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Alert Application of Flat Products (January 2016)

1. **An efficient modeling technique for analysis of AC field measurement probe output signals to improve crack detection and sizing in cylindrical metallic structures**. A. Khezri, S. Sadeghi, R. Moini, M. Sharifi. Read more
2. **Effect of spectral reshaping on frequency modulated thermal wave imaging for non-destructive testing and evaluation of steel material**. V. Arora, R. Mulaveesala, P. Bison Read more
3. **Multi-objective optimization of a magnetic circuit for magnetic flux leakage-type non-destructive testing**. J. Parra-Raad, S. Roa-Prada. Read more
4. **On-line monitoring of environment-assisted cracking in nuclear piping using array probe direct current potential drop**. J. Yoon, Y. Kim, S. Choi, W. Nam, I. Hwang, L. Bromberg, P. Stahle, R. Ballinger. Read more
5. **Improvement of anti-aging property at low temperature by Cr addition in bake hardenable ultra low nitrogen steels**. N. Maruyama, N. Yoshinaga, H. Sawada, M. Takahashi. Read more
6. **Formation of fine austenite through static recrystallization in low carbon micro-alloyed steels**. X. Shen, S. Tang, J. Chen, Z. Liu, G. Wang. Read more
7. **New interpretation to disputed matter of 300 to 400 degrees Celsius peak in hydrogen-detecting thermal desorption spectrum and potentiality of hydrogen generation through this phenomenon**. Y. Ishiguro, S. Ootsuka, D. Mizuno, K. Fujimura. Read more
8. **An experimental study on the joint structural capacity of RC columns and steel outriggers with steel plate and studs**. H. Shim, J. Lee. Read more
9. **Shear force of headed shear studs, high-strength shear studs and steel plate embedded in concrete: an experimental study**. H. Shim, J. Lee. Read more
10. **Simulation research on microstructure distribution and hardness prediction of boron alloy steel during hot forming**. X. Li, Z. Zhang, Y. Zhao. Read more
11. **Phase transformation mechanism of low carbon high strength low alloy steel upon continuous cooling**. Y. Guo, G. Sui, Y. Liu, Y. Chen, D. Zhang. Read more
12. **Fatigue crack propagation and metallographic mechanism for steel ADB610 welded joints**. T. Zhang, L. Guo, Y. Zhang, J. Shi, R. Xu. Read more
13. **Microstructure and mechanical properties of a TRIP-aided martensitic steel**. K. Sugimoto, A. Srivastava. Read more
14. **Experimental and computational analysis of abnormal grain growth**. G. Pimentel, I. Toda-Caraballo, C. Capdevila. Read more
15. **Describing the deformation behaviour of TRIP and dual phase steels employing an irreversible thermodynamics formulation**. S. Li, P. Honarmandi, R. Arroyave, P. Rivera Diaz del Castillo. Read more
16. **From High-Entropy Alloys to High-Entropy Steels.** Dierk Raabe, Cemal Cem Tasan, Hauke Springer, and Michael Bausch. Read more
17. **Prior austenite grain size and tempering effects on the dislocation density of low-C Nb–Ti microalloyed lath martensite.** S.C Kennett, G. Krauss, K.O. Findley. Read more
18. **Identification of resistance spot welding parameters for ultra-high-strength steels by use of finite element calculations**. F. Schreyer, S. Weihe. Read more
19. **Influence of tailored blanks on forming of cold forged functional elements in a sheet bulk metal forming process**. D. Gröbel, P. Hildenbrand, U. Engel, M. Merklein. Read more
20. **Through process levelling technologies to meet ever increasing demand for final plate flatness**. S. Maillard, S. Samanta, N. Champion. Read more
21. **Microstructure and phase transformation evolution in the SBHS500 steel during TMCP process.** Wei-Chih Chung; Tze-Ching Yang; Ching-Yuan Huang. Read more

22. **Niobium microalloying in the automotive steels for light-weighting.** Dr. Bian Jian. Read more
23. **Fracture mechanics characterization of sintered 30 vol.-% Al2O3 / TRIP steel composites using SENB miniature samples.** Ralf Eckner, Alexander Illgen, Markus Radajewski and Lutz Krüger. Read more
24. **Effect of Ni and Mn on the formation of Cu precipitates in α-Fe.** O.I. Gorbatov, Yu.N. Gornostyrev, P.A. Korzhavyia, A.V. Rubana. Read more
25. **Investigation on new steel grades for construction of wind energy mills for sustainable energy supply**. G. Golisch, S. Münstermann, W. Bleck, S. Ufer, U. Reisgen, P. Langenberg. Read more

