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Book of Abstracts

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REAL-TIME AND CONTACTLESS MOLD THERMAL MONITORING: IMPROVING METALLURGY, QUALITY AND PRODUCTIVITY OF BILLETS AND BLOOMS

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Today the mold thermal mapping technology is typically applied to the CCMs for slabs with solutions based on the installation of thermocouples (TC) or optical fibre cables (OFC), inserted into channels machined in the plate molds. The final installation is complex since every single mold must be machined and the quantity of cables is considerable, making any mold change a complex and time-consuming activity. Extending TC or OFC application to billets and blooms would require invasive and expensive CNC machining of the curved mold tubes. In order to overcome these limits, Ergolines designed a new system based on contactless ultrasound technology, which provides the real-time mold thermal map without the need to machine the copper, offering a new reliable tool also to the CCMs for small sections. By providing real-time data of the thermal distribution of the mold, Ergolines' system can be fruitfully used by the technical personnel to improve the casting practice, the steel quality and the plant productivity.

Environmental aspects / 1

TREATMENT AND DISPOSAL OF Cr(Vl) CONTAMINATED STEEL PLANT WASTE PRODUCTS

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Several disposal options exist for waste products from steelmaking operations. The production of Cr-containing steels requires specific attention since slags and dust generated in melting processes often contain water-soluble Cr(VI). Due to the toxicity of hexavalent Cr landfill options are usually not considered feasible. Regulators apply concentration limits in respective leachates. Important parameter deciding on safe disposal is Cr(VI) which can be manipulated by appropriate treatment concepts and products. KRONOS ecochem is a supplier of iron salts dealing with environmental issues already since 1974. Besides offering solutions for water treatment the company is strongly involved in the cement industry providing products and expert service for Chromate reduction. With MKN Technologies they expanded their field of Fe-salt use to new applications, namely the metal industry with production of FeCr and Cr-alloyed steels. Utilising MKN's stainless steelmaking expertise melting shop processes have been investigated where KRONOS ecochem technology is able to adequately address Cr(VI) issues. After identifying problem zones and determining toxicity levels suitable process steps were developed. Transferring learning points and methodology from cement operations assisted in specifying equipment and procedures needed to facilitate Chromate reduction. This paper discusses how stainless steelmaking dust is successfully treated enabling subsequent safe disposal by landfill. Main focus is given to the sustainability of Cr(VI) conversion, user-friendliness of the process and economical attractiveness of the entire concept.

Environmental aspects / 2

ENERGY AND ENVIRONMENTAL SOLUTIONS FOR STAINLESS STEELMAKING: SUCCESSFUL PROJECTS & INNOVATIVE PRODUCTS

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Environmental protection and energy efficiency have become a decisive factor for steel producers over the recent years. Existing as well as new plants have to comply with the most stringent environmental regulations set by national and local governments. It is a global trend that emission and energy efficiency standards are lowered worldwide. Primetals Technologies has a vast experience in the area of gas cleaning and waste heat recovery from off-gases to comply with all actual standards for revamp as well as greenfield projects under the constraint of cost efficiency and minimum operational expenses. The paper discusses the integration of an AOD in an existing steel plant in Slovenia with special focus on the off-gas de-dusting system including a novel gas cooler. Also a waste heat recovery project based on an innovative hot water cycle for internal heat usage of an Italian EAF based steel mill will be introduced. A new innovative bag filter system based on concrete structure which features extremely low dust as well as noise emission levels at minimum ID fan power consumption will be presented. Furthermore, know-how based solutions which incorporate various energy efficiency measures across the gas cleaning plant and linking the de-dusting operation to the steel production will be introduced. Such digitalization approach either reduces the energy consumption or increases the suction capacity.

Metallurgy / 3

ADVANCED TECHNOLOGIES FOR CONTINUOUS BRIGHT ANNEALING OF STAINLESS STEEL STRIP PRODUCTS IN PURE HYDROGEN ATMOSPHERE

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Stainless steel strip products have a variety of challenging applications in different market segments.
Depending on the application of the final product, different heat treatments concepts are required to achieve the target properties required by customers in the most cost-efficient way.
This paper reviews the versatile heat treatment applications of continuous bright annealing lines operating under pure hydrogen process atmosphere.
Typically, such lines are used to process various stainless steel grades or special alloys with austenitic, ferritic or martensitic microstructure, whose alloying elements (Cr, Ni, Mn, Ti, Mo, etc.) have a high affinity to oxidation and are therefore heat treated in a hydrogen atmosphere with lowest dewpoints to maintain a brilliant surface finish.
The product portfolio to be processed via such a continuous bright annealing line ranges from foils with 0,02 mm thickness up to heavy gauges with 4,5 mm thickness. So many different market segments can be served.
The paper will give a practical overview of typical use cases, challenges and benefits of such lines in different market segments, such as
• Classical austenitic, ferritic, martensitic grades with highest production rates
• Precision strips with focus on ultra-thin gauges
• Ni-base alloys with highest peak metal temperatures

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TIME-TEMPERATURE-PRECIPITATION AND PROPERTY DIAGRAMS FOR THICK-WALLED DUPLEX STAINLESS STEEL

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Duplex stainless steels consist of almost equal amounts of austenite and ferrite due to their chemical composition and thermal history. The balanced microstructure of austenitic islands embedded in the ferritic matrix is achieved by solution annealing followed by water quenching to room temperature. Thick-walled plates have locally fairly wide austenite spacing as compared to thin sheets. This can have a negative effect on the mechanical properties and make the material more sensitive to hydrogen induced stress corrosion cracking (HISC) in subsea applications or pressure vessels. As sigma (σ), chi (χ) and R phases, secondary austenite (γ2), nitrides and carbides form at elevated temperatures; the long-time service temperature for these alloys is limited to maximum 250°C (TÜV) or 315°C (ASME BPVC) depending on which standard is used. These alloys may, however, also be subject to elevated temperatures for longer time during processing, particularly in the heat-affected zone while multipass welding. The sensitivity to precipitation of carbides or nitride and formation of intermetallic phases is thus of vital importance for optimizing the fabrication. A newly reported arc heat treatment method was employed to thermally age discs extracted from a 30 mm thick 1.4462 / UNS S32205 plate. The discs were heat treated for different times using a stationary tungsten inert gas (TIG) arc to generate a steady-state temperature field from ambient to melting temperature. The resulting microstructure was investigated using light optical microscopy (LOM), scanning electron microscopy (SEM) and micro-hardness testing. Sensitization of the microstructure was confirmed by etching in oxalic acid. The experimental results were compared to thermodynamic calculations using JMatPro. Finally, time-temperature-precipitation and property diagrams were created.

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APPLICATIONS OF X-RAY DIFFRACTOMETRY ON PHASE QUANTIFICATION IN STAINLESS STEELS

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Performance of stainless steels (SS) is a direct function of the microstructure, and phase quantification is an important experimental procedure for microstructural characterization. X-ray diffratometry (XRD) is widely used in phase identification of SS, and analysis of the diffracted intensity peaks of the phases allows the determination of their volume fractions. X-ray diffraction patterns using as X-ray sources of copper or chromium targets were obtained from two different SS. The first group of samples are composed of a duplex stainless steel (DSS) solution-treated at three different temperatures, in order to obtain different ferrite-to-austenite volume fraction ratios. The other group was composed by quenched and tempered samples of a supermartensitic stainless steel (SMSS) with different amounts of retained and/or reversed austenite. It was found that copper source of X-rays results in better quantification of phases for both SS studied. However, the technique was influenced by crystallographic texture in DSS phases quantification; in the absence of marked texture, XRD results in quantification similar to other techniques. Only SMSS samples with higher amounts of coarse reversed austenite (in this case, samples tempered for 2 h at 625 or 650 °C) could have austenite partially quantified, being magnetic measurements a better indirect technique for quantification of phases in SMSS.

Simulation and modelling / 6

THERMO-CALC® AND DICTRA® SIMULATIONS OF THE SOLUTION HEAT TREATMENT OF SUPERDUPLEX STAINLESS STEELS

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The aim of the present work is to perform computational simulations of the equilibrium and phase transformation kinetics of a superduplex stainless steel UNS S32750 in two different heat treatment cycles: i) during heating to 1250°C from its initial duplex condition, or ii) during heating at temperatures for duplex structure from the equilibrium microstructure obtained at 1250°C solution treatment. Thermo-Calc® and DICTRA® simulations were executed, as well as the experimental validation in the laboratory of the results of these simulations. The experimental validation showed, by quantitative stereology, that equilibrium phase fractions stabilize after 30 min of heat treatment in both heat treatment cycles, reaching 71% of ferrite in cycle "1" and 51% of austenite in cycle "2", validating the kinetic simulations concerning phase fractions. However, simulations showed that during heat treatment cycle "i", although ferrite fraction stabilizes between 100s and 1000s (16 min), chemical elements took 2160s (36 min) to come into equilibrium in ferrite, and 36000s (10h) in austenite, indicating that equilibrium is only fully attained long after the phases' fraction stabilizes, a fact which the experiments are not able to detect. The geometric model that simulates planar grains and considers only the main chemical elements of interest is the one that best describes the experimental results.

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DICTRA® SIMULATIONS OF SIGMA PHASE FORMATION IN DUPLEX STAINLESS STEELS

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In duplex stainless steels (DSS) the desired microstructure after solution heat treatment is a ferritic matrix with austenite islands, maintaining approximately equal amounts of both phases. However, during several manufacturing processes, such as welding, the formation of deleterious phases could happen, and the one of greater influence is the sigma phase, resulting in loss of corrosion resistance and toughness. The present study worked on developing DICTRA ® simulation models that could describe the volume fraction of sigma as a function of the aging time of DSS, obtained in previous experimental works of these research team. Simulation models analysed have planar or spherical symmetry with different dimensions for ferrite and austenite. It is concluded that the simulation model which best describes the formation of sigma phase is a spherical configuration with austenite in the centre, surrounded by ferrite, placing sigma as active phase between the two former phases with negligible thickness. It was assumed ferrite and austenite volume fractions and compositions as the same obtained in Thermo-Calc ® equilibrium calculations of the solution treatment temperature, and sigma phase composition as obtained in equilibrium simulation at the aging temperature studied.

