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HEAT TREATMENT EFFECTS ON MICROSTRUCTURE, MECHANICAL PROPERTIES AND DURABILITY OF UNS N06625 ROLLED RINGS FOR OIL & GAS APPLICATIONS

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In this work, the effects of solution annealing and aging on an ESR Ni based superalloy are reported. The starting ingot has been hot worked as a rolled ring. The ring has been cut in several chunks, these were heat treated according an experimental design including trial solution annealing and aging at different temperatures and holding times. The microstructure, mechanical properties and durability of the alloy were evaluated after the treatments according the typical requirements for Oil & Gas forgings. The results confirmed the expected increase of secondary carbides at the grain boundaries after the aging, furthermore a γ' morphology change is noticeable. A substantial growth of YS (over 70 ksi) and UTS are obtained only after a long time exposure at the aging temperature, moreover a low temperature impact toughness drop is noted after this heat treatment but the material is able to reach values significantly over the 27 J limit. The aging treatment shows in every case a detrimental effect on the material susceptibility to intergranular corrosion, when tested as per ASTM G28 method A. On the other hand, also after tens of hours at the aging temperature, the pitting corrosion subsequently 24 h in the ASTM G48 method A solution is negligible.

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STUDY ON THE KEY TECHNOLOGY & THE ROUTINE OF INTELLEGENT MANUFACTURING FOR OPEN DIE FORGING

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Intelligent Manufacturing (IM) technology belongs to the advanced & the new production technologies. Recent years, China government published several policies to support the discrete production type industry including open die forging industry to develop IM. However, there is few of the open die forging plants responding actively. Comparison with the volume production type industry, the open die forging plants is facing greater difficulty and challenge in developing IM technology. In this paper, the main difficulties and the reasons are analyzed based on the production characteristics, the technology foundation and the existed realistic situation in the open die forging plants. The inherent meaning of IM and the necessary to develop IM for open die forging industry are studied based on the economic profit data and the background investigation, statistics and analysis. The urgent problems to be solved first and the priority to be done by IM for the open die forging industry is proposed based on the actual requirements of the open die forging industry and the manufactures,. Considering the combining the basic survival needs and the necessary foundation of developing IM for open die plants, 6 techniques or research achievements are proposed by this paper based on many year continuous studies. Those technical achievements construct the basis to develop the advanced IM in Chinese open die forging industry. Based on the above technical achievements, the basic progress routine map for Chinese open die forging plants to develop and realize IM is given generally. The study may attract more researchers to study on the IM for open die forging industry, it may provide reference idea for the

open die plants to develop IM in order to realizing transforming & upgrading, it may also have certain valuable for software and hardware suppliers of the open die forging plants to adjust and to improve their future products and services.

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Process integrated production of complex workpieces in open-die forging

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Open-die forging is an incremental bulk metal forming process, which is mainly used for the production of long and straight workpieces with simple geometries. The production of complex geometries usually requires additional manufacturing steps or can only be realised by a high amount of machining. A new and innovative manufacturing approach is based on the idea to realise the production of complex workpieces through superimposed manipulator displacements during a forging stroke. Due to the plastic state of stress during a stroke, already relatively small superimposed forces are sufficient to form the workpieces towards the intended geometry. This new open-die forging process is based on the idea, that the manipulator is used to actively control the material flow and form the workpiece towards the intended geometry. Since usually the manipulator is not designed to actively form the material, in a first step a new kinematic concept was developed which allows the required movements during forging. This kinematic concept was successfully transferred to the industrially open-die forging setup at IBF. Based upon this, the influence of different process parameters on the final geometry is discussed by numerical simulation and experimental validation. Besides the common forging parameters as bite ratio and height reduction, the bending angle, bending velocity and bending direction have a decisive influence on the resulting workpiece geometry. Both the numerical and experimental investigation prove that the new process concept can be used to drastically increase the range of producible geometries in open-die forging and therefore could offer a promising approach to realize the near net shape production of complex workpieces.
Keywords: Open-die forging; bending; Manipulator; Curved workpieces; Stress superposition

