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MODERN METALLURGY 2023

IRON AND STEELMAKING

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Session: Iron and Steelmaking

DEVELOPMENT OF A PHYSICOCHEMICAL MODEL OF FE-SI-CR ALLOY SMELTING AND ITS IMPLEMENTATION FOR THE PRODUCTION OF NEW CHROME ORE REDUCERS – CROSIMAX ALLOYS

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Abstract: This article presents a four-reactor physicochemical model of melting in a submerged arc furnace of silicon-iron-chromium alloys containing Cr min. 21 wt%, Si min. 61 wt% and with an Al content in the range of 0.5-4.0 wt% and Ca in the range of 0.31-2.1 wt%. and characterized by a Cr/Fe ratio of min. 2.0. These alloys are then subjected to secondary metallurgical decarburization refining reducing the content of C to a maximum of 0.02 wt% and under the name of Crosimax are used as new reducers of chromium ores in the production of low-carbon ferrochrome, where their main advantage is a high reduction potential to Cr_2O_3. The developed physicochemical model for the production of Crosimax alloys is based on the Gibbs recursive energy minimization algorithm and is an extension of the earlier two-reactor physicochemical models of melting by carbothermal reduction in resistance-arc furnaces of iron-silicon alloys. The physicochemical model developed before the start of the test production of Crosimax alloys made it possible to determine the basic parameters of the technological process and to determine the scope of their change. The validation of the developed model took place in industrial conditions through its implementation into the metallurgical practice at ferroalloys plant ReAlloys Ltd., which showed that, while maintaining the appropriate technological regime, the deviation between the indicators calculated in the model and those achieved during production did not exceed 3%.

Keywords: Crosimax; ferroalloys; submerged arc furnace; carbothermic reduction; low-carbon ferrochrome; physicochemical model; Gibbs minimalization.

THE INFLUENCE OF LIME REACTIVITY ON THE OXYGEN STEELMAKING PROCESS

J. Brankov, S. Nafornita, F. Ponchon, B. Bulko, R. Findorak, J. Legemza, P. Demeter, D. Baricova

Abstract: An ultimate goal of oxygen steelmaking process is formation of a basic slag using fluxes (lime, dolime) to remove impurities, like phosphorus and sulphur. Fluxes dissolution efficiency is important to achieve basic slag at the early stage of the process and protection of refractory lining. Limiting step in the slag formation process in the BOF represents lime dissolution kinetics in the primary acidic slag. Lime for the steelmaking process must be soft-burnt, as only this type has a high reactivity - ability to transition to the slag phase. Experimental work was carried out in a Marsh furnace to determine the mechanism of lime dissolution in the slag. Dissolution rate of different types of lime (soft, medium, and hard-burnt lime) in the typical BOF slag were compared. It has proven an excellent solubility for the soft-burnt lime, which is related to its high reactivity and a lower solubility for the hard-burnt lime. After determining the mechanism of lime dissolution in the steel slag, high-temperature experiments were performed in the induction furnace. Results were used to quantify the level of lime dissolution in the steel slag, compare it with a standard lime reactivity measurement, and for development of Value in Use Model. This in-depth study was conducted to understand the importance and to evaluate the influence of lime characteristics on BOF steelmaking process and their quantification through total cost of ownership. Besides lime dissolution, thermodynamic and the fluid dynamic approach was used, together with mass and heat balance. Value in Use Model proves the importance of lime characteristics and its impact on steel cleanliness, metallurgical results, productivity, and total cost of steel production including notably energy and CO2 balance. The model can calculate the savings and cost benefits for given inputs, including lime and dolime, and operating parameters for respected case.

INFLUENCE OF ADMIXTURES OF MINERAL ELEMENTS IN REDUCING AGENTS ON THE STRUCTURE OF FESI AND FeSiCr FERROALLOYS

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Abstract: The publication presents the chemical compositions of carbon reducers used in the production of ferroalloys, with particular emphasis on the content of: Al, Ca, Mg, Mn, Cr, Ti, P or S in their mineral substance. A certain amount of these elements is transferred to the produced alloys, creating inclusions and precipitations in the metal structure. Most of them are undesirable and adversely affect the final effect of the production process. The work includes sample images of the microstructure of alloys, chemical compositions of samples at the test point and diffragrams. On the basis of the obtained metallographic data, technological observations are made, especially of the crushing process and the amount of obtained grain fractions.

Keywords: Ferrosilicon, submerged arc furnace, casting ladles, improving purity of alloy

KIH TESTING OF API 5L X42 AND X52 SEAMLESS STEEL TUBES

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Abstract: This paper deals with the fracture toughness testing of seamless steel tubes made of API 5L X42 and X52 steel grades. The tubes in focus were produced in Železiarne Podbrezová a.s. a prospective line pipe components for transportation of a gaseous hydrogen. The toughness itself was determined in terms of KIH values, i. e., the stress intensity factor material resistance in presence of hydrogen. The testing was performed by RINA Consulting – Centro Sviluppo Materiali SpA (Italy) and the procedure itself has been conducted according to the following standards: ASME B31:12: Hydrogen Piping and Pipelines; ASME BPVC Section VIII, Division 3: Alternative Rules for Construction of Pressure Vessel; Article KD-10: Special Requirements for Vessels in Hydrogen Service; ASTM E1681 – 03, Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials.

Acknowledgements

The results published in this paper are based on testing, evaluation and results reporting made by RINA Consulting – Centro Sviluppo Materiali SpA as a service ordered by Železiarne Podbrezová a.s.

