TOTAL QUALITY

By Christopher Peacock

Beyond Statistical Process Control: rheology gives product quality a boost

Seals Eastern looks forward to continued gains in quality and efficiency by combining statistical and rheological techniques in the design and manufacture of engineered rubber products.

About the author
Christopher Peacock joined Seals Eastern Inc. in 1984 as a quality control engineer and was named quality control manager in 1986. He has a bachelor of arts degree in mechanical engineering from Brown University.

Statistical Process Control was adopted by Seals Eastern more than five years ago. While we may have been at the forefront of SPC implementation in the rubber molding industry, many other companies have since invested in SPC programs. There have been notable successes, and some failures along the way, as rubber molders, spurred by the increasingly stringent quality requirements of their customers, have worked to get their operations under control. Today, as highly repeatable statistically controlled molding equipment comes into wider use, the need for ever more tightly controlled raw ingredients is becoming evident.

Control of the physical properties of vulcanized material is now well-established. Tomorrow's frontier is the control of the rheological properties of rubber necessary to ensure the consistency of processing and molding, so that we can make additional progress toward the goal of supplying defect-free molded goods to our customers.

Long regarded as a quality supplier of molded rubber seals to the automotive, oil and gas, and fluid control industries, Seals Eastern knew that the implementation of modern quality control techniques was essential to future growth and profitability. SPC was chosen as the main vehicle of process improvement, and the centerpiece of a revamped quality control program.

There are many reasons, some better than others, for initiating an SPC program. In the case of Seals Eastern, the choice was made as a matter of survival. SPC was seen as the most powerful tool available to improve our manufacturing processes, to reduce scrap and rework, and ultimately make the company more competitive. At the time, the big push toward SPC by the automotive companies was just taking shape.

It would be a couple of years before SPC was a prerequisite for doing business in Detroit, but Seals Eastern would be prepared. This foresight helped the company to avoid a fire-drill to meet the new requirements of our customers. Those companies that were less well-prepared undoubtedly suffered as a result. Crash programs in SPC -massive training programs, consultants, and flashy new equipment - tend to be expensive and wasteful.

Implementation of SPC at Seals Eastern proceeded in a piecemeal, sometimes disorganized, fashion. The areas with the biggest potential for improving the bottom line were looked at first. Seals Eastern is a custom molder, and like many rubber molders, we are also our own custom mixer. In other words, we supply our most important raw ingredient, mixed rubber compound. Were our mixing processes in control? Were we supplying the most controlled product possible to our molding operation? In light of the lack of statistical evidence one way or the other, the answer was probably not. It was realized by everyone involved that control of our molding operations would not be possible until our mixing was under control.

Applying SPC to the materials control lab seemed at first a daunting challenge. Fortunately, Seals Eastern was familiar with the work of a talented and creative computer program designer named Paul Hertzler, who was already putting the finishing touches on a program called "RheoLogic" (*Elastomerics,* August 1985, (pp. 24-27) This program collects and analyzes the output from a Monsanto oscillating disc rheometer, our principal quality control tool for mixed compound batches.

The investment in computer equipment and software was substantial, but the returns began immediately. The application of SPC in this instance was a fine example of the problem-solving approach so suited to SPC: A specific operation, mill mixing, was studied with a simple tool, mainly X - moving range charts, providing the information necessary to improve the process. The actual mechanics were made practical by a relatively new tool, the personal computer.

The first thing we learned was just how badly we were doing. We had a wide distribution of cure curves, and even with the broad spread, we still had batches that were easily shown to be statistical outliers. The most immediate improvement in the rubber that we were supplying to our molding operation was the elimination of these outlying batches. Further improvement came simply because the operators knew we had better surveillance of the mixing, and they began to try to do a more consistent job. However, the real work of improving the control of the mixing lay ahead.

It must always be emphasized that SPC in and of itself does not improve a manufacturing process. Sure, it helps to identify special causes, e.g. operator mistakes, machine malfunctions, and off-spec materials, but it can't do anything to change the inherent capability of a process. This task can only be accomplished by management. In many cases, this means the top management of the company. How did we improve the capability of our mixing processes? Not by exhorting the mill men to be more careful; most operators were already trying their best.

Real process improvements, as shown by tightened control limits, are always the result of management working on the process, which means spending some time, effort, and money to make real changes. In the case of mill mixing at Seals Eastern, these included such items as an improved cooling system for the mill rolls, dip tanks, improved mixing instructions, better scales, and a better work environment including dust collection and better housekeeping. The results of these efforts are well illustrated by Figures 1 and 2, which show the distribution of Ts2 (scorch time) in 1985 and 1988, respectively, for one of our important compounds. The standard deviation today is less than half, a definite improvement in this processing characteristic.

