June 21, 2011 (Tuesday)   55th EOQ Congress

CONCURRENT SESSIONS — **Tuesday 13:30 – 17:30**

KEMPINSKI HOTEL CORVINUS — **Erzsébet tér 7-8, Budapest V.**

REGINA BALLROOM I.

10.2. INNOVATION AND QUALITY II.

Session Chair: ***Kostas N. Dervitsiotis***, *University of Piraeus, Greece*

15.55 **Examples of Technology to Improve Quality Beginning from Development to Production for Steel Strips**
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He finished studying Mechatronics in Linz/Austria in 1998. He joined Voestalpine Trust in 1998 in a department for development of measurement devices. Since October 1998 he works at Vatron GmbH. Main focus was dealing with optical measurement devices in different rolls: development of source codes and projects, project management for R&D projects, customer care and product management as well as business unit management.

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vatron

Examples of Technology to Improve Quality beginning from Development to Production for Steel Strips

(Dipl.-Ing. Helmut Hlobil, vatron gmbh)

About vatron:

vatron gmbh is a subsidiary of voestalpine and Siemens VAI with headquarter in Linz, where roughly 130 employees work for the company.

Vatron's core expertise is in development, production and start-up of mechatronic measurement and control devices for industrial systems (mechatronics is a symbiosis of mechanical engineering, electronic engineering and information technology).

The high-tech equipment and the many years of experience of our highly skilled employees provide our customers with both standard designs and highly specialised system solutions.

About the author:

Helmut Hlobil finished studying Mechatronics in Linz/Austria in 1998. He joined voestalpine in 1998 in a department for development of measurement devices. Since October 1998 he works at vatron gmbh. Main focus was dealing with optical measurement devices in different rolls: development of source codes and projects, project management for R&D projects, customer care and product management, business unit management.

Introduction:

Improving quality is in general a matter of several stages during development and production. The quality and – which is a precondition for quality – a stable and reliable process observed at the example of the steel industry can be divided in three steps: process and product development; process and product monitoring; laboratory product testing.

The last step – laboratory testing – is time consuming and the results are available with delay. The goal is to avoid these tests. As this is especially in steel industry not possible the aim is to reduce these tests to a minimum and to look for new methods that allow implementing them in line – at best contactless at full production.

The article shows examples from steel industry for all three steps:

1. The example of the annealing simulator "anneal.sim" which allows controlled annealing processes with the feature of freezing the sample for material analysis helps to optimize the production cycle in order to ensure reliable quality.

2. After finding the optimum process parameters with the help of the simulators it is necessary to monitor the production process inline. One example is vatron's inline material steel strip property measurement device "property.mon". Second is watching the side trimming process with the "edge.mon" Edge Inspection System.

3. After production laboratory tests cannot be avoided completely. Innovative measurement devices for material development like checking the retained austenite in samples or quantification of other quality aspects like measuring ferrite particles in the surface dirt of rolled steel strips are used to get important additional information on the product and process.

Simulators for product and process development:

Process simulators are a R&D focus of vatron gmbh. They are a useful tool to develop and improve steel strip quality as well as the task processing the material in a reliable way. Beside alloy components hot rolling, cold rolling, annealing and skin pass are the main process steps influencing the mechanical steel strip properties.

Developing new process recipies on the production plant disturbs the production process. Additionally it is time consuming and – especially for rolling of high alloyed steel grades – it is dangerous for the plant (breakage due to overload). This is an additional aspect for using simulators as a higher relative stress can be reached with it and extreme rolling situations can be simulated.

The philosophy of vatron's simulators is now shown on the example of the anneal.sim-structure, the annealing simulator for structural research support (Figure 1).

Figure 1: Assembly of annealing simulator

The simulator is very well applicable and efficient for studying metallurgical reaction during the annealing cycle. Optimum annealing cycles (in respect to time, heating-up, cooling-down gradients and stability) can be found.

The basic idea of this simulator type is the heat-up by current in the secondary circuit of a 100 kVA transformer under tension. The annealing process is performed in air.

