INVESTIGATION OF THE INFLUENCE OF COLOR ON PLASTIC PRODUCT FAILURE
Or
SNAP-FITS WHICH KILL

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Abstract

The color of a polymeric compound must be engineered just like any other desired resin property such as mechanical or thermal. Reaching the desired color can be adversely affected by processing or the combination with modifiers and additives in the resin system. Even if colors can be achieved by increasing the amount of pigment used in the formulation, other performance attributes such as mechanical properties may be adversely affected as well. This paper discusses these color matching concerns.

Introduction

In 1947, at the Western Reserve University in Cleveland, Ohio, a surgeon named Claude Beck was performing an operation on a 14-year-old boy whose heart arrested. Heart arrest, also known as cardiac arrest, cardiopulmonary arrest, or circulatory arrest, is the cessation of normal circulation of the blood due to the failure of the heart to contract effectively. Arrested blood circulation prevents delivery of oxygen to the body. The doctor performed a cardiac massage and gave the kid various medication. None worked. He tried an experimental defibrillator from his laboratory. By administering an electric shock, such a device can save the patient's life by resuscitating a heart that had stopped beating. This was the first time this device was used on a human being – and the boy survived.

Ten years later, in 1957, a German couple moved from Munich, Germany, to the state of Washington, USA. They had two sons. The young one, only two when moved to the United States, grew up to become a general superintendent and member of a local union, got married, and had five children. In 2002, while he was working in California, he had an accident and was brought to a local hospital. While being treated he had a cardiac arrest. The nurse reached out and grabbed an automated external defibrillator (AED), the FirstSave® 9000 model, made by Survivalink Corporation of Minnetonka, Minnesota (see Figure 1).

However, the AED did not work. The reason why the AED failed was that the snap fit latch design feature holding the battery in the AED was not locked. The snap fit did not snap, so no electrical connection was made. The current was not received by the defibrillator, and the patient died. He was just 46 years old.

When activated by the operator (in this case the nurse), the AED releases an electric shock, which is required to resuscitate the patient. To provide electricity for the defibrillator devices, non-rechargeable lithium sulfur dioxide batteries are used (see Figure 2). Once charged, the battery can hold a charge for one to five years.

The batteries are enclosed in a polycarbonate acrylonitrile butadiene styrene alloy (or PC/ABS for short) case made of Cycoloy® C2950 polymer, initially manufactured and sold by GE Plastics and, since 2007, manufactured and sold by SABIC Innovative Plastics which that year acquired the GE Plastics business for almost twelve billion dollars.

Discussion

The AED battery case was made in two halves ultrasonically welded together. One of the case halves had an energy director feature (Figure 3) along the joint area that allows the amorphous polymer to be ultrasonically welded.

The other half of the non-rechargeable lithium sulfur dioxide battery case incorporated a snap fit latch design feature. The battery was designed to be assembled to the AED device with the assistance of the latch snap fit design feature (Figure 4).

During the defibrillator development period, the Minnetonka company employed the polymer mechanical properties – such as stress-strain curves - for natural color made available by the resin vendor, in this case GE Plastics.

The stress-strain curves for all thermoplastic polymers, which are made available by the material suppliers to designers and engineers worldwide, are based on only one color - natural color. For all other colors, users have to test and generate their own data, regarding the stress-strain curves. There are a few material suppliers who generate additional data for some black pre-compounded polymers for certain projects.

For the defibrillator project in this particular case, the stress-strain curve for the PC/ABS alloy having the registered name of Cycoloy® C2950, natural color, is shown in Figure 5. The polymer strength at yield is just below 60 MPa.

However, when the AED product, FirstSave® 9000 series, was released for sale in the marketplace, its color was no longer natural; it was matched to a painted sheet-metal chip called "warm red C." The amount of pigment used to match the polymer's color to the painted metal chip exceeded the maximum level of 2% by weight - almost doubling it.

The stress level for polymer colored to match a painted "warm red C" sample employing close to 4% pigment can drop by as much as 50%.

The performance of the snap fit design feature was verified by conducting a finite element analysis (FEA) using the nonlinear material properties (see Figure 6 for the 3-D model, Figure 7 – for the FEA mesh, and Figure 8 – showing the Von Mises effective strength levels).

The result shows the Von Mises stress level present in the snap fit beam when it is deflected to be fully engaged into the mating part (defibrillator housing). In this case, the total deflection is 3 mm which generates a Von Mises stress level of 58.1 MPa or 8,424 psi. This stress level is very close to the yield point of the natural color polymer which is 60 MPa (see Figure 5).

Furthermore, the colored pre-compounded polymer matched to be identical to the color chip called "warm red C" has lower yield strength capabilities than natural color resin.

The engineering calculations were conducted based on the stress-stain curves provided by the material supplier, which had been tested just for natural color. In addition during the injection molding process, any small variation in the preset parameters for the injection-molding machine will result in lower mechanical properties such as the maximum yield strength that the polymer is capable of sustaining.

Conclusion

To perform well when in use, a snap fit must always be in the pre-yielding strength range until the end of life for that given product. Once the yield strength levels are reached, the snap fit design feature incorporated into the battery case will deform when pressed. However, it will not snap back to its original position because the polymer will yield and stay deformed – thus not snapping back to secure the battery into the AED – as was the case here when a man died because of it.