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Alternative Methods for Determining Microcleanliness: A Study Based on Hot Work Tool Steels

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This study focuses on the development and comparison of standard and alternative methods to evaluate the cleanliness of hot work tool steels used for dies on a microscopic level. The steels subjected to this study are hot working tool steels produced by an electric arc furnace (EAF) and ladle furnace (LF). After re-melting by an electric slag (ESR) or a vacuum arc (VAR) furnace the forged or rolled specimen were taken as subject for the investigation with different methods. The standard investigation method for non-metallic inclusions (NMI) is light optical microscopy (LOM) according to different standards such as ASTM E45, ISO 4967, DIN 50602, EN 10247, JIS G0555, ... Following alternative methods were investigated: Giga cycle fatigue (GCF) tests including SEM-EDS-investigations, automated scanning electron microscopy and energy

dispersive X-ray spectroscopy (SEM-EDS), electrolytic extraction method and X-ray computed tomography (XCT) with a maximum resolution of 1 μm voxel size. For comparative results the specimens used for XCT experiments (diameter of approx. 2 mm and length of approx. 20 mm) were destructively investigated with automated LOM. Additionally samples from the same lots were investigates acc. to LOM-standards to give a comparison of ASTM E45, ISO 4967, DIN 50602, EN 10247, JIS G0555 to the above mentioned alternative Methods. The correlations of different methods are illustrated in diagrams. Comparative results for the different production routes show a similar size of NMI within each method. Each method has its advantages and disadvantages concerning additional information, e.g. time for preparation and measurement and costs.

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Automatic Ultrasonic Inspection of Open Die Forged Parts and Forged Steel-Bars for the Energy- and Aviation-Industry

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BÖHLER EDELSTAHL is as part of the VOESTALPINE Special Steel Division, next to the production of Tooling Steel, High Speed Steel and Special Steel grades, a qualified and approved supplier for several renowned customers in the worldwide Energy- and Aviation-Industry. To fulfill the high requirements of our customers to the product quality, are, next to several destructive testing methods or non-destructive surface inspection methods, also different ultrasonic testing methods with automatic inspection equipment's required. These equipment's and the additional required qualified, certified and authorized inspection personnel guarantee a secured and reproducible inspection of the volume respectively the inner quality of the produced products. In the forging line are followed automatic ultrasonic inspection equipment´s in use.

- Two conventional disc inspection equipment´s in Contact Technique method for part diameters up to 2.2 meter
- One conventional Immersion Technique equipment with 5 control-axes for parts with simple contours or bars in flat or round shape and up to a length of 6.5 meters.
- One Phased Array Technique equipment based on a water chamber system in quasi immersion technique for round bars up to a length of twelve meters.

All equipment´s have a numerical control system for the automatic inspection process including a recording program of the detailed position- and inspection data´s to present the A-Scan and C-Scan analysis as minimum. The mentioned inspection equipment´s and there different inspection techniques will be described in this elaboration on the basis of practical inspection tasks of pre-machined open-die parts as well of steel bars including a presentation of the final application of the finish part.

Products for industries / 6

Materials and Manufacturing of Container and Stem Forgings for the Extrusion Industry

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Extrusion tools, such as containers and stems, are expensive components and it is important to use the most suitable materials to gain a long service life. However, it has to be pointed out, that

not only the applied materials determine the life time of these tools, but also melting and forging techniques, as well as heat treatment have an essential impact. Since many years, Bohler Special Steel Open Die Forge is a supplier of forged high-quality components for the extrusion industry, e.g., mantels, liner, liner holder, stems, and accessories for containers. Our material knowledge covers all tool steel and high-speed steel applications, as well as special materials for power generation, aerospace, automotive, oil and gas, and engineering with all possible interactions. This paper reports on experiences and research activities in the fabrication of forged components for containers and stems for the extrusion industry and covers material selection up to achieved mechanical properties and NDT results. Moreover, heating and Finite Element Method (FEM) modelling of stress distributions in the container during the extrusion process in order to optimize and predict the life time of these components is discussed. From the material side, the focus is set on the classical steels of the 5\% chromium class, up to the high alloyed and sophisticated Maraging steels for stem application, mainly in indirect extrusion processes, with the highest compressive stresses required.