Technical data:

Dimension of specimen:	550 mm x 300 mm x 0,4-5 mm (L x W x T)
Heating rate for reference specimen:	< 60 K/s
Typical soaking temperature:	700 – 880 °C

Cooling facility	*cooling rate* (Figure 2)
Slow gas jet cooling	5-20 K/s
Rapid gas jet cooling	< 120 K/s
Mist jet / spray cooling	< 300 K/s
Hot / cold water quenching	> 1000 K/s
Tensile force	< 20 kN

The facility is equipped with various cooling modules, designed to simulate different cooling methods as used in continuous annealing technology, such as slow gas jet cooling, rapid gas jet cooling, spray cooling, water quenching (water temperature: 20–100 °C).

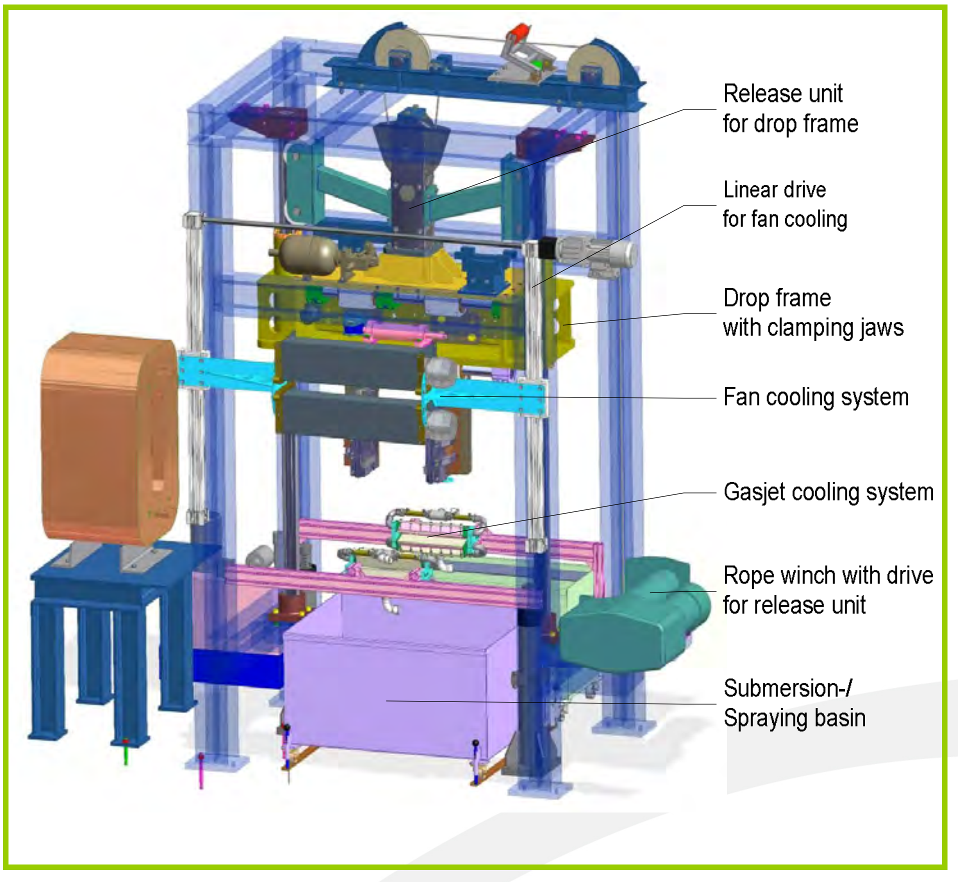

Figure 2: Cooling strategies

With the help of the simulator a lot of different annealing cycles for a certain steel grade can be tested in short time. Additionally it is possible to freeze the microstructure by water quenching at any time of the process. This is an indispensable tool for analyzing the microstructure and the behaviour of the material during the annealing cycle (Figure 3, Figure 4).