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RELATION BETWEEN PITTING POTENTIAL AND PREN VALUES FOR FERRITE AND AUSTENITE IN DUPLEX STAINLESS STEELS

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Duplex stainless steels (DSS) are composed of ferrite and austenite in approximately equal amounts combining properties of both phases. Pitting Resistance Equivalent Number "PREN" is a theoretical way to measure pitting corrosion resistance of steels based on the composition of the material. Nevertheless, in a duplex structure the alloy elements may be partitioned between the phases resulting in different PREN values for α and γ. This work aims to investigate the relation between PREN of α and γ and the pitting potential of UNS S31803 DSS, solution-treated between 1040 and 1150 °C, generating samples with different α and γ fractions and, consequently, different alloy element partition between ferrite and austenite. Thermo-Calc ® thermodynamic simulations were performed to predict the chemical composition of each phase allowing the PREN calculations. Potentiodynamic polarization tests were conducted in 0.6M NaCl solution at 70°C for pitting potential (Epit) determination. It was found that increasing solution-treatment temperature leads to the increase of ferrite volume fraction, as predicted by Thermo-Calc ® . However, as ferrite volume fraction increases, its PREN decreases due to the alloy elements partition. Opposite behavior is observed for austenite, but the increase of PREN is less significant for this phase. The increase of ferrite volume fraction leads to the decrease of Epit, and this may be related to the decrease of Cr and Mo content in α phase that reflects directly in PREN.

Applications / 9

APPLICATION OF HIGH STRENGTH DUPLEX STAINLESS STEEL WIRE FOR OFFSHORE FISH FARMING CAGES AND GEOLOGICAL PROTECTION SYSTEMS

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In the areas of protection against falling rocks and the protection of fish in aquaculture, there are good opportunities for the use of stainless steels to ensure a sustainable use of materials. As a result of increasing needs and shrinking resources, aquaculture is gaining progressively significance in the recent years. Ecological issues such as negative effects on the ecological system due to the high fish density in the farms, the use of textile/polymer material for the nets and copper as antifouling strategy etc. are very present, particularly regarding the increasing number of fish going to be produced in farms in the future. Current trends focus on larger farms operated offshore. To make these farms working safe and economical, reliability has to be improved and maintenance costs need to be reduced. Also, alternatives with higher mechanical strength compared to current textile net materials as well as common metal wires might be necessary. The first part of this work shows the development and application of a new material system from high strength duplex stainless steel wires as net material with environmentally compatible antifouling properties for off-shore fish farm cages. Therefore, current net materials from textiles (polyamide) shall be partially replaced by high strength duplex stainless steel in order to have a more environmentally compatible system which meets the more severe mechanical loads (waves, storms, predators (sharks)). With a new antifouling strategy current issues like reduced ecological damage (e.g. due to copper disposal), lower maintenance costs (e.g. cleaning) and reduced durability shall be resolved. High strength steel wires are also widely used in geological protection systems, for example rockfall protection or slope stabilisation. Here normally hot-dip galvanised carbon steel is used. But in highly corrosive environments like coastal areas, volcanic areas or mines for example, other solutions with a high corrosion resistance are necessary. Protection systems made of high strength duplex stainless steel wires enable a significantly longer service life of the protection systems in thus a higher level of security.

Simulation and modelling / 10

UNDERSTANDING AND OPTIMIZING AOD PROCESS WITH CFD SIMULATIONS

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Numerical simulations like CFD and FEM have constantly evolved in the last decades and nowadays play an important role in the design and development of modern steelmaking converters. Although the flow inside the converter is highly complex and comprises a whole lot of physical phenomena like chemical reactions, heat transfer and the flow of gas bubbles in the liquid melt, it's possible to capture major effects for the design of new converters with modern simulation tools. It is well known that the decarburization reaction is strongly influenced by the partial pressure of CO. To ensure a low partial pressure of CO a flat bath design with low bath height shows advantages. On the other side the bath height needs to be sufficient to ensure sufficient time for the reactions of the rising gas plume with liquid melt as well as proper mixing. Primetals Technologies has used extensive numerical simulations to compare various bath geometries for a 120t AOD to improve bath mixing and the interaction between slag and steel phase. As a result an optimized flat bath geometry could be found for both good decarburization and reduction reactions. Within its continues improvement initiative Primetals Technologies has also optimized its bath blowing equipment including the valve station, the process media supply as well as the automation and control concept.
In this paper the most important aspects of numerical modelling the flow and mixing inside an AOD converter are described, followed by a detailed comparison of different vessel geometries and presentation of an optimized version.

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MAGNETIC EFFECTS ON AUSTENITIC STAINLESS STEELS AFTER A LOW TEMPERATURE CARBURIZATION

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Austenitic stainless steels have a very good combination of mechanical properties e.g. formability associated with corrosion resistance. Due to the cubic face-centered lattice at room temperature, these steels are not magnetizable and a conventional hardening is not possible. Due to the low hardness, these steels are not optimal for tribological stress and in many cases show low performance. Therefore tribologically loaded components made of these steels, are often treated with a low-temperature carburization for surface hardening. Carbon atoms are embedded on interstitial places and generate an expanded austenitic lattice, also called expanded austenite or S-phase. The corrosion resistance is not affected by this treatment. Some stainless steels show magnetic effects after this heat treatment. The aim of this work is a better understanding and sourcing of these effects. The investigation includes different stainless steels which were treated with a low temperature carburizing process for various times. To evaluate the layer formation, metallographic cross-sections were prepared and examined by means of various etching methods on a light microscope. In addition, hardness profiles and the magnetic properties were measured. To get some more information about the lattice properties the determination of the lattice expansion took place with XRD measurements and also with EBSD.
In order to determine the magnetizability, measurements were made with the Fischer Feritscope and also SQUID measurements. The structure of the magnetic layer was determined by MFM measurements and ferrofluid (Fe3O4-Suspension). In order to determine more precisely the possible reasons for the formation of these magnetic effects, further examinations with TEM and SANS are required. There is a relationship between the alloy composition of austenitic

stainless steels and the magnetizability after the low-temperature hardening, as can be seen in the classification of the materials in the Schäffler diagram.

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PITTING SUSCEPTIBILITY OF METASTABLE AUSTENITIC STAINLESS STEELS AS A FUNCTION OF SURFACE CONDITIONS

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The influence of surface roughness and local defects on pitting susceptibility of type 304 (UNS S30400) and type 301 (UNS S30100) in chloride solution were investigated. Because the mechanical properties can be regarded as decisive for the aachieved surface quality, different properties of the base material were obtained by cold rolling the metastable austenites. This was done before the surfaces were finished. Therefor the surfaces were treated by different grinding parameters to generate different surface conditions and different defects. As a reference, different standardised surface finishes were used. By using and comparing different methods for the characterization of surface roughness and surface texture, it is possible to find a relationship between the quantity and characteristics of local defects on the one hand and pitting susceptibility on the other hand in some processing methods. The automated application of software-based solutions for estimating the pitting susceptibility of machined surfaces and components will be discussed using concrete examples.

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THERMOKINETIC SIMULATION OF σ PHASE IN DUPLEX STEELS

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The formation of σ phase in various technological steel grades is crucial for materials properties due to embrittlement caused by the precipitation of σ phase at the grain boundaries. Thus, understanding and prediction of its temperature and composition dependent stability is required, which can be obtained by thermodynamic modeling. Its phase description should represent the correct crystal chemistry, thermodynamic stability and phase composition and extend properly to multi-component systems. Originally, the σ phase of Fe-based alloys [1] was modelled as (Fe)8(Cr)4(Cr,Fe)18 with extension to multicomponent systems where for example Ni can substitute Fe on 1st and 2nd sublattice Mo substitute Cr on 2nd and 3rd sublattice. However, the site occupancies of this model are not respectful to the known crystal structure of σ phase [2]. This discrepancy between modeling and physical base leads to questionable predictions of the phase stability in complex systems. We developed a new sublattice model for Fe-Cr system first [3] which is written (Cr,Fe)10(Cr,Fe)4(Cr,Fe)16 and correctly describes the crystal chemistry of the σ phase [3].
This model is being extended to multicomponent systems including Mo, Si and Ni within other elements which are soluble and stabilize the σ phase in steel. Validation of the predicted phase stability and composition is obtained by experimental close-to-equilibrium observations.
Based on the revised model, we have carried out thermokinetic simulation of precipitation of σ phase in duplex steels, which allows us to understand the nucleation and growth behavior of σ

phase formation as function of steel composition, temperature and time, targeting at optimised alloy and process design for improved materials properties.

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[3] A. Jacob, E. Povoden-Karadeniz, E. Kozeschnik, Revised thermodynamic description of the Fe-Cr system based on an improved sublattice model of the σ phase, Calphad 60 (2018) 16–28.

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COMPUTATION OF COMPETITIVE PRECIPITATION OF ETA CARBONITRIDE PHASE, Z-PHASE NITRIDE, AND INTERMETALLIC G-PHASE AT VARYING NITROGEN CONTENTS IN Nb- AND Si-ALLOYED AUSTENITIC STAINLESS STEEL

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We propose a new thermodynamic model description of carbonitride Cr3Ni2Si(N,C) "eta-phase" with M6C-type structure. Diamond-structured face-centered cubic Cr-Ni-Si Carbonitride eta-phase precipitates have been reported in some Si-containing 20-25 austenitic stainless steel grades [1] and irradiated type 316 [2]. This phase forms typically after long-term aging of at least several hundred hours. Once nucleated, the phase shows faster growth than nitride precipitates Z-phase [3]. Eta-phase will thus significantly affect microstructure and consequently influence creep strength of the material. Due to structural and morphologic similarities, eta-phase is often hard to distinguish experimentally from M23C6 and G-phase. A better knowledge of the theoretic stability of eta-phase, by evaluating its Gibbs energy computationally, is a valuable contribution for the prediction of phase relations and related microstructural development of stainless steels. The applicability of conventional M6X-model with 4 distinct crystallographic sites for [U+F068]-phase is discussed. It is shown that this model leads to an artificial phase stability and wrong composition at high nominal Si-contents. An improved model with 5 different crystallographic sites can solve this problem and reproduces the experimental tendencies of eta-phase stability. The site occupancies in the new eta-phase description were based on first-principles compound energies. With available compound energy models for intermetallic G-phase, and Z-phase nitride [4], relative precipitate stabilities as function of varied steel composition and heat treatments of stainless steels, as predicted by thermokinetic simulation, are discussed. The role of Si-segregation and altered diffusion behavior by irradiation for the precipitate evolution [5] is illuminated. [1] T. Sourmail, H.K.D.H. Bhadeshia, Metal. Mater. Trans. A, 36A (2005) 23. [2] J.M. Titchmarsh, T.M. Williams, "Precipitates in Neutron-Irradiated Austenitic Stainless Steel". in: G.W. Lorimer, M.H. Jacobs, P. Doig, Eds., Quantitative Microanalysis with High Spatial Resolution, pages 223-228, London, 1981. Institute of Metals. [3] V. Vodarek, Minor phase evolution in AISI 316LN+Nb steels during creep at 650°C, Proceedings of Metal 2010, 18.-20.5. 2010, Roznov pod Radhostem, Chech Republic. [4] E. Povoden-Karadeniz, MatCalc Engineering Database ME-Fe, version 1.000. Wien, 2017. [5] J.-H. Shim, E. Povoden-Karadeniz, E. Kozeschnik, B.D. Wirth. Modeling precipitation thermodynamics and kinetics in type 316 austenitic stainless steels with varying composition as an initial step toward predicting phase stability during irradiation, Journal of Nuclear Materials, 462 (2015) 250.

