Exploring the secrets of the microstructure of steel

Research partnership: Dillinger decodes the DNA of steel

Dilinger is exploring the secrets of the microstructure of steel. Europe's leading manufacturer of heavy plate steel is fostering research into the microstructure of special steels with an integrated research partnership. Newly developed, sophisticated analysis techniques and simulation methods offer a glimpse into previously unknown depths of the steel microstructure and into the decisive influences on its formation during the production process. The researchers are seeking a new understanding of the interdependencies that will enable them to precisely predict the attainment of increasingly demanding property profiles in extreme high-performance steels – and, subsequently, to implement them in the production of industrial products. This Steel Development 4.0 underpins Dillinger's leading position as an innovation driver in heavy plate production.

In the foundation elements and platforms for offshore constructions, heavy plate steel must deliver decades of unsurpassed performance. Extreme conditions where it is used such as arctic temperatures, high static and dynamic loads make life difficult for the steel. With excellent properties adapted to the specific application, such as customized yield strength, tensile strength and toughness, high-performance plates from Dillinger withstand these continuous loads over the long term. Indeed, Dillinger's reputation as a global quality and technology leader is based on its plate for the most demanding specifications. To continue to fulfil the trust this entails as well as future customer requirements at this level, the long-established company is constantly working to develop new products and innovative processes along the entire value chain. In addition to cutting-edge production facilities and leading processing expertise, this is also demonstrated by the extensive R&D activities of this high-tech steel manufacturer. Whether internally or in cooperation with research institutes and universities all over the world, by developing innovative processes and applying new findings, Dillinger regularly expands the limits of possibility and advances the manufacture of groundbreaking new products.

Since 2015 the company's research partnership with the University of Saarland (UdS) and the Material Engineering Center Saarland (MECS) has been a key focus in the search for new, even better solutions. Dillinger established a three-year strategic partnership then with three institutes for materials science and technology and supported them with almost one million euros. Now the company is continuing this successful cooperation for another three years with follow-up funding in the same amount. The aim of this integrated research project is the systematic enhancement of microstructure-based material design through targeted modelling of microstructures and properties of special steels. The internal composition of these steels is the key to developing innovative property profiles. With an objective understanding of the microstructure and the parameters influencing it, the microstructure can be precisely fine-tuned to the customer’s specific conditions by modifying the manufacturing process as needed. The three participating departments at the University of Saarland are working to develop innovative analysis techniques, simulation methods and material models aimed at continuously advancing this insight into the internal structures. They are integrating these methods and models with each other as well as with Dillinger’s application-oriented research activities. They use simulation to link process phases with the product in order to model the microstructure and thus the desired product properties. The simulation can be achieved much faster in plate production than with real laboratory tests and, most importantly, can be exactly reproduced accordingly. The findings together with knowledge collected over many years and new insights gained through modelling and simulation have resulted in previously unimaginable leaps in development that enable Dillinger to respond to increasing customer requirements more precisely, flexibly and innovatively than ever before. The Department of Functional Materials headed by Professor Frank Mücklich, who has also taken on coordination of the research projects, is dedicated to characterizing and classifying materials. Materials treatment is the focus of research for the Department of Experimental Methodology in Materials Science, headed by Professor Christian Motz. The Department of Engineering Mechanics under the direction of Professor Stefan Diebels primarily focuses its research on mechanical material modelling.

Microstructure classification using machine learning methods

The basis for linking the manufacturing process, internal properties and product properties of steel is the objective description of the microstructure according to composition, number, type and distribution of its components. Prof. Mücklich and his team of researchers are working to decipher the de facto limitless geometric diversity of the structure at the micro and nano level. To get to the bottom of these parameters, the scientists examine the microstructure down to the smallest detail. With reproducible contrasting, they make the microstructure visible and thus enable reliable quantification of the structural building blocks, which contain the history of the manufacturing process from the nanometer to the micrometer range. The analytical techniques developed allow the exact structure of the microstructure to be represented, i.e. the microstructure to be chemically, crystallographically and geometrically depicted, read out and objectively analyzed.

As part of the first funding project, the structure was contrasted, segmented and classified in the upper classes ferrite, perlite, bainite and martensite using appropriately developed data mining methods. The data used for this was based on the individual pixel “environments,” or special geometric features (morphology variants), of the studied components of the microstructure. The analysis method, also developed for systematic and objective evaluation using modern machine learning tools, can now automatically analyze and objectively classify 60 percent of Dillinger steels. In the follow-up project that has now been initiated, the researchers of this department are optimizing and expanding the previously developed data mining concept by focusing on examining and classifying bainitic substructures according to type of structure, size and composition. These substructures are subdivided for this purpose into further subclasses in order to correctly record and classify the tiniest differences in the microstructure. The result will enable automatic classification of a further 15 percent of the steel microstructure.