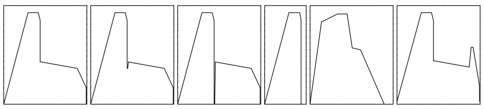

Figure 3: Different heat cycles

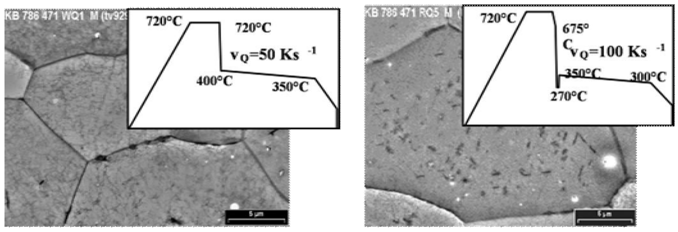

Figure 4: Influence of different cooling rates

Furthermore the anneal.sim-structure is useful for studying galvannealing by performing experiments on galvanized samples from the plant.

Inline monitoring of the production process – measurement of steel strip properties:

Mechanical steel strip properties cannot be measured contactless directly. The method that is used is to measure the magnetic properties of the steel strip. Figure 5 shows the schematic sketch of the used sensor.

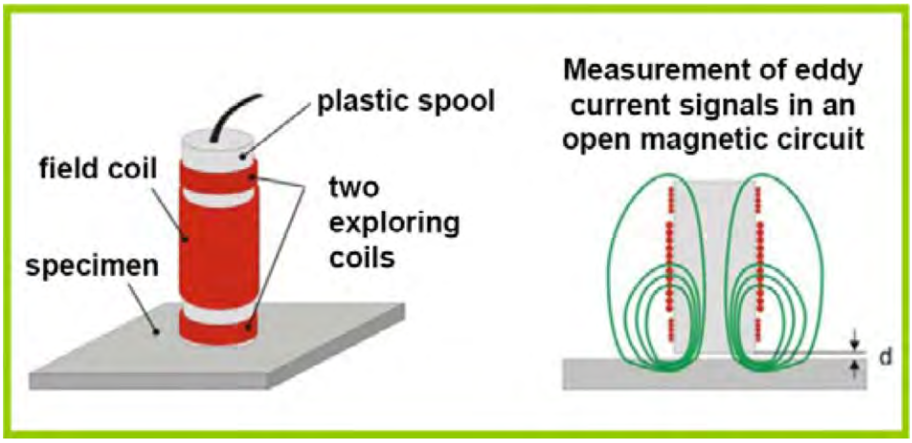

Figure 5: sensor arrangement

It is based on an electromagnetic eddy current principle. The field coil induces a primary field to the steel strip with different frequencies. This is necessary to get response from different depth zones of the steel strip. The steel strip reacts with a distortion of the field that is measured with the two exploring coils. The distortion of the field is depending on different parameters of the steel grade: alloy components, microstructure, dislocation density, residual stress…

This reversal of magnetism (distortion of the field) leads to a secondary field. The time signal of the measurement voltage transformed to frequency spectrum by Fourier Transformation leading to 24 harmonic measurement values representing the magnetic properties of the specimen. The effect used is that there is a relationship between the magnetic properties and the mechanic properties (Figure 6).