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Journal of Nondestructive Evaluation, March 2016

An efficient modeling technique for analysis of AC field measurement probe output signals to improve crack detection and sizing in cylindrical metallic structures. A. Khezri, S. Sadeghi, R. Moini, M. Sharifi

The paper proposes an efficient modeling technique for predicting the output signal of an AC field measurement (ACFM) probe when encountering a fatigue crack in a cylindrical metallic structure. The proposed technique is used to determine the electromagnetic fields around an arbitrary-shape surface crack in a cylindrical metal, induced by a high frequency alternating-current-carrying coil of arbitrary shape. The modeling technique involves two steps. First, the finite-difference method is used to solve the governing Laplace equation inside the crack region. Then, the normal component of magnetic field at the crack opening on the metal is obtained to derive a closed-form solution in the Fourier domain for the regions outside the crack. Experimental and theoretical results associated with prototype ACFM probes confirm the validity of the proposed technique while demonstrating its remarkable computation efficiency. The latter is an important feature of the proposed modeling technique as a fast "forward" solver that results in a remarkable improvement in solving the "inverse" problem required for the sizing of fatigue cracks in cylindrical metallic structures, particularly in real-time applications.

Effect of spectral reshaping on frequency modulated thermal wave imaging for non-destructive testing and evaluation of steel material. V. Arora, R. Mulaveesala, P. Bison

Infrared thermographic techniques show their potential usage for non-destructive testing and evaluation of various materials due to their inherent capabilities such as whole field, non-contact, qualitative and quantitative to detect surface and sub-surface anomalies. This contribution introduces a novel data analysis scheme by spectral reshaping of linear frequency modulated temperature profile captured over a mild steel specimen. Time and frequency domain based processing methods are adopted on the generated temporal thermal data to reveal the hidden defects. Obtained results show the potential capabilities of spectral reshaping based on Gaussian windowed chirp with enhanced resolution and sensitivity for sub-surface defect detection.

Multi-objective optimization of a magnetic circuit for magnetic flux leakage-type non-destructive testing. J. Parra-Raad, S. Roa-Prada

The magnetic flux leakage technique is a widely used method for non-destructive testing of pipe-lines. The inspection of pipelines is typically performed with the assistance of a robotic tool called PIG, which is equipped with an array of magnetic circuits responsible for inducing a magnetic field in the pipeline wall. This magnetic field leaks out of the pipeline wall at the locations where potential anomalies are present. The optimization of the geometrical configuration of these magnetic circuits, as a method to improve the probability of detection of the technique, has been a question of great interest in recent studies. Drawing on the concept of Kirchhoff's laws and the application of the finite elements method, this paper makes use of the forward analysis of the magnetic circuit to suggest a methodology for its design optimization. A lumped parameter model was proposed and calibrated to yield similar results as compared to the finite elements model. Following a multi-objective approach, a Genetic Algorithm was implemented in order to minimize the dimensions of the magnetic circuit while looking at the same time for the maximum magnetic flux leakage at locations with pipeline damage. The optimum design obtained by means of the Genetic Algorithm was experimentally validated. The results demonstrate the superior performance of the optimal magnetic circuit in comparison with two other non-optimal circuits.

On-line monitoring of environment-assisted cracking in nuclear piping using array probe direct current potential drop. J. Yoon, Y. Kim, S. Choi, W. Nam, I. Hwang, L. Bromberg, P. Stahle, R. Ballinger

