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SYSTEMATIC DEVELOPMENT OF NEW STEEL GRADES ON THE BASE OF EXPERIMENTAL SIMULATION[1]

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Abstract

Efficient product and process development is only possible with state of the art equipment. Our target is to identify the most important process steps and separately simulate these steps in a laboratory scale. This modular approach gives an extremely high flexibility for process development. Experimental simulation starts with an analysis concept derived from experience in the manufacture of this steel grade, normative or customer requirements, as well as operational possibilities. A test cast is produced on a laboratory scale and then hot rolled and cold rolled. Thanks to the investments in a technology center, with the simulator equipment for hot and cold rolling / skin passing, annealing and hot-dip coating, it is now possible to close the continuous process chain for steel manufacture in the laboratory. Our target is to identify the most important process steps and separately simulate this step in a laboratory. Considering it the objective of this paper is to demonstrate the benefits and importance of Vatron's simulators. On the client side, the aim is to gain an extensive knowledge of the parameters that define the process. This can even lead to a high reduction of the start up time for new lines, due to preparation of preset parameters from systematic experimental simulation test, and the development of new steel grades.

Key words: Hot rolled; Cold rolled; Annealing; Hot-dip coating.

DESENVOLVIMENTO SISTEMÁTICO DE NOVAS CLASSES DE AÇO BASEADO EM SIMULAÇÃO

Resumo

Produção eficiente e desenvolvimento de processos só são possíveis com a utiização de equipamentos no estado da arte. Nosso trabalho é identificar os passos mais importantes do processo e separadamente simulá-los em escala laboratorial. Esta análise modular fornece uma alta flexibilidade para desenvolvimentos de processos. A simulação experimental começa com análise do conceito derivado da experiência na fabricação de classes de aços, normatização e as necessidades o cliente. Uma gama de testes é produzida em escala laboratorial e então o material é laminado a quente e a frio. Graças aos investimentos em centros de tecnologia, com o simulador para laminação a quente, a frio, recozimento e galvanização, é possível se aproximar da cadeia de processo de fabricação de aço no laboratório. Considerando isso, o objetivo deste trabalho é demonstrar os benefícios e importância dos simuladores Vatron. Do lado do cliente, o alvo é obter um extensivo conhecimento dos parâmetros que definem o processo. Isto pode inclusive levar a uma redução do tempo de start-up para novas linhas devido à preparação dos parâmetros pré-ajustados provenientes da simulação e ao conhecimento e no desenvolvimento de novas classes de aço.

Palavras-chave: Laminação a quente; Laminação a frio; Recozimento; Galvanização.

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1 INTRODUCTION

Efficient product and process development is only possible with state of the art equipment. The aim is to gain a extensive knowledge of the parameters that define the process. This can even lead to a high reduction of the start up time for new lines due to preparation of preset parameters form systematic experimental simulation test.
In order to strength the position there is a clear trend from premium steel producer to build technology center as a core area for development, a research facility equipped to simulate the entire process chain, ranging from the manufacture to processing of steel on the lab scale.

2 METODOLOGY

Experimental simulation starts with an analysis concept derived from experience in the manufacture of this steel grade, normative or customer requirements, as well as operational possibilities. A test cast is produced on a laboratory scale and then hot rolled and cold rolled.Thanks to the investments in a technology center, with the simulator equipment for hot and cold rolling / skin passing, annealing and hot-dip coating, it is now possible to close the continuous process chain for steel manufacture in the laboratory
A geneneral theoretical description of the effects on the material with a mathematical solution is too complex due to nonlinear behavior like phase transformation. Thanks to the fact that all experimental simulation is made with real material the complete investigation range is possible with little specimen quantities.
The specimen can be tested to evaluate their uni-axial properties and forming characteristics. In addition, microstructural evaluation can be done by means of electron imaging techniques (SEM and TEM), X-ray diffraction and internal fricton testing (vatrons carbon.checker):