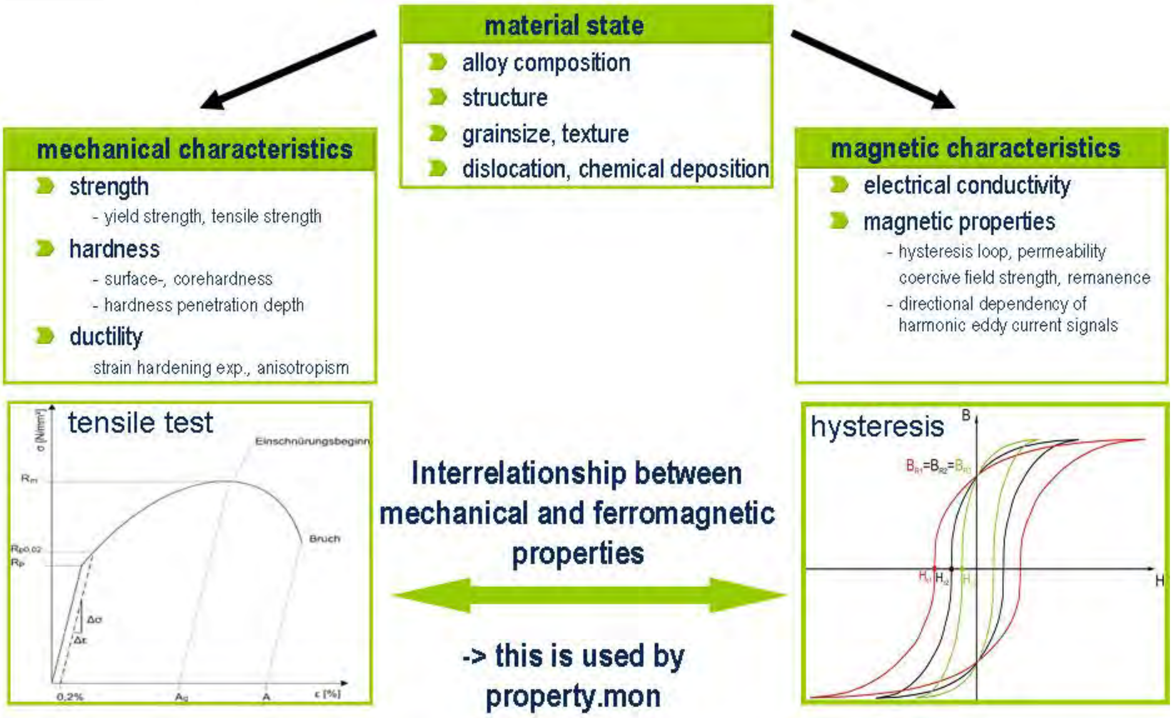

Figure 6: relationship between mechanical and magnetic characteristic

The method of using different frequencies for penetrating the material with the result of 24 harmonic values (used at the moment) represents a big range of the hysteresis loop.

By use of regression calculation in combination with results from the tensile strength test the mechanical steel strip properties can be calculated for the whole steel strip (Figure 7).

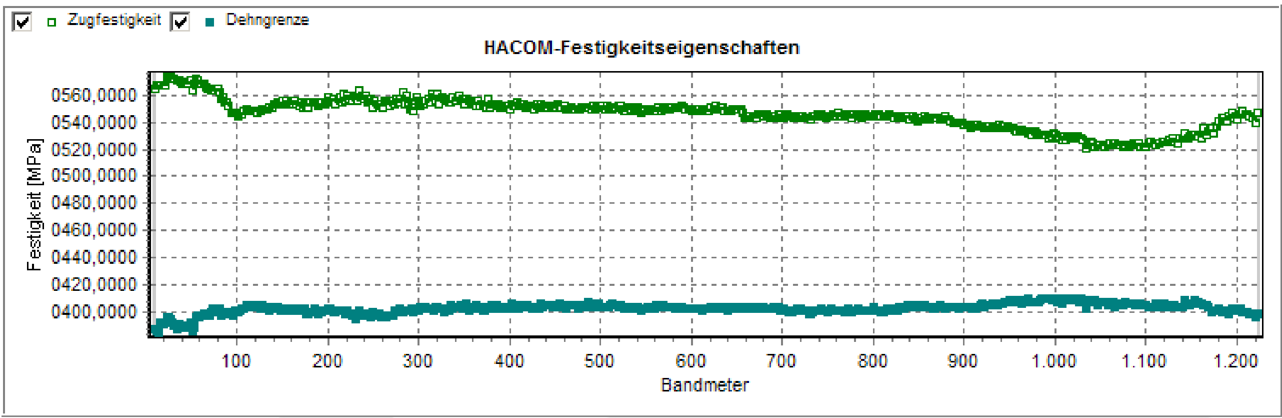

Figure 7: result of measurement

So this is a method where material characteristics can be distinguished where the material has the same remanence inductivity but different shape of the hysteresis loop. This allows measurement without knowledge of process and product parameters. Many testing series on different steel grades and steel thicknesses show the high accuracy of 3 % for tensile strength and 1,5 % for yield strength of the system (Figure 8).