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DEVELOPMENT, IMPLEMENTATION AND RESULTS OF LARGE BOTTOM POURED INGOTS AT ELLWOOD QUALITY STEELS

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Large forgings for power generation, ship shafts and plastic extrusion dies require large high quality ingots. In 2008, Ellwood Quality Steels (EQS) implemented a 2-ladle, interrupted pouring process to produce 70 Mton bottom poured ingots. Commissioning of the new 90 MN North American Forgemasters (NAF) open die press in early 2016 generated the need for much larger ingots. To produce ingots greater than the nominal heat size and maintain quality represents a challenge for a Steelmaker. It was determined that the interrupted bottom pouring process was not feasible to expand from a 2-ladle to a 4-ladle pouring process while continuing to meet quality requirements. Various methods were investigated and Sandwich Pouring was selected to be the optimal choice to produce high quality bottom poured ingots up to 165 Mton at EQS. The existing 45 Mton and 70 Mton bottom poured ingots, were scaled up using the suitable L/D ratio, hot-top volume and throat opening during the design stage of the larger ingots. Finite element analysis (FEA) software was used to model hot top configurations and insulating materials in order to achieve ideal solidification behavior. The training of the bottom pour crews took place on ingots 70 Mton and smaller with the modified teeming car and the ladle-to-ladle shroud manipulator prior to startup of the 90 MN NAF open die press. Once the 90 MN press was commissioned, the first 90 Mton (2 ladles) and 125 Mton (3 ladles) ingots were produced using the Sandwich Pouring Process. The ingots were forged on the 90 MN NAF press, located in the same complex as the EQS Melt Shop. The segregation pattern, micro cleanliness and ultra sound inspection of the steel forgings have been extensively assessed. The resulting forged pieces have been found to have low segregation, good micro-cleanliness and have met rigorous power generation ultra sound requirements. The continuing development and FEA modeling of the 165 Mton ingot(4 ladles) is also presented.

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Development of NiCrMoV Steel with Lower Nickel for Generator Rotor Forgings

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3.5%NiCrMoV steel has been widely used for generator rotor forgings for the purpose of obtaining high strength, toughness and magnetic permeability. Although the added alloy elements are important to achieve specified mechanical properties, reducing the amount of alloy elements is also important to contribute to natural resource savings and cost savings. In this study, the effects of Ni and Cr on mechanical properties of NiCrMoV steel were investigated. As the result, a new lower Ni steel has been developed with mechanical properties equivalent to 3.5%NiCrMoV steel, which has been used for generator rotor forgings for several decades. Developed steel has been applied for commercial generator rotor forgings, and the mechanical properties have been evaluated through joint research with GE Power. At present, the expansion of its applications is progressing.

Numerical analysis and simulation / 9

STUDY ON EVALUATION FACTORS FOR VOID CLOSURE IN MULTIPASS FORGING

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In order to ensure closure of a voids in a large steel ingot and obtain a good internal quality, it is necessary to establish the quantitative evaluation method for void closure in multi-pass forging. Although many evaluation formulas with equivalent strain, εeq, have been proposed as evaluation methods for void closure in single-pass forging, there is few reports of detailed study on it in multi-pass forging. The authors have investigated the void closure behavior in multi-pass forging by numerical experiments to consider the appropriate evaluation factors for void closure in multi-pass forging. The results obtained are as follows: 1) The void closure behavior in multi-path forging can be predicted with not εeq but true strain in z-direction, εz . 2) In the case of closing the voids by reduction in z-direction, the εz used in multi-pass forging is quite similar to the value in single-pass forging. 3) If εz required for void closure in multi-pass forging is less than the value in the single-pass forging, the void closure behavior of the multi-pass forging can be evaluated by the single-pass forging.