Session: Foundry, Non Ferrous and Non - Metallic Materials

DETERMINING OPERATING PARAMETERS OF AN ELECTRIC FURNACE FOR CASTING OF BRONZE AGE REPLICAS

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Abstract: In previous work, a small electric furnace with a capacity of 3.5 kg of liquid copper, capable of reaching temperatures up to 1200°C, and with nominal power input of 2.1 or 6.2 kW at 230 V was designed and constructed. The purpose of this furnace was to melt metals for casting replicas of historical weapons, tools, and jewellery from the Bronze Age. The theoretical operating parameters, such as electric energy consumption and the time required to melt the batch of metal, were derived from the design calculations.

This study focuses on the experimental determination of the furnace's operating parameters. Experiments were conducted to determine surface heat losses from the furnace, as well as electric energy consumption and the time required to melt aluminium and copper batches of various quantities during cold starts and continuous furnace operation. The data from these experiments were subsequently analysed to determine the thermal efficiency of the furnace and the cost of energy consumed for melting a batch under given conditions.

The experimental results indicate that the furnace does not reach a steady state regarding heat transfer within the time required for melting a batch during cold starts. As a result, the surface heat losses are lower than initially calculated in the theoretical analysis. This leads to shorter required melting times, lower energy consumption, and lower energy costs for the batch compared to design values.

Keywords: electrical furnace; energy consumption; energy efficiency; replica casting

Funding: This work was supported by the Slovak Research and Development Agency, Grant No. APVV-18-0134 and APVV-19-0170.

INNOVATIVE PROCESS CONTROL FOR ROTOR DEGASSING OF ALUMINIUM MELTS

Ondrej Fazekaš

Vesuvius Moravia s.r.o

Abstract: The production of Aluminium castings globally is dominated by the automotive industry. To ensure that the correct casting quality is achieved, a more effective and technically sound melt treatment is essential, followed by a well-designed and controlled pouring practice. Automotive industry requests process reproducibility and so any melt treatment adopted must be capable of achieving consistent levels of cleanliness and hydrogen control. Many quality management systems also require a 100 % record of production data, so again a sophisticated melt treatment with data storage capabilities becomes more attractive.

SMARTT - innovative degassing control - offers a comfortable interface to program all necessary treatment steps, it reads or measures the starting conditions before every rotary degassing and predicts the best treatment parameters for different schemes. An integrated report system stores all data per treatment in Excel format and enables the melt shop manager to run further analysis on the process.

The use of SMARTT for degassing processes provides a melt on a constant hydrogen level independent from inconsistent starting conditions in a foundry.

SMARTT enables the foundry to always reach this in a cost-effective way, there is no need for compensating these variations in overrunning the treatment which wastes time, inert gas and graphite consumables.

In upgassing – often used in wheel foundries – even small changes in environmental conditions or melt temperature have an enormous impact on the hydrogen content after the treatment. These complex relationships can only be managed by a mathematical model. SMARTT, based on the batch degasser software, is an intelligent solution to handle data for rotary degassing.

QUALITY ASSESSMENT OF ALUMINIUM CASTINGS BY COMPUTED TOMOGRAPHY

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Abstract: The article deals with the use of computed tomography, an advanced method for evaluating the quality of aluminium castings. Casting quality is a key factor in ensuring safety and reliability in industrial applications. Computed tomography is a comprehensive method allowing a three-dimensional, high-resolution view of the internal structure of materials. The main focus of this paper is the study of BRACKET REAR aluminium castings, manufactured in two-piece molds using a high-pressure die-casting technology. In this paper, four castings have been analyzed which are produced in one cycle. The focus is on the problem of porosity and open stagnation in the castings. A numerical simulation has also been used to illustrate the occurrence of porosity, which can be used to determine both the occurrence of porosity and the occurrence of unfilled volume. The experimental part of the paper describes the methods used to evaluate the BRACKET REAR castings. The numerical simulation was performed in ProCAST to determine the occurrence of porosity in the castings under study. The evaluation of computed tomography was performed in myVGL 2023 software to analyze the internal defects in the castings. The evaluation focused on assessing internal defects and their subsequent effect on the functionality of the final casting.

Keywords: computed tomography; microstructural analysis; non-destructive testing; secondary aluminium alloys; porosity.

Acknowledgments: The paper was funded by the Technology Agency of the Czech Republic within the TREND program, as part of project Reg. No. FW03010609 “Research and development of shape molds made of H-13 and DIEVAR for die casting of aluminium alloys in the application of modern technologies of additive production, heat treatment, surface treatment and numerical simulations”.

INTRODUCTION TO THE METHODOLOGY OF QUALITY MONITORING OF ZINC ALLOY CASTINGS PRODUCED BY HPDC IN ADDITIVELY MANUFACTURED SHAPED MOULD PARTS

Kamil Koza [1, 2, *], Karel Gryc [2], Ladislav Socha [2], Martin Pinta [1, 2], Roman Kubeš [3], Václav Sochacký [3], Adnan Mohamed [2] and Jaromír Trobl [3]

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Abstract: This article evaluates zinc-alloy castings produced through high-pressure die casting, comparing those cast in conventional moulds to those cast in moulds with additively manufactured shaped parts. Additive manufacturing allows production of conformal cooling channels that enhance cooling and bolster production efficiency. To assess the performance of additively manufactured shaped parts, GD Druckguss designed and deployed experimental moulds addressing critical production geometries. Castings were subject to evaluation in both shaped part variations using 3D scanning, coordinate measuring machine and roughness measurements. These tests were conducted on castings from new shaped parts and subsequently after approximately every 100,000 shots. Results indicated higher dimensional stability in castings from conventional shaped parts, yet both variants exhibited decrease of dimensional deviations over time. Castings from the new additive shaped parts displayed higher roughness levels, but roughness values equalized with continued use of the shaped parts. Overall, no significant adverse effects were observed during the use of the additive shaped part, with its benefits prevailing. However, hundreds of thousands more shots are required to make a final recommendation on the suitability of such manufactured shaped parts for actual operating conditions.