None of these changes could have been accomplished by the workers themselves, nor are they due simply to running control charts. SPC techniques, and the use of RheoLogic in particular, do their part by showing management what needs to be done.

Further improvement in the consistency of the rubber supplied to our press room is still possible, and indeed necessary as I'll discuss below.

Statistical process control was applied next in Seals Eastern's molding operations. The main goal was to try to reduce the frequency of defective molded parts. Our problems, by and large, did not involve dimensional variation or other characteristics easily quantified with variables data. We needed to employ attribute-type control charts, principally the percent-defective chart, or p-chart. It was decided to keep a p-chart for every part that was molded above a certain volume.

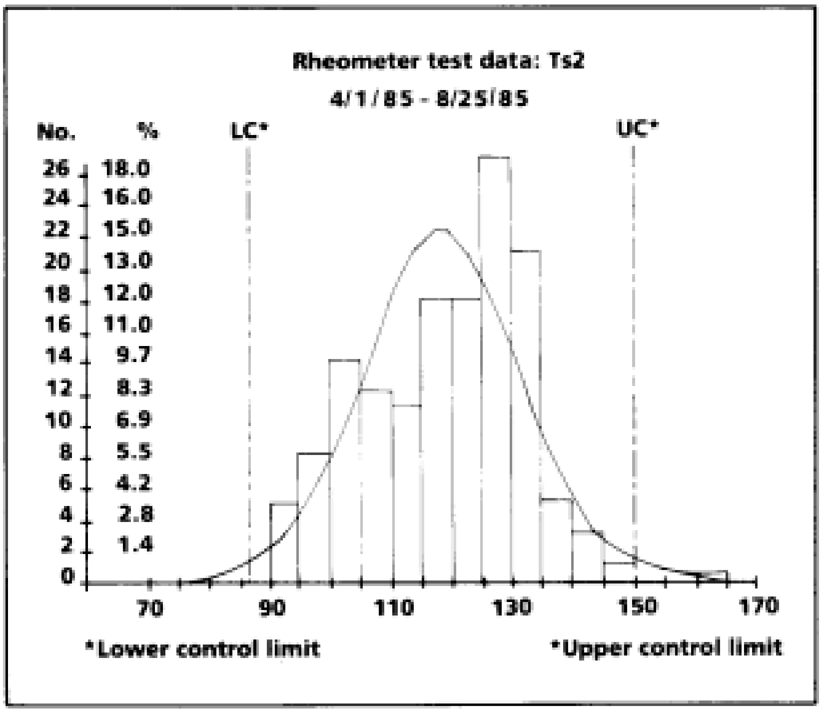

Fig. 1. Distribution of Ts2 for compound 7013 — 1985.

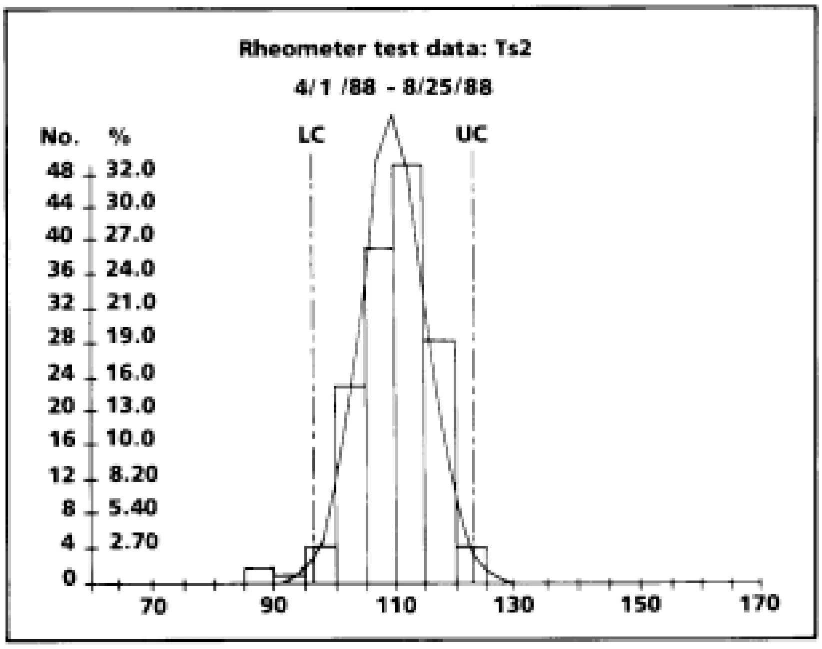

Fig. 2. Distribution of Ts2 for compound 7013 — 1988.

Seals Eastern's chief inspector, Maria Robles, uses an optical comparator to measure the dimensions of a molded part.

Again, the job was accomplished using personal computers and commercially available SPC software. P-charts are posted on a bulletin board in the press room, and are updated three or more times per shift. Even with the computerization, this requires a substantial commitment of Q.C. department resources.