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Modelling of microstructure and damage in ring rolling

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Ring rolling is an incremental bulk metal forming process for the production of seamless rings up to 10 m in outer diameter and up to 4 m in height. In ring rolling, the process layout is of high importance for the reduction of material waste and chipping. Simultaneously, waste due to product errors e.g. form errors, cracks and coarse grains has to be prevented. Nowadays, the waste due to form errors for rectangular cross-sections is of minor importance due to highly developed control systems of the ring rolling mills. However, the waste due to cracking and coarse grains is more relevant than ever, especially for highly loaded and safety critical applications, where the used materials are expensive and often challenging to roll. To prevent waste due to cracking, material allowances based on empirical knowledge are used, which usually lead to larger allowances than necessary. The finite element analysis can be used to improve the process layout of ring rolling processes by predicting geometrical evolution during the process and therefore reducing

allowances. Furthermore, by the application of damage criteria during the simulation, predictions of damage evolution can be made. Also, by the application of microstructure calculation tools, microstructure evolution can be predicted. In this paper it is shown how the process layout can be improved by the use of the finite element analysis which ultimately can lead to waste reduction: During the simulation of the ring rolling process different damage criteria are calculated online by using a subroutine. Furthermore, the microstructure of the ring is modeled in a post processing step. Consequently, a process design with regard to microstructure and damage parameters could be possible. However, by the application of different damage parameters the strong dependency of the damage parameters of the load type is presented.

Plant engineering and equipment / 12

INSTALLATION AND PERFORMANCE OF A NEW 90MN OPEN DIE FORGING PRESS AT NORTH AMERICAN FORGEMASTERS

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Keywords: open die press; open die forging; forging manipulator; forge furnace; large steel ingots

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Manufacturing process and mechanical properties of large-sized high tensile strength intermediate shafts

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Recently, the needs for eco-ships have been increasing from the viewpoint of the strengthened environmental regulations and the demands for improvement of fuel consumption. The engine design places importance on higher power in low revolution range, so that the stroke of engine becomes longer. As a result, the higher torsional vibration is subjected to the intermediate shafts. The torsional vibration stress can be lowered by the increase of shaft diameter, or strengthening of materials. In particular, the higher tensile strength material can lead to reduce shaft weight, and omit the torsional vibration damper. In April, 2015, the special approval of alloy steel which has a minimum specified tensile strength beyond 800 and less than 950 MPa can be used for intermediate shaft material in the Appendix I of IACS UR M68. Because of this special approval, it is expected that the application of high tensile strength alloy steel increases for intermediate

shafts. This paper reports the results of the manufacturing and the mechanical properties test of the large-sized intermediate shaft with the length over 10 meters for large container ships. Its specified tensile strength is 930 MPa. This large-sized one has never been manufactured in KOBE STEEL, LTD, due to the size of the conventional polymer quenching tank. At this time, the vertical quenching tower is applied to the quenching after austenitizing. As this is the first heat treatment of intermediate shafts using the vertical quenching tower, we consider the heat treatment condition in advance. In particular, the heat treatment condition to satisfy the product specification is optimized based on the tensile strength estimation equation derived from past productions of low alloy steel, and the cooling rate by thermal analysis. The measured cooling rate during the quenching is corresponded well with the calculated value, and the desired mechanical property is achieved.

Advanced and new forging materials / 14

Trial production of large sized gas turbine disk of Ni based superalloy FX550

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Currently ferritic heat resistant steels are mainly used for large industrial gas turbine disks because large disks made of ferritic heat resistant steels can be produced easily. On the other hand, it is well known that Ni based supperalloys such as Alloy706, Alloy718, Waspaloy, etc., on have much higher strength at elevated temperatures than ferritic heat resistant steels. Alloy718 has very high strength at high temperature but it contains a large amount of alloying elements and it is difficult to produce its large ingots because it has tendency to cause freckle defects. It is easier to produce large ingots of Alloy706 than Alloy718 but Alloy706 has lower strength at high temperature than Alloy718. Therefore a high strength Ni based superalloy which has the same strength at high temperature as Alloy718 and of which large ingots can be produced easily is required for large gas turbine disks in order to increase the operating temperatures of gas turbines and power generation efficiency. It is necessary to reduce the tendency to form freckle segregations of Alloy718 in order to produce a large ingot of a high strength Ni based superalloy such as Alloy718. A new Ni based superalloy with the same strength as Alloy718 and lower tendency to form freckle segregations, FX550, was developed by modifying the alloy compositions of Alloy718 to minimize the liquid density difference between condensed and average chemical compositions at a co-existing temperature of solid and liquid. Previously a large ingot of FX550 without freckle segregations was produced by VIM-ESR-VAR process and a gas turbine disk with a diameter of 1.5m class was produced1). In this study, larger disk with a diameter of 1.9m class was tried to be produced. In the same way as the previous trial, in order to design disk forging process and predict of the microstructure, computer simulation was used. Finally, a trial production of FX550 were demonstrated based on computer simulation results.

