Machine Learning and Shot Peening: The Beginning of a Beautiful Friendship

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A recent research collaboration between TUBACEX and the University of Cantabria has revealed the potential benefits of implementing Machine Learning with Artificial Neural Networks for problem solving, know-how generation, and cost reduction in the metallurgic sector of shot-peened parts.

WHY SHOT PEENING?

TUBACEX is the second largest producer worldwide of seamless tubes in stainless steel and high-nickel alloys. It is one of the few companies that has integrated all production stages including steel manufacturing, hot extrusion and cold rolling of tubes. TUBACEX has industrial facilities in Spain, Austria, India, Thailand and the United States, and a network of commercial offices all over the world.

TUBACEX researchers have been working on the development of new stainless steel tubes for high added-value applications such as boilers for the so-called supercritical and ultra-supercritical thermal power plants. Shot peening the internal surface of these tubes has been identified as the key process for this application because of its ability to improve the mechanical and fatigue behavior as well as the oxidation resistance. These aspects are extremely important under in-service conditions. Two protective mechanisms develop after shot peening: first, a layer of steel with a thickness of hundreds of microns is plasticized, inducing compression stresses that delay or even remove the appearance of fatigue phenomena, and second, the high in-service temperature enhances chromium diffusion giving rise to a Chromium Oxide (Cr_2O_3) enriched layer on the inner surface of the shot-peened tube. This protective layer prevents the formation of iron oxides which tend to exfoliate. Figure 1 shows a picture obtained through Scanning Electron Microscopy (SEM) where the ~100 microns layer formed after shot peening can be appreciated.

Machine Learning
Machine learning is the study of computer algorithms that improve automatically through experience. It is seen as a subset of Artificial Intelligence. Machine learning algorithms build a mathematical model based on sample data, known as "training data", in order to make predictions or decisions without being explicitly programmed to do so. (Source: Wikipedia)

Artificial Neural Network (ANN)
Artificial Neural Network (ANN) is a group of algorithms that are used for machine learning. (Source: Wikipedia)

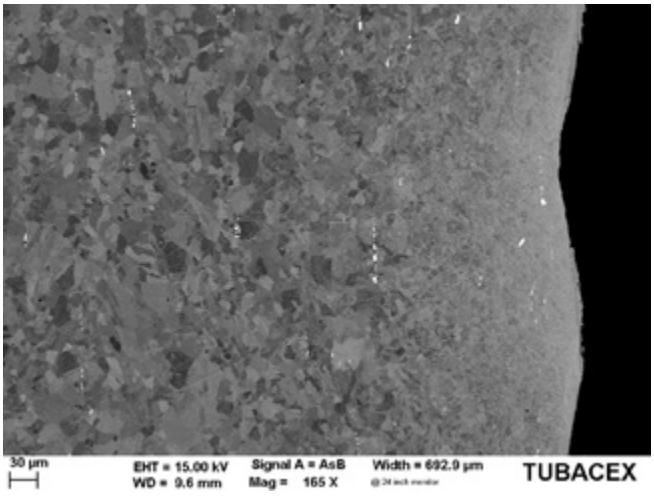

Figure 1.

Considering that the shot used in the process maintains its hardness, grade and size (which is guaranteed through the system of filters of the machine) over time, the outcome of shot peening depends on the four working parameters of the blasting machine, namely, the pressure, shot flow, line speed and rotation speed. A peened tube is accepted if the increase in hardness with respect to the initial hardness of the material (bulk) belongs to a certain interval, which was selected to avoid either underpeening or overpeening. It would be extremely advantageous to have some kind of procedure to estimate the correlation between the processing parameters and the final hardness of the material after peening, thus avoiding the use of resources and time-consuming destructive tests.

THE QUALITY CONTROL OF SHOT-PEENED TUBES

Shot peening is, to some extent, a stochastic process. To ensure the homogenous quality of the final product, a destructive experimental characterization is needed. Thus,

small and randomly selected samples are taken from peened tubes and after a careful preparation, they are subjected to microhardness Vickers tests at a depth of 40 microns from the internal surface of the tube. The increase in hardness from the bulk (not peened) condition is considered as a proxy for the intensity of the shot peening. This process is expensive and time consuming and cannot be implemented online. Our research was aimed at developing a novel inspection device to ensure the full coverage of shot peening on the internal surface of the tubes, and validating a Machine Learning algorithm for the prediction of the microhardness of peened tubes as a function of the manufacturing parameters. Hereafter we will focus on the details of this algorithm.

