UNDERSTANDING THE PHENOMENA OF INTELLIGENT HEAT-TREATMENT

S. Khan, R. Qayyume and A. Tauqir*

Heat-treating has been a long history of development and is considered to be a mature technology. Few industries have equaled the response of the heat-treating industry to rapid changing requirement of manufacturing. Often, this response has required the development of new materials or sensors to implement existing production and control techniques. At the same time, new understanding of high-temperature reactions has been required to keep the cost of heat treatment low in response to energy shortage and "upsets" in manufacturing.

Today, major driving forces for change are the need for greater flexibility of production and more predictability of results from the heat treatment process. This has led to greater material standardization, tailoring of material composition to achieve predicted properties and application of cellular approaches to heat treatment system.

Enhanced control of processes and production allow the heat-treatment industry to contribute greatly to the modernization of manufacturing. Better sensors permit a more reliable analysis of the heat-treating parameters. Improved software enables interactive control of processes with sophisticated mathematical models, and modular hardware and software not only allow flexibility, but also provide reliability and continued enhancement of control capability as new developments in software became available. In addition, interfacing heat-treatment systems with production computers permits rapid optimization of plant productivity. These developments point to a new life-cycle curve for the heat-treatment industry.

Role of Heat Treatment in Manufacturing

Heat treatment is often considered as an art, not a science. The heat treatment system can be linked with assembly process so that common operation can be grouped together right in the production line on the factory floor. The subsequent operation after heat treatment is dependent upon the performance of heat treater. Therefore, a relationship exists between Just-in-time (JIT) and heat treatment that one can go from raw material to finish product in one continuous manufacturing flow.

Most of the time people involved with heat treatment face manufacturing deadline and production demand. Heat treater has to adopt Just-in-time (JIT) principles, which means "getting the job done right in time every time". Just-in-time (JIT) manufacturing is a fundamental prerequisite for success in today's manufacturing environment. It is not a specific technique, but rather a manufacturing philosophy and economics. The principles that form the foundation of Just-in-time (JIT) are based on common sense, and its success depends upon its ideas becoming part of manufacturing line. To accomplish this goal one must keep in mind the key aspects of heat-treating, essential for success of JIT-heat treatment[1]. The key aspects are as under:

- To know, metallurgy, what is needed to accomplish.
- To be able to predict the outcome of a heat treatment operation.
- To have repeatability built into the process.
- To use state-of-the art heat-treating equipment and methods.
- To be aware of changes to other manufacturing operations.
- Do not compromise on quality.
- Know your costs.
- Designing equipment and automation with Just-in-time (JIT) manufacturing goal in mind.

The eighth factor is important for to day's heat treater for

- Handling the job in time.
- On line reporting system.
- Relying on statical process control (SPC) techniques to assure that manufacturing flow is totally reliable.
- SPC and JIT-heat treatment makes the cost and quality of the products competitive.

* Metallurgy Division, Dr. A.Q. Khan Research Laboratories, Kahuta, P.O.Box No. 502, Rawalpindi - 46000, Pakistan.

To take full advantages of the process and control the heat treaters need to emphasis on these factors to have a better quality of the products.

Intelligent Heat Treatment

When it is aimed to produce high quality product it motivates heat treater to adopt "Total Quality Management" (TQM) procedures. This comprises of computer-based management, documentation and process control system, which provide necessary information needed by the customers.

Properly implemented computerized monitoring and control procedures can help heat treaters:

- To control cost.
- Improve scheduling.
- Boost productivity.
- Optimization of equipment operations.
- High quality of the products.

With tighter process control afforded by a computer aided design, rework and rejection rates are minimized. Rework saving could be enhanced upto to 98%[2-5].

A computer-aided heat-treating system (CAHTS) has significant impact on users, as the operators are free to perform other duties. More time can be spent in fixing properly the next load, evaluating report and making strategies for heat treatment production, can alert the operator to potential problems before a crisis occurs.

Implementation of "Total Quality Management" (TQM) requires the collection and analysis of large amount of data which include process variable such as time and temperature for carburizing and/or process results such as effective case depth. Data can also include in terms of parts within specification limits vs. those parts outside specification limits, or the number of promise dates set vs. number made.

For an SQC/SPC effort to be successful and long-lived, the data collection of the system must be the mainstream information flow. Data collection must be rule rather than the exception to ensure that statical process control (SPC) soft ware will be used as a simple method of obtaining information. In addition, a convenient method of organizing data for analysis must be built into the system which structuring and formatting the way information is entered into the system, should have the flexibility and ease of retrieval. If set up properly, database will permit a single entry to be accessed many times in various ways. To accomplish this, the data must be stored with all of the possible indices and parameters that future selection of information might be based upon. This includes the shop order number, part type, heat treat process type and as-quenched hardness value.