Using a mathematical model to achieve the ideal microstructure

Professor Motz and his team are using physical process simulation methods to study the influence parameters like chemical composition, heat treatment, process times and rolling temperatures have on the microstructure and thus, ultimately, on the mechanical properties. Using mathematical models, they describe how the structure of special steels changes during the individual treatment steps of the production process. Based on studies of how temperature differences during deformation or different rolling techniques influence properties such as strength, the change in austenite grain size and thus the development of the microstructure is modelled. As part of the second funding project, the development of the microstructure will be extended to include the processes involved in finish-rolling. For selected alloy concepts and process routes, the physical process simulation enables the prediction and control of the austenitic state during the process steps. The simulation is expanded for this by analyzing the size of individual austenite grains, their elongation and their deformation state, thus considerably expanding the range of steels that can be modeled. Dillinger will implement the findings in the rolling model to control the development of the microstructure in the manufacturing process. The resulting understanding of the process parameters and influencing factors is the key that will allow process parameters to be optimized to the properties profile of the steel desired by the customer.

Simulating micro effects to achieve the perfect product

Researchers in Prof. Diebels' department are dedicated to studying the correlation between microstructure and properties in dual-phase steels. This will allow the mechanical behavior of new steel grades to be predicted even while they are being developed. In the first funding project, a method using a mathematical-physical model was developed to describe the flow curve, i.e. the development of deformation of Dillinger steels under load. This phase-related, three-dimensional model based on the microstructure parameters phase fraction, phase size, morphology and distribution determines the macroscopic, mechanical behavior. The follow-up project expands the simulation of micro effects to include effects of grain structure-dominated steels. This requires a finer resolution of the previous phase-based model and inclusion of smaller areas and their individual properties. The prerequisite for this is the imaging of the crystallographic grain structure of the ferrite. To predict its microstructure-dependent properties as accurately as possible, various numerical methods are tested. This makes it possible to simulate the deformations within a grain as well as the interactions with the adjacent grains. The continuous comparison of simulation and experiments guarantees the reliability of this property prediction. This will also make it possible to predict the flow curve for more complex microstructures.

Research Partnership 4.0 as a gain from start to finish

The cooperation between Dillinger and the research teams at the University of Saarland has proven to be beneficial for everyone involved in multiple ways: The systematic enhancement of microstructure-based material design provides Dillinger with an intelligent tool for developing and manufacturing new, exacting special steels. It is an ideal complement to data-based steel design, which is based on experience and references. The microstructure-based design makes it possible to design and implement entirely new properties profiles. Understanding the microstructure and microstructural mechanisms on the basis of new, reliable analysis methods allows the steel manufacturer to use modelling and simulation to test specific properties profiles for their suitability for the application and to design all production steps accordingly. As a result, Dillinger will in the future be able to precisely define the way a special steel microstructure needs to look to remain optimally prepared for applications under Arctic operating conditions, for instance. The close cooperation between science and real-world practice translates the theoretical considerations directly into the application and, conversely, practical results flow directly back into the work of the researchers. Last but not least, the scientific exchange is also accompanied by a transfer of the minds. Numerous graduates and doctoral candidates from the University of Saarland now work for Dillinger and, as a result, continue to drive continuous innovation at the high-tech steel company. Dillinger is consistently expanding its role as a leading European manufacturer of heavy plate with this strategic research partnership and with digital product development.

11.740 Zeichen inkl. Leerzeichen

AG der Dillinger Hüttenwerke

For more than 330 years, Dillinger has thrived on its extraordinary passion for steel. Today Dillinger is propelled by a successful product of enormous weight in the most literal sense: steel, from ore to customized heavy plate and ready-to-install elements. A wide range of experience, strong research and development, continuous investments and a networked ability to innovate make the heavy plate manufacturer a global quality and technology leader with steel grades that are for the most part less than ten years old. With these high-performance materials for applications that require extreme load-bearing capacity under the most adverse conditions, the business units for steel construction, mechanical engineering, offshore, offshore wind power, line pipe, construction machinery, mining or pressure vessel construction are among the preferred partners of the best in the industry.

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Picture 1: Steel Development 4.0: Heavy plate steel of Dillinger are becoming more and more efficient due to the precise predictions of demanding property profiles in extreme conditions.

Picture 2: Through extensive R&D activities and research partnerships with the University of Saarland Dillinger regularly advances the manufacture of groundbreaking new products in its rolling mills.