Keywords: die casting; zinc alloy; additive manufacturing; H11 steel; 3D scanning

Funding: The paper was prepared in the scope of the TREND programme, project FW03010323: Research and development of shaped moulds from hardenable steels for casting zinc alloys in the application of modern technologies of additive production, heat treatment, surface treatment and numerical simulations, supported from the resources of the Technology Agency of the Czech Republic.

Session: Recycling of waste from metallurgical processes

POSSIBILITIES OF RECYCLING WASTE FROM METALLURGY WITHIN THE RECYCLING CENTER AT THE INSTITUTE OF RECYCLING TECHNOLOGIES IN KOŠICE

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Abstract: Within the Recycling Center at the Institute of Recycling Technologies, Faculty of Materials, Metallurgy, and Recycling, Technical University of Košice, the Laboratory of Processing Industrial Waste was established in 2013 as a result of cooperation between the Institute of Recycling Technologies and ŽP VVC s.r.o. (Research and Development), especially in the field of EAF dust recycling. The area of interest gradually expanded to practically all types of industrial waste containing metals. The presented paper describes the chronology of the Recycling Center's activities (laboratory and applied research) in the field of metallurgical waste recycling, characterizes the technical equipment of the workplace, and also provides information about awards and outputs. The Recycling Center is equipped with a pilot semi-operational facility for hydrometallurgical processing of EAF dust (with the possibility of application to other fine-grained waste). Using the proposed technology, marketable products based on Zn, specifically ZnO and ZnSO4.nH2O, have been obtained from industrial waste (EAF dust). The ZnO obtained through this technology was used for the production of a semiconductor component-varistor, which the Industrial Property Office of the Slovak Republic registered as a utility model in January 2023. The activity of the Recycling Center can be presented as an example of successful cooperation and the connection of science with practice, which yields results in the form of salable products in the recycling of industrial waste, information and recommendations for industrial partners in the field of technological procedures, as well as the education of qualified experts for industrial practice.

Keywords: Industrial waste; Recycling; Secondary raw material; hydrometallurgy; slag; EAF dust; Laboratory od Processing Industrial Waste;

Acknowledgments: This paper was created within of the grant VEGA MŠ SR 1/0678/23 and with its financial support.

GALVANIZED STEEL AND SUSTAINABLE CONSTRUCTION: SOLUTIONS FOR A CIRCULAR ECONOMY

Petr Strzyž

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Abstract: Europen General Galvanizers Association (EGGA) is the industry organization for Europe´s general galvanizing sector. It is a federation of 14 National Associations representing industry in Europe. EGGA puts the sustainability benefits of zinc hot-dip coated steel at the forefront of its communications and works hard to substantiate the claim that it is the most sustainable building solution. The European initiative for galvanizing in sustainable construction was launched at the beginning of the second millennium with a comprehensive analysis that resulted in the publication in 2008 of Galvanizing and Sustainable Construction: A User's Guide.

In April 2021, EGGA has released a new publication, Galvanized Steel and Sustainable Construction: Solutions for the Circular Economy. This is an 80-page book, produced by a small working group of EGGA members, which focuses on the development of the galvanizing sector, with galvanized steel continuing to be the basis for solutions to combat climate change and for building a circular economy, which has become both an upcoming goal and a starting point that has already been realised.

Galvanized steel offers a range of innovative solutions that optimize the service life of steel structures and components and enable their use in the circular economy.

Session: Process simulations

REFINING LIQUID STEEL WITH ARGON IN THE CONTEXT OF MODELLING RESEARCH

Saternus Mariola, Merder Tomasz, Pieprzyca Jacek

Abstract: The circulating motion of the liquid steel is necessary both to homogenize the temperature and to achieve chemical homogenization of the liquid steel and to support the flotation of non-metallic inclusions. This is due to the introduction of gas bubbles into the liquid steel. Therefore, the important process parameters in this case will be the intensity of gas bubble injection and the configuration of argon injection. This process is extensively analyzed in the context of the selection of process parameters, mixing and homogenization in the ladle, the behavior of gas bubbles from the moment of detachment from the plugs hole to the gas-liquid cone, the behavior of inclusions at the steel-slag interface and in liquid steel, and the formation of slag eye. These studies are possible thanks to the use of water models, i.e. physical modelling, and the obtained results allow for a relatively good understanding of the phenomena occurring during the process. Still, many aspects of the process remain experimental. The paper presents an overview of the conducted model tests.

BADANIA MODELOWANIA FIZYCZNEGO PROCESÓW METALURGII STALI

Jacek Pieprzyca, Tomasz Merder, Mariola Saternus

Abstract: Stojące przed producentami stali zadanie ograniczenia negatywnego wpływu jej wytwarzania na środowisko jest powodem konieczności zmian w dotychczasowo prowadzonych technologiach. Zmiany te wymagają często zidentyfikowania mechanizmów przebiegu zjawisk fizycznych, głównie hydromechanicznych, zachodzących w reaktorach metalurgicznych. Identyfikacja tych mechanizmów w warunkach przemysłowych z zasadniczych przyczyn jest trudna, a często niemożliwa. Powszechnie stosowanym w tych przypadkach narzędziem badawczym jest modelowanie fizyczne. W artykule przedstawiono przegląd osiągnięć w tej dziedzinie, stosowane zasady matematyczne stanowiące podstawę konstrukcji modeli reaktorów metalurgicznych oraz najnowsze trendy ich wykorzystania.

