A successful heat treating operation is defined by the ability to satisfy quality requirements consistently and economically. Quality requirements may be defined by such characteristics as hardness, dimensions, surface condition, uniformity, properties, microstructure, and so forth. This article reviews the steps that are important to produce quality parts, with a brief practical explanation of each.

In addition, final inspection is necessary to verify that specifications have been met, but evaluation of as-received material and in-process testing is also important to determine whether a problem occurred during processing and at what stage it occurred. It is certainly not economical to complete an expensive heat treatment only to find a problem that could have been caught in an early stage of processing. From strictly an economic point of view, the part generally has a value of 10 to 20 times the actual cost of the heat treatment; therefore, if a heat treating operation produces a scrap rate of only 1 to 2%, any profit from that operation is lost.

Quality assurance program

The components of a program to ensure quality in heat treating should include:

- Proper material and design of the part.
- Proper equipment and control of its operation.
- Determination of whether the process is capable of heat treatment to the required specification.
- Statistical process control (SPC), control charting, and in-process inspection and testing.
- Statistical quality control (SQC) and final testing (sampling) to verify the results.

Quality can be assured if these factors are incorporated into the heat treating operation, including the proper methods of statistical analysis. Quality cannot be inspected into a part, but proper attention to each step of the process can identify sources of problems and prevent them.

As higher quality and increased documentation are demanded of heat treaters, the subject of automatic collection and use of process information in a SPC/SQC format has become mandatory. Data acquisition and documentation a few years ago meant a chart recorder for temperature and a log sheet for the operator’s dew point readings. Today, it more than likely means a computer system tied into key points of the heat treating equipment and process with the objective of logging important information for later review, or perhaps being taken into account in real time.

Statistical control

Understanding SPC and SQC techniques requires some definitions. The principles of SPC rely on the science of statistics: the collection and classification of facts from which conclusions can be drawn with a given degree of certainty. Statistics may be used to analyze such data as that obtained in coin tossing, throwing dice, measuring dimen-

Heat treating is based on metallurgical principles that relate processing, properties, and microstructure. Therefore, close control of process variables will result in products of high quality. Image courtesy MT Heat Treating, Mentor, Ohio.

Jon Dossett* is a retired process metallurgist and materials engineer with over 42 years of experience. He is an expert in thermal processing and heat treatments, and served as the Senior Editor of ASM’s Journal of Heat Treating from 1986 to 1991.

Jon Dossett*
Consultant
Chandler, Arizona

*Fellow of ASM International
The normal distribution curve is a bell curve in which 68.3% of all data lie between plus and minus sigma (standard deviation). It can be shown that in a normal statistical distribution, the square root of the result is the standard deviation, and this number is designated as sigma (σ). When standard deviations are plotted, as shown in Fig. 2, bell-shaped curves are obtained. This is the difference between the maximum and minimum values measured. As an example, suppose HRC tests are made on 20 pieces from each of two different batches. For each batch, individual hardness values are listed (x), the average (\( \bar{x} \)) calculated, the difference between each value and the average is found, and this number is squared.

When standard deviations are plotted, as shown in Fig. 2, bell-shaped curves are obtained in both batch A and batch B, but the values in batch B are grouped much closer to the average than in batch A. The average calculated for each batch is 50.3, but the standard deviations are 3.79 for A and 1.30 for B. Also, the range for batch A is 16 and for batch B is 5. Clearly, the processes used to harden the two batches differed considerably in the control exercised.

The calculations to determine these values are quite tedious to carry out by hand, and most processes analyzed by statistical methods would consist of many data values. Fortunately, computer programs are available to calculate all important quantities for \( \bar{x} \) by merely entering data points.

Process capability

Before statistical sampling techniques can be applied to a process, a capability study should be conducted that demonstrates that the process can hold the prescribed specification or specifications. For heat treating, characteristics frequently measured are hardness and case depth. Because these metallurgical characteristics are sometimes difficult to define, specifications may initially need to be clarified with regard to the exact test scales or test methods, and the critical locations where these tests are to be made before a capability study is conducted.

Process results for many metallurgical and heat treating processes depend on material-related characteristics such as hardenability, material chemistry, and/or part geometry that also make the process test results sensitive to those variables. After the metallurgical requirements are clearly established, a basic process capability study may be conducted. A minimum of 31 samples must be tested for each variable. Care should be taken so that the parts tested are from the loading locations representing the extremes in process variability.

A good guideline for test sample locations is to use the nine loading locations prescribed for temperature uniformity surveys — each corner and the center of a rectangular furnace load. For continuous processes, it is important to collect the samples over a sufficiently long period of time to reflect process fluctuations or other process abnormalities that could be time dependent.

Frequency distribution and normal probability graphs or a suitable computer program for data representation and plotting are highly recommended. If the data do not plot as a straight line indicating a normal distribution, a metallurgical or process-related reason for this “skewness” should be apparent or be determined.

Overall process capabilities may be the result of many contributing factors:

- **Base materials:** Unique materials characteristics, materials defects, and hardenability differences. These can vary from lot to lot and also between materials.
- **Part-related:** Part geometry and section size variations.
- **Process-related:** Temperature uniformity as affected by process control and mass effects, time control, atmosphere control, and cooling method (as determined by uniformity and average severity).
• Evaluation method: Standards accuracy and testing method accuracy.

Choosing SPC or SQC

A distinction should be made between SPC and its relative, SQC. Because SQC is an after-the-fact tool, it is best applied in the control of continuous processing, where trends can be observed and corrected before significant damage occurs. However, in batch processing, SQC is of little value in preventing problems because at least one entire load of parts will be adversely affected before a problem can be detected.

Even if the problem is caught after one load, the proposed solution cannot be tested without committing yet another load. Statistical quality control can be very helpful in batch or short run type (setup dominated) processes for analyzing setup variables. If the process is then adjusted to optimal parameters (as determined by experimentation or evaluation of part outputs), parts will necessarily meet specifications.

The idea behind true SPC is that the results of a process can be guaranteed if none of the relevant process parameters are allowed to stray outside of previously established control limits.

The longstanding problem in applying SPC to heat treatment has been finding methods to quantify and measure process parameters that are of known importance (aside from the obvious). Many SPC programs are based on charting controlled parameters such as temperature, atmosphere carbon potential, quenchant temperature, and so forth.

While this approach is certainly not incorrect, it does often lead to a situation in which a deviation in an SQC chart (output results) commonly cannot be attributed to any deviation in a corresponding SPC chart (processing parameters) because all the things being charted are controlled variables that by design do not normally change.

With induction and flame heat treating, parts are typically processed one at a time. Using part evaluation techniques (SQC) to predict negative results becomes difficult and impractical. Thus, the focus must shift to SPC and the identification, monitoring, and controlling of the process variables. Electric power, flame temperature, scan speed, coil dimension, part positioning, and quenchant pressure and temperature are some variables that need to be considered.

A fact of life in any heat treating process is that the equipment gradually succumbs to the wear and tear of constant operation. The challenge is to counter this natural deterioration with corrective action before out-of-specification parts are produced. Statistical process control techniques can measure furnace performance and address process deterioration in heat treating. By monitoring key process variables and/or key process outputs, preferably in online fashion, trends can be spotted and action taken before nonconforming product is produced.

For more information: Practical Heat Treating may be ordered from Customer Service, ASM International, Materials Park, OH 44073; tel: 800/336-5152. Or visit www.asminternational.org and click on the “Bookstore” button to view the table of contents or read a chapter.