Fabrication, forming and welding / 15

Nd-YAG LASER PULSED WELDING: EFFECTS ON THE SUPERDUPLEX STAINLESS STEEL UNS S32750

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The use of superduplex stainless steels in industry increases due to its characteristics that combine good mechanical properties and resistance to corrosion. The study of super duplex stainless steels is very important due to the development of activities in the area of oil and natural gas, mainly with the recent discovery of the pre-salt oil in Brazil. These industries operate in critical atmosphere, as a result of the presence of sea water and oil. The UNS S32750 consist of a biphasic structure with volumetric fractions of 50% ferrite and 50% austenite. Therefore, the development of techniques for improving welding of super duplex steels is necessary in order to ensure that phase balance and properties of the material are not severely damaged in the process. The objective is to characterize joints of UNS S32750 duplex stainless steel welded with the Laser Nd-YAG (Neodymium-Doped Yttrium Aluminium Garnet) pulsed process. Welds were performed in the autogenous condition, varying the heat input introduced by the process. Then, an analysis of the base metal, the weld beads and the heat affected zone, will be performed through optical microscopy, Vickers hardness tests, corrosion tests (CPT), EDS (Energy Dispersive Spectroscopy) and, SEM (Scanning Electron Microscopy). The results obtained will be related to the welding parameters used. The success of the research will provide knowledge parameters and properties in the welded joints of this superduplex stainless steel.

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COMPARISON BETWEEN AUTOGENOUS WELDING AND WITH ADDITION OF NICKEL ON Nd:YAG PULSED LASER WELDED UNS S32750 DUPLEX STAINLESS STEEL

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Duplex stainless steels (DSS) have a biphasic microstructure with equal proportions of austenite and ferrite, which gives them excellent mechanical strength and corrosion resistance compared to austenitic stainless steels. Nd:YAG pulsed laser welding affects the microstructure of DSS resulting in unbalanced microstructure which compromise their properties. As way to obtain a balanced microstructure we have the addition of austenite forming elements, such as nickel or nitrogen. The present work reports the effect of nickel addition on the microstructure and microhardness of UNS S32750 duplex stainless steel welded by Nd:YAG pulsed laser. Two conditions were used: autogenous welding and with addition of nickel (electrolytic nickel foil with 30 μm thickness placed on the contact surface of weld joint). The addition of nickel affected both the microstructure and microhardness resulting in equal proportions of austenite and ferrite in the weld bead and increased the microhardness.

Duplex stainless steels / 17

INFLUENCE OF THE PROCESS PARAMETERS ON THE TRANSFORMATION BEHAVIOR OF 2205 DURING LASER BEAM WELDING

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The laser welding process is characterized by a high heating and cooling rate as well as large temperature gradients. The dwell time between heating and cooling is minimal. Especially when welding thin-walled (d $\leq$ 1 mm) duplex stainless steels, the austenite content in the joint zone is reduced. However, a balanced phase ratio of ferrite and austenite combines high levels of mechanical stability with outstanding resistance to corrosion. During laser welding, duplex stainless steels suffer from profound microstructural transformations, which influence the distribution and phase balance in the different areas of the weld seam and can lead to a loss of mechanical and corrosion resistance. For austenite formation in the joining zone and heat-affected zone, there are several model approaches which allow an estimate of the amount of austenite in the weld metal. The suitability of these models, especially for laser welding, is low, since the influence of the extremely high cooling rates is only insufficiently taken into account. The higher the cooling rate, the faster the conversion range is crossed and the less ferrite is converted to austenite. Furthermore, a three-dimensional heat flow is often the basis, but with thin-walled structures a two-dimensional heat flow can be assumed. This paper addresses the effect of process parameters on the cooling rate and thus directly on the phase balance between austenite and ferrite in the joining zone the grade 2205. Conclusions on the transformation behavior were obtained from the experimental welding tests and the modeling of the joining zone during the welding process. By means of metallography, scanning electron microscopy (SEM) and X-ray diffractometer (XRD), the weld seams were analyzed. The results are presented on the basis of a model, from which a direct estimate of the expected phase ratio from the process parameters is possible. By formulating boundary conditions, the model captures the extremely high cooling rates of the laser welding process. Based of the analysis the importance of the individual process parameters on the austenite transformation are shown.

Simulation and modelling / 18

SIMULATION OF ELECTROMAGNETIC STIRRING IN CONTINUOUS CASTING OF STAINLESS STEEL

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Electromagnetic stirring in the bending zone of a continuous casting machine is known to increase the amount of equiaxed crystals. A simulation model for the liquid steel flow and temperature under the influence of an electromagnetic stirrer has been developed in order to optimise the design of such a stirrer. The turbulent flow of the liquid steel inside the strand as well as the magnetic field and its forces acting on the liquid steel are calculated in transient simulations. The stirring intensity and the stirrer position are varied in the simulations. The influence of the stirring on the flow, especially on the mould surface flow, and on the superheat are compared for the different parameters. The results show that above a certain stirring intensity, the mould flow is significantly influenced by the stirring and thus the stirring intensity should be chosen below this critical intensity. The superheat temperature is lowered by the stirrer in a region that is distinctly larger than the magnetic field of the stirrer. The results show how these regions vary with the stirrer position. Nevertheless the difference between stirring and no stirring is significantly higher than varying the position of the stirrer.

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FORMATION OF AUSTENITE DURING AGEING OF 17-4 PH PRECIPITATION HARDENING STAINLESS STEEL

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The 17-4 PH is a precipitation hardening stainless steel with good mechanical and corrosion properties. Mechanical properties strongly depend on the heat treatment of the steel, namely, the isothermal ageing process. The formation of Cu-rich precipitates dictate the steel hardness, as they start to form the hardness rises, they coarsening however causes a substantial drop in hardness. However formation of reversed austenite ca also be observed during ageing. The evolution of the microstructure during ageing was thoroughly investigated in order to explain the processes that have effect on formation of the reversed autenite. The reaustenitization was analyzed with a dilatometer, while the coarsening of Cu-rich precipitates was observed by transmission electron microscope. The amount of austenite was measured with X-ray diffraction and the impact of austenite on the fracture appearance transition temperature was observed. It was found that the amount of reverse austenite does not only depend on the amount of transformed austenite during ageing but also on its chemistry, as it dictates its ability to transform into martensite during cooling.

Duplex stainless steels / 20

THE DUPLEX-STAINLESS-STEEL 1.4462 FOR FLOW LINES

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ABSTRACT
Today the duplex-steel 1.4462 is often used for flow-lines and a lot of money is spent worldwide into finding the right joining process for the circumferential welds of these pipes. A worldwide central collection of welding variables and their efficient processing could result in a prediction of the mechanical properties and fracture mechanical values out of the data of the preceding joining process and would save a lot of trial and error and therefore costs.
This paper deals with the prediction of the mechanical properties, such as yield strength, tensile strength, impact energy, and hardness, and the fracture mechanical values, as CTOD- (Crack Tip Opening Displacement-) values, from welding parameters, for example heat-input, of the joining process. The problems in determining and predicting the yield strength, the tensile strength, the impact energy, the hardness, and the crack tip opening displacement are discussed in detail and the results are compared. Finally the different resulting values are compared with each other, with the values of the base material, and with numerous values from literature.
The tested materials have been the base material, the weld metal, and the heat affected zone of welds, using different welding processes, as for example Manual Metal Arc Welding, Gas Metal Arc Welding, Gas Tungsten Arc Welding, or Submerged Arc Welding, of the duplex-steels 1.4462.

Corrosion and in service problems / 21

CORROSION BEHAVIOUR OF SLM 316L FOR DIFFERENT BUILD DIRECTIONS AND SURFACE CONDITIONS

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Electrochemical polarisation tests using a three-electrode set up (reference-working-counter electrode) were performed to evaluate the corrosion and the pitting potential as well as the corrosion rate in a 0.5 molar NaCl solution of Selective Laser Melted (SLM) S316L specimens. The evaluation of the corrosion potential (OCP) showing the lowest tendency to corrode for the polished SLM surface. Surprisingly the as-build surface exhibits higher OCP values than the polished sheet metal. The corrosion rate of the SLM as-built and the polished sheet metal, gave comparable results. Here again the polished SLM showed the lowest corrosion rate. Using LOM, Raman and EDS surfacial and microstructural analyses, a link to the observed corrosion behaviour could be found basically. The result of higher interest is the good corrosion behaviour of the as-built surface, whereat no further polishing production step would be neccessary, which means a further economical advantage.

Applications / 22

DEVELOPMENT OF FERRITIC STAINLESS HOT-ROLLED STEEL SHEETS FOR EXHAUST PIPE FLANGE

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From the viewpoint of initial rust measures of the automotive exhaust system, an application of various type of ferritic stainless steel sheets is carried out. In addition, the replace from C-steel sheet to ferritic stainless steel sheet are promoted from the viewpoint of initial rust characteristics-resistant in the flange part. When the automobile is transported particularly on the sea, the initial rust at the point of appearance of the exhaust system part becomes the problem. From a result of corrosion-resistant examination for C-steel and ferritic stainless steel sheets in consideration of marine transportation, the initial rust characteristics of the 11% Cr ferritic stainless steel are extremely superior than C-steel, and the 17% Cr ferritic stainless steel is superior. However, the thick ferritic stainless steel hot-rolled steel sheets containing Ti with high Cr are have a problem in low-temperature toughness in comparison with C-steel. In this study, from particularly viewpoint of low-temperature toughness Nb-added and Nb and Mo-added 17% Cr ferritic stainless hot-rolled steel sheets have been developed with microstructure control for the exhaust pipe flange. NSSC®430R3M, Nb-added 17% Cr-Low C, N was superior to conventional Ti-added 17%Cr steel sheet in low-temperature toughness and high-temperature strength. NSSC®436LNB-M, Nb and Mo-added 17% Cr-Low C, N, for the part that or the part that the characteristics of high heat resistaince and corrosion resisitance are more necessary in the environment corresponding parts such as EGR flange. NSSC®436LNB-M was superior to conventional Ti and Mo-added 17% Cr steel sheet in low-temperature toughness and high-temperature strength. Furthermore, the low-temperature toughness of the flange part and the flange part welded to an exhaust pipe were estimated by the drop weight test because the ductile-brritle transition temperature in Charpy impact test using the specimen with V-notch may not support with the low-temperature toughness of the real flange part. In this study, the method of drop weight impact test in low-temperature for the flange part and the flange part welded to an exhaust pipe has been developed. From the results of this method, the flange parts using NSSC®430R3M and the parts welded to exhaust pipe showed superior low-temperature toughness at -40°C. Other than the characteristics mentioned above, the developed ferritic stainless hot-rolled steel sheets are superior mechanical properties, corrosion and oxidation resistances. Thanks to various types of characteristics regarding the developed steel sheets, they can be used in automobile exhaust flanges.