A direct current potential drop method utilizing array probes with measurement ends maintaining an equalized potential designated as equi-potential switching array probe direct current potential drop (ESAP-DCPD) technique has been developed earlier at Seoul National University. This paper validates ESAP-DCPD technique by showing consistency among experimental measurements, analytical solution and numerical predictions using finite element analysis (FEA) of electric field changes with crack growth in metals. In order to examine its viability as an on-line monitoring of environment assisted crack growth at the inner surface of piping welds, artificial inner surface cracks were introduced in a full-scale weldment mockup pipe and stainless steel metal mockup pipe. The weldment was joined by low alloy steel and stainless steel pipes. The pipes were monitored by using ESAP-DCPD in laboratory environments. Optimization of electrical wiring configuration has produced results with significantly reduced noise for adequately long period of time. Then optimized experimental results were compared with the FEA prediction results for the mockup to show a good agreement. Also a round-robin measurement has been made at three laboratories. It has been found that the developed ESAP-DCPD can detect circumferential cracks with a depth of 40 % of wall thickness in stainless steel with a good detectability for further growth behaviors. For axial cracks, however, the measurements showed poor detectability. Hence the developed ESAP-DCPD system can be used to monitor large circumferential cracks that existing nondestructive examination techniques often fail to detect until leakage takes place.

ISIJ International, December 2015

Improvement of anti-aging property at low temperature by Cr addition in bake hardenable ultra low nitrogen steels. N. Maruyama, N. Yoshinaga, H. Sawada, M. Takahashi

The effect of Cr, Mn, Mo, V, Nb, and Al on bake hardenability (BH) at 170°C and anti-aging properties, i.e. the inhibition of the appearance of yield point elongation (YPE) after low temperature aging, in ultra low N steels was investigated. It was found that Cr addition of 0.5–1.0 mass% apparently inhibit the appearance of YPE after aging for 3.6 ks at 100°C without much decreasing the amount of 2%BH at 170°C. The reason for the inhibition by Cr addition was discussed on the diffusion trap model, by using the interactions among Cr atom, N atom, and vacancy evaluated by first-principles calculation. The estimation indicates that (1) Cr would not inhibit the diffusion of N atoms as a repulsive interaction was expected for Cr–N complexes, (2) a small amount of vacancies introduced by skinpass rolling, which attracts strongly with N atoms, seems to play a main role on the inhibition of the diffusion of N atoms, (3) Cr could retard the annihilation of vacancies which trap N atoms during aging, since Cr atom attractively interacts with vacancy–N complexes. Moreover, the effect of annealing temperature and coiling temperature on bake hardenability was investigated, and the effect was found to be understood by the change of solute N, owing to the precipitation of CrN which has a precipitation nose at 650–700°C.

Formation of fine austenite through static recrystallization in low carbon micro-alloyed steels. X. Shen, S. Tang, J. Chen, Z. Liu, G. Wang

The feasibility of further refinement of recrystallized austenite in a low carbon micro-alloyed steel was investigated through warm deformation of the overcooled austenite followed by reheating to the austenite non-recrystallization region. The results showed that static recrystallization of the deformed austenite happened at a higher degree of overcooling due to the increased driving force by warm deformation. The fraction of recrystallized austenite during reheating increased with increasing degrees of overcooling. After warm deformation at 550°C, the fraction of recrystallized austenite reached about 20.9%, and the average grain size was less than 5 μm. In addition, if a second deformation was imposed to the overcooled austenite at 550°C, considerable recrystallization was activated, resulting in a dramatically higher fraction of recrystallized austenite (94.0%) and a finer austenite grain size of 3.3 μm.

New interpretation to disputed matter of 300 to 400 degrees Celsius peak in hydrogen-detecting thermal desorption spectrum and potentiality of hydrogen generation through this phenomenon. Y. Ishiguro, S. Ootsuka, D. Mizuno, K. Fujimura

This paper provides an answer to the ever-lasting discussion concerning the interpretation of the hydrogen-related peak at 300 to 400°C in hydrogen-detecting Thermal Desorption Spectrum which often appears in a hydrogen-introduced steel sample, particularly which has undergone an outdoor exposure or wet/dry cyclic accelerated-corrosion test and/or by acid immersion. Up to now, the focus of the discussion of the peak has been held with respect to whether the reaction is caused by diffusible hydrogen or not. However, the peak does not correspond either to a typical diffusible hydrogen peak at around 200°C or to a typical non-diffusible peak at over 400°C. Rather, the 300 to 400°C peak in TDS comes from the formation of hydrogen through a rust-related chemical reaction where iron (III) oxide-hydroxide (oxyhydroxide) of goethite "FeOOH" reacts into iron (III) oxide of hematite "Fe2O3". It should be noted that the origin of FeOOH comes from rust which is too small to detect and which, even if you are sure that the surface is perfectly smooth and cleaned off by hand-polishing, is not removed due to deeply-rooted and small diameter rust particles, and cannot be detected by the naked eye. In addition, following on from this new interpretation of the controversial spectrum, this phenomenon is re-interpreted as a new process to produce hydrogen gas, and the potentiality and the mechanism are also discussed.