- Material structure studies
- Metallographic studies
- Texture studies
- Surface investigations
- Magnetic properties
- Mechanical properties (tensile test)

Requirements are:

- Results must be transferable to the industrial situation. Veryfication of test results in line trials ensures the quality and effectiveness of product and process development.
- Specimen size must be sufficient to allow material characterization as well as detemination of application properties.
- Systematic parameter variations must be possible in a very defined way with a high level of reproducibility.
- Testing of process parameters which are not realized on existing lines - giving the possibility of testing very exotic and innovative materials or process steps
- High productivity, which means test runs which are easy to handle for a single operator with high throughput at comparatively low costs.
- Generous installation of sensor equipment that is to some extent not even possible in th industrial line.
- For easy evaluation the measurement values must be stored in a central data base.

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All simulators of vatron are PC-based, which gives a simple setting of the desired test parameters with an intuitive HMI without knowledge of a programming languages. Different test parameters (recipes) can be stored and are ready for use. The PC-based solution allows also easy setup of a connection to the local network. The test data can be evaluated just after the test by researchers from different office workplaces. In the event that site service is required then support via remote control is available.

3 RESULTS AND DISCUSSIONS

3.1 Casting

3.1.1 Casting.sim

The main aim of the casting simulator is to studie the fluid dynamic of the system. Melted steel has a very similar fluid behaviour than water. Therefore the water distribution represents the steel flow in the mold during casting.
Small balls out of different polystyrene are put into the water and are used to help to visualize the fluid dynamics.One side of the mold is made of transparent material and a video system is used to record the simulation.
With this simulator it is possible to achieve valuable information about the steel flow in tundish, SEN and mold to optimize the design of the system. Special steel flow for different SEN designs and SEN immersion depths can be evaluated.
Additionaly typically situations that can be simulated:

- automatic and manual filling of the mold
- casting with different casting speeds
- tundish change (Software simulation)
- breakout situations
- clogging situations

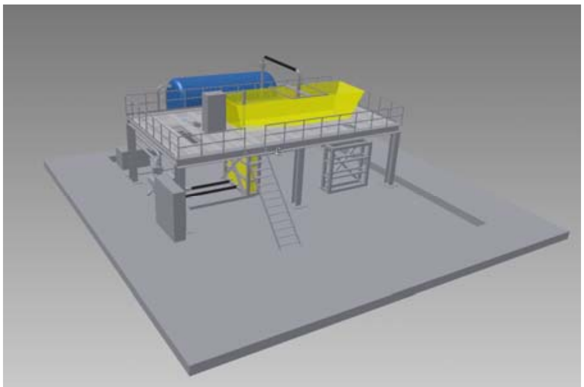

Figure 1. Sketch of water model.

The Water Model is installed into a steel structure and the tundish and mold model will be strengthened with a steel frame.

3.2 Annealing

The annealing process is a very important step in the production of cold rolled or hot dip galvanized steel strip. Beside the mechanical properties determined by microstructure and tecture (Figure) the strip surface is also conditioned.