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DEVELOPMENT, IMPLEMENTATION AND STARTUP OF STATE-OF-THE-ART MULTI-DIRECTIONAL FORGING COMPLEX AT ELLWOOD CRANKSHAFT GROUP

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Ellwood Crankshaft Group (ECG), one of the world's largest producers of industrial crankshafts, has invested in a modern horizontal multi-directional press to complement the CGF Loewy Press originally built in 1960. This new facility will produce monolithic medium speed engine crankshafts, industrial crankshafts, and a multitude of none crankshaft geometries. The new 310MN press operations extends the product capability range through the largest medium speed four stroke monolithic crankshafts.

The project execution marks the fulfilment of extensive technology and market research beginning as early as 2005. All modern competitive solutions and internal capabilities were examined, including TR, RR and modified technology. In the end, ECG's technical team and partner engineered the world's largest horizontal multi-direction press center exploiting our internal capabilities of the Loewy equipment and adding state-of-the-art process technology.

The new facility is located in Sharon, Pennsylvania, USA and houses combustion furnaces for forging, the forging press itself, water and poly quench capabilities, material testing laboratory, rough and semi finishing up to 16 meters x 2 meter swing x 60 tonne work piece inside nearly 40,000 square meter facility.

The new ingot's at Ellwood Quality Steel, including 70Mton and 90Mton ingots and North American Forgemaster's new 90MN open die press will be utilized to provide high quality forged bar for conversion into crankshafts and other product.

The investment is scheduled for production 1Q2017. The facility will allow for the conversion of traditional open die crankshafts and other new shapes to be produced in a near net geometry and can include turbine shafts, hollows, elbows, etc. to meet broad market requirements including marine, industrial, oil and gas, aerospace, and defense requirements with material grades including but not limited to alloy and stainless steels.

Testing and QM / 17

APPLICATION OF DEVELOPED AUTOMATED UT SYSTEMS FOR FORGED ROTORS AND DISCS

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Japan Casting & Forging Corporation (hereafter JCFC) has developed an automated Ultrasonic Testing (UT) system for the improvement in reliability and applied it to the practical examinations on more than hundreds pieces of rotor forgings for steam and generator components in electric power plants since 2010. After that, further amelioration of the testing condition has been conducted through the commercial inspection to expand the applicable rotor diameter. JCFC has consequently succeeded in increasing the size up to 2,264 mm dimeter by means of the optimization of signal noise ratio for a rise in the performance of flow detection near the surface. In addition, JCFC has introduced a new automated UT system for the forged discs. The system has been equipped with a phased array device to raise the examination efficiency. This paper will describe the improvement in the inspection technology to increase in the capable diameter on the current automated UT system for rotor forgings and the outline of the new facility for gas turbine discs. A future plan on the development of the phased array device will be mentioned.