Materials Research Innovations S8, November 2015

An experimental study on the joint structural capacity of RC columns and steel outriggers with steel plate and studs. H. Shim, J. Lee

The current study investigated loading occurrences within real structures, with respect to components for connecting steel outriggers to reinforced concrete columns, in addition to the materials and sizes of outrigger elements. Four models have been developed for joint structural capacity evaluation of the steel outrigger connection component. Automatic dynamic incremental non-linear analysis was employed for non-linear finite element analyses of the developed models, in addition to experimental testing. Finally, the joint structural capacity of the outrigger was analysed in terms of failure mode, strength, displacement and crack occurrence

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Shear force of headed shear studs, high-strength shear studs and steel plate embedded in concrete: an experimental study. H. Shim, J. Lee

Diverse shear studs and steel plate are frequently installed within engineering structures to increase resistance of external shear force at steel frame and reinforced concrete joints. In the current study, tests were undertaken in order to compare both variable shear stud strength (normal-strength shear studs and high-strength shear studs) and type (normal shear studs and headed shear studs) with steel plate. Results have been evaluated in the context of experimental data, finite element analyses results and the current ACI318-11 code.

Simulation research on microstructure distribution and hardness prediction of boron alloy steel during hot forming. X. Li, Z. Zhang, Y. Zhao
Hot forming of boron alloyed steel is used increasingly to reduce the weight of the automobile and enhance its safety. Hot forming model of partial B pillar is established by using a full coupled metallo-thermo-mechanical model. Based on this model, phase transformation and hardness prediction were studied. The results showed that the cooling rates at top and flange locations were far higher than that at wall A and wall B because of high contact pressure and thickness. Almost full martensite at top and flange could be obtained after quenching 5 seconds. But for wall A and wall B, 15 seconds quenching time was needed to get full martensite. After 15 seconds quenching, the hardness of top and flange was 499 HV, which was higher than that at wall A and wall B.

Phase transformation mechanism of low carbon high strength low alloy steel upon continuous cooling. Y. Guo, G. Sui, Y. Liu, Y. Chen, D. Zhang
The transformation characteristics of low-carbon high strength low alloy steel for various cooling rates were systematically investigated by means of dilatometric measurements and microstructure observations. According to the results, it is recognised that the increase of the cooling rate could lead to microstructure evolution from a mixture of polygonal ferrite, acicular ferrite and bainite ferrite to the dual phase of acicular ferrite and bainite ferrite. The kinetics mechanism of the phase transformation was further studied by a modified analytical phase transformation model, which involves site saturation, diffusion/interface-controlled growth, impingement correction for randomly distributed growing particles. It is demonstrated that diffusion-controlled polygonal ferrite and acicular ferrite phase transformation precedes the interface-controlled bainite ferrite phase transformation. For the diffusion-controlled growth, the transformation is slowed down with the increase of the cooling rate, which prevents the diffusion process to some degree and increases the diffusion activation energy QD. For the interface controlled growth, the interface migration activation energy shows a declining trend with the increase of cooling rate, thus promoting the transformation

Fatigue crack propagation and metallographic mechanism for steel ADB610 welded joints. T. Zhang, L. Guo, Y. Zhang, J. Shi, R. Xu
High-strength steel ADB610 is a low carbon bainite steel and was newly developed in China. Fatigue crack propagation rate experiments and metallographic experiments for butt welded joints of steel ADB610 were investigated. The welding method is shielded metal arc welding. The fatigue crack propagation experiments were done under a constant load using compact tension samples and MTS810 TestStar materials testing facility at the stress ratio of 0·1. Seven data polynomial method was used to calculate fatigue crack propagation rate (da/dN) of each compact tension samples. All da/dN and ΔK of base metal samples, heat-affected zone samples and weld metal samples were fitted, respectively, and the formula based on Paris for base metal, heat-affected zone and weld metal were obtained. Fatigue crack propagation experimental results indicate that fatigue crack propagation rate in base metal is higher than that in heat-affected zone and weld metal, and the one in weld metal is the slowest during the early and middle stage of crack propagation, but during the end stage of crack propagation the fatigue crack propagation rates for the three regions of steel ADB610 welded joints were nearly at the same level with slight fluctuations with each other.