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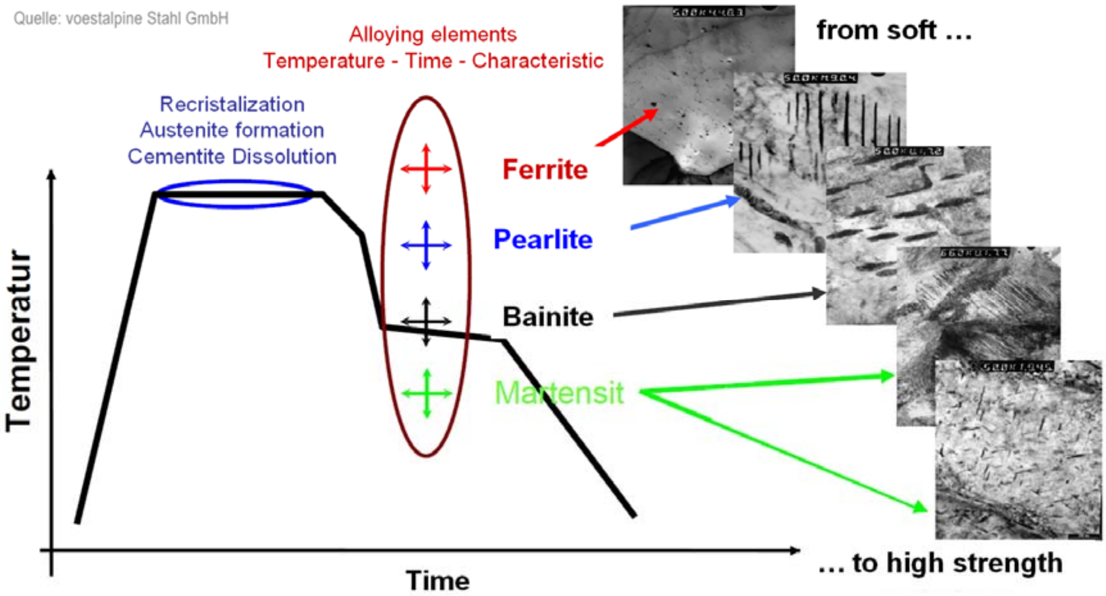

Figure 2. Relationship between chemical composition, heat treatment and resulting micro structure.

The aim is to get an excellent homogeneous temperature distribution on the specimen during heating and cooling. This is more difficult if the specimen is large or of different size.
For simulation of the heating process different methods are possible and used:

- Conductive – fast heating (typical up to 100 K/s for 0,7 mm specimen thickness) with excellent homogeneity in the filet. The specimen is connected as a resistor in the secondary circuit of a powerful transformer and is directly heated by the current. The process computer automatic controls the required electric power by means of a phase-controlled thyristor.
- Hot wall – gas atmosphere at the same temperature as furnace wall like in the industrial plant. The heating tube is made of heat-resistant steel and act as resistor and is diretly heated by current fed by a transformer. No refractory is used.
- Infrared – adjustable temperature distribution by means of an controlled array of quarz-lamps.
- Inductive – often used in industrial lines for fast heating

For the cooling process various cooling modules were designed such as gas jet cooling and quenching. For cooling without protective atmosphere also mist jet and spray cooling as well as water quenching.
For the module water quenching the specimen is mounted on a carriage that can be dropped in to a quench tank with high dipping speed. Thanks to the variabel water temperature up to 100 °C a wide range of cooling rates can be covered.
Over time, vatron developed different annealing simulator concepts to match different customer needs. An overview can be seen in Table 1: “Comparison of vatron annealing simulators”.
All annealing simulators from vatron use several thermocouple elements for automatic temperature control. The thermocouples are directly welded onto the specimen. The actual specimen temperature is measured by this termocouples and used as a feed back signal for the control circuit.
Control is handled by personal computer and programmable logic controller (PLC’s). Thanks to this hardware, it is very simple to feed the desired temperature-time curve and other test parameters in the computer. The complete record of all measured

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values is stored in a database.
Any physically feasible heat cycle can be programmed with the process computer (Figure 3. 3). So a wide variety of possible heat cycles can be simulated with outstanding accuracy.