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PARAMETER EXTRACTION FROM DUPLEX STAINLESS STEEL MICROGRAPHS AND THEIR CORRELATION TO MACRO PROPERTIES

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Impact toughness is a key parameter for many applications of duplex stainless steels. Conventional parameters that are known to have a strong influance on macro properties include phase fraction and austenite spacing. In this paper, we illustrate how image analysis can be used to extract new parameters and demonstrate that these parameters have an even stronger correlation to macro properties such as the impact toughness. Two novel parameters with a particularly high correlation to impact toughness were:
(1) a serrated boundary index, which measures the ruggedness of the phase boundary
(2) an austenite distance algorithm, which measures directionally independent inter-austenite spacings. This is particularly useful for non-directional structures, as can be found in cast material or in transverse cross sections of rolled material.
The relevance of these indices is proven in a correlation exercise where automated evaluation is used to extract features from more than 2000 light optical micrographs. These new indices, together with conventional entities such as austenite spacing, phase fractions, heat compositions etc., were matched with impact toughness data. The new indices came out with strong correlations.

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EARLY STAGES OF DELETERIOUS PHASES IN SUPER- AND HYPER DUPLEX STAINLESS STEEL AND THEIR EFFECT ON TOUGHNESS

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Duplex stainless steels combine excellent mechanical properties and corrosion resistance, while simultaneously maintaining lower alloying costs than comparable types of stainless steels. Consequently, they are in frequent use in various types of highly demanding applications, like Oil&Gas, chemical processing and desalination plants. An increasing amount of alloying elements, as used in Super or-Hyper Duplex Stainless Steels (SDSS and HDSS), improves mechanical strength and corrosion resistance; likewise, the susceptibility to the formation of deleterious phases increases. Avoiding these unwanted phases is crucial during heat-treating and welding, so proper cooling conditions are necessary since small fractions already massively deteriorate toughness and corrosion resistance. Consequently, this paper deals with the isothermal sensitisation between 700 and 1000°C in SDSS and HDSS and highlights possible cooling conditions to minimize the formation of unwanted phases. Conductive heating by a Gleeble enables rapid and reproducible heat-cycles, with varying sensitisation times from 20 to 1000 seconds, within the aforementioned temperature span. Both SDSS and HDSS suffer from sensitisation during most of the examined time-temperature combinations, with HDSS being remarkably prone. TTT-Diagrams result from the degradation of charpy-v impact toughness and the relative phase fractions of Sigma-, Chi-Phase and chromium nitrides. The degree of sensitisation is characterised by optical and electrical microscopy and charpy-v impact toughness at -46°C. Chi- and Sigma-Phase both result in severe embrittlement. Nitrides also precipitate rapidly, however are significantly less detrimental to toughness.

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SCC BEHAVIOR OF SEVERAL AUSTENITIC STAINLESS STEELS IN PROTOTYPICAL SYNGAS CLEANING SYSTEM CONDITIONS

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In view of the increasing pressures to reduce greenhouse gases, and in general the use of coal as a fossil fuel it could be expected that the future of coal-based power plants be very short. However, the technical solutions provided to improve the efficiency, as well as the improvements in the technology of production and capture of CO2 have made the IGCC and IGFC plants back on paper as a viable technological solution for a "cleaner" production of energy. USA with the construction of the Edwardsport and Kemper plants and Japan with Nasoko and Osaki are a clear example of the commitment to this technology at a time when coal seemed to have been buried again.
Although it is true that in Spain the only IGSCC plant, operated by ENDESA in Puertollano, was closed in August 2015, it is also true that has been acquired experience in operation and in the problems associated with the management of its materials over more than 15 years that should be considered for the design and operation of future installations and developments in these or other power generation systems.
This work describes the corrosion problems found in the synthesis gas cleaning system and the tests carried out by CIEMAT under simulated operating conditions on a super-austenitic stainless steel (904L: UNS S08904) and a super duplex steel (Zeron 100: UNS S32760) as alternative materials to 316L steel stabilized with Ti, used as a replacement for the original carbon steel, cracked in service by SCC, which finally justified its replacement.
There was no cracking indication by SCC under simulated conditions of operation in any of the materials, although there was loss of material by corrosion. Kinetic corrosion curves were obtained for each tested material. Although no growth of cracks has been detected by SCC, its appearance in service is not ruled out given the high sensitivity to small local changes in chloride/sulphide concentration in the environment. From the point of view of corrosion resistance 316 Ti and 904L are comparable, however Zeron 100 has shown lower resistance.

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TAILORING THE MECHANICAL PROPERTIES THROUGH THE CONTROL OF HEAT TREATMENTS IN A PRECIPITATION HARDENING MESTABLE STAINLESS STEEL

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Ultrafine grained austenitic microstructures (˜280-440 nm) have been obtained after applying isochronal heat treatments (0.1, 1, 10 and 100 °C/s) to a cold-rolled (CR) metastable stainless steel. A detailed investigation has been carried out to characterize the heavily deformed initial microstructure and to understand how the martensite-to-austenite transformation takes place. Several complementary experimental techniques have been used in the microstructural characterization; microhardness Vickers tests (Hv), electron probe microanalysis (EPMA), magnetization measurements, scanning and transmission electron microscopy (SEM, TEM) and electron backscattered diffraction (EBSD). Besides, the mechanical behavior of partially and fully transformed austenitic microstructures has been characterized by tensile testing on sub-size

samples. The transformation occurs diffusionally and in two-steps for all heating rates, which is attributed to the chemical banding present in the initial microstructure. The shear reversion mechanism has not been observed even for the highest heating rates. The severe deformation of the martensite present in the initial microstructure along with the formation of Chi-phase and Ni3(Ti,Al) nano-precipitates are responsible for the grain refinement, especially upon slowly heating at 0.1 °C/s. The mechanical response of mixed martensite/austenite microstructures is influenced by the volume fractions of these phases, the mechanical stability of the austenite (TRIP effect), and the presence of Ni3(Ti,Al) nano-precipitates in the martensite phase. A wide range of strength (2.1-1.1 GPa) and elongation (3-25%) values can be obtained through the control of the microstructure. In fully austenitic microstructures the strength can drop to 0.35 GPa and the elongation increases to 40% depending on the grain size. This investigation provides a better understanding of the processing-microstructure-properties relationship in metastable stainless steels.

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DEVELOPMENT OF AUSTENITIC STAINLESS STEEL SHEET WITH EXCELLENT HEAT RESISTANCE FO AUTOMOTIVE EXHAUST SYSTEM PARTS

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For mileage improvement and purification of exhaust gas, a high temperature exhaust gas and lightweight vehicle body are required. The heat-resistance of austenitic stainless steel is superior to ferritic stainless steel for the automotive exhaust manifold of a high-temperature exhaust gas engine and turbocharger systems at temperatures above 900°C. In turbocharger systems in particular, the replacement of austenitic cast steel or Ni-based alloy with austenitic stainless steel sheets may be effective from the viewpoint of lighter weight, lower cost, and higher turbocharger performance. Therefore, a new austenitic stainless steel sheet having heat resistance superior to conventional SUS310S (25%Cr-20%Ni) and SUSXM15J1 (19%Cr-13%Ni-3%Si) is necessary. In this study, in order to respond to the automotive exhaust manifold of a high-temperature exhaust gas engine and turbocharger systems, an excellent heat-resistant austenitic stainless steel sheet has been developed. By the fundamental researches of the effect of elements on high-temperature strength in austenitic stainless steel sheets, it was confirmed that the addition of N, C, and Mo was effective. Based on this result, 24%Cr-12%Ni-2%Si-0.6%Mo-0.1%C-0.2%N was selected as the optimum chemical composition for a new austenitic stainless steel sheet. The developed steel (NSSC®701) has higher strength than SUS310S and SUSXM15J1 between 700°C and 1000°C. At 900°C, 0.2% proof stress of the developed steels is 111MPa, and is approximately equal to Alloy 718 (Ni-based alloy), 1.8 times of SUS310S, 2.1 times of SUSXM15J1, and 4.3 times of SUS444 (19%Cr-2%Mo) with the highest high-temperature strength in ferritic grade. In addition, at 800°C and 900°C, the minimum creep strain rate of the developed steel was equal to or less than SUS310S and SUSXM15J1. Furthermore, regarding the high-temperature sliding property required for the internal parts of the turbocharger, the depth of the wear mark after pin on disk type friction and wear test of developed steel was less than half that of SUS310S and SUSXM15J1. In addition to the characteristics described above, the developed steel sheet shows superior characteristics in mechanical properties, high-temperature strength after aging, high-temperature high-cycle fatigue strength, and oxidation resistance in comparison with the conventional steel. Thanks to the various characteristics of the developed steel sheet, they can be used in the automotive exhaust system and turbocharger system parts.

Martensitic stainless steels / 30

DEVELOPMENT OF A NEW MARTENSITIC HIGH NITROGEN STAINLESS STEEL GRADE

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Conventional martensitic stainless steels for use in bearings, stainless tools or cutlery require high carbon and chromium contents in order to achieve the desired properties. However, they are prone to precipitate coarse carbides, which is a drawback in strength and corrosion properties. High nitrogen martensitic stainless steels with a fine dispersion of carbides or nitrides, that show high strength and good corrosion properties, are produced by pressurized-eletro-slag-remelting (PESR) which is an expensive process. The aim of this research is to develop a high nitrogen martensitic stainless steel with a good combination of mechanical and corrosion properties, which can be produced by conventional route (electric arc furnace, hot rolling, and subsequent heat treatment). A heat was cast, forged to bars and subsequently heat treated. The effect of hardening and tempering temperature on the mechanical and corrosion properties were studied. Hardening was carried out at temperatures between 900 and 1100°C for 30 minutes and quenched in water. Some specimens were deep freezed by -80 °C immediately afterwards. Tempering was carried out at temperatures between 160 and 760°C. Mechanical properties were determined through tensile, impact toughness and hardness (HRC). Corrosion properties were investigated in terms of rate of mass loss (ASTM ASTM G48 Practice A) and pitting corrosion resistance with potentiondynamic polarization technique (ASTM G61). The microstructure was characterized by optical and electronic microscopy and X-RD. The steel showed a fine martensitic microstructure with uniform dispersion of carbides. Hardening temperature has an influence on the microstructure and hardness. Increasing hardening temperature decreases hardness due to the high content of retained austenite. High nitrogen martensitic stainless steel shows a good combination of hardness, toughness and corrosion properties, with a room temperature UTS level of up to 2000MPa. These optimal mechanical and corrosion properties can be achieved with the correct selection of the heat treatment parameters.