Metallography, Microstructure, and Analysis, October 2015

Microstructure and mechanical properties of a TRIP-aided martensitic steel. K. Sugimoto, A. Srivastava

This paper deals with the microstructural and mechanical properties of a transformation-induced plasticity-aided martensitic (TM) steel that is expected to serve as an advanced structural steel for automotive applications. The microstructure consisted of a wide lath-martensite structured matrix and a mixture of narrow lath-martensite and metastable retained austenite of 2–5 vol% (MA-like phase). When 1%Cr and 1%Cr–0.2%Mo were added into 0.2%C–1.5%Si–1.5%Mn steel to enhance its hardenability, the resultant TM steels achieved a superior cold formability, toughness, fatigue strength, and delayed fracture strength as compared to conventional structural steel such as SCM420. These enhanced mechanical properties were found to be mainly caused by (1) plastic relaxation of the stress concentration, which resulted from expansion strain on the strain-induced transformation of the metastable retained austenite, and (2) the presence of a large quantity of a finely dispersed MA-like phase, which suppressed crack initiation or void formation and subsequent void coalescence.

Materials Science and Technology - Applications of Irreversible Thermodynamics in Metallurgy and Materials Science, October 2015

Experimental and computational analysis of abnormal grain growth. G. Pimentel, I. Toda-Caraballo, C. Capdevila

The mechanisms involved in the abnormal grain growth of the iron based oxide dispersion strengthened alloys are analysed in the present work. Its microstructural evolution takes place at high temperatures (0.9Tm) and is characterised by an initial submicrometre size microstructure and a strong <110>| rolling direction (RD) texture that evolves into a few extremely coarse grains (mm sizes) with <112>|RD orientation. The analysis of the observed grain boundaries has been completed by molecular dynamics simulations. Microstructure evolution consists of an extended recovery process, followed by an abnormal grain growth stage, consequence of the orientation pinning mechanism and the proximity to a symmetric tilt boundary family between the <110>|RD and <112>|RD grains.

Describing the deformation behaviour of TRIP and dual phase steels employing an irreversible thermodynamics formulation. S. Li, P. Honarmandi, R. Arroyave, P. Rivera Diaz del Castillo

The plastic deformation of multiphase steels is described employing an irreversible thermodynamics formulation. Transformation induced plasticity and dual phase grades are described within a single theoretical framework. The approach describes the plastic deformation of each individual phase in terms of the evolution of dislocation density, subject to dissipative mechanisms associated to dislocation generation, glide and annihilation. The collective behavior of the ensemble of phases into a single microstructure is ensured through a self-consistent approach based on the iso-work approximation. The parameterised model shows very good agreement with several alloys studied experimentally and available in the literature.

Steel Research International, June 2015

From High-Entropy Alloys to High-Entropy Steels. Dierk Raabe, Cemal Cem Tasan, Hauke Springer, and Michael Bausch

Inspired by high-entropy alloys, we study the design of steels that are based on high configurational entropy for stabilizing a single-phase solid solution matrix. The focus is placed on the system Fe–Mn–Al–Si–C but we also present trends in the alloy system Fe–Mn–Al–C. Unlike in conventional high-entropy alloys, where five or more equiatomically proportioned components are used, we exploit the flat configurational entropy plateau in transition metal mixtures, stabilizing solid solutions also for lean, non–equiatomic compositions. This renders the high-entropy alloying concept, where none of the elements prevails, into a class of Fe-based materials which we refer to as high-entropy steels. A point that has received little attention in high-entropy alloys is the use of interstitial elements. Here, we address the role of C in face-centered cubic solid solution phases. High-entropy steels reveal excellent mechanical properties, namely, very high ductility and toughness; excellent high rate and low-temperature ductility; high strength of up to 1 GPa; up to 17% reduced mass density; and very high strain hardening. The microstructure stability can be tuned by adjusting the stacking fault energy. This enables to exploit deformation effects such as the TRIP, TWIP, or precipitation determined mechanisms.

