Gallery of Goofs

This is the first in a continuing series that reports on errors of judgment made in the design and engineering of actual plastic parts and products. This case history describes how a lack of awareness of the design requirements for plastic materials, coupled with an accelerated product-development schedule, resulted in a major accident and a large financial loss. The author is Glenn L. Beall, president of Glenn Beall Plastics and a former design editor of Plastics Design Forum *magazine. Beall has extensive experience serving as an expert witness in liability cases such as the one presented*

The plastic part involved in this situation was an injection-molded acetal valve body. It was used on heavy earth-moving equipment as a part of the hydraulic-oil distribution and control circuit.

While the machinery was in use, the valve body cracked, and hot hydraulic oil sprayed onto the operator, causing severe burns and pain. The operator jumped from the moving machine and received additional injuries. Complications resulting from the treatment of these injuries subsequently led to his death.

The family filed a lawsuit against the deceased's employer and the equipment manufacturer, and enjoined all of the related suppliers to the original-equipment manufacturer. I was retained as an expert witness by the defense for the custom injection molder who had molded the valve body.

In cases of this type it may be difficult to determine the facts, because each of the involved parties understandably attempts to appear blameless. But based on the data produced during the pretrial litigation, the following scenario was put together.

The original-equipment manufacturer had designed and developed the valve body as a minor part of the overall hydraulic-control circuitry. A machined aluminum model of the design was fabricated in the company's model shop. Except for normal minor modifications, the model of the valve functioned as anticipated.

At this point, upper-level management exerted normal influence to reduce both the cost and the delivery time for the new and improved hydraulic-control circuit. Model shop drawings of the machined aluminum model were submitted to custom injection molders for cost quotations. As was expected, the injection-molded parts turned out to be significantly less costly than the machined aluminum valve bodies.

During the course of the quoting procedure, the original-equipment manufacturer asked the various molders for suggestions on which plastic materials would be suitable for the application. A variety of high-temperature plastics, including acetal, were suggested. It appears as though the original-equipment manufacturer specified acetal for the valve body; however, it was difficult to prove who actually specified the plastic material that was subsequently used. There was no question, though, that the OEM approved the plastic material and the molded parts.

In retrospect, acetal was a good choice for this application. Acetal is a strong, high-temperature material that is not affected by hydraulic fluid.

Trial moldings of the valve body, made after the accident, did not reveal any defects in the mold or the molding process. The molded parts, however, were another matter. The parts contained obvious weld lines, sink marks, and internal voids that could not be eliminated by molding-cycle adjustments.

The valve body was a boxy, solid part with a wall thickness ranging from 0.300 to 0.800 inch. No attempt had been made to core out or reduce the walls to a more appropriate thickness. All indications pointed to the probability that the mold cavity had been cut according to the original drawing intended for the aluminum valve body, which was to have been machined from bar stock.

Although acetal was a good choice of material for the application, it was not a good material for a thick-walled part such as this valve body. Acetal has a high mold-shrinkage factor. Highly crystalline materials such as acetal change abruptly from a liquid to a solid with only a few degrees' change in temperature. During the cooling portion of the molding cycle, the plastic material that is in immediate contact with the relatively cool surfaces of the mold's cores and cavity sets up quickly and becomes rigid. This happens long before the center of the 0.800-inch-thick sections have had a chance to cool.

As the center section slowly cools, it contracts or shrinks and attempts to pull the outer walls inward. The outer walls, which already have become rigid, resist this force. This results in the creation of a negative internal pressure as the centers of the thick sections continue to cool and contract. The negative internal pressure draws unreacted monomer, volatile gas, or moisture out of the plastic material to relieve the negative internal pressures. This condition results in a high level of molded-in stress and the voids that are shown in Figure 1.

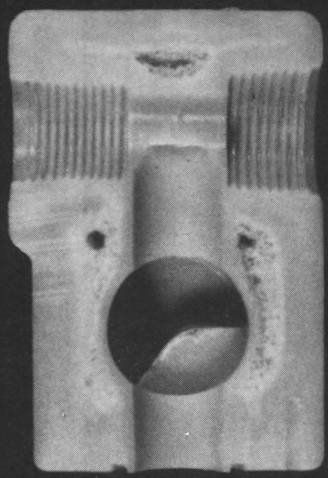

Figure 1.