Simulation and modelling / 31

LOW TEMPERATURE SURFACE HARDENING OF STAINLESS STEEL; PREDICTING COMPOSITION AND STRESS PROFILES

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The case developing during low temperature surface hardening of austenitic stainless steel by nitriding, carburizing or nitrocarburizing consists of a supersaturated interstitial solid solution of nitrogen and/or carbon in austenite. The favorable wear, fatigue and anti-corrosion properties of this so-called expanded austenite depend on the profiles of interstitial concentration and associated composition-induced residual stress over the case. The prediction of composition and stress profiles for a certain steel grade from the process parameters gas composition, temperature and treatment time would enable targeted surface engineering of stainless steels. Furthermore, such a numerical model would enable the design of new stainless steel grades that are tailored for optimal performance during low temperature surface hardening, equivalent to the well-known nitriding steels. Preferably, such a numerical model departs from the state of knowledge of microstructure evolution in order to arrive at accurate predictions. For this purpose the availability of fundamental parameters as determined experimentally on homogeneous powders and foils under well-defined conditions is essential. In the present contribution an overview of the current state of understanding of the evolution of the microstructure, composition and residual stress during low temperature surface hardening of stainless steels is presented. The presentation showcases the joint achievements of many co-workers in the last 20 years. The overview concerns theoretical, experimental and modelling aspects of expanded austenite, both as a homogeneous phase and as a case on stainless steel.

Austenitic stainless steels / 32

AN OVERVIEW OF MECHANICAL PROPERTIES OF TODAY'S GRAIN-REFINED AUSTENITIC STAINLESS STEELS

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In recent years numerous studies have demonstrated that a short reversion annealing following cold rolling is an efficient method to refine the grain size of metastable austenitic stainless steels down to a micron-scale. Commercial grades such as EN 1.4310 (AISI 301) and EN 1.4318 (AISI 301LN), EN 1.4371 (AISI 201L) have been found suitable for the treatment. In addition to resistance heating of small samples, also induction heating of large sheets in a pilot plant has provided equal results. A cold rolling reduction as low as 32% has been shown to lead to considerable refinement of the grain size enhancing the yield strength and high-cycle fatigue strength to be more than double compared to those of the commercial EN 1.4318 steel. Elongation is only slightly decreased. In spite of higher strength, drawability is equal to that of the commercial annealed EN 1.4318. The paper gives an overview of the level of mechanical properties which can be achieved under conditions related to industrial processing and discuss the properties which should be further investigated to reveal the work-shop fabricability of these grades.

Austenitic stainless steels / 33

INFLUENCE OF HEAT TREATMENT AND THERMO-CHEMICAL SURFACE ENGINEERING ON THE HIERARCHICAL MICROSTRUCTURES OF 3D PRINTED AUSTENITIC STAINLESS STEEL

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Additive manufacturing (AM) of austenitic stainless steel has been shown to be capable of producing samples with a unique combination of high strength and ductility. This increase in yield strength without the conventional ductility trade-off is usually attributed to the non-equilibrium, hierarchical microstructure produced by AM, particularly the cellular subgrain structures and dislocation network1. However, little attention is paid to the influence of the nitrogen content, which is known to generally increase the strength without severely reducing the ductility. The austenitic stainless steel powders for AM are commonly gas-atomised in nitrogen as this is an economical method for producing powders with a high degree of sphericality. Furthermore, most AM processes use nitrogen as a protective (but not inert) atmosphere during the printing of stainless steel. Both the atomisation and AM processes therefore have the potential for adding nitrogen to stainless steel, which is measured in the powder as well as the printed parts.
This research focuses on characterisation of the hierarchical nature of AM-manufactured austenitic stainless steel using electron microscopy, electron backscatter diffraction, X-ray diffraction and hardness measurement. Special attention is paid to the nitrogen content and its influence on the microstructure and mechanical performance. The enhanced nitrogen content is also taken into account when investigating the effect of various heat treatments and their effect on microstructure evolution. Conventionally, austenitisation is carried out in a hydrogen atmosphere, which can result in a loss of nitrogen and associated beneficial properties. Instead, an "active" austenitisation with a low pressure of N2 is utilised in order to keep the enhanced nitrogen content from the as-printed material and retain the mechanical properties. Furthermore, the effect of hardening treatments such as solution nitriding and low temperature nitriding on the microstructure is investigated.

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INFLUENCE OF THE ALLOY COMPOSITION OF FILLER METALS ON THE MICROSTRUCTURE OF WIRE AND ARC ADDITIVE MANUFACTURED COMPONENTS MADE OF DUPLEX STAINLESS STEEL

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Abstract For the successful welding of high-alloy and corrosion-resistant duplex stainless steels, a number of welding recommendations have been established over the past decades which guarantee the required material-specific properties of the welds. These include, inter alia, compliance with defined heat input and interpass temperatures as well as the use of filler metals over-alloyed with nickel compared to the base material. Despite of the rapid cooling, the higher nickel content guarantees a sufficient austenite content in the weld metal of welded joints or weld claddings. Investigations by Posch et al. [1] for the production of additive manufactured turbine blades with the filler metal 22 9 3 N L have shown an excessively austenitic structure with ferrite contents of less than 30 %. Studies by Hoefer et al. [2] have shown that the excessive formation of austenite and the precipitation of secondary austenite are caused by repeated heat input and passing through the temperature range of 1200 to 800 °C when welding the following layers. Stützer et al. [3] have shown that the cooling time also increases with the number of layers. This additionally promotes the formation of austenite and leads to a significant reduction in strength. The slow cooling rates during wire and arc additive manufacturing therefore require an adjustment of the alloy composition with regard to the nickel-over-alloying of the filler metal. This presentation informs about the possibility of influencing the microstructure by varying the alloy composition of the filler metal. For this purpose test specimens with modified filler metals (nickel concentration of 5.5 up to 8.8 % & silicon concentration of 0.5 up to 0.8 %) were manufactured and inspected by material testing (metallography, ferrite measurement, hardness measurement, X-ray examination). In order to determine the influence of the chemical composition, spectral analyses (OES) and melt extractions were carried out on the filler material as well as on the weld metal. In addition, the microstructure was specifically adjusted by mixing alloys using cold wire feed - gas metal arc welding process. The reduction of the nickel equivalent proved to be an effective way of reducing the austenite content in the weld metal. Especially the reduction of the nickel concentration but also the increase of the silicon concentration resulted in an increase of the ferritic microstructure. With cold wire additions, test specimens with ferrite contents of 46 up to 72 FN (32 - 50 %) could be produced. The homogeneous mixing of electrode wire and cold wire could be verified by EDX-Line-Scans. Furthermore, the addition of cold wire resulted in an increase of the average specimen height by approximately 30 %.
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INCLUSION OF FORTA FDX 27 (UNS S82031) INTO ASTM A1084

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The new duplex steel FDX 27 should be implemented into relevant standards. As for other duplex stainless steel grades, correct solution annealing is one of the most critical aspects for achieving good material properties and a relevant standard in this respect is of great importance for delivery of material with good quality. Testing of high alloyed duplex stainless steels is covered in ASTM A923 which focuses on the detection of detrimental levels of intermetallic phases. For leaner duplex stainless steels ASTM A1084 is the standard focusing on testing appropriate material properties. This standard does not concentrate on intermetallic precipitates but rather on properties affected by nitrides that precipitate at too low solution annealing temperature or too slow cooling at solution annealing situations. For a number of thin sheet materials of FDX 27 different heat treatment conditions, as received conditions, different isothermal sensitizations as well as solution annealed under different cooling situations, has been performed. Local corrosion resistance and microstructure has then been examined according to ASTM A1084 method A and C. A modified test solution for method C has also been evaluated and is proposed as a more relevant solution for the inclusion of FDX 27 and other mid-range duplexes into ASTM A1084. As reference measurement, testing according to ASTM G150 in 0.1M NaCl has been performed and a TTT-diagram has been compiled.

Fabrication, forming and welding / 36

AN APPROACH FOR PREDICTION OF COIL SPECIFIC FORMING LIMIT CURVES

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Forming limit curves (FLCs) are widely used for predicting failure of sheet metals in press shop operations. An FLC is a borderline between safe and unsafe regions in the principal strain space. In other words, this curve defines the extent by which a specific material can be deformed without developing localized necking and incipient failure. In Europe, FLCs are commonly determined in the laboratory using the Nakajima test according to ISO 12004-2. In the testing procedure, a series of dog-bone shaped blanks is stretched with a hemispherical punch until failure occurs. Optical strain measurement equipment is used to measure the strain field on the surface of the specimen. The limit strains are then calculated based on an objective mathematical criterion. Measurement of FLCs is extremely time-consuming. Therefore, a variety of empirical and statistical methods have been proposed for predicting FLCs based on parameters that can be measured with relative ease. Unfortunately, almost all proposed methods have been developed using carbon steel and alloy steel as test material. Stainless steel possesses somewhat different forming characteristics than carbon steel. Therefore, it is questionable whether the methods proposed for prediction of FLCs can be applied as such to stainless steel. In the present work, an empirical method is developed for predicting the entire FLC of stabilized ferritic stainless steels. Predictive equations are derived based on statistical correlations between measured FLCs and the strip properties. The accuracy of the new method in comparison with the experimental uncertainly of forming limit curve points obtained with the Nakajima test according to ISO 12004-2 is discussed.

Surface properties / 37

NEW DEVELOPMENTS IN HIGH TEMPERATURE SOLUTION NITRIDING OF STAINLESS STEELS

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High temperature solution nitriding (HTSN) of stainless steel was originally developed by Prof. Berns in the early 1990s and is in many aspects the "stainless" analogue to carburizing of steels. The process entails dissolution of nitrogen in stainless steel at temperatures above, say, 1050°C, from an atmosphere consisting of molecular nitrogen at a fixed partial pressure. Austenitic, ferritic, duplex and martensitic stainless steels can all be high temperature solution nitrided. In general there are two different strategies or reasons for performing HTSN: i) to obtain a nitrogen-enriched austenitic case on austenitic, duplex and high Cr ferritic stainless steels for improved corrosion performance, or ii) to obtain a nitrogen containing martensitic case on martensitic and low Cr ferritic stainless steels for improved wear, fatigue and corrosion performance. Hitherto, the HTSN process has been somewhat niche in industry owing, in part, to the high temperatures involved and in particular to the inherent challenges associated with the process and the resulting microstructures.
The present contribution will provide an overview of the state of the art of HTSN and associated heat treatment processes for different classes of stainless steels - including the different challenges associated with HTSN. In addition, new developments in the optimization of the HTSN process and the resulting microstructures will be presented. In the examples shown, emphasis will be given to treatment of martensitic stainless steels, where special heat treatment processes are required in order to exploit the full potential of HTSN, and to austenitic stainless steels where drastic improvements in wear and corrosion resistance can be achieved – in particular when combined with low temperature surface hardening processes. It is anticipated that HTSN will gain more industrial interest in the future. Particularly, the rapid development in additive manufacturing of stainless steel products could benefit from improved materials properties and performance as provided by HTSN.