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Retained austenite measurements and magnetic response of 17-4 PH stainless steel under magnetic particle testing

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Abstract Patriot Forge is a producer of 17-4 PH stainless steel components for the gas turbine and gas compression industry. To meet the demand of this high strength precipitation hardening steel in large forgings, Patriot has commissioned a new 5000 ton press. This alloy is open die forged from air melted, bottom poured ingots of different sizes. For the mentioned above application non-destructive testing is indispensable to guarantee high quality and expected performance in the field. The use of larger ingots has resulted in increased segregation. This paper studies elemental segregation being detected during magnetic particle inspection. There will be a discussion about the relevance or non-relevance of these indications. Highly segregated areas can give false indications based on magnetic response of different phases present in the steel. SEM microscopy and X ray diffraction were used to carry on this investigation. Also magnetic particle inspection was performed under a microscope to analyse the magnetic particle behaviour around different phases present in 17-4 precipitation hardening stainless steel. Comparative data regarding mechanical properties of areas with non-relevant indications versus other areas within the forging will be presented.

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Development of high creep resistant MARBN steels for forged components in high efficient power plants

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Over decades Böhler Special Steel has been a full package supplier of customized high quality special steels and forgings. Böhler Special Steel fosters close relationships to plant manufacturers with the aim to provide products ahead of its time. This paper provides some results of our research activities to raise the operating temperatures of 9% Cr steels from 625 °C (1157 °F) to 650 °C (1202 °F). Increasing the operating temperature requires adoptions of our processes and manufacturing methods to produce optimized microstructures which meet customer specifications and increase creep rupture strength at the same time. The microstructure of two Boron containing 9% Cr steels (FB2-2-LN and NPM1-LN) developed within the framework of our COST activities is compared after heat treatment and discussed after creep rupture. The results show a dependency of the creep rupture strength on the stability of precipitates and on the recovery of dislocations within the first 10 000 h of creep exposure at 650 °C. Heat treatment allows to reduce the total amount of dislocations and to decrease their recovery during creep. The creep rupture time of both steels was increased by more than 30% without negatively affecting the creep rupture strain and impact values.

Environmental management / 20

Installation of advanced 500-ton forging furnaces

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In the production of the large forgings, a reduction in exhaust carbondioxide and nitrogenoxide is a key issue from the viewpoint of the environmental protection, and a decrease in fuel consumption of gas combustion type forging furnaces is therefore in highly demand. Japan Casting & forging Corporation (JCFC) has introduced new regenerative burners for the furnaces since 1999. In a furnace having a capacity of 500 metric tons, the burners replaced from the recuperators in the

exhaust heat recovery system have achieved a reduction in the amount of the combustion fuel by about 30%. To raise the production capacity, JCFC has subsequently brought in three new large forging furnaces, together with a new 13,000 tons forging press in 2010. Further improvement of the advanced furnaces in addition to the regenerative burners has been conducted to cut down the fuel as follows: 1) Development of the materials and the construction method for the ceramics fiber heat insulator on the inner surface of the ceiling and the door to suppress the radiation heat capacity, 2) Restriction of the air flowing into the furnace by means of a decrease in the cooling air for fuel nozzle and a refinement of the mechanical seal to lower the density of oxygen inside the furnaces, 3) Introduction of a control unit for the whole exhaust on the regenerative burners to elevate the exhaust heat recovery efficiency. Above further improvements for the new forging furnaces have successfully provided a reduction in the fuel consumption by roughly 34% in comparison with the prior regenerative burner furnace introduced in 1999.

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LATEST DEVELOPMENTS IN ABRASIVE CUTTING AND GRINDING OF LARGE-SCALE FORGINGS

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Prior to further processing of semi-finished steel and special alloy products, it must be ensured that the surface of the work pieces is free from scale and flaws.
In addition to that, these products also need to be cut and the cut surface needs to be free from heavy burr and surface hardening.
For both applications, even for increasingly large product dimensions and regardless if the product to be ground or cut is cold or hot, BRAUN provide a state-of-the-art solution, either with the multi-functional HP (high-pressure/high-performance) grinding machine or with the high-performance abrasive cut-off machine.