Data collection should be implemented in a typical order-path through a heat treatment plant. Technical information on part processing first be entered on process master. Then order is generated (order entry), processing begins with system checking and recording to ensure that planned processing steps have taken place in correct sequence. In-process inspection to determine information such as if specific as-quenched hardness or case depth is required, which is the part of statical process control (SPC) data in the mainstream line information flow. Final inspection, key point in the processing route where final hardness and other mechanical properties are measured. Certification follows with a general review of all processing and the preparation of documents to confirm that heat treatment meets customer's criteria.

In general Just-in-time (JIT) heat treatment, tighter process control, on line data collection all are the part of "Total Quality Management" (TQM), and once these have been established properly, it means-doing intelligent heat treatment.

Computer Controlled Heat Treating Problems

In the past, the computer control system technology was not available, the heat treaters were not able to measure completely and accurately all of the process variables that can affect materials during heat treatment. However, recent advancements in control-system designs, sensor technology, digital communications have made it possible to develop a computer control system that enables heat treater to meet both process-control and cost reporting requirements.

On line Data Collection Flow Chart is shown in Figure 1 [6,7]

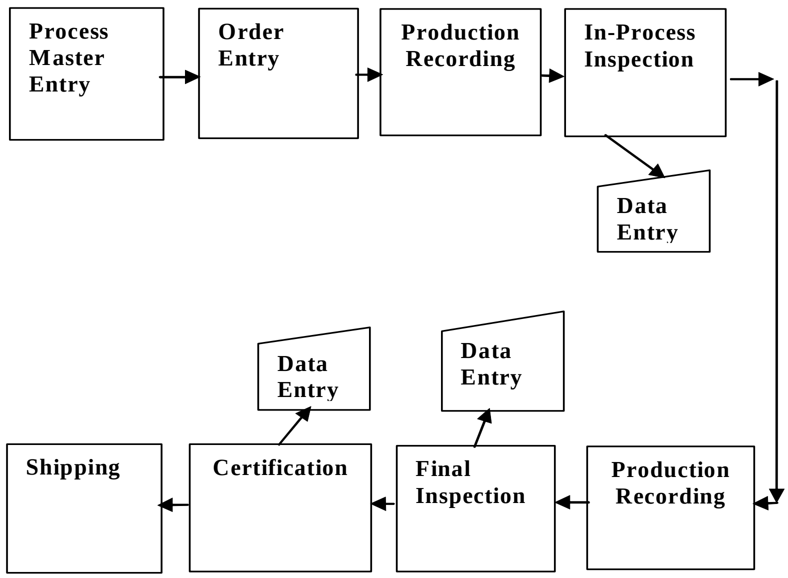

Figure - 1: Shows the Flow Chart Block Diagram. Data Collection should follow the Typical Order Path through a Heat-Treating Plan

The Model so Developed Shown in Figure 2

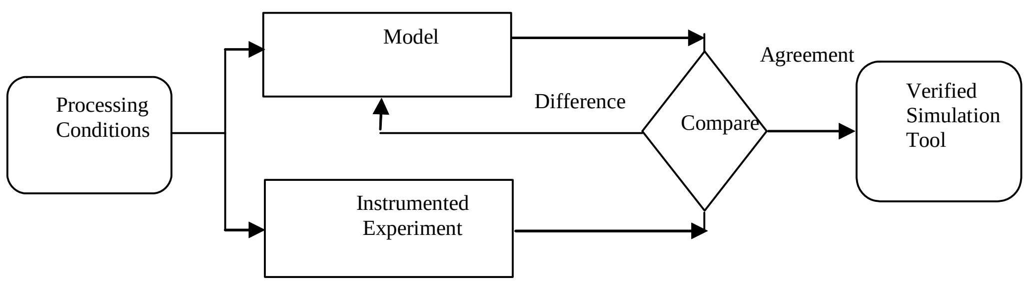

Figure – 2(a): The Finite-Element Model of a Heat-Treating Process can be verified by Comparing Key Parameters with those from an Instrumented Experiment