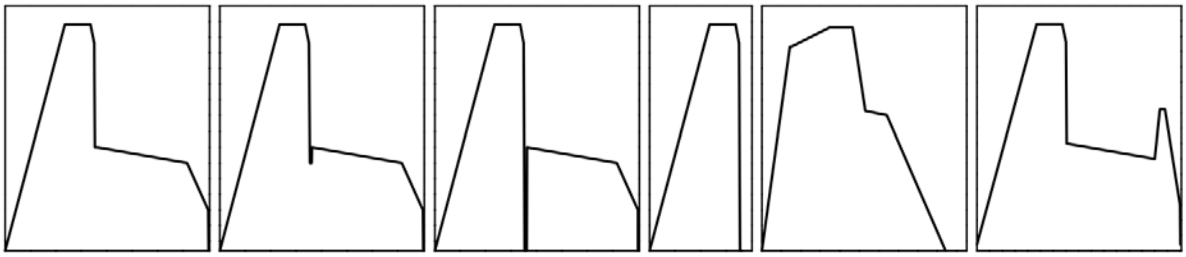

Figure 3. Different heating cycles for continous annealing and hot-dip galvanizing lines.

Table 1. Comparison of vatron Annealing Simulators

vatron Simulator Product Name	Specimen Size [mm]	Process Gas	Heating	Annealing Temp. Max. [°C]	Quench	Controlled Tension
anneal.sim-lab	fixed - 300 x 40	YES	conductive	1.200	YES	YES
anneal.sim-structure	Variable max - 550 x 250	NO	conductive	1.200	YES	YES
anneal.sim-surface	fixed - 340 x 130	YES	Infrared	1.150	NO	YES
galva.sim	fixed - 220 x 130	YES	Infrared Hot Wall (Inductive)	1.000	NO	NO

Source: Internal database.

- **Process gas**
  If annealing is performed in normal air scale will develop on the surface of the specimen.
  If scale is not wanted the use of process gas is necessary. The process gas atmosphere can be chosen from different individual gases like inert gases as well as reactive gases. Possible process gases mixed out of: N2, HNx, (0 … 100) % H2, and Ar. Also, importantly, the dew point can be adjusted over a broad range by means of direct humidification.
  To analyze the process gas a mass spectrometer is used in combination with a dew-point mirror. Thus, real-time measurements can be carried out in different points.
  Additonal the simulator makes a valuable contribution torwards process optimization by determining and controlling the industrial line strip temperature more precisely. By simultanous measurement of the specimen temperature with standard thermocouples and the pyrometer from the industrial line all simulators with process gas also are able to determine the emissivity. Using this specific emissivity data of the relevant steel grade the control models of the industrial plants and thus the quality of the product can be improved.
- **Annealing temperature**
  For the development of some special steels (like silicon steels) an annealing temperature up to 1200 °C is required.

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- **Quenching**
  In orde to gain an in-deepth understanding of the genesis of the final microstructure at any desired point on the temperature-time curve the specimen can be cooled at maximum rates. Thanks to cooling rates up to 1000 K/s the intermediate state of the material can be "frozen". As a result, micro section allows studies of the material structure at the selected temperature-time point to investigate these intermediate conditions.
- **Controlled strip tension**
  On the industrial plant there is always force on the specimen. Strip tension can be adjusted to meet the actual manufacturing conditions.

3.2.1 Anneal.sim-structure

Is a well-proven annealing simulator that can be found in centres for material development of the leading European (Salzgitter, ThyssenKrupp, voestalpine Stahl) and Chinese (Bengang, Magang, Shougang) steel manufactures as well as universities such as TU Munich and Pohang University in South Korea.
This simulator has maximum flexibility regarding the specimen size. The specimen is conductive heated. To feed current to the specimen it is fixed by water-cooled clamps. On the other hand the clamps can be moved by hydraulic pistons so that a defined strip tenson can be adjusted.

3.2.2 Anneal.sim-lab

The new annealing simulator combines ultra compact design, defined strip tension and highly flexible heating and cooling rates. Dynamic conductive heating up to 1200 °C with process gas atmosphere and adjustable dew point over a broad range makes this simulator a first choice for modern steel development. Unique rapid quenching in process gas atmosphere for systematic microstructure studies is realized as well as detection of phase transformations.