New batteries made since this accident are of different colors, like the dark blue, which holds better polymer mechanical properties than red does.

At the end of 2014 the U.S. Food and Drug Administrations (FDA) website showed 107 recalls of medical devices, including AED, made since it started keeping records 10 years earlier. Most manufacturers are on the FDA recall list for various reasons, including plastic part design.

References

1. Tres, P. A. "Designing Plastic Parts for Assembly", 7th English edition, Carl Hanser Verlag, Cincinnati, OH, 2014
2. Tres, P. A. "Automotive Plastic Part Design" seminar manual, ETS Inc., Bloomfield Hills, MI, 2015

Figure 1. Automated external defibrillator.

Figure 2. Snap fit design feature of the AED lithium batteries in two colors: warm red C and dark blue

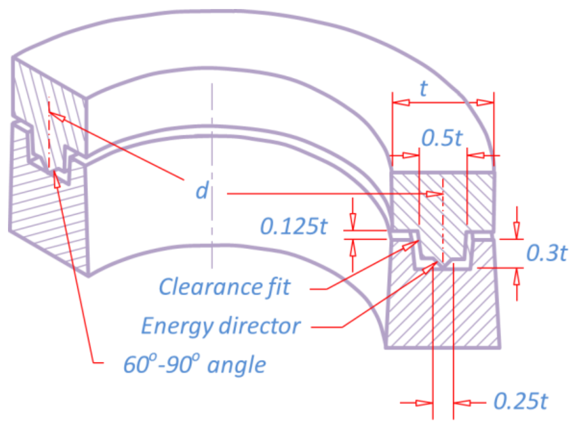

Figure 3. Energy director feature used to ultrasonically weld the two halves of the battery housing together (*t* – represents the wall stock, in this case 2 mm).

Figure 4. Side view of snap fit latch for the AED lithium batteries in two colors: warm red C and dark blue

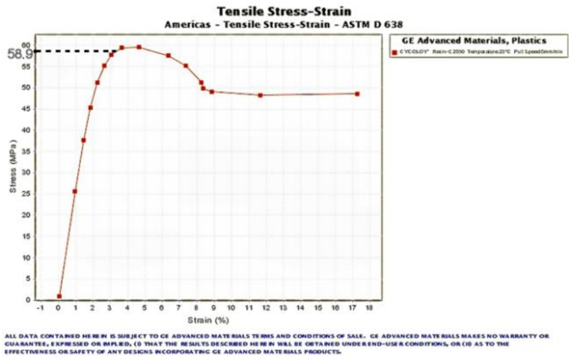

Figure 5. The stress/strain curve for the Cycoloy® C2950 polycarbonate acrylonitrile butadiene styrene (PC/ABS) alloy at room temperature

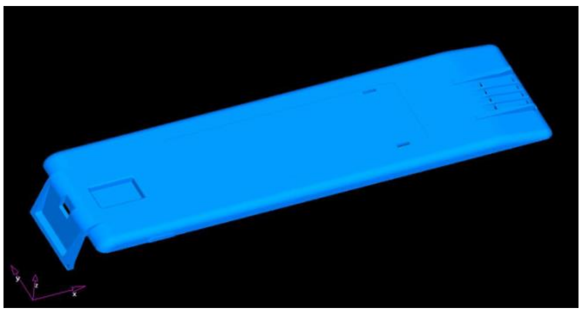

Figure 6. 3-D model of the upper portion of the case holding the lithium battery having the snap fit latch feature shown on the left hand side.

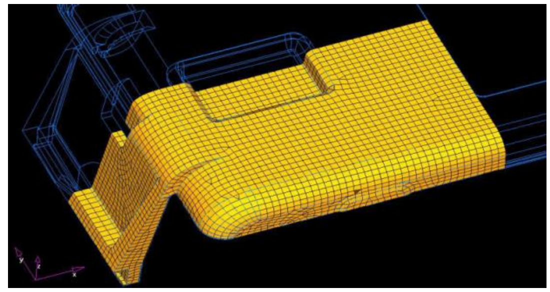

Figure 7. Solid brick element mesh of the snap fit feature created for the nonlinear finite element analysis

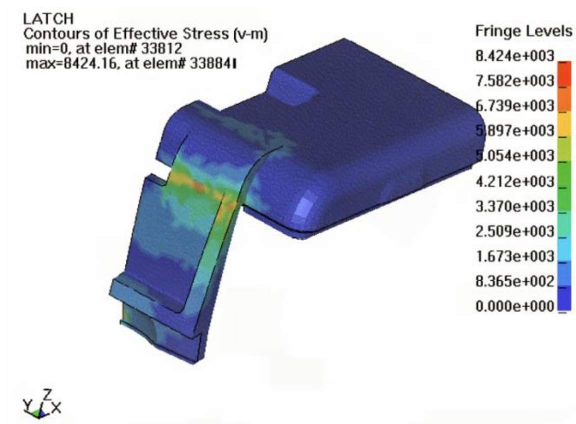

Figure 8. Contours of effective Von Mises stress level present in the snap fit feature when deflected 3 mm to engage into the defibrillator device housing the battery case made of natural color Cycoloy® C2950