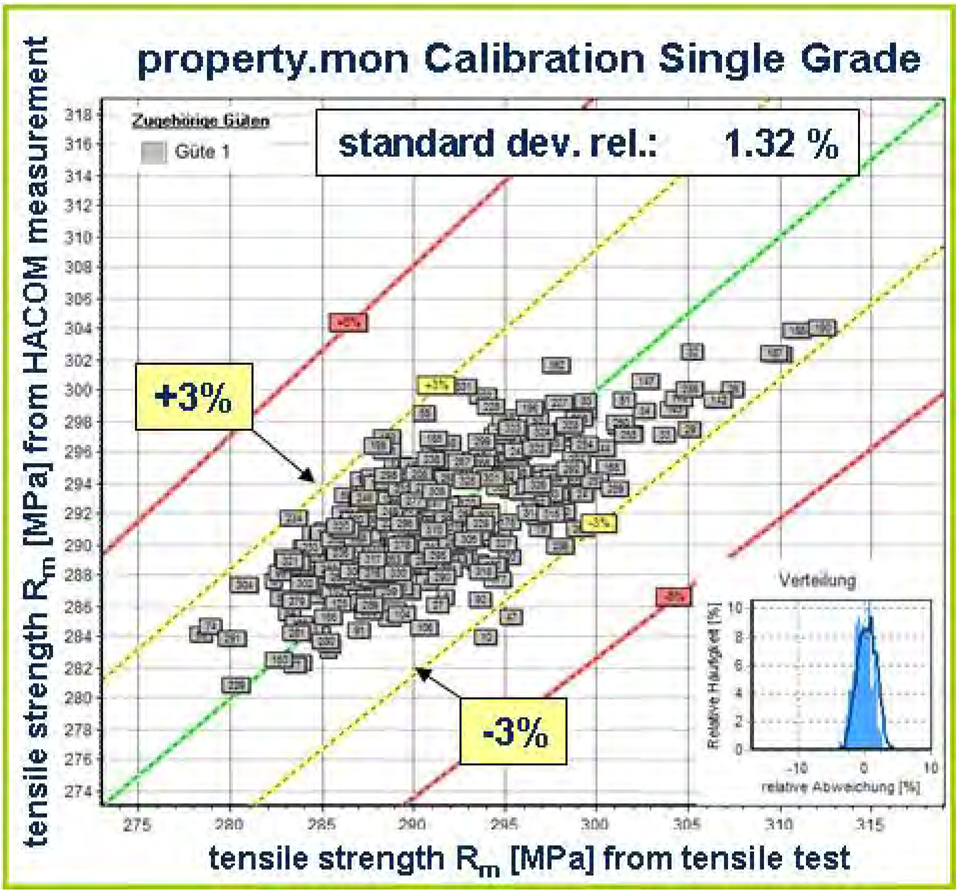

Figure 8: accuracy of tensile strength

This device showed one example for measurement of a characteristic that was not possible up to now. With the help of this device it is now possible to have a closer look at the process. It helps to find relationship between the mechanical steel strip properties and different product and process parameters (alloy composition…, rolling and skin-pass parameters, annealing parameters…).

<u>Inline monitoring of the production process – monitoring the strip edge quality:</u>

The second technology that is shown has a similar background. The process of trimming a steel strip with rotary side trimmers was not monitored up to now. So the setting of the knife parameters (mainly gap and overlap as well as prediction of knife abrasion) is based on individual experience of the operator which is rudimentary documented. Monitoring this process is more and more interesting as the quality demands and the process speeds increase more and more. Bad strip edge quality may lead to defects on process parts (e.g. rubber coated rollers) as well as lower productivity and standstills (e.g. by strip breakage due to knife breakouts).

The system edge.mon is based on a line scan sensor (Figure 9). Target of this development was and is to implement automatic algorithm to classify the trimmed strip edge quality. For this it is necessary to have a defined clipping of the knife independent of the process speed. This is achieved by synchronizing the sensor with the circumference of the trimming share knife.