Our experience with the p-charting has been a more qualified success. We've set statistically determined limits of percent defective for many jobs so that we know when a special cause is responsible for higher rates of defectives. We can detect significant variation between operators to help determine when a worker requires additional training, or reassignment. And percent defective charting, along with Pareto analysis, has been especially effective for studying new processes. But we've not always been successful in achieving substantial process improvements on existing jobs. In particular, we've learned that some of our older production lines just will not meet the requirements of our customers today, even when they are running under statistical control. In other words, it is time to improve or replace these processes.

Seals Eastern also has the necessary dimensional SPC techniques available, for example, in process size control using X-bar and R charts, and automated equipment for performing process potential studies. In short, we have in place a nearly complete SPC system. This helps us tremendously in satisfying the quality control system requirements of our customers. In particular, of course, the automotive companies and their suppliers insist on a systematic approach to SPC before they will do business with you. For some companies, I suspect this is reason enough for investing in SPC.

Seals Eastern is not alone. Many, many companies have successfully begun worthwhile SPC programs. We've reduced the number of customer returns even while our volume of business has grown. We've reduced the total amount of material scrapped. SPC has given the management of many small companies a new ability to prioritize their investments so as to further improve their critical processes.

Another advantage of an SPC database is increased knowledge of our processes. We can tell our customers a great deal about their product, and this is really only a byproduct of the SPC program.

With the help of the rheometer at left, the author, left, and chief chemist Hermann Bussem keep close tabs on compound quality.

A given customer may not be satisfied with the number of defective parts he is receiving. But our customers are surprised and pleased when we can show that our processes are in control. Often we can even determine the exact proportion of specific types of manufacturing defects in our product. Of course, our customers still want fewer defects, but the starting point for discussions is different now, to everyone's advantage.

The push to implement SPC, spurred especially by the auto manufacturers, has also produced disappointments. Many companies have been left wondering where the payoff is from their huge investment in SPC. Some common mistakes in implementing SPC are now apparent. Too often, companies have tried to please their customers by developing impressive SPC campaigns. Many investment dollars have been squandered on training programs and SPC consultants. An unknown proportion of the countless control charts now produced every day by auto industry suppliers are basically useless. Not even the most well guided program is innocent of overly prolific charting.

Management's responsibilities for making SPC programs pay off are sometimes poorly understood. SPC contributes only a small part of possible quality improvement by itself. Most quality improvement is brought about by improving the manufacturing processes and by using statistical data to guide these investments. Confusion between common causes and special causes of defects must be eliminated. It is estimated that up to 94% of problems and possibilities for improvement belong to the system; that is, they are the responsibility of management. SPC by itself can only eliminate the special, or assignable, causes.

SPC is an extremely powerful tool for process improvement. Even though some efforts have been misguided, large gains in quality and productivity have already been made. In the future, however, I believe that we are going to see changes in the implementation of SPC if we are to realize its full potential. There is going to be a stronger emphasis on results and on problem-solving, and less emphasis on methods and systems. The companies that have made the big push for SPC in the first place will likely take the lead in reforming the way we all put it to use.

I'd like to present a specific example of a problem in the rubber molding industry, a problem that must be addressed with statistical process control concepts. For over 15 years, one of Seals Eastern's largest selling items has been a rubber-to-metal bonded journal cross bearing grease seal. These are purchased by the millions by a company that is a major supplier to the automotive industry.

Back in the old days, they bought these on a 2.5 AQL sampling plan, and the quality of our product was quite satisfactory. Our molding process, state-of-the-art 20 years ago, has not been updated in any important way since then. However, the quality requirements of our customer have changed drastically.

We have a compression molding process,

highly labor intensive, that cannot meet the expectations of our customer today. We have a rate of nonfills that cannot be reduced further on the present equipment (see Figure 3), and a customer demanding essentially defect-free product. The process is now being converted to injection molding. Nobody is under any illusion that this is going to solve all our problems, but it is a big step in the right direction. An injection molding machine, cycling consistently, can produce heat after heat of defect-free product. Our experience injection molding a similar but smaller part has been very good; the upper control limit on percent defective of our in-process samples is 0% (see Figure 4). Our next generation of injection molding equipment is designed to be even more reliable. We are reducing the human element through automation, and the automated equipment is self-monitoring to detect any abnormal conditions such as slower than normal injection.

Experience has also taught us that there are no better quality control devices for rubber than screw-plasticating injection molding machines. Finishing one batch of rubber and starting on the next is often enough to upset the molding process. By and large, one batch runs as well as the next, but having to readjust the process between batches is routine. This hurts our productivity, and it hurts the overall quality of our product.