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Application of Optimum Forging Pass Schedule for the void consolidation

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A [U+3000] forging pass schedule affects a closing behavior of internal void in ingots. To evaluate a void consolidation behavior, the parameter Q-value, which is calculated from the hydrostatic stress and the equivalent strain, is reasonable. The recent progress of forging simulation technology makes Q-value calculation easier. A forging pass schedule has been decided by forging ratio. It only depends on the first/last cross-sectional area of the forging product, so a void consolidation behavior changes depending on other forging conditions (e.g. shape of forging tools, reduction ratio, deformation resistance of material) even though the forging ratio is same. These conditions were decided empirically. In some cases, low productivity conditions were decided to prevent internal void defect. To deal with productivity and internal quality at the same time, an optimum forging pass schedule was designed with calculating Q-value under the capacity of press machine. Moreover, trial manufacturing with designed forging pass schedule was conducted. Detected maximum UT defect size was φ2mm (MDDS [U+FF1A] φ1.8mm [U+FF09] and it was showed that this pass schedule provide enough void consolidation effect. Also, the productivity was improved 7%. It is confirmed that a useful forging pass schedule could be determined for actual forging.

For the future, to use Q-value more readily (without calculating in each case), the formulation between Q-value and forging conditions is carried forward.

Keynote / 23

Update on Forged Special Steels, Remelting and Powder Metallurgy

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The presentation will highlight the recent developments in the world of Forged Special Steels and remelted steels (nickel alloys, stainless steel, alloy tool steel and alloy steel) as well as will give an overview about end-user demand and structures of these special steels and also summarize the actual status of installations (forging presses and remelting units) on a global scale. The speech will also focus on the production of Metal Powders and Powder Metallurgical Steels and especially its associated production technologies like HIP, MIM and AM. As they are and will become key future core technologies for a number of demanding products and thus for the usage in different associated industries. The presentation will also highlight the actual supply and demand situation of metal powders and the manufactured metal powder steels, will introduce leading manufacturers of both powders and steels, and summarizes installed capacity and new capacity that are on the way.

Plant engineering and equipment / 24

DEVELOPMENT AND INSTALLATION OF ADVANCED MULTI-FUNCTIONAL HYDRAULIC PRESS, INTENDED TO IMPROVE ENGINE VALVE QUALITY

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FUJI OOZX Inc. (OOZX), who are pursuing their global growth in the field of automobile engine valve production, further improving quality of the valves, had installed the world's state-of-the-art Multi-functional Hydraulic Press that made it possible to make wide variety of forging. This report describes the characteristics of the state-of-the-art equipment and of the effect of quality improvement.
Mitsubishi Nagasaki Machinery Mfg. Co., Ltd. (MNM), based on the findings and knowledge from the 5-axis (up-down/right-left axis) multi-way hydraulic press we delivered some years ago, had introduced the newest hydraulic servo-control technology and delivered the Multi-functional Hydraulic Press to OOZX. The characteristics are:
Quality improvement and extension of die life by forging speed differences in engine valve hot forging procedures
In one pressing operation of multi-way press, a forging speed difference between forging of 1st procedure and those of 2 - 3 procedures is realized. Together with deformation amounts of respective procedures, forging speeds (distortion speeds) are also controlled, making quality aspect better and die life aspect improved.
Suppression of burr development in forging by continuous "vibrating" forging[U+3000]
Using hydraulic servo control on 1-axis, "vibrating" forging is realized. By vibrating forging, improving lubricity between die and work contact part, smooth deformation plasticity was realized, and burr development is reduced.
Using hydraulic press, cycle time 3 seconds/1 piece realized.

In order to match the cycle time of the previous screw press, by adapting special structure cylinders on the hydraulic press, the operation speed compares well with that of a screw press. By installation of the newest machine, not only extension of die life, but also manufacturing of engine valve with further improved quality is now made possible. By that quality improvement, increase of OOZX's share in the world is expected.

Testing and QM / 25

DEVELOPMENT OF A NON-CONTACT MEASUREMENT SYSTEM USING IMAGING SENSOR

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When rolling rings with high-precision and a high speed, it is crucial to accurately determine the dimensions of the ring. The conventional method for measuring this was to push a measuring device in direct contact with the ring. Recently ring measurement is shifting from mechanical measuring with a measuring cylinder towards non-contact measurement methods like laser sensors. However, there are several downsides to laser sensor measurement; e.g. the dependency of the measurement accuracy on the distance between the laser and the target, but also the need to adjust the mechanical structure of the machine for the installation of the laser sensor. Therefore, we have started the development of a new non-contact measuring system using an imaging sensor in 2013. The purpose of this system was to be able to perform stable and precise measuring. We have installed it at an actual production facility in November 2015.
The imaging sensor consists of a high-quality camera, attached with ball screw to a mounting block which can be moved horizontally through an AC servo motor. In other words, the imaging sensor itself is able to follow the ring as it grows. The captured images are projected on a monitor, which already displays a predetermined reference line. The position of the camera is controlled based on the Manipulated Variable (MV), which is the difference between the edge (position on the ring rolling surface) of the ring and the imaging sensor reference line. The ring outer diameter is determined by the sum of "the position of the camera" and "difference between the reference line and the ring surface". The imaging sensor's measurement accuracy is approximately ±1mm. We have confirmed the following benefits of this system: There is no mechanical wear when measuring with the imaging sensor. It is more cost-effective than lasers sensors since it requires only 1 imaging sensor. It can be applied to other equipment as well, so it is not limited to ring rolling mills.

Testing and QM / 26

APPLICATION OF LASER TRACKER FOR DIMENSIONAL INSPECTION OF LARGE FORGINGS AND ITS UNCERTAINTY EVALUATION

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Dimensional inspection is essentially important to prove conformance to specifications of customers' drawings in terms of quality assurance. Requirements concerning geometry of products are getting detailed and strict as represented by GPS (Geometrical Product Specifications) standards currently being developed by ISO/TC 213. Dimensional inspection by conventional measuring equipment such as steel tape measure, micrometer, templates etc. highly relies on the skill and ability of inspectors. In order to satisfy strict geometrical requirements with confidence, we have introduced

a portable CMM (coordinate measuring machine), Leica Laser Tracker AT960-LR, which enables to perform dimensional inspection everywhere in machine shops with high accuracy. There are some cases where the evaluation of measuring uncertainty is needed, however, it is challenging for laser tracker especially because the uncertainty depends on the measuring strategy, namely the number of data points to obtain, the location of data points, evaluation method of obtained data points, etc. Here we discuss uncertainty of the distance between two points as well as uncertainty of center point and radius of best-fit (least squares method) circle and sphere by the analysis of uncertainty propagation of least squares method. It is concluded that introduction of laser tracker can reduce the measuring uncertainty and contribute to reliable dimensional measurements.
Keywords: Dimensional inspection: Laser tracker; CMM; Uncertainty

Advanced and new forging materials / 27

Development of 617 alloy rotor forging for 700oC[U+2103] advanced USC powder plant

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With the rapid development of economic, it is urgently need to develop coal-fired power generation technology of further increased value of steam parameters in China. National 700[U+2103] USC coal-fired power generation technology innovation consortium has been founded to develop the 700[U+2103] USC technology and key components of steam turbine in 2010. All the forgings used for 700[U+2103] and higher steam parameter are manufactured by Ni-base alloy, which is easy to crack and get mixed and coarse grain structure in forging process compared to heat-resistant steels. It is very difficult to obtain large Ni-base alloy forgings with grain size of 4-6 class after several times of upsetting and elongating. Numerical simulation is used to provide structure prediction and optimize wrought parameters in the deforming process of large 617 alloy forgings. Furthermore, we investigate the influence mechanism of heat treatment process on high-temperature stress rupture of Ni-base alloy forgings, and get excellent high-temperature microstructural stability with serrated grain boundary, nano scale gamma-prime precipitated phase and grain size of ASTM level 2-4 by optimization of heat treatment parameters. The extrapolated value of creep rupture strength is above 185 MPa at the condition of 700[U+2103], 100000 hours.

Plant engineering and equipment / 28

Innovative technology for calibrated rolls in CELSA "Huta Ostrowiec"

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Production of calibrated rolls for steel industry in the Forge Division began in 70's and have lasted incessantly. Rolls made of forged steel are able to work in extreme conditions and can transfer heavy loads.
In the past few years technology of roll production has changed in Forge Division of CELSA Huta Ostrowiec