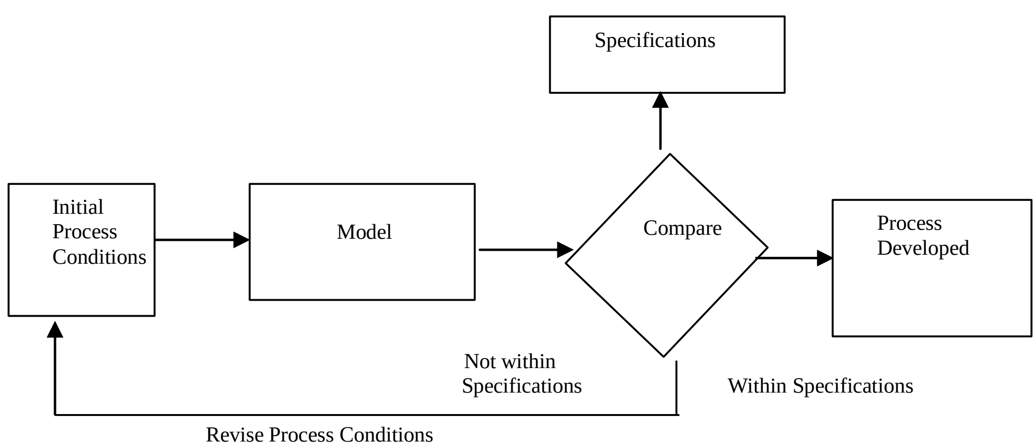

Figure – 2(b): The Verified Finite-Element Model of a Heat-Treating Process can be used to Improve Quality of the Product.

The recently developed modeling tool encompasses the capability to analytically determine the behaviour of steel components during heat treatment. Once the process parameters for the type of quenching and the steels properties have been determine, this analysis is used to predict the effect of process changes, such as part shape, material specification, and quench conditions on final products[6, 8].

was given trial run on computer, rather than costly trial-and-error experimentation on the shop floor. The improved and optimized process can help to:

- Reduce scrap or rework rate.
- Reduce or eliminate final grinding of parts to meet specifications.
- Reduce trial and error in developing process parameters for new parts.
- Allow tighter tolerances to be achieved via better control of heat-treating process.

This technique is used for virtually all of the major heat-treating and surface-modification process to produce critical parts. The processes include carburizing, nitriding, hardening, tempering, annealing and stress reliving. In addition, it is also applied to an extremely broad range of part shapes and materials. To date, most of the efforts have been on parts made of various low-alloy steels, such as AISI 4140, 4335 and 4340 etc. However, this technique can also be applied to other metals and alloys. Specific applications are hardening of gun barrels, heat treatment of fasteners and heat-treating of high performance gears. For each application, heat transfer data, numerical data and process parameters are input into a numerical model. The model is then used to determine distortion or residual stresses.

- **Gas Carburizing By Computer**

The gas-carburizing process provides the best illustration of these developments theoritical explanations for the gas reaction enable engineers to predict and control the carbon gradient in alloy steels[9-12]. This understanding enables design engineers to produce fatigue-resistance parts at lower material cost.

Precise control of carbon profile on the carburized parts is now possible with the advent of this control technology (numerical model). The key control gases (CO_2, CO & other gases) could not be possible to measure accurately and reliably in the parts in industrial heat-treating furnaces. Today, however, infrared analyzers permit continuous analysis of CO_2, CO and other gases. In addition, the introduction of the solid-electrolyte oxygen sensor, which is based on the changes in electrical properties of zirconia in the presence of minute amount of oxygen, permits rapid determination of sensitive carbon-reactive variables. These developments led directly to the application of mathematical model to the carburizing process.

Computerized systems are applied to control the gas-carburizing process, on line monitoring of carbon diffusion into the parts. These systems not only regulate the gas carbon profile but also calculate carbon mass transfer and diffusion. Fig. 3a demonstrates the carbon profile illustrates by comparing the target specified and actual profile during the process, and Fig. 3b produces the carbon profile of steel gears that agree with values predicted by the computer simulation. Carburized parts having this profile provide high fatigue resistance and reproducibility, especially on surfaces requiring grinding after treatment.

This technique is reliable in obtaining the surface carbon concentration and case depth needed to achieve a given carbon content.

Heat Treatment Industry of The Future

The heat treatment industry is recognized as vital part of the manufacturing operation, and is characterized by long-term partnerships with customers, supplier universities and government. To keep a balance relationship with these agencies heat treaters will have to look upon[3]:

- What technological advances will the heat treaters to work with?

- How the technological advances enable heat treaters to meet customers demand while keeping their products competitive and profitable?