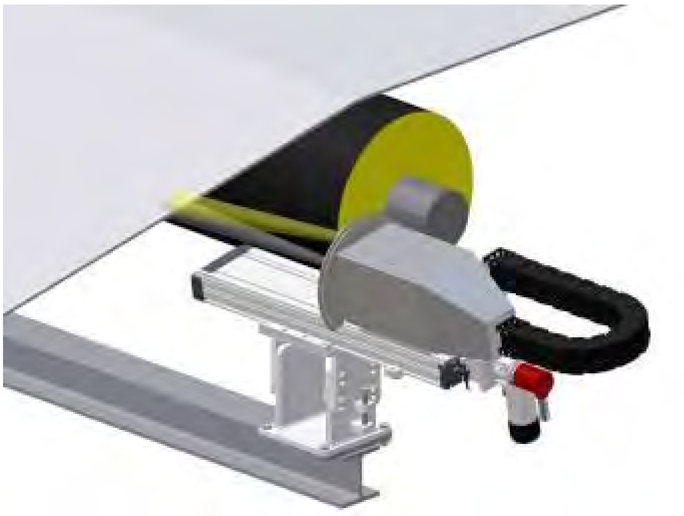

Figure 9: edge.mon sensor for trimmed strip edges

Based on this sensor a PC collects the information of the steel strip edge and processes it with the image processing algorithm. By analysing the behaviour of the (beside others) cutting zone and breaking zone the algorithm delivers values about homogeneity and straightness of this phases. From this decisions about the quality are deviated. With this defects like knife breakouts can be detected as well as general information about the quality of the edge can be deviated (Figure 10).

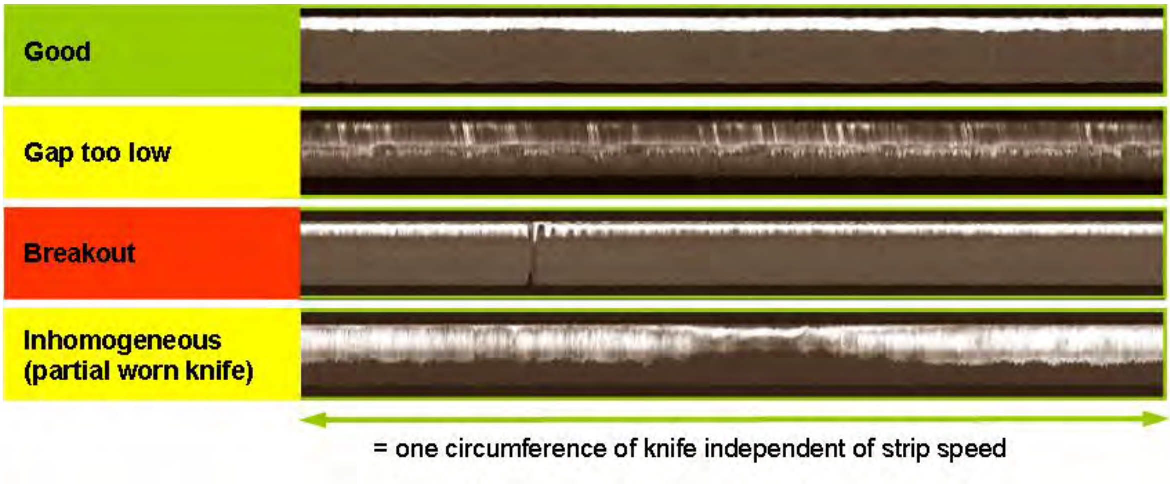

Figure 10: examples of evaluation of strip edge surface condition

With the help of the system it is no more necessary for the operator to have a regular look at the strip edge quality. He now is automatically informed if the quality changes.

So this lowers the effort of the quality assurance employees and allows collecting process data in order to learn more about the process itself with the goal of a lasting improvement.

Laboratory Testing – measurement of retained austenite:

Although technology is very well developed some material characteristics cannot be measured in-line or non-destructive. So laboratory testing is of decisive significance. As they cannot completely be avoided the goal is to get the measurement results in shortest possible time after taking the specimen from the plant.

The following example informs about measurement of retained austenite which is an important value for high quality steel like TRIP-steel (Transformation Induced Plasticity). Here the amount of retained austenite influences the tensile strength.

The application of the magnetic yoke (Figure 11) of vatron is based on the fact that ferrite and austenite differ completely in their magnetic behaviour. Ferrite with its bcc structure is a magnetic material whereas austenite with its fcc-structured atomic lattice is non-magnetic.