3.2.3 Anneal.sim-surface

This simulator is mainly aimed for simulating surface properties as well as the recrystalization process. Therfore the annealed specimen are suitabel for studying surface properties primarily determined by reactions of the strip surface with the annealing atmosphere like phosphatibility, surface cleanliness or elctrogalvanizability. So the gas reaction of the sample covered with emulsion oil and the process gas can be studied directly during annealing by analyzing the process gas as well as the annealing atmosphere from each zone.
To avoid bending of the specimen tension is applied.
Beside the time-temperature cycle the chemical composition of the annealing gas and its dew point during the simulation is essential and can be accurately adjusted. Mixtures between 100% nitrogen and 100% hydrogen can be used and the drew point can range from - 50°C to + 30°C.
The simulator is equipped with a lock to change the specimen without poluting the process gas atmosphere in the other zones.

3.3 Rolling

3.3.1 Rolling.sim-cold

Rolling trials for detailed analysis of the transformations during cold and skin pass rolling are accomplished in batch operation. roll.sim-cold can be operated as a duo- or quarto mill stand (2 high for skin passing, 4 high for cold rolling). The special

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solution employing hydraulic cylinders for adjustable strip tension together with modern control systems leads to tight tolerances in both properties and geometry. Thanks to the special design unique elongation control for skin pass tests is realized. Specimen size is generously dimensioned for technological tests and tailored for samples gained from an annealing simulator to be skin-passed and gained from the hot rolling simulator **rolling.sim-hot** or implant rolling in the hot-rolling mill to be cold rolled to a homogeneous thickness down to 0,23 mm.

3.3.2 Rolling.sim-hot

The relation between the fundamental processes occurring during hot deformation like strainhardening, dynamic recrystallization, static and metadynamic recrystallization, grain growth, straininduced precipitation, etc. can be studied in detail on a laboratory scale.
The coupling of the mill to a runout table simulator adds an additional level of flexibility to the postrolling thermal treatments allowing for a more accurate control of the cooling pattern.
Improved sensors, data acquisition and control systems are installed in order to achieve narrow tolerances in both properties and geometry of the laboratory processed materials.
The high performance hot rolling laboratory mill by vatron allows extrapolating this laboratory experimental conditions to industrial hot rolling to be related successfully to industrial processing conditions (e.g. rolling forces) and final strip or plate product properties (e.g. microstructure, grain size, strength and elongation).

3.4 Galvanizing

To simulate the complete annealing and galvanizing cycle for hot dip galvanizing lines. To special studie the influence of various DFF-treatments like pre-oxidation on galvanizing behaviour the simulator galva.sim can also be used in combination with the anneal.sim-dff simulator. Because of the same sample geometry sample of anneal.sim-dff can be easily processed further with galva.sim.

3.4.1 Galva.sim

To analyse the relationship between heat treatment, gas atmosphere and zinc bath as well as material and surface characteristics.
The simulator has a modular design with differen zones like

- manipulation of the spezimen with bulkheads,
- infrared heating,
- inductive heating (special for galvannealing cycle),
- soaking (hot wall),
- cooling and
- the zinc bath with stirring device and air knifes

on the top of each other.
The specimen is moved up and down by means of a driving mechanism with transport rods between the individual zones.
The zinc is in a pot with bath heating capable for processing various coatings like zinc, zinc-aluminium and zinc-magnesium.
The stirring device allows to simulate the movement of strip in the industrial line. To adjust the zinc layer the wipping pressure and the distance of the air-knifes to the sample as well as the sample speed during passing the wiping system can be varied.

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3.4.2 Anneal.sim-dff

The DFF (direct fired furnace) is a very important step in the hot-dip galvanizing process. In combination with the annealing section it is possible to influence the surface chemistry of the steel surface concerning wettability and reactivity with the Zn-bath.

The simulator enables research on oxidation kinetics of different steel grades in respect to furnace parameter such as lambda, furnace temperature and residence time. According to our recherches the DFF used to be a kind of black box - there was no possibility of simulating this process step in a line-comparable manner.