OPTIMIZING OF PIG IRON DESULFURIZATION USING PHYSICS-INFORMED NEURAL NETWORKS (PINNs)

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Abstract: The aim of the presented research was to optimize a pig iron desulfurization process through data-driven machine learning methods. Utilizing historical data, chemical analysis of pig iron and slag, thermodynamics of the process including simulations of the chemical reactions between individual phases was trained a neural network for predictive modeling of desulfurization efficiency. The accuracy of the model was enhanced by integrating Physics-Informed Neural Networks (PINNs), which incorporate chemical reaction principles. Results show better performance of PINNs in comparison to Feedforward Neural Network (FNN) in generalization of desulfurization process, bringing better reliability to the model.

Keywords: Pig Iron, Steelmaking, Desulfurization, Neural Networks, Physics-Informed Neural Networks (PINNs), Data Analytics, Process Optimization, Chemical Reactions, Predictive Modeling, Cost Savings, Simulations

Acknowledgment: This paper has been supported by grant "The study of the nature of steel flow processes during continuous casting and analyse of the high temperature interactions in complex metallurgical systems using thermodynamical and physical tools supported with mathematical simulations" – VEGA 1/0212/21.

Session: Recycling of waste from metallurgical processes

CHALLENGES AND LIMITATIONS FOR SOME METALS RECOVERY FROM CARBON STEEL EAF, FECR AND STAINLESS STEEL SLAGS

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Abstract: Iron and steel-making slags belongs to the significant secondary metals source, but the situation in slag processing/utilization is not satisfactorily solved worldwide, yet. Some metals occurring in slags (V, Mn, Nb etc.) are critical for EU and it is demanding to prepare the feasible concept for returning metals from slags to the life cycle. Beside the partial utilization of iron/alloys or mineral character of slags in metallurgy, cement or road constructions, the extraction of other metals from slags is not usually applied. The aim of the work is to investigate and point out the problematic aspects of the different approaches of slag treatment (hydrometallurgy, roast-leach technique) and recovery limits of Cr and V from steel and ferrochromium slags.

Keywords: Slag, EAF, Stainless steel, FeCr, Metal recovery, Chromium, Vanadium, Leaching, Roasting

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Session: Decarbonisation and Energy Transformation in Industry

VALORIZATION OF CRUDE REFINERY´S BY-PRODUCT: A CASE STUDY ON HEAVY RESIDUES GASIFIER

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Abstract: Conversion of locally available low value materials to useful products and media, thereby replacing high-quality and high-cost resources, belongs to one of the pillars of circular economy in industrial conditions. A study on potential implementation of mixed oxygen- and steam-blown heavy vacuum residues gasifier in a refinery processing 5 to 6 million t per year crude is performed, evaluating its mass and energy balance, and identifying and assessing synergies of gasifier placement in a refinery rather than its erection as a standalone plant. Industrial heat and power plant and hydrogen production plants represent production units directly affected by gasifier implementation, while several other technical and economic issues result in the operation of steam network, in heavy residues handling and in refinery´s natural gas balance. Natural gas is currently the most important resource for hydrogen production in the refinery and its partial replacement by hydrogen from gasifier has different energetic and environmental impact, based on the considered natural gas composition (current situation, natural gas with 10 % vol. renewable hydrogen and natural gas with 20 % vol. renewable hydrogen content). Power production and overall refinery´s power balance, carbon dioxide emissions both within the refinery and external ones and natural gas balance change are evaluated. Preliminary results show that while the gasifier commissioning is associated with an over 1 billion € investment, it can represent one of the few available solutions of how to reasonably dispose of heavy residues, utilizing it both from energy content and material potential point of views.

Keywords: vacuum residue; gasification; hydrogen; refinery; carbon dioxide

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MULTI-CRITERIA EVALUATION OF ENVIRONMENTALLY FRIENDLY ALTERNATIVE FUELS

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Abstract: In order to fulfil the environmental goals set for the coming years, industrial companies are motivated to look for clean technologies and green solutions. Replacement of common fuels in the transport sector can also contribute to the reduction of emissions. In this work, we focus on four alternative fuels. The main raw materials are hydrogen together with carbon dioxide or used cooking oil. We analysed seven technologies of low-emission hydrogen production. However, in such types of production, it is often a problem with combination of the environmental side with the economic one because they are usually in conflict. The solution can be found using multi-criteria decision analysis (MCDA). Individual fuels were compared as well as hydrogen production processes using three criteria: minimum selling price, carbon footprint, and maturity of technology in order to find the most suitable alternative. The main advantage of our MCDA approach is the objectivity of the final ranking. On the other hand, the complexity of this method also provides the possibility of subjective choice of criteria preferences, which allows each decision-maker to focus on his target of interest. Data-driven decision making also provides an opportunity to incorporate sensitivity analysis into the study.

Keywords: low-emission hydrogen; transport; decision making; green technologies

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INFLUENCE OF PROCESS PARAMETERS ON ENERGY CONSUMPTION IN A STEELMAKING ARC FURNACE

Piotr Migas, Mirosław Karbowniczek, Dariusz Józefiak

The detailed characteristics of the operation of the electric arc furnace nowadays becomes extremely important for economic and ecological reasons, its result may be the optimization of energy consumption in the melting process. Sustainable development of steel production technology requires constant evaluation of the conditions for conducting the most energy-intensive processes, such as arc process. The paper presents the results of analyzes of the operation of a real arc furnace from the point of view of identifying electricity consumption depending on the parameters and conditions of the melting process. The characteristics include selected process data such as oxygen, gas blows, time at currrent, and CaO consumption for 5 selected steel grades. The process as a whole stage and its individual components were analysed: subsequent melted scrap baskets and among others, stages of melting, tretmant-refining. Based on the results, differences in the qualitative and quantitative character of changes in energy consumption for a given type and stage of the melting process were found.