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INFLUENCE OF THE ANNEALING TREATMENT ON THE TOUGHNESS OF DUPLEX STAINLESS STEEL TYPE EN-1.4462

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The duplex stainless steel family is widely used in many structural applications due to its high mechanical resistance with a yield stress of about two times the austenitic's and its outstanding corrosion resistance. An example of this is the grade EN-1.4462 with a yield stress value usually higher than 450 N/mm2 and the tensile strength value between 650 and 880 N/mm2. Another important mechanical property of the duplex is its toughness, which must be higher than 100 J at room temperature and above 40 J at -40° C. The mechanical properties are sensitive to the microstructure, especially the toughness and more this property at low temperature. So the annealing treatment, following the hot rolling stage, must be designed to get the right microstructure and the desired mechanical properties.
The present paper describes the investigation carried out to evaluate the influence of the annealing conditions on the microstructure and toughness at low temperature of duplex EN-1.4462. Several commercial hot rolled samples of this grade steel have been treated at lab scale with different temperatures and holding times. After that, the toughness specimens have been machined and tested at -40° C. Finally, the microstructure of the treated samples has been analysed by light and (field emission gun) scanning electron microscopy.

The results of the investigation have shown that the impact test results strongly depend on the microstructure, not only on the phase balance and the presence of intermetallic phases but also on the size and recrystallization level of the main phases.

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MONITORING THE SURFACE QUALITY OF STAINLESS STEEL SLABS WITH REVEAL CAST - FINDINGS AND SUB-SEQUENT QUALITY IMPROVEMENTS

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Quality of stainless steel semi-products is important for the cost-efficient production of final products. Yield losses due to the excessive grinding, losses due to the down-grading or scrapping the whole semi-finished product may impair the profitability of the production. By monitoring the surface quality of the hot slabs during the casting on line, it is possible to get valuable information for making improvements in caster condition and in composition of a steel grade to improve castability and surface quality. This research was concentrating on the monitoring of surface quality of stainless steel, but the same principles apply also for carbon steel. This paper shows how Reveal CAST surface inspection system can be used to identify different types of defects from the hot surface of cast slabs. The paper also describes the relationship between the caster condition and the slab surface quality. As an example, using the reporting tools included in Reveal CAST together with automatic defect detection features, it was easy to find out that with Ti-alloyed austenitic stainless steel, the rate of the sticking defects was clearly higher during summer time compared to winter time. The reason for increased sticking defects during summer time is explained. The same phenomenon was also found earlier, but with much more time-consuming work. Similar studies are easy to do with Reveal CAST. Using Reveal CAST in the hot band inspection, it is possible to evaluate, which of the defects on the slab surface are causing the defects on the rolled strips. Grinding of the rolled strips is clearly more expensive than the grinding of slabs. Monitoring during grinding of the slabs ensures removal of defects without extensive grinding losses. This paper shows that monitoring the surfaces of semi products on line with Reveal CAST can result in cost savings and in quality improvements.

Martensitic stainless steels / 40

HIGH AND LOW TEMPERATURE SURFACE HARDENING OF MARTENSITIC STAINLESS STEELS

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In the present work high and low temperature (surface) hardening of X30Cr13 (AISI 420) martensitic stainless steel is addressed. High temperature solution nitriding (HTSN) was performed on thin specimens for obtaining a uniform distribution of nitrogen over the specimen thickness, reflecting the equilibrium nitrogen solubility. Three different nitrogen pressures were analysed, leading to three different equilibrium nitrogen contents in the steel and associated microstructures. The purpose of this work is to investigate the nitrogen absorption as a function of nitrogen pressure and the fraction of retained austenite after martensite formation (on cooling) as a function of nitrogen content.
Also, low temperature surface hardening (LTSH) of the three microstructures obtained by HTSN, was investigated. LTSH was achieved by gaseous nitriding in ammonia gas in the temperature range 380 to 420°C. The process was performed in ammonia for a fixed nitriding time, with the aim of analysing the nitrogen content and the final microstructure obtained as a function of LTSH temperature. This work leads to a better understanding of the combination of high

and low temperature hardening for optimizing a heat treatment chain in order to improve the surface performance of this martensitic stainless steel (fatigue and tribological properties, i.e. adhesion and galling resistance) without impairing, but preferably improving the corrosion resistance. ThermoCalc is used for calculating the appropriate HTSN parameters. Reflected light microscopy, scanning electron microscopy, with energy dispersive spectroscopy, EDS, and electron back-scattered diffraction, EBSD, and X-ray diffraction were applied for the characterization of the morphology and composition of the developing case. Micro-hardness Vickers indentation provides information on the depth dependence of the hardness.

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COMPUTATIONAL THERMODYNAMICS AND KINETICS TOOLS FOR DEVELOPMENT OF ADVANCED STAINLESS STEELS

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The prediction of alloying effects on phase equilibria and transformations in advanced stainless steels and in particular duplex stainless steels is complicated. This makes computational thermodynamics and kinetics an indispensable tool for the materials industry. It has been successfully deployed in the alloy development of steels for decades and continuously developed towards use in more and more applications. In this work, the performance of the current state-of-the-art commercial thermodynamic database was improved specifically for stainless grades containing high contents of Cr, Ni, N, W, and other elements. Several binary, ternary, and quaternary systems were re-evaluated, and the thermodynamic models for certain phases were improved. The database thus provides a better and more reliable tool for designing new alloys, optimizing heat treatments and studying precipitation of secondary phases at intermediate temperatures. The description of secondary phases which are typically detrimental for mechanical and corrosion properties was revised including the Epsilon-nitride, Sigma, Chi, Laves, Pi-nitride phases. In addition, a nitride phase (Eta) which has proven to be a critical equilibrium phase in super-austenitic stainless steels but previously was not included in any commercial steel databases, was modelled and added to the database. Another key improvement for the high-temperature phase equilibria reflects that several grades of duplex stainless steels crystallize by fully ferritic solidification, supported by new experimental evidence. Furthermore, the balance of matrix phases, ferrite and austenite, in the database has been improved in the critical temperature region for duplex stainless steels.

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DESIGN AGAINST BRITTLE FRACTURE IN DUPLEX STAINLESS STEEL CONSTRUCTIONS BY USING THE EN 1993-1-10 MODEL AND THE INFLUENCE OF PLATE THICKNESS ON THE IMPACT TOUGHNESS

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Abstract: In the design of steel structure, the avoidance of brittle fracture is of great importance as e.g. steel bridges are exposed to low temperatures and fatigue loads. In the supplementary rules for the design of stainless steel structures in the European standard EN 1993-1-4 as part of the

Eurocode 3-familiy, toughness requirements for stainless steels are given. However, the toughness requirements for duplex stainless steels are insufficient. Due to this fact, first investigations have been carried out on various duplex stainless steel base materials and welded specimens based on the fracture mechanic based concept of EN 1993-1-10. The results have been transformed into the general approach used in EN 1993-1-10, which was originally developed for carbon steel considering the structural detail of a welded longitudinal attachment with a semi elliptical surface crack at the weld toe. The results show that the investigated duplex stainless steels show a very good toughness behaviour and that the EN 1993-1-10 model can be transformed for application of duplex stainless steels. The paper also discusses the influence of the plate thickness for some duplex grades on the sub-zero temperature Charpy V impact toughness.
Keywords: Duplex stainless steel, steel construction, fracture toughness, impact toughness, choice of steel material.

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THE EFFECT OF HEAT TREATMENT AND SURFACE HARDENING OF 3D PRINTED AUSTENITIC STAINLESS STEEL AlSl316 ON CORROSION AND WEAR PROPERTIES

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Due to the high cooling rates and layer by layer building characteristics of the additive manufacturing (AM) process Selective Laser Melting (SLM), the as-fabricated parts can contain strongly inhomogeneous microstructures, porosities, rough surfaces and residual stresses. For example, the as-fabricated microstructure of SLM 316L typically consists of elongated austenite grains with a cellular substructure of approximately 1μm cell width, wherein the dislocation rich cell boundaries are enriched in Cr and Mo. Therefore, post-processing by heat treatment or surface finishing is often necessary to optimize the materials properties and performance. For the austenitic stainless steel AISI 316L heat treatment has always been essential in order to obtain the desired corrosion performance. Conventionally, AISI 316L is austenitized in a hydrogen atmosphere or in high vacuum at temperatures in the range 1040 -1120°C, to ensure a fully austenitic structure with optimal corrosion resistance. In AM some producers prescribe nitrogen gas as the “inert” atmosphere for SLM of AISI316L. Nevertheless, nitrogen pick-up in the solid state occurs for a temperature above, say, 900°C. Such uncontrolled nitrogen dissolution in the stainless steel can have a positive or a negative effect on the electrochemical and mechanical properties. Hitherto, the effect of “nitrogen alloying” in printed parts has received little attention in the literature.
Dissolution of nitrogen in austenitic stainless steels is also be carried out as the *deliberate* surface treatment referred to as high temperature solution nitriding (HTSN). HTSN improves the corrosion resistance and slightly enhances the hardness by the addition of up to 0.7 wt% nitrogen, depending on the alloy composition. Low temperature surface nitriding (LTSN) dissolves much higher nitrogen contents in the surface of the stainless steel (even more than 8 wt%) and results in the formation of expanded austenite, which significantly increases the surface hardness (up to 1200 HV).
With the increasing popularity of SLM 316L, there is a need to investigate the corresponding corrosion properties of the inhomogeneous microstructures formed by SLM and the effect of subsequent heat treatment and thermochemical surface treatment on the microstructure-property relations. The present work investigates how SLM 316L with a heterogeneous microstructure, responds to different heat- and thermochemical surface treatments, and how such processes affect the corrosion properties. Specifically, conventional austenitization in hydrogen, resulting in loss/removal of nitrogen from the printed part, and a new process termed “active austenitization”, where a controlled nitrogen pressure adjusts the amount of nitrogen in the printed part, were investigated. Additionally, the influence of the thermochemical surface treatments HTSN and LTSN on microstructure, corrosion and wear properties was investigated. The microstructure

of the specimens was investigated with X-ray diffraction, reflected light optical microscopy and scanning electron microscopy. Micro-hardness measurements and wear testing (pin-on-disc) were used to characterize the mechanical properties, while the corrosion properties were evaluated with potentiodynamic polarization testing.

