge boss, as well as the cause of the failure, namely the substantial level of molecular degradation resulting from the molding of the parts. This information was used to alter the design and molding, both to reduce the level of interference stress and to improve the inherent mechanical properties of the formed parts. The full value of performing the failure analysis cannot be completely calculated. However, it appears likely that had the failures been dismissed as chemical attack by an unknowing user, further product field failure would have been likely. ■

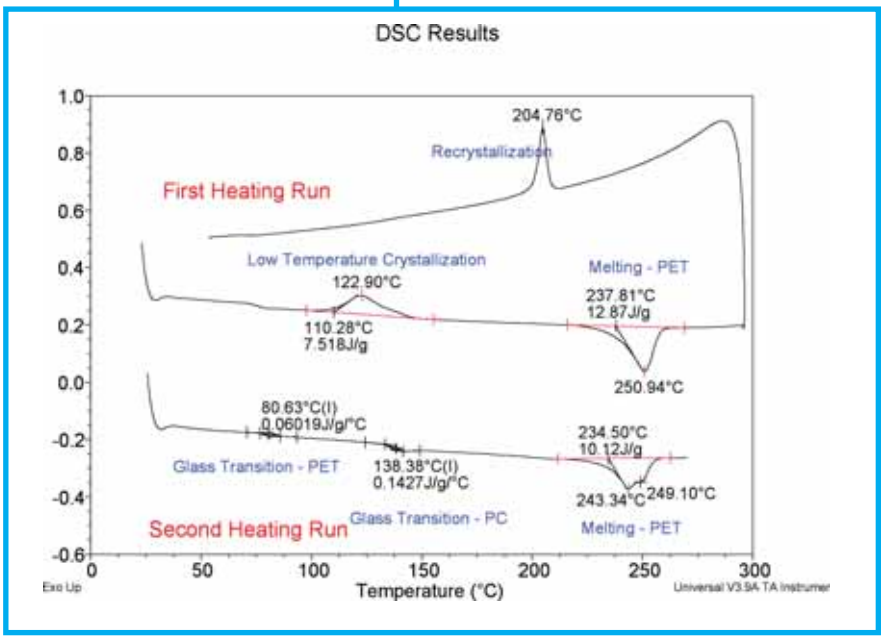

Fig. 6. DSC thermograms showing the first and second heating response of the failed monitor case material.