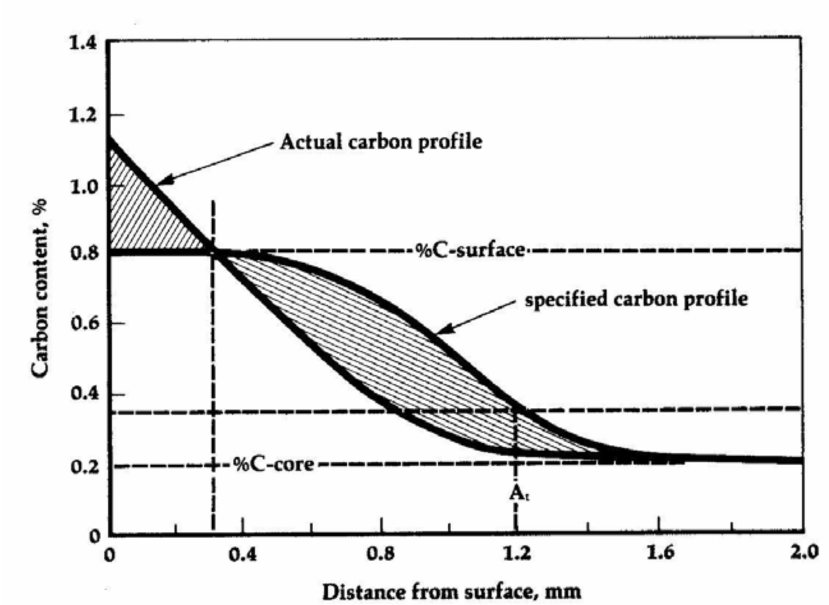

Figure - 3(a): Total Carbon-Profile Control may be Illustrated by Comparing the Target (Specified) and Actual Profiles during the Process. The Shaded Areas Represent the difference between the Integral of two Profiles

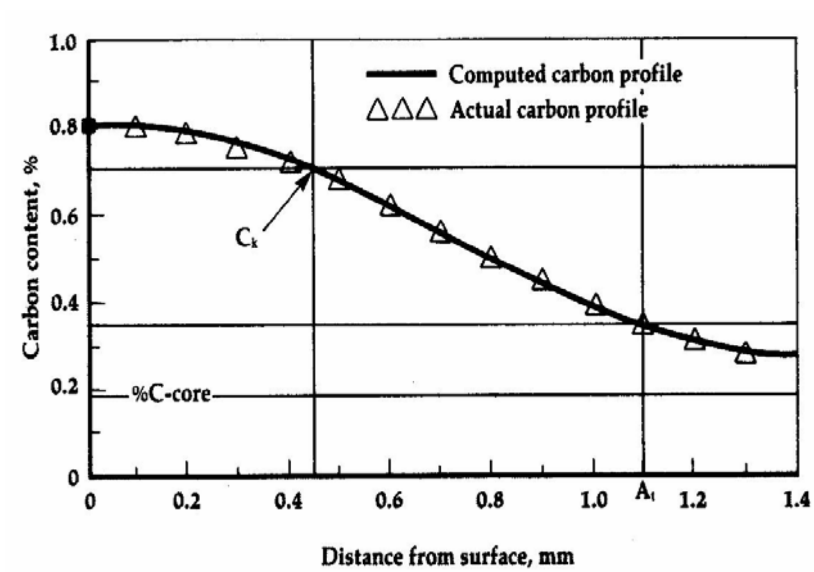

Figure – 3(b): Carbon Profiles that agree with Values Predicted by Computer Simulation, Shown for Steel Gears

A technological road map, describing the specific strategies, needed to be developed and implemented for "A Vision of a Heat Treatment Industry Of The Future".

The heat treaters should have to adopt following strategies for application of advanced technologies:

- **Global Standards**-have to be established for materials, heat treated parts, safety of the work force and environmental friendliness. Standards also to be established for electronic communications enabling quick and reliable transmission of information between the heat treaters and customers.

- **Operations Of Captive Facilities-**are value-added profit center characterized by advanced technology, well trained workers and low operation cost. Large captive facilities have decentralized their heat-treating operation and may include a heat-treating system on each production line. Some of these "in-line" systems are operated by commercial heat treaters on a contract basis. In other capacities, separate heat treating operations are carried out by commercial heat treaters.

In both captive and commercial facilities, higher production reduced energy usage and improved environmental performance has been achieved by means of increased throughput and focused energy processes.

- **Environmental Impact**-of heat-treating should be reduced to zero; completely self-contained, closed loop systems are standards. Quenchant are used should be non-polluting and nonflammable. Emission of chemicals, heat and gases should be eliminated.