The problem is that we just don't know how much of our mixed compound variability is due to variation in the unblended polymer. Further, we don't know which of several competing compounds offers the best average properties or the best manufacturing control. It's difficult to find out, because very little data that shows important information about the rheological (flow) characteristics of their products under the very high shear rates involved in injection molding is currently available from polymer suppliers. Typically, the information available from a certificate of compliance lists the results of physical property testing of a standard formulation. Maintaining required physical properties of the finished product is not our biggest problem: consistent processability of the material is.

The material in question in this example is a 34% ACN nitrile rubber. We are going to be injection-molding 1000 lbs/week for our most important product and we absolutely need to find the best choice of the many brands available. Best means most consistent and easiest processability. Factors that should be taken into account include not only Mooney viscosity and molecular weight, but also, molecular weight distribution, percent gel, and other characteristics which affect the rheological properties of the rubber. What information is available from the various suppliers? Mooney viscosity figures are provided, but these are not an indication of flow characteristics under the much higher shear rates encountered during injection molding.

We recently obtained samples of eight different candidate materials, and carefully mixed the compound batches from each in our lab. The Mooney viscosity of the test batches varied between 21 and 30 ML 1 + 4(100°C). We then tested the flow characteristics of each batch in a controlled high shear rate situation.

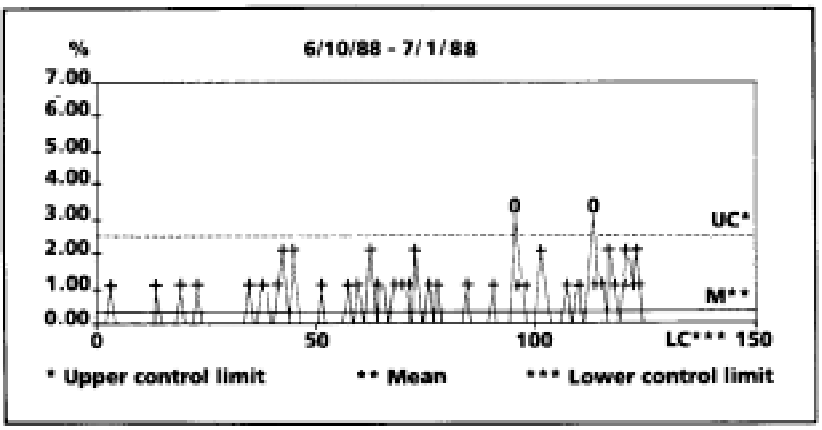

Fig. 3. P-chart for molding nonfills, typical compression-molded part.

The material that flowed the most freely had the highest Mooney viscosity of the lot. Preliminary results of this material in an injection molding machine were encouraging.

The rubber molding industry needs more information from the polymer producers. In general, the rubber molder has no way to tell whether a polymer plant is run under statistical control. Further, the information that is provided isn't what is really needed. The science of rheology offers great hope for further improvement in rubber molding, but much work will have to be done to reach agreement on the type of test results that will be the most useful.

We hope that polymer producers will freely provide the information once there is a consensus on what is needed. The rubber molding industry is not dominated by a handful of large companies, and small companies don't have the clout to demand SPC data from very large vendors. However, our customers are frequently large companies, the automobile companies and their suppliers that have popularized SPC in the first place. This is an area that these companies are already becoming interested in. To date, their investment in SPC (and ours!) has not produced the gain in the quality of molded rubber products that is needed. Whether or not their involvement is invited, our customers have a vested interest in the outcome of this effort. Rheological and statistical methods must be used together to continue to improve the quality, and lower the cost, of engineered rubber products.

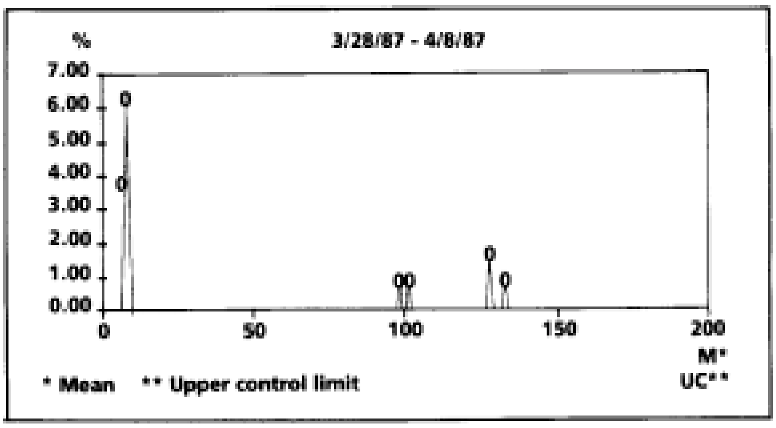

Fig. 4. P-chart for molding nonfills, injection-molded part.