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IMPACT OF ENERGY PARAMETERS OF THE POWER SUPPLY SYSTEM ON ELECTRICITY CONSUMPTION IN A STEELMAKING ARC FURNACE

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Abstract: The paper presents the results of analyzes of the operation of a real EAF from the point of view the impact of energy parameters of the power supply system on electricity consumption. The characteristics include selected process data such as average primary voltage, average primary current, average secondary current and average foaming index per melt for 2 selected steel grades. The obtained significant statistical relationships are different for both grades of produced steel. This may be due to certain technological differences, especially in the field of batching (mainly different grades of scrap) for the smelting process, as well as significant heterogeneity in the quality and form of scrap in each group. The results contained in the article are part of the research carried out in framework of the projects funded by The National Centre for Research and Development (Poland); number POIR.01.02.00-00-0162/16 and POIR.01.02.00-00-0179/16.

Poster session

THE EFFECT OF DIFFERENT SHAPED IMPACT PADS ON THE FLOW OF STEEL IN THE TUNDISH

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Abstract: The aim of this research was to compare the flow of steel in the tundish, which was influenced by different shaped impact pads during the casting process on the continuous casting equipment. For the research, a 2-strand symmetrical tundish with three differently shaped impact pads located in the area of steel inflow into the tundish was used. The evaluation of the character of the flow was carried out on the basis of the assessment of the correct refining of liquid steel. The research was carried out on a physical model. In addition, numerical simulations were used to determine the vector and velocity fields, as well as monitoring the highest velocities in certain parts of the tundish, which could cause significant wear of the refractories lining.

Keywords: Tundish; numerical modelling; CFD; impact pad

Acknowledgements: This research work was performed under the grant project No. 1/0212/21 and was financially supported by VEGA ME SR and SAS, and project APVV-21-0396 was financially supported by APVV.

HYDROGEN ENRICHMENT OF NATURAL GAS: IMPLICATIONS FOR BURNER OPERATION

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Abstract: This paper presents the results of increasing hydrogen concentration in natural gas distributed within the territory of the Slovak Republic. The range of hydrogen concentration in the mathematical model is considered from 0 to 100 vol.% for the resulting combustion products, temperature, heating value, and for the scientific assessment of the environmental and economic implications. From a technical perspective, it is feasible to consider enriching natural gas with hydrogen up to a level of 20% within the Slovak Republic. CO_2 emissions are estimated to be reduced by 3.76 tons for every 1 TJ of energy at an operational cost of €10,000 at current hydrogen prices.

Keywords: Hydrogen; Natural gas; Combustion

EXTRACTION OF LEAD FROM HYDROMETALLURGICAL PROCESSING OF COPPER SHAFT FLUE DUST

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Abstract: Pyrometallurgical copper production is carried out in thermal aggregates. Input waste materials with a copper content of between 5 % and 99 % Cu are treated in the individual aggregates. In a shaft furnace, except for molten black copper, slag and shaft flue dust (SFD) are produced as waste. SFD is emitted from the melt and then is captured by fabric filters. This kind of SFD is defined as 'hazardous waste' according to the European Waste Catalogue. SFD contents attractive quantity of valuable metals like Zn, Sn and Pb. This work is focused on the hydrometallurgical treatment of SFD from secondary copper production with the aim of obtaining usable lead-based products.

Keywords: copper dust; hydrometallurgical processing; lead precipitation; shaft flue dust

Funding: This research was funded by the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic through grant project VEGA 1/0408/23.

OBTAINING USABLE PRODUCTS BY PROCESSING CONVERTER FLUE DUSTS FROM COPPER PRODUCTION

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Abstract: Copper converter flue dust (CFD) is one of the solid wastes generated during the pyrometallurgical production of secondary copper. Due to its fine grain character and content of toxic heavy metals, CFD is classified as hazardous waste. CFD contains lead, zinc, and tin in the form of oxides. The aim of the paper is to design a complex hydrometallurgical process of CFD treatment in order to obtain commercially saleable products based on zinc, tin, and lead. The proposed CFD treatment process consists of leaching in acetic acid, cementation of lead from leachate by zinc, and subsequent precipitation of zinc with carbonate ions.

Keywords: converter flue dust, thermodynamics of leaching, hydrometallurgy, copper

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PREPARATION OF ROTOR GEOMETRY FOR SETTING UP NUMERICAL MODEL OF FLOW IN REFINING LADLE

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Abstract: Foundry Degassing Units (FDU) are used for refining aluminum alloys. For an ideal refining process using FDU unit it is necessary to select several parameters, which are linked to each other. For a rotary impeller, we search for several parameters, such as its optimal shape, speed in the liquid alloy and distance from the bottom of the refining ladle, where the aforementioned parameters contribute to the overall wear and life of the rotor and, consequently, of the rotor shaft. The Computational Fluid Dynamics (CFD) method can be used to determine the above-mentioned parameters. This paper describes the particular steps of preparation of rotor geometry for subsequent setting up the basic numerical model.