- **Government Relationship**-should play their role in terms of tax incentives, availability of funds for industrial growth and modernization, encouragement of bank loans for implementation of advanced technologies.

- **Heat Treating Employees**-means giving some benefits to the heat-treating personnel by providing them safe, clean and comfortable environment. Organizing short courses and training program in collaboration with universities/other educational institutions. Heat-treating companies should recognize that progress is readily needed with educated, confident and flexible people.

- **Materials And Process**-complete technical know-how should be obtained for the part to be heat-treated.

Industry Challenges

The heat-treating industry faces technological, government, profitability, customers, structural and workforce challenges to achieve the set goal.

- **In The Technology Area-**research priorities include developing more efficient furnaces, longer-lasting material for furnace hardware, more precise control of processes, and improved cooling medias. Achievements of these research goals can be accelerated through co-operative projects with federal agencies. Such program would involve industry, technical societies and universities.

- **The Work Force Of The Future**-is another major challenge. The industry must attract people who have the potential to learn and train them to become skillful employees who will hold good jobs in a clean and safe environment. Heat treaters should promote friendly relation with technical societies, trade associations, universities and community colleges for the education of engineers and technicians.

- **Government Regulations & Product Liability-** must be mitigated if heat-treating is desired to be prospersed. Collaboration replaces confrontation to help the industry develop technologies that ensure workers safety and environmental friendliness. Reforms are required so that new products can be developed without the fear of frivolous low suits. This is proper way to reduce the expenses and the industry can be globally competitive.

- **Profitability**-must be improved in order to attract the capital that drives technology advances. This will follow from aggressive research and development program funded by the industry in collaboration with universities and national laboratories.

- **Customer/Industry Relationships-**must be established right from product design phase. The industry must take active part in programs like; helping and providing guideline for selection of materials that low in cost yet develop advanced properties after heat treatment.

• **The Structure Of The Industry**-today's manufacturers is out sourcing parts of the manufacturing process. A possible scenario for heat-treating could be that of specialized segment in the production line. Such as "heat-treating module" could be the complete responsibility of independent heat treaters.

CONCLUSION

• Design of heat-treating processes can be improved and made more efficient through numerical simulation.

• Computer-aided control offers heat treaters the capability to meet the most stringent customer's material-specification requirements.

• Better sensors, improved computer software and adaptive process control permit optimization of heat-treat production.

• With tighter process control, rework and scrap are reduced.

• Computer controls enable workers to work in a clean, comfortable environment. In order to efficiently operate and maintain this advanced equipment, workers will be among the most technologically capable in manufacturing.

• The industry faces significant challenges in areas of training and partnerships. Lack of knowledge about industry by young people may result in a diminishing pool of future work.

• The importance of close working relationship with customers and suppliers must be recognized if heat treaters are to improve the profitability of all product manufacturing.

• Effective solution of the challenges requires collaborative efforts between industry, technical societies, government, and academia.

REFERENCES

1. D.H.Herring, R.Mowry and C.I.Hayes; Advanced Materials and Processes Inc., Metal Progress, p.81, vol. 132(3), Sept. 1987.
2. M.B.Bomba and E.D.Jamieson; Conf. Proc., 13th ASM Heat Treatment Conf. & Exposition, 22-24 Oct., Ohio, 1991.
3. N.B.La Marca and M.S.Handelsman; Conf. Proc., 13th ASM Heat Treatment Conf. & Exposition, 22-24 Oct., Ohio, 1991.
4. T.D.Brown; Conf. Proc., 13th ASM Heat Treatment Conf. & Exposition, 22-24 Oct., Ohio, 1991.
5. T.D.Brown; Advanced Materials & Process, vol. 7, p.14, 1992.
6. L.E.Jones and E.D.Jamieson; Advanced Materials & Processes, vol. 3, p.33, 1990.
7. Lindberg Heat treatment Co. report; Advanced Materials & Processes, vol. 7, p.14, 1992.
8. D.Persampieri, A.S.Roman and P.D.Hilton; Advanced Materials & Processes, vol. 3, p.19, 1991.
9. J.G.Conybear; Advanced Materials & Processes, vol.10, p.38, 1989.
10. B.Edenhofer and H.Pfau; Heat Treat. Met., vol.16 (1), p.22, 1989.
11. K.H.Edler, A.Knierem and J.Mueller-Ziller; Metallurgia, vol. 5(2), p.88, 1988.
12. B.Edenhofer an J.Muller-Ziller; Conf. Proc., 11th Heat-treating Conf., ASM 1988.
13. ASM News Report; Advanced Materials and Processes, vol. 12, p.32P, 1996.