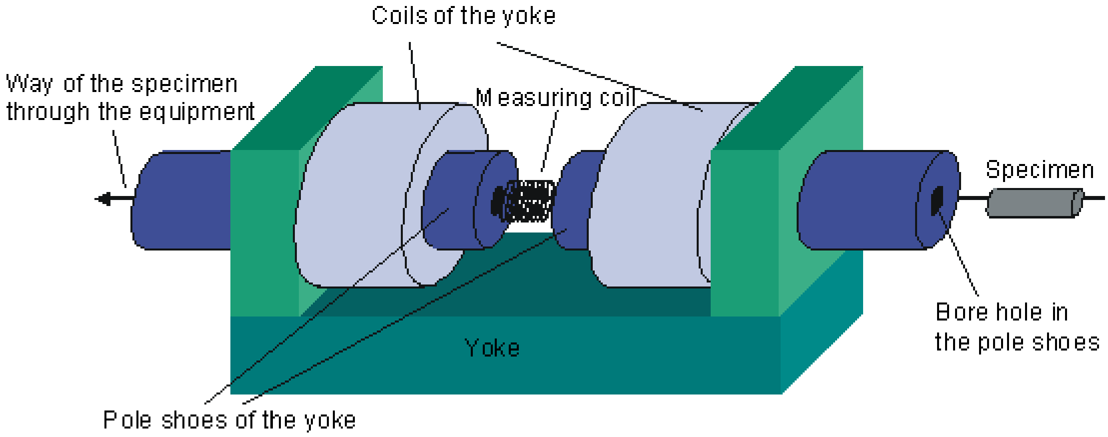

Figure 11: assembly of retained austenite

When a ferrite specimen is brought into a magnetic field it is magnetized. Is this magnetized specimen pushed through a measurement coil a voltage pulse is induced in the coil. The magnetization is proportional to the integral of the voltage pulse.

$$J_m \propto \int U_{ind}\, dt$$

J_m: Intrinsic induction of the specimen

U_{ind}: Induced voltage in the measuring coil

Austenitic material does not show this behaviour. This means the higher the amount of austenite in a sample is the lower is J_m.

So, in the case of magnetic saturation J_m can be used to calculate the amount of retained austenite in the measured samples. For this theoretical intrinsic induction the austenite-free material of the same chemical composition is needed. This can be calculated as follows.

$$J_s^{Fe} - \sum \alpha_n A_n$$

J_s^{Fe}: Intrinsic induction of pure iron in the state of saturation

α_n: decreasing factor of element n

A_n: Amount of the element n in the specimen

The intrinsic induction of pure iron in the state of saturation and the decreasing factors are known from literature. The amount of retained austenite now can finally calculated to:

$$A_{aust}[\%] = \frac{J_s^{Fe} - \sum \alpha_n A_n - J_m}{J_s^{Fe} - \sum \alpha_n A_n} \cdot 100\%$$

A_{aust}: Amount of austenite in the specimen

J_s^{Fe}: Intrinsic induction of pure iron in the state of saturation

J_m: Intrinsic induction of the specimen

α_n: decreasing factor of element n

A_n: Amount of the element n in the specimen

This example shows a physically / chemical effect measurable with magnetic field that was customized to production-laboratory environment.

Conclusion and Outlook:

Development of measurement devices like the example of retained austenite is a recent focus but also an important focus for future: Research and Development must not stop after a method is developed and scientifically defined. It is an important step after the classic research to implement these technologies user friendly for regular use.

The paper showed a chain of different methods of improving product quality beginning from material development, furthermore inline monitoring of certain parameters as well as finalizing with laboratory testing by use of different physical methods (model based control of processes, eddy current signals in open magnetic circuit, image processing, magnetic yoke…). Especially for automotive industry material parameters within smallest possible borders as well as highest quality of surface is demanded more and more. Even for these high developed steel grades it is necessary to increase the output of perfect material. Reliability and degree of automation are on a very high level. But there are process steps that are still not controllable in all parameters. One example is the micro structure in steel. Controlling the process is done by models and procedures examined by trial or simulation because the measurement and control loop is not available up to now.

Besides modelling it will be important for the near future to find new methods to characterise unknown process steps. To be able to improve or control that the first step is to measure the phenomenon to get significant information about the relationship between behaviour and process or product data. This will allow finding new additional control strategies for the production process.

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