Keywords: aluminum refining; FDU unit; 3D CAD; Computational Fluid Dynamics (CFD)

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COMPREHENSIVE MATERIAL RESEARCH OF FE AND MN ORES AND ASSESSMENT OF POSSIBILITIES FOR THEIR REDUCTION WITH HYDROGEN

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Abstract: The energy policy of the European Union brought to the fore the question of reducing dependence on fossil fuels, which resulted in the demand for the maximum possible use of renewable energy sources and non-carbon reagents. Hydrogen is very important among the non-carbon reagents, which can also be used in iron, steel and ferroalloy metallurgy technologies. The report specifies the results of the material research of Fe and Mn ores and the selection of the most suitable ores for hydrogen reduction. These were the iron ores of Krivbas, Rudomain and Carajas and the manganese ores of Burkina Faso, Gabon, Ghana and South Africa. In the case of iron ores, they were oxidic ores based on hematite and hydrohematite, which are the most suitable for hydrogen reduction. In the case of manganese ores, it was one of the highest quality manganese ores in the world, since the potential of hydrogen reduction can only be used in the case of manganese ores in the reduction of higher Mn oxides (mainly MnO2) up to the reduction to MnO. From the results of determining the physico-chemical and metallurgical properties of Fe and Mn ores, it follows that the Brazilian Fe ore Carajas and Mn ore Gabon are the most suitable for initial hydrogen reduction experiments. Both ores contain easily reducible phases – in the case of Carajas Fe ore, it is hematite, and in the case of Gabon Mn ore, it is pyrolusite. The aim of the research was to create a tool for designing the most suitable thermodynamic and kinetic conditions for the reduction of Fe and Mn ores with hydrogen.

ANALYSIS OF CURRENT KNOWLEDGE OF HYDROGEN APPLICATION AS A REDUCING AGENT IN METALLURGICAL PROCESSES OF IRON PRODUCTION

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Abstract: Within the contribution, an analysis and study of current knowledge focused on the applications of hydrogen as a reducing agent in metallurgical processes for iron and steel production were conducted. Globally, processes based on MIDREX, HYL, and ENERGIRON technologies are gradually evolving and improving, utilizing hydrogen and carbon monoxide-based reducing gases generated through natural gas reforming. The goal of these new technologies is to increase the proportion of hydrogen in the synthesis gas, ultimately leading to the use of pure hydrogen in iron ore reduction. The theoretical study is primarily focused on laboratory investigations of the reduction of iron-bearing materials to gather as much information as possible about the materials under examination, furnace equipment, reduction conditions, and the impacts of various parameters on the reduction process and resulting product properties. Most experimental setups worldwide are based on proprietary methodologies, with techniques often relying on TGA (thermogravimetric analysis) devices, fluidized beds, and reduction retorts, all with meticulous monitoring of gas compositions. The analysis reveals that the mineralogical composition of the used iron ores significantly affects hydrogen reduction, with hematite-type ores being the most suitable. Hydrogen reduction temperatures typically range from 500 to 900°C, depending on the studied commodity and experimental objectives, while reaction times varied between 10 to 60 minutes. Reaction rate and degree of reduction increase with rising reduction temperature, with the transformation of wüstite into iron being the slowest step within the reduction reactions. The analysis indicates that reduction with H2 occurs more intensively and rapidly than with CO or in H2/CO mixtures. The analysis of current knowledge regarding hydrogen's application as a reducing agent in metallurgical iron production processes has established a suitable framework for the development of new metallurgical technologies utilizing hydrogen and its impact on the technological and environmental parameters of iron production processes.

THE IMPACT OF IMPLEMENTING CARBON BORDER ADJUSTMENT MECHANISMUS ON THE STEEL INDUSTRY THROUGH 2034: A FORECASTING STUDY

Slavomír Hubatka, Branislav Buľko, Dana Baricová, Lukáš Fogaraš, Andrii Pylypenko, Dominik Dubec, Jaroslav Demeter, Peter Demeter

Abstract: The metallurgical industry is one of the main pillars of European economy. Steel is important not only for modern economies of developed countries but is an essential part of building infrastructure in developing countries. In an era where environmental concerns increasingly influence global trade policies, the implementation of Carbon Border Adjustment Mechanisms (CBAM) emerges as a critical factor affecting various industries, notably the steel sector. This study aims to demonstrate the impacts of introducing CBAM on the development of the steel industry through the year 2034. Employing a multi-method approach that includes econometric models and scenario analyses.

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COMPARATIVE STUDY OF INNOVATIVE "SPHERIC" AND STANDARD IMPACT PAD SYSTEMS IN BOAT-TYPE TUNDISH

Lukáš Fogaraš, Slavomír Hubatka, Peter Demeter, Branislav Buľko, Andrii Pylypenko, Jaroslav Demeter, Dominik Dubec

Abstract: Rising requirements for steel cleanliness and simultanious effort to economize production in continuos steel casting are creating need for process innovation and development of innovative technologies. Currently, employing simulations remains the most economically viable method to implement such innovative developments. The tundish, as the final reactor with a refractory lining, offers ample scope to ensure the required cleanliness of the steel while simultaneously minimizing the intermix zone, ensuring optimal efficiency in steel casting. This study presents a detailed comparative analysis of three different shapes of impact pads: conventional standard and two unique spherical impact pads, utilizing a 1:3 scale physical water model of a boat-type tundish, to simulate steel casting processes. Research focus is on the dynamic of steel flow, intermix conditions within the tundish, and their associated metallurgical implications. Each pad is thoroughly evaluated based on C and F-curves according to specific parameters such as min. and max. residence time, 80/20 and 90/10 criterion, and visual comparison of flow. The study reveals insights and offers an understanding of how various configurations of impact pads as a key source in a boat-type tundish can optimize steel cleanliness and economize production in continuous steel casting.