Scripta Materalia June 2015

Prior austenite grain size and tempering effects on the dislocation density of low-C Nb–Ti microalloyed lath martensite. S.C Kennett, G. Krauss, K.O. Findley

The dislocation density of two as-quenched and quenched and tempered low-C Nb–Ti microalloyed martensitic steels was measured with X-ray diffraction for a range of prior austenite grain sizes. The dislocation density decreases with increasing prior austenite grain size in the as-quenched condition but the opposite occurs after high temperature tempering. The flow strength of all conditions is a function of dislocation density and follows a Taylor hardening model. The properties are insensitive to Nb microalloying for the two alloys assessed.

METEC & 2nd ESTAD, June 2015

Identification of resistance spot welding parameters for ultra-high-strength steels by use of finite element calculations. F. Schreyer, S. Weihe

A finite element model has been set up in the FE code ABAQUS with sequential coupling of the electro-thermal and the mechanical calculation. By use of this model, temperature profiles, residual stresses and the location of the softening zone were evaluated. The application of the model was performed by an iterative adjustment of the contact resistance being based on experimentally determined potential, current and electrode force curves. Furthermore, the relevant welding parameters causing the formation of the softened zone of the investigated steel 22MnB5 were identified by numerical investigations. Therefore, temperature-dependent mechanical properties like stress-strain curves and thermal conductivity were evaluated experimentally. Finally, the results were compared to welding tests by means of metallographic examinations and hardness indentation measurements verifying the locations of the softened zone and spot diameters.

Influence of tailored blanks on forming of cold forged functional elements in a sheet bulk metal forming process. D. Gröbel, P. Hildenbrand, U. Engel, M. Merklein

To encounter new challenges regarding the economic and ecological aspects of the forming of functional components, Sheet-Bulk Metal Forming (SBMF) has been introduced as a new approach. However, underfilling of the molds used to form functional elements is often observed. One possible solution to this problem is the utilization of locally thickened tailored blanks. In order to investigate possible advantages of this strategy, tailored blanks manufactured by rolling and orbital forming are utilized in a SBMF forging process, which enables the forming of two geometrically differing functional elements. Besides the blank type, material and placement strategies have been investigated in addition. This study reveals that both types of tailored blanks are effective in enhancing the form filling and that the effect is independent from the remaining factors. If the same dead stop is used for all blanks, the initial sheet thickness determined the forming efficiency in this experimental setup.

Through process levelling technologies to meet ever increasing demand for final plate flatness. S. Maillard, S. Samanta, N. Champion

For thick plate levelling, different roll configurations are realized through the use of specific cassettes with different roll diameter and pitch, enabled by an innovative spindle support adaptive design. Apart from the common control of direct hydraulic roll gap and deflection control, individual roll adjustment is the key feature to enable an optimized material path in case of the first solution. For the second solution, the key feature is to minimize deflection of the mechanical components, for a precise management of machine stretch and roll positioning. For both solutions, the intelligent control system along with an adaptation algorithm ensures the precise control of roll gaps, along with individual torque and speed control of each motor, resulting in the best flatness and minimum residual stress in the final levelled product. When implementing these solutions into an existing or new plant, the decision on design selection is made considering the overall manufacturing path for the related product mix. Examples of strategies to master the flatness will be highlighted, considering the various stages of plate manufacturing from rolling, cooling and shearing

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SEAISI Quarterly Journal March 2015

Microstructure and phase transformation evolution in the SBHS500 steel during TMCP process. Wei-Chih Chung; Tze-Ching Yang; Ching-Yuan Huang

The SBHS500 high-performance bridge steel plates produced by thermo-mechanical control process (TMCP) were developed in China Steel Corporation (CSC). This SBHS500 steel is designed as the low carbon bainitic (LCB) microstructure to satisfy the requirement of high yield strength, toughness and weldability. In this research, the TMCP thermal cycles of the SBHS500 steel with various accelerated cooling (ACC) rates and finish cooling temperatures were simulated in the quenching and deformation dilatometer to study the phase transformation evolution of the LCB steel. The result indicated that the lath and sheaf sizes of bainite would be refined using higher ACC rates. Also, the change of ACC finish cooling temperatures led to different morphologies of the micro-phases. The fully bainitic microstructure can be produced under the unique TMCP thermal cycles. The SBHS500 high-performance bridge steel plates were developed successfully by CSC.

Niobium microalloying in the automotive steels for light-weighting. Dr. Bian Jian.