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ELECTRICALLY ENHANCED PLASTIC DEFORMATION OF DUPLEX STAINLESS STEEL UNS S32750

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It is well known that increasing the temperature soften the materials and increase its formability. This could be done in many ways, one of which is by joule heating. In the late fifties, an enhancement of formability for certain alloys, when heated by electrical current compared to traditional heating method, has been observed . This led the researcher to investigate the effect of electrical current on the plastic flow of metallic materials discovering a new effect called Electroplastic Effect (EPE). EPE is used in the so called Electrically Assisted Manufacturing processes (EAM). The stacking fault energy (SFE) describes the dislocation dynamics of metallic materials and it has been hypothesized an a-thermal effect which is caused by direct interaction between dislocations and electrical current. High SFE materials shows an increase of formability while low SFE materials reach the fracture prematurely. In this work duplex stainless steel (DSS) UNS S32507 has undergone uniaxially tested with the aid of continuous and pulsed electrical current in order to study the EPE of an alloy with s two phases: high SFE (ferrite) and low SFE (austenite). It has been tested under different current densities (continuous and pulsed). In order to separate the EPE from the effect of temperature, some thermal tensile counterpart tests have been conducted. The DSS was then characterized through optical microscopy, scanning electron microscopy and x-ray diffraction. The DSS shows an increase in the elongation at rupture either for the continuous current set-up and much more evident in the case of the pulsed current , compared to the thermal tests while the ultimate tensile strength and the yield strength were barely affected.

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HIGH NITROGEN HIGH CARBON STAINLESS STEEL

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High strength medium carbon austenitic stainless steels have been developed through partial and total replacement of nickel by nitrogen. Stainless steels containing 0.4% carbon with different combinations of nickel and nitrogen were produced in 10kg induction furnace under different nitrogen pressures. The produced stainless steels were cast and hot forged and the total nitrogen was determined. Furthermore, the produced forged steels were subjected to either only solution treatment or solution treatment followed by ageing process. Nonmetallic inclusions such as carbides and nitrides were separated by electrolytic dissolution. Nitrogen as nitrides was determined and soluble nitrogen was calculated. XRD technique was used to investigate the types of nonmetallic inclusions. The microstructure of produced stainless steels was observed and the grain size was measured. The tensile properties at room temperature were determined. The influence of grain size, total nitrogen, insoluble and soluble nitrogen on tensile strength was investigated. All

produced stainless steels as-quenched were aged at temperatures range from 450 °C to 950 °C for different times. Hardness test was carried out for aged stainless steels and the optimum ageing conditions were determined. After solution treatment of the investigated stainless steels at 1050°C, a great portion of alloy carbides and nitrides is observed to be taken into solution. Nitrogen in solid solution increases both yield and tensile strengths. At optimum ageing temperature, this portion in solution precipitates, mainly as Cr2N, was causing higher precipitation strengthening. The yield strength and ultimate tensile strength of the aged stainless steels were found to increase at average rates of 706 MPa/1 mass % nitrogen and 723 MPa/1 mass % nitrogen, respectively. On the other hand, the increase of nitrogen content deteriorates the steel ductility.

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PREDICTING FERRITE FRACTIONS IN SINGLE PASS SUPER DUPLEX STAINLESS STEEL WELDS - THERMAL CYCLE ANALYSIS AND PHASE TRANSFORMATION MODELING

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Super duplex stainless steels (SDSS) combine superior mechanical properties and high corrosion resistance, which makes them an attractive choice for demanding applications. The welding of SDSS, however, is more challenging than for standard and lean duplex stainless steels as the desired balanced ferrite fraction sometimes is conflicting with the more rapid formation of deleterious phases in SDSS. The relationship between process parameters, determining the welding thermal cycle, and the final microstructure is, therefore, of a great importance for reliable fabrication of welded SDSS structures. The present study was primarily aimed at investigating this relationship for root/single pass welding of type 2507 SDSS. Fourteen welds were produced using GMAW, GTAW, SAW, and SMAW with different joints geometries, plate thicknesses, and welding parameters. Thermal cycles were recorded using several thermocouples attached to the plates and thermocouples were also harpooned into the weld pool. Weld pool geometries and base metal dilution in the weld metal were determined for all welds. Ferrite fractions were measured using Feritscope and image analysis for all single pass welds. Results allowed the influence of dilution and cooling rate on the ferrite fraction to be determined. Kinetics of austenite formation was also modelled using computational thermodynamics (Thermo-Calc & DICTRA) to predict the ferrite fractions in the weld zone and calculated fractions were compared to experimental results. Furthermore, based on the results from the single pass welds, a geometrical approach was proposed to predict the dilution in multipass welds. Results will be discussed, and it is shown that the above approach can be used for prediction of the ferrite fraction of duplex stainless steel single- and multi-pass welds.

Ferritic stainless steels / 50

SCIENCE AND TECHNOLOGY OF HIGH PERFORMANCE FERRITIC (HiperFer) STEELS

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In numerous branches ferritic-martensitic steels are operated close to their application limits today. The advancement of thermal power generation efficiency for example was governed for decades by the further development of the ferritic-martensitic (FM) 9 - 12 Cr steel grades, which enabled a rise of appr. 120 °C in live steam temperature over a period of 60 years, but stagnates since the introduction of grade 92 in the 1990s. Since then all attempts to combine sufficient creep strength and increased steam oxidation resistance in new FM steels at temperatures beyond 620 °C failed. Furthermore the German "Energiewende" poses a lot of new challenges for structural high temperature materials, because operation modes change from mainly base load to flexible residual load compensation operation.
Another example of such limitation are martensitic hot-working die steels applied for example in the production of automotive chassis parts from high strength TRIP and TWIP steels. The durability of such martensitic stamping tools is strongly limited because of both lacking mechanical long-term strength and oxidation resistance at temperatures exceeding 620 °C.
These limitations are due to the conflict of complete martensitic transformation only being possible as long as the level of chromium is suitably low (< 12 wt.-%), while oxidation resistance beyond 620 °C necessitates Cr contents higher than 15 wt.-%. Low cost carbide / nitride strengthened martensitic steels thus seem to hit hard technological limits and alternatives are strongly desired. This paper describes the scientific background and technological properties of a new family of Laves phase strengthened, **Hi**gh **per**formance **Fer**ritic (HiperFer) stainless steels, under development at Forschungszentrum Jülich, Germany and designed for highest resistance against thermomechanical fatigue, fatigue crack propagation and creep as well as aqueous corrosion and steam oxidation. Microstructure, especially the role of plastic deformation for material strength, mechanical properties and application potentials will be addressed in detail.

Simulation and modelling / 51

FLEXIBLE AOD OPTIMIZATION TECHNOLOGY FOR STAINLESS AND SPECIAL STEELMAKING

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The demand in stainless and special steel products is growing continuously and there is a clear trend to new steel grades with higher tensile stresses, tight quality margins and new material properties observable. On the other hand the raw material situation tends in opposite direction, which means the steel producers are forced to process less sorted raw materials as well as more oxydic alloys for instance to reduce conversion costs to a competitive level. The production of smaller batches with very special compositions and dual or even multiple treatments requires an accurate detail planning of the production and the assigned resources along the process route. In addition it's crucial that the treatment can be finished within the given time window to keep the scheduled plan. All these upcoming challenges need to be covered with an comprehensive automation concept, which allows the operator to administrate the complex melt shop production with interacting digital assistance tools. This means by selection of the desired steel grade and heat size the entire production and data chain is updated automatically. Based on steel grade date bases, production rules and digitalized operational knowledge the production schedule and the process route are adjusted from EAF, AOD, Secondary Metallurgy and Casting. Multiple heat treatments are distributed to available production aggregates, set-points for Level 2 and in the following Level 1 systems are generated including arcing, heating, flux addition and batch alloying based on detailed process models. State of the art steel making models provide optimization models for cost reduction and flexible material handling and give an online feedback of the ongoing process to the process supervisor. In addition some kind of prediction of the final analysis, the remaining time demand and exit values are also available. In combination with a comprehensive data management for data exchange and structured long-term storage the idea of flexible steelmaking for stainless and special steel fits fully to the global trend of Digitalization of the metals industry.

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INFLUENCE OF SIGMA PHASE PRECIPITATION IN THE 600 TO 750 °C RANGE ON MECHANICAL PROPERTIES OF SAF2205

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SAF 2205 duplex stainless steel has good corrosion resistance, mechanical strength, weldability at relatively low price. But it is susceptible to sigma phase precipitation. The sigma phase is a hard and brittle intermetallic phase that occurs in the Fe.-Cr system. The temperature range from 600 to 950 °C is critical for the sigma phase precipitation. The effects of time and temperature on the intermetallic phase precipitation and phase transformations in SAF 2205 were investigated. The influence on mechanical properties was studied. The specimens were isothermally annealed at different temperatures from 600 to 750 °C for 1 min, 10 min, 100 min and 1000 min. The specimens were investigated by optical microscopy and ferritoscope measurements. Mechanical properties tensile strength, hardness and impact toughness were analyzed. The detrimental effect of sigma phase precipitation was studied.

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ON THE USE OF COMPUTATIONAL THERMODYNAMICS FOR PREDICTING THE PRECIPITATION AND GROWTH OF SECONDARY PHASES IN STAINLESS STEELS

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Stainless steels are high-alloyed, usually with multiple components and often also dual matrix phases, as for duplex stainless steels. This makes predictions and calculations of alloying effects on equilibria and phase transformations a challenge. Computational thermodynamics has emerged as an indispensable tool for calculations within these complex systems on predictions of equilibria and precipitation & growth. This paper offers examples illustrating how computational methods can be applied both to thermodynamics, kinetics and coarsening of stainless steels in order to predict microstructure comprising of the desired matrix phases ferrite and/or austenite, as also the less desired secondary phases such as intermetallic phases and nitrides.

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THE USE OF NICKEL-CONTAINING ALLOYS IN THE CHEMICAL INDUSTRY

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This paper will focus on the use of nickel in stainless steels and nickel alloys in preventing corrosion in severe applications within the chemical process and related industries. It will begin with an overview of the available nickel-containing alloys and discuss conditions under which they should be used. The role of nickel in these alloys will be explained. It will also summarize their resistance to general and localized corrosion attack. Examples of the use of nickel-containing alloys will be presented which will show which alloys are successful in a wide range of applications, including production of the common acids and alkalies. Where appropriate, comparisons will be made with other alloys being used under similar conditions emphasizing the benefits of nickel-containing alloys.**

Metallurgy / 55

CONTROL OF SOLIDIFICATION STRUCTURE IN CONTINUOUS CASTING OF FERRITIC STAINLESS STEEL

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In this study, we discussed the control of casting structure to improve the forming and ridging quality of ferritic stainless steels of which the casting structure in the continuous casting process directly affects the final product's quality. For refining the casting structure of ferritic stainless steel, EMS optimization was developed in continuous casting process. Moreover heterogeneous nucleation technology was developed through oxide control in deoxidation process. As a result, the forming and ridging quality of final product could be improved through the refinement of the casting structure, furthermore the low temperature ductility of welding region was improved by refining the solidification structure of that through the oxide control technology.