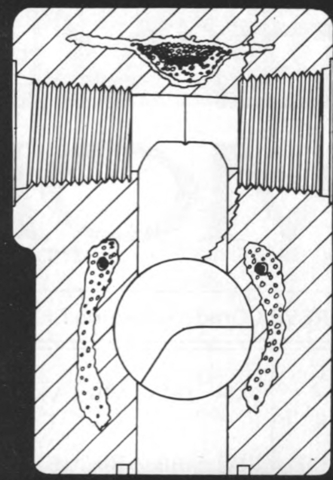

Figure 2.

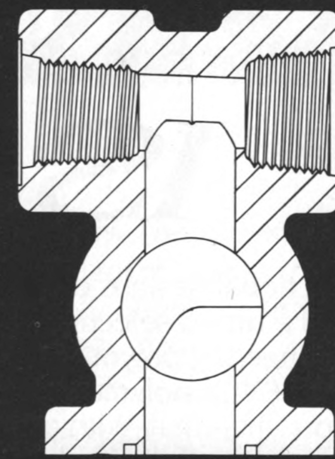

Figure 3.

The prosecution jumped to the conclusion that the internal voids, which obviously are not shown on the part drawing, were a manufacturing deviation that rendered the valve body unreasonably dangerous. If these accusations could be proved, the custom molder would have been guilty of having produced a defective part.

Careful examination of the part involved in this accident revealed that the valve body leaked through a crack that was in no way associated with the internal voids (Figure 2).

The cause of the crack through the side wall of the valve was traced to a sharp transition between the innermost thread and the valve body in a location near an abrupt change in wall thickness. The force that caused this sharp, stress-rising comer to develop a crack was provided by a threaded metal fitting that had been driven too deeply into the inside thread on the valve body. The threaded metal fitting had actually left an indentation on the valve body at the bottom of the thread.

The molding experiments indicated that it was not possible to mold the valve body as designed without internal voids, weld lines, and high levels of molded-in stress. The printed literature from the material supplier indicated that internal voids were to be expected on thick-walled parts such as this valve body. These voids were due to the design of the part. If the voids rendered the part defective, then that defect must be considered a design defect. The sharp stress-rising corner at the bottom of the thread was also a design defect. Overtightening of the threaded metal fitting also contributed to the problem.

The part design and the assembly operation were both clearly the responsibility of the original-equipment manufacturer.

The custom molder's attorney took the position that the cause of the accident was a design and assembly defect for which his client had no responsibility. The case was favorably settled from the molder's perspective.

This case was settled before it went to trial, and the diverse opinions expressed by the opposing expert witnesses were never tested. However, it is reasonably safe to assume that this accident could have been avoided by proportioning the part design for the plastic material chosen and the manufacturing process being specified.

The weld-line weakness and high levels of molded-in stress could have been minimized and the internal voids could have been eliminated by redesigning the part to have uniform, thinner walls (Figure 3). Stress at the sharp junction between the innermost thread and the valve body could have been reduced by replacing the sharp corner with a radius. A shorter threaded metal fitting or a deep inside thread on the valve body would have prevented the threads from bottoming out.

The valve body may have been properly designed for a metal part that was to be machined from bar stock. However, the part was not designed according to the state of the art for an injection-molded, high-mold-shrinkage, crystalline plastic material. It is a simple fact that all parts must be specifically designed to accommodate the special limitations and peculiarities of the material, process, and tooling approaches that will be used to produce the part.

Similar errors in judgment have been made in producing plastic parts by using part drawings originally prepared for cast iron, wood, glass, diecast aluminum, and fabricated sheet metal. The undesirable practice may appear to save the time and cost of preparing new part drawings. More often than not, the resulting parts turn out to be of lower quality and higher cost than a properly designed part.

Any plastic part worth producing deserves to be properly proportioned for the combination of the manufacturing process and the plastic material that will be used to produce the part.