To optain the desired values e.g. several samples are driven through the simulator at varying lambdas and keeping a constant final specimen temperature.

Oxide thickness can be determined either by pickling in inhibited HCl of galvanostaic stripping (for sample with less than about 0,5 g/m² of oxid).

Exampels of steel research to investigate oxidation kinetics for a rephosphorised IF-steel grade can be found in a paper from voestalpine. The reproducibility was excellent, as can be seen from the parallel specimen and the obtained results clearly showed a drastic increase in the obtained oxide-thickness for lambdas higher than 0,98.

3.4.3 Coating.sim

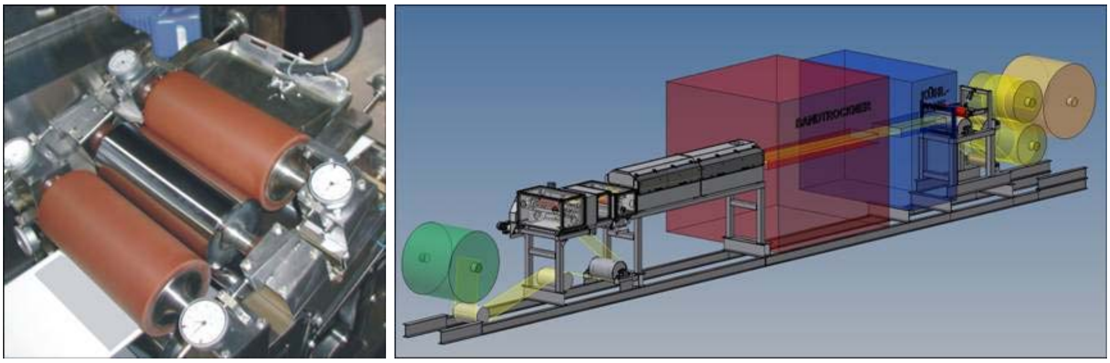

Figure 4. Laboratory Coating & Pilot Coil Coating Plant.

The Laboratory Roll Coater with three Rolls allows both simulation and reproduction of production conditions of a coil-coating-plant on flat probes, testing and optimisation of enamels (groundings and lacquers) and parameters for industrial coating. The flexible fitting of the rolls-execution system makes it possible to integrate them as up- and downside varnished plants in Pilot-Coil-Coating-Plants with on and off reeling, drying and curing units (UV and IR), as well as film lamination. Substances (e.g. undercoats, lacquers, adhesion) can be examined about their coating and bonding abilities. Thereby, necessary settings prior to the bit on the world-scale plant can be ascertained and optimized in the laboratory. The process ensues at the laboratory apparatus through the accomplishment of the probe on a conveyor under the applicator roll. In the Pilot-Coil-Coating-Plant the reel is conducted over a (powered) steel roller and the applicator roll will be pressed on the strip.

- Reverse- and forward-operation mode
- 3-rolls operation mode, simulated and real 2-rolls operation mode (quick adaptation)
- Enamel circulation system allows quick and easy adjustments to coating-thickness and composite
- Reproducibility of the parameters

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- Low effort for service and cleaning because of simple assembly
- Arrangement of EX Zone 1-T3 (optional)

Advantages

- Little amount of enamel necessary
- Testing of enamel at the laboratory
- Research of parameters for industrial use
- Thinnest layer thickness and absolutely homogenous varnish spreading

4 CONCLUSIONS

Vatron gmbh is a daughter company of voestalpine and Siemens-VAI. Mechanical engineering, electronic engineering and computer sciences in perfect symbiosis with focus on steel industrie is the distinctive mark of vatrons solutions and systems.
The company has specialized, for many years, in material development and process optimization by physical simulation and has achieved a position as a innovativ leader. The vatron philosophie is not to build a small copy of the industrial process but to identify the the most important process steps and separately simulate this steps in a laboratory scale. This modular approach gives a extremely high flexibility for process development.