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APPLICATIONS OF TUNGSTEN ALLOYS IN THE ENERGY SECTOR

Brožová Silvie, Macháčková Adéla, Slíva Aleš

Abstract: A new area of application for flywheels is for electrical energy storage, which is achieved by connecting a motor-generator with a power converter to the rotor axis. Flywheels for energy storage are characterized by the fact that they allow a large number of charges and deep discharges without the risk of damage. Disadvantages of flywheels include constant operating losses and initial high acquisition costs. The highest specific energy stored in the flywheel is achieved in rotors made of composite materials. However, flywheels for energy storage that have even higher speeds, i.e. above 10 k rpm, are constructed from steel materials due to the significantly lower cost. Waste multimetallic can be used as another material for the construction of flywheels material that can no longer be used.

RESEARCH AND DEVELOPMENT OF NEW HIGH-ENTROPY ALLOYS FOR HYDROGEN STORAGE

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Abstract: Hydrogen is a key element in the changing energy sector and access to conventional fossil fuel sources. Agreements such as Clean Europe or Net Zero Emission by 2050 Scenario support actions to reduce CO_2 and increase carbon neutrality [1,2]. The system of ten high-entropy alloys was prepared based on the Hume- Rothery rules. One of the biggest advantages of these alloys is their storage capacity, which reaches the highest value among known alloys intended for hydrogen storage. Alloys based on Al-Ti-Nb-Zr elements with different atomic fractions show interesting accumulation capabilities with fast absorption kinetics and low specific gravity. Each alloy underwent to high-pressure gravimetric absorption and desorption tests. The main goals of the work are to prepare alloys with the lowest possible specific gravity and the highest possible storage capacity. One alloy from the system shows storage capacity values similar to commercial alloys, without of rare earth elements.

Keywords: hydrogen, metal hydride, high-entropy alloys, storage capacity

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STATE AND PERSPECTIVE OF FOUNDRIES IN SLOVAKIA

Ondrej Kožej, Iveta Vasková

Abstract: Foundry, just like in the past so today, is overall one of the strategic branches of industry. In a fact, all aspects of modern life depend on casting, as regards brake discs, medical implants, marine engines, even aircraft like turbine blades. Foundries provide supplies to all sectors of modern industry, including automotive, aircraft, medicine, power generation, etc.. The Slovak economy largely depend on the automotive industry for which the casting is necessary. Cast components are used not only for engines, chassis, drives, but also in vehicle bodies. This article reports on information about current amount of foundries in Slovakia, the number of produced castings tons and melding methods, casting techniques in various foundries and type of cast metals. It considers about income of individual foundries, the impact of the economic situation and assumptions of further development.

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THE BENEFITS OF USING AN ADVANCED MATERIAL FOR PRODUCTION OF SPHERICAL IMPACT PAD IN TUNDISH

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Abstract: In order to meet the increasing cleanliness quality in steel production, it is imperative to devise innovative solutions. The tundish, which serves as the final reactor lined with refractory material, offers space to lower inclusions contents by optimizing the flow of steel. At the heart of the tundish lies the impact pad, a main component that dictates the steel's flow pattern and plays an important role in tundish metallurgy. To avoid the formation of dead zones and slag red-eye in the layer of slag around the ladle shroud, the ideal steel flow within the tundish should facilitate the removal of inclusions through interactions at the steel-slag interface. Additionally, this flow should prevent excessive erosion of the tundish's refractory lining. This study undertakes a comparison between the conventional impact pad and the spherical impact pad using physical modeling, assessing residence times and flow characteristics within the tundish across three distinct casting speeds.

For the practical use of the results of mathematical modeling, the development of special refractory concrete was started, from which prefabs were subsequently produced. The shape of the prefabs is defined as a result of the optimization process of the metal flow in a tundish. Prefabs, spherical impact pads, are produced by casting refractory concrete into molds.

Keywords: steel; spheric impact pad; continuous casting; tundish; physical model

Funding: This research was funded by project APVV-21-0396: The development of a spherical impact pads in ladles and tundishes for high-quality steel grades.

THE IMPACT OF THE PRODUCTION OF CAST IRON CASTINGS IN A CUPOLA FURNACE ON THE ENVIRONMENT

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Abstract: The production of cast iron castings in cupola furnaces is a significant industrial process that has a notable impact on the environment. This paper examines and describes the environmental impact of this process, specifically focusing on the generation, characterization, and utilization of waste materials through data analysis and collection. Approximately 102 million metric tons of castings are produced worldwide each year, with approximately 1 ton of foundry waste generated for every ton of castings. The slag from this waste can amount to as much as 7.14 million metric tons annually. Most of the slag ends up in landfills, which is expensive and represents a waste of potential secondary raw material. Therefore, it is necessary to find ways to utilize this waste in other processes or industrial sectors. Cupola slag, given its high phosphorus content, can be used as agricultural fertilizer or in the production of ceramic foam used in foundries as filters during casting. In the construction industry, slag can be used in the production of concrete as a partial substitute for fine aggregate. This concept not only mitigates the environmental impact of waste disposal but also aligns with the circular economy concept, promoting resource efficiency.

Keywords: cupola furnace, cast iron, cupola furnace slag, concrete

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COMPARISON OF DEGASSING EFFICIENCY ON A FOUNDRY DEGASSING UNIT USING DIFFERENT ROTOR TYPES

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Abstract: The present paper describes a comparison of the efficiency of different types of rotors used in the refining of aluminium melt at a foundry degassing unit (FDU). Physical modelling was used to obtain data for six different rotor types under defined experimental conditions. In order to evaluate the data from the physical model, an evaluation method based on the interpolation of degassing curves was developed in such a way that the resulting characteristic can be expressed by a single parameter. Using the new methodology, the datasets were replaced by a single dimensionless parameter "a", which characterizes the rotor performance at a given gas flow rate. Based on the comparison of these performance parameters, it was possible to mutually compare the rotor efficiency depending on the selected conditions. The results showed the differences between the rotors at the same gas flow rate and also how the observed differences could be compensated by a different gas flow rate. The comparison is also demonstrated on the expected degassing time to a certain required concentration.