Picture 3: The continuous caster CC 6 already today underlines Dillinger's leading role in the production of high-quality continuous cast slabs.

Picture 4: Dillinger reviews the new products in the fully automated, innovative steelworks laboratory.

Picture 1-4: © Dillinger

We would be pleased to send you these or other images in printable resolution via email.

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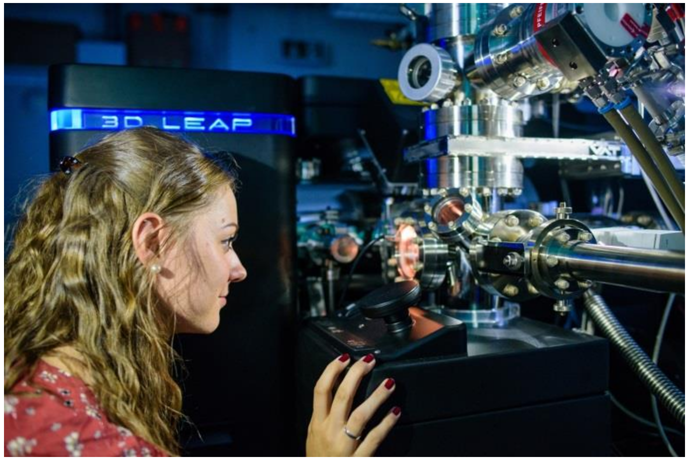
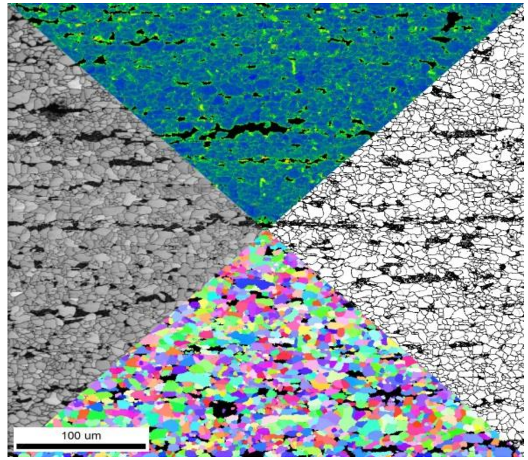
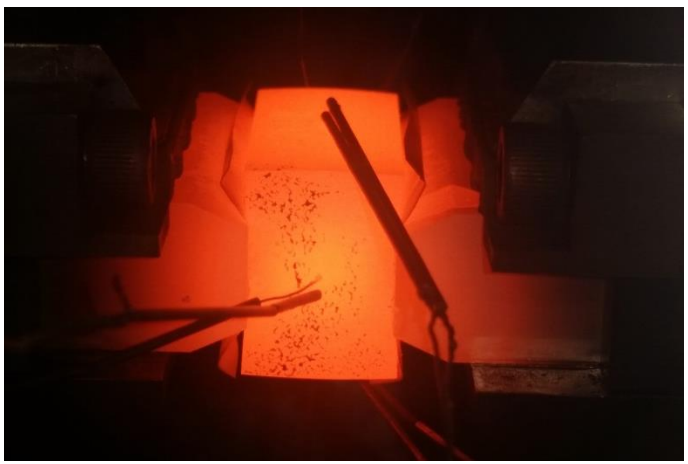


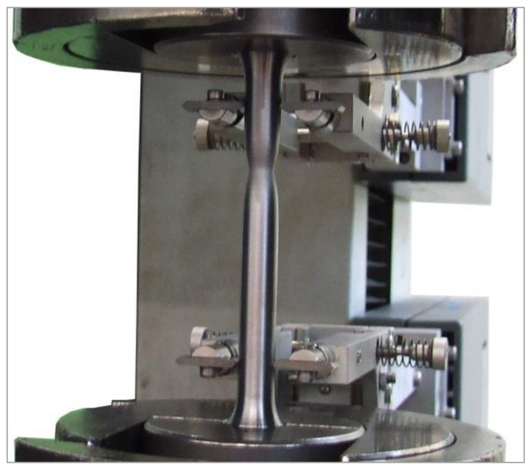
Picture 5: In the research partnership with the University of Saarland the microstructures and properties of steel are examined and made precisely predictable.



Picture 6: This material collage shows different methods for characterizing the microstructure of the steel.



Picture 7: In mechanical experiments, the research cooperation of Dillinger and the University of Saarland investigates influences of parameters such as heat treatment or rolling temperatures on the microstructure.



Picture 8: Material sample during the tensile test: The impending fracture can be recognized by the constriction of the sample.

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