MACHINE LEARNING COMES INTO PLAY

Two research groups of the University of Cantabria in Spain—LADICIM (Laboratory of Science and Engineering of Materials) and GTI (Group of Information Technologies)—have successfully collaborated with TUBACEX to implement Machine Learning methods as a tool for decision-making during manufacturing. There are many references in the scientific literature that provide details about the local response of a material subjected to the impact of an individual shot as well as the interaction between impacts using statistical and numerical (Finite Element in particular) methods. The importance of this bottom-up approach to provide insight about the physical details of the process cannot be underestimated. However, the extrapolation to the actual fabrication conditions is far from clear. For this reason, our approach has been top-down. The idea is quite simple: a number of parameters are tuned during fabrication, namely, rotation speed, line speed, material flow, air pressure and nozzle size. In addition, the internal diameter of the tubes is also considered as a variable. Due to the intrinsic complexity of the process and the interactions between variables, it is difficult, if not impossible, to quantify the influence of each of these parameters on the final hardness of the tube. This is precisely the type of problem in which machine learning can bring enormous added value. The dataset collected by TUBACEX over the years, including the manufacturing parameters previously mentioned and the final hardness of the material, was employed for the training and testing of an Artificial Neural Network (ANN) to provide the mean and the standard deviation of the hardness for each of the combinations of input variables. This neural network was able to faithfully reproduce the experimental results and, as can be seen in Figure 2, there is a strong correlation between the experimental results and the predictions provided by the neural network.

Machine Learning with ANN seems to be a good and accurate alternative to predict process outputs, based on the inputs (process parameters).

WHAT'S NEXT?

Nobody knows. Accenture, a global services and consulting company, foresees that current AI technology can boost business productivity by up to 40%. According to a recent survey by Deloitte, a multi-national professional services network, machine learning is reducing unplanned machinery downtime between 15-30%, increasing production throughput by 20%, reducing maintenance costs 30%, and delivering up to a 35% increase in quality. Our research is ongoing but the

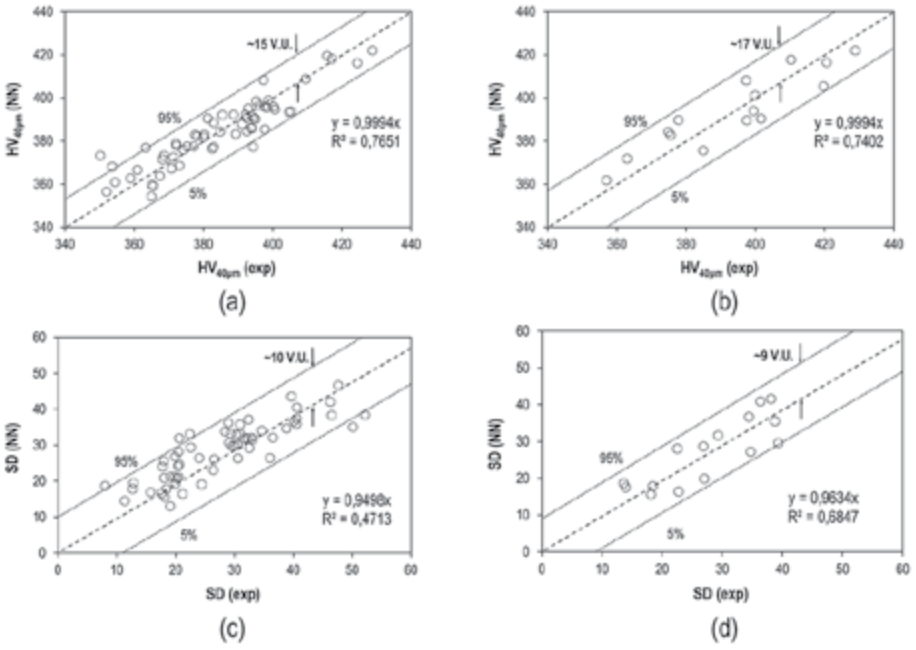

Figure 2.
Comparison between experimental (X-axis) and ANN-predicted data (Y-axis).
(a) Mean values, training data set
(b) mean values, test data set
(c) standard deviation, training data set
(d) standard deviation, test data set

results are already promising. Now, TUBACEX has a tool to predict the final quality of the product in real time and to make decisions during fabrication in order to avoid underpeening or overpeening. Machine Learning provides countless possibilities that are now being explored. Once more, the collaboration between a company and a research group leads to a successful outcome.

About TUBACEX

TUBACEX SA manufactures exclusively seamless stainless steel and nickel alloy tubes and pipes.

The company has its own industrial facilities in Spain, Austria, the USA, Italy, India, Thailand, Saudi Arabia, Norway and UAE; a global distribution network; as well as sales offices located around the world.

The main demand segments for the tubes manufactured by TUBACEX are the Oil & Gas, Powergen and Petrochemical industries, among other industries.

TUBACEX SERVICES is the business unit of the Group devoted to service and customized solutions applied to steel products. TUBACEX SERVICES provide complete project management improving organizational efficiency working in collaboration with key industry stakeholders, cultivating win-win relationships.

One of the main activities of TUBACEX SERVICES is shot peening, applied inside stainless steel tubes. Our experience and know-how assure a complete control on the process and results, always satisfying customer specifications and requests.

This is one of the shot peening machines in the TUBACEX SERVICES facility located in Spain. These seamless stainless steel tubes are specially designed to be used in industrial processes where high temperature, pressure and corrosion conditions take place. Some of these tubes are shot peened and used in industries where those conditions cause a major impact.