Keywords: physical modelling; aluminium; degassing; data processing; rotor efficiency

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OPTIMISATION OF THE STEEL STRIP HEATING PROCESS BY CHANGING THE EXCESS COMBUSTION AIR

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Abstract: Reducing energy consumption and increasing energy efficiency have been especially topical issues recently, affecting all areas of energy consumption, including industrial sectors. Continuous annealing lines, as important industrial production facilities, operate with high energy consumption, which can be analysed and optimised using predictive mathematical models. For purpose of this paper, a mathematical model was developed to compare 5 variants of different excess combustion air operating with the same heat input and fuel consumption. The reference variant had an excess combustion air with a value of 1.279 and the steel strip temperature at the outlet of the heating chamber was 609.5°C. In terms of energy saving, variant 1 can be considered as the optimal variant, which had an excess combustion air of 1.15 and a steel strip temperature at the outlet of the heating chamber of 637.3°C.

Keywords: continuous annealing line; heating chamber; steel strip; mathematical model, energy

ACTIVE SURFACE OF THE PURGING PLUG ON THE EFFECTIVENESS OF THE ARGON BLOWING PROCESS IN THE LADLE

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Abstract: Jednym z najważniejszych kryteriów oceny jakości stali jest jej czystość metalurgiczna. Dlatego w celu ciągłego jej zwiększania prowadzone są różne zabiegi rafinacyjne na wszystkich etapach produkcji. Podstawowym z nich jest wdmuchiwanie strumienia gazu obojętnego do ciekłej stali przez kształtkę gazoprzepuszczalną zainstalowaną w dnie kadzi stalowniczej podczas obróbki na stanowisku pieca kadziowego. Wieloletnia praktyka stosowania tego zabiegu doprowadziła do opracowania niezwykle zawansowanych rozwiązań konstrukcyjnych kształtek gazoprzepuszczalnych generujących wymagany mechanizm tworzenia się kolumny gazowej. Jedną z metod dalszego rozwoju tej techniki rafinacji stali może być zwiększenie objętości kolumny gazowej w stosunku do objętości ciekłej stali w kadzi. Spełnienie takiego założenia wymaga zastosowania nowych rozwiązań konstrukcyjnych dystrybutora gazu. W artykule przedstawiono wyniki badań modelowych z wykorzystaniem modelu wodnego stanowiska pieca kadziowego, mających na celu potwierdzenie słuszności sformułowanych założeń i skuteczności opracowanej nowej konstrukcji dystrybutora gazu obojętnego.

W artykule zaprezentowano wyniki badań modelowych przeprowadzonych na stanowisku badawczym wyposażonym w fizyczny model wodny kadzi stalowniczej. Badania miały na celu określenie znaczenia wielkości powierzchni aktywnej kształtki wykorzystywanej w trakcie wdmuchiwania argonu do kadzi na wspomniane wyżej czynniki. Jako kryteria oceny skuteczności procesu przedmuchiwania ciekłej stali przyjęto minimalny czas całkowitego wymieszania cieczy modelowej w modelu kadzi oraz stopień dyspersji gazu w objętości cieczy modelowej. Minimalny czas wymieszania określono na podstawie wyznaczonych krzywych RTD, natomiast stopień dyspersji gazu w cieczy na podstawie badań o charakterze wizualizacji.

STABILNOŚĆ STRUKTURALNA STALI MARTENZYTYCZNYCH DLA ENERGETYKI

Kinga Rodak

Abstract: Zmiany struktury wysokostopowych (9-12 % Cr) odpornych na pełzanie stali austenitycznych X10CrMoVNb9-1 i 12CrMoWCuVNb analizowano w warunkach długotrwałego wyżarzania w temperaturze 550Oc w czasie 100 000h. Badania realizowano przy zastosowaniu skaningowego transmisyjnego mikroskopu elektronowego. Skład fazowy wydzieleń analizowano z wykorzystaniem analizatora składu chemicznego EDS oraz dyfrakcji elektronów. Po długotrwałej ekspozycji wykazano w strukturze obecność wydzieleń węglików M23C6 oraz wydzieleń fazy Lavesa. Dodatkowo w stali 12CrMoWCuVNb stwierdzono obecność wydzieleń fazy Z.

EVALUATION OF FACTORS AFFECTING THE THICKNESS EVOLUTION OF THE MgO-C REFRACTORY LINING OF THE BOF

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Abstract: Identification of the factors influencing refractory lining wear and its residual thickness in BOF is a prerequisite for optimization of the steelmaking process. In this paper, the factors that contribute significantly to the wear of the refractory lining in the most stressed areas of the banded lining, i.e. the trunnion ring area and the slag line area, have been identified. Knowledge of the rate at which a given factor acts on refractory wear is closely related to the development of techno-logical procedures aimed at limiting its influence. This paper evaluates the technological causes and describes the lining wear mechanism, together with the thermodynamic parameters of the reactions between the MgO-C - metal - slag - gunning material phases. The results show that the combination of technological factors, mechanical action of the raw materials, blowing and free oxygen in the metal, silicon from the pig iron and slag viscosity have the greatest influence on the residual thickness of the MgO-C refractory lining in BOFs. Refractory gunning material con-sumption, its effect on campaign length and the cost effectiveness of repair work were also ana-lyzed in the paper.

Keywords: MgO-C lining residual thickness; refractory lining wear mechanism; wear factors; slag viscosity; gunning material

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