Applications / 56

HOT CRACK TENDENCY IN THIN-WALLED HIGHLY ALLOYED AUSTENITIC STAINLESS STEEL

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Summary: Increased interest in light-weight solutions for exhaust systems drives the need for application of thin-walled elements, and in consequence using more and more advanced materials. However, welding of thin-wall parts made of highly alloyed austenitic steels can result in hot cracking in heat affected zone. The paper discusses weldability of highly alloyed 1.4539 grade with the respect to this particular issue. Metal Inert Gas (MIG) method was used to perform welding trials on flat and plastic deformed samples. Welded samples were prepared using varying torch position and varying heat input in order to reveal relation between process parameters and susceptibility to hot cracking. Macro and micro-structure were investigated using optical microscopy, particularly focusing on weld seam geometry and size of heat affected zone. Solidus temperature was determined by means of differential thermal analysis (DTA) both in initial and equilibrium condition. Microstructure changes in heat affected zone were studied using scanning electron microscope (SEM) and energy dispersive x-ray spectrometry (EDS). Presence of relatively large partially melted zone was revealed in samples made using pushed torch, even at relatively low heat input. Mo-rich precipitates were detected at grain boundaries, which suggest grain boundary liquation as primary mechanism leading to hot crack formation.

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DUPLEX STAINLESS STEEL MARKETS IN 2019 .... AND BEYOND

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Duplex stainless steels count for less than 2% of the stainless steel market today, but are expected to grow healthy (significantly higher than the overall stainless market) in the next 10 years.
The presentation will show the historic development and status quo of the supply- and demand side of the duplex stainless steel market. It will list the biggest 20 producers world-wide and show the market structure by product form (plate, HRC, CRC, wire rod/wire, bars, tube and re-bars). Also the market structure by steel type (lean duplex, 22%, 25%) will be shown and discussed.

A discussion of the future market drivers and inhibitors for the 3 market segments (projects, maintenance and new applications) will be discussed and shown. Finally a 5 year market forecast (to 2023) will be provided. In order to put duplex into the context of the overall stainless steel industry a few key facts about the total stainless steel industry will be provided. Especially the new NPI based '4-in-1' production technology in Indonesia will be introduced and the potential impact on the rest of the world discussed.

Corrosion and in service problems / 59

HYDROGEN UPTAKE OF DUPLEX 2205 AT H2 PARTIAL PRESSURES UP TO 100 BAR

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Microbiological methanation is investigated in an underground natural gas reservoir. Since H2 is involved in the process, hydrogen embrittlement of steel must inevitably be considered. Therefore, a routine for testing has been developed and a unique autoclave test bench was designed to simulate field conditions. The 2205 duplex stainless steel (UNS S31803) was investigated. Constant load tests (CLTs) and immersion tests with subsequent hydrogen analyses were performed. The specimens were exposed to different partial pressures of H2 under both dry and wet conditions (with brine). Additionally, the influence of CO2 under wet conditions was covered. Tests were performed at two different temperatures (25 °C and 80 °C) and lasted for 30 days. In general, the duplex stainless steel shows a good resistance to hydrogen embrittlement, but significant differences to other steels in hydrogen uptake were measured.

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PASSIVITY OF STAINLESS STEELS - CHEMICAL COMPOSITION, ACTIVATION AND REPASSIVATION

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Passive layers determine corrosion properties of stainless steels. Passive film structure, thickness and defect density is important to understand localised corrosion phenomena such as pitting, crevice and intergranular corrosion. The very limited thickness of passive films - in many cases in a range of a few nanometers - makes them difficult to visualise and to investigate them directly. The paper summarizes the literature and own results on chemical composition and stability on passive layers of various stainless steels. By means of XPS and 3D atom probe passive layers have been investigated and characterised with respect to chemical composition, thickness and structure. Results show that thickness and density of passive layers can vary significantly with alloying content and additional alloying elements such as manganese. In addition the kinetics of formation of passive layers as well as the conditions when activation and repassivation happens as function of pH is shown.

Ferritic stainless steels / 61

DEVELOPMENT OF HIGH FORMABLE FERRITIC STAINLESS STEEL FOR AUTOMOTIVE EXHAUST SYSTEM

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The design of an exhaust system has become complicated due to exhaust gas regulation and fuel economy improvement. Therefore ferritic stainless steels for automotive exhaust system should have higher formabilities such as deep drawability and pipe bendability in order to avoid crack during manufacturing automotive parts. Recently, a high formable ferritic stainless steel has been developed for automotive market trends. R-value (Lankford's coefficient) of high formable ferritic stainless steel has been improved by advanced texture-control engineering compared to typical ferritic stainless steel. In this study, initial texture and stored energy of differently processed hot-rolled coils partly related to high formable ferritic stainless steel in laboratory scale were quantified by Electron backscattered diffraction (EBSD) & Kernal average misorientation (KAM) methods. Recrystallized gamma-fiber texture development, closely related to high R-value, in cold rolled and annealed sheets with differently processed HR coils was observed and correlation between stored energy and deformation texture during hot & cold rolling and gamma-fiber development after annealing was discussed. Moreover developed high formable ferritic stainless steels have been applied in exhaust pipes and mufflers and the applicable other industrial parts such as boiler were discussed.

Simulation and modelling / 62

PREDICTION OF PERCENTAGE OF FERRITE AS A FUNCTION OF HEAT INPUT IN ROBOTIC GAS METAL ARC WELDING OF DUPLEX STAINLESS STEEL SAF 2205 WELDS

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Dual phase duplex stainless steel comprised with ferrite and austenite performance shows its strength and corrosion resistance in many aggressive environments based on outstanding performance in the last years. The current worldwide rapid growth, demand, and consumption of duplex stainless steel, particularly in petrochemical, marine, power plant, food industry and other engineering application, where the multiphase steels are being utilized that require welding for fabrication components. Joining of duplex alloys is a challenging, due to number of embrittling precipitates and metallurgical changes. Generally, the quality of a weld joint is strongly influenced by parameters during welding process; inappropriate welding conditions and imbalance phase ratio of austenite/ferrite leads to solidification cracking, corrosion susceptibility, and lower ductility. To achieve high quality welds mathematical models that can predict the bead geometry for obtaining the desired mechanical properties of the weldment has been developed. This paper focuses on determining the percentage of ferrite in GMAW welds of duplex stainless steel SAF 2205. Previously established models for the prediction of weld bead geometry were applied. The values of weld penetration and reinforcement were calculated using statistical approach and applying the rule of mixture, and using the Schaeffler diagram. The amounts of ferrite in the duplex stainless steel welds were determined and compared with experimentally-determined ones. The results show that the developed models for predicting weld bead geometry can also be applied to estimate the percentage of ferrite in the duplex stainless steel weldments.

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3D ViSE - SIMULATION OF A COMPLETE PROCESSING LINES

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State of the art metal processing lines need to suit to customer requirements, which are driven by short commissioning periods, fast start-up curves, large material flow rates and high demands in product quality. Projects in the past have shown that already minor problems encountered in engineering phase have big impact to meet these requirements. To solve engineering problems during commissioning takes lots of time and goes along with enormous additional costs for customers and sellers. Lessons learned of finished projects give important information about customer needs like to learn the efficient operation of the new production line in a short time to start immediate production after commissioning. 3D ViSE is a tool which was developed to help identifying software engineering faults in a first approach. The complete production line is integrated in an external 3D environment and acts as virtual Level 0. In an early state of software engineering it is possible to test the engineered automation program and sequences against the digital twin. Logic faults can be identified immediately. A second approach of 3D ViSE includes an integration of virtual control elements to allow operating the whole virtual production line. This gives a big amount of application areas. To test and optimize the whole automation program before commission, to train operator personnel on the digital twin any time, and to shorten amount of commissioning days, are just a few use cases of 3D ViSE.

Environmental aspects / 64

EFFLUENT FREE STAINLESS STEEL PICKLING

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A large variety of surface treatment processes is applied in stainless steel pickling. Mixed acid containing hydrofluoric and nitric acid is used as a standard treatment for hot and cold rolled material. The metal-fluorides and -nitrates from the waste acid can be pyrohydrolyzed by the Andritz Pyromars process. The recovered acid is recycled into the pickling process and the metal oxides are re-used in the steel making process. In the CAPL (Cold rolled annealing and pickling line) an electrolytic process using Sodium Sulphate is used. Due to the pH-neutral solution the metals precipitate as metal hydroxides, but Chromium VI stays in solution (as Chromic Acid salts). The Neolyte Recovery process uses an acidification and a Sodium Thiosulphate addition to reduce Cr VI to a harmless Cr III hydroxide. Additionally the new ZEMAP process (Zero Effluent Mixed Acid Pickling) recovers the valuables from the rinse water from the stainless steel pickling line. A neutralization process using ammonia prior to a multi stage evaporation unit produces a highly concentrated Metal-Fluoride/Nitrate stream that can be recovered by the a.m. Pyromars process. The clean condensate can be reused in the rinsing process. Overall, Nitrate-free effluents can be achieved.

Fabrication, forming and welding / 65

MONOBLOCK 4.0: THE NEXT EVOLUTIONARY STEP IN THE STANDARD STAINLESS STEEL COLD ROLLING MARKET

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It is time for the brandnew Sundwig MonoBlock. The 20-roll mill is the perfect combination of engineering, effectiveness und service. As a milestone in cold rolling technology the Sundwig MonoBlock will help you to be even more successful in your business. Experience the Sundwig MonoBlock!

Surface properties / 67

DATA DRIVEN CONTINUOUS QUALITY MONITORING IN ROLLING MILLS

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Over the past decades, huge volumes of quality data collected through continuous and regular monitoring of individual processing lines from the rolling industry have been accumulated. Now is the time to reap returns on past investments made in expensive and precise quality measuring equipment. These data await being put to better use.
Any anomalous or divergent quality data require an action to be taken by the monitoring personnel. This action may be repairing, rerouting or in the worst case scenario, scrapping a coil resulting in losses. A huge amount of time and effort is typically invested in pin-pointing the exact cause of the defect(s).
This paper talks about finally pulling out these hidden or unused yet, available data for the purpose of continuous quality improvement. The data is scoured for previously unseen correlations using one or more classification algorithms. When relations are found, the data is arranged in relational trees. These trees can then be converted into new rules that are implemented immediately and further help in predicting and detecting errors and defects at an earlier stage on the processing line. The newly inducted rules thus help in generating better quality data. These newly generated and more precise data are again fed to the data correlator, which in turn comes up with newer and better correlations, which can be converted into even more intelligent rules based on a great deal of past experience as well as current, improved data. These rules continue to improve the quality of the output coils while at the same time allowing for an easier and earlier root cause analysis of a problem. The feedback based system contributes to bettering itself, thereby resulting in continuous quality improvement.