Over the last decades lightweight has become the most important strategy in the car body manufacturing and it can be achieved most economically by using high strength steels in the aspects of material, processing and joining. In some recent car models high strength steels have already reached 80% among which conventional high strength steels like HS-IF, HS-BH and HSLA steels remain to be the most widely used steel grades due to their global availability, reasonable price and easy processing. However advanced high strength steels like DP, CP, MS and press hardening steel will increase application due to their high potential for light-weighting. For the car body engineering mechanical properties like strength and elongation are not solely important criteria. With increasing strength level which generally leads to increase of carbon content other parameters like formability, weldability and crash behaviors of the chosen steel grade become dominate factors to the entire body concept. In order to meet the requirements for the automotive application steel industry has developed appropriate metallurgical solutions to tailor these specific properties. This paper will explain how to use niobium microalloying to optimize automotive high strength steels for an optimum integration of strength, formability, weldability and crash performance.

Materials Science Forum, March 2-15

Fracture mechanics characterization of sintered 30 vol.-% Al2O3 / TRIP steel composites using SENB miniature samples. Ralf Eckner, Alexander Illgen, Markus Radajewski and Lutz Krüger

Ceramic particle reinforced metal matrix composites (PRMMCs) combine the strength and brittleness of ceramics with the toughness of a metallic matrix. In order to use these materials in construction and operational design their fracture mechanical behavior must be evaluated. In this study, a 30 vol.-% Al2O3 reinforced austenitic TRIP steel processed by powder metallurgical technique was investigated using precracked miniature SENB-specimens in 3-point-bending. An elastic-plastic analysis by means of the J-integral method in combination with optical crack observation showed the materials ability of stable crack growth, i. e. R-curve behavior. In addition to the mechanical tests microstructural studies were performed, whereby particle debonding and fracture as well as martensitic phase transformation and crack bridging within the matrix were identified as fracture energy dissipating mechanisms.

Scripta Materalia, February 2015

Effect of Ni and Mn on the formation of Cu precipitates in α-Fe. O.I. Gorbatov, Yu.N. Gornostyrev, P.A. Korzhavyia, A.V. Rubana

Decomposition in bcc Fe–Cu–Ni and Fe–Cu–Mn alloys is studied using statistical thermodynamics simulations with ab initio effective interactions. It is demonstrated that magnetic state strongly affects the effective interactions in these systems, substantially increasing phase separation tendency with magnetization. Simulations show that Ni is promoting precipitation of Cu by segregating to the precipitate–matrix interface, while Mn produces almost no effect distributing more homogeneously in the system. The obtained distributions of Ni and Mn are in good agreement with experimental data.

Metallurgical Research & Technology, July 2014

Investigation on new steel grades for construction of wind energy mills for sustainable energy supply. G. Golisch, S. Münstermann, W. Bleck, S. Ufer, U. Reisgen, P. Langenberg

In regard to the sustainability of future cities, an increase in sustainable energy sources needs to be managed. Therefore, the German government decided on increasing the ratio of green energy up to 20% by 2020. In accordance with this, offshore wind energy parks will be constructed, as they provide the advantage of lasting air cleanliness and preserving natural resources. To ensure construction safety, wind energy mills are constructed using ductile steels of large thickness. Here, an application of high-strength steels provides the possibility of reducing the amount of material while construction safety is still ensured. Considering the long life cycle of wind energy mills' foundation structures and the recyclability of the steel grades used, their construction becomes a relevant factor in reducing CO2 emissions. Furthermore, the use of less material reduces CO2 emissions. Due to existing safety concepts, however, the application of high-strength steels is only conditionally allowed. Thus, the current study concerns the development of a safety concept based on the existing concepts to allow the application of high-strength steels. Furthermore, as the structural steel parts need to be joined, an energy-efficient welding process is utilised: electron beam welding. The structural steel parts and weld joints are investigated with respect to their mechanical properties by analysing their loadability in combination with safety concepts. The load on the material is evaluated to ensure construction safety. In addition to the investigation of safety requirements, the supplied mechanical properties are investigated. As the weld joints show different properties from the base material, the joints are considered the critical part. The joints are investigated concerning strength and toughness. Afterwards the mechanical properties are correlated with the wind energy structures. The prevention of failure is fulfilled when the mechanical properties of the weld joints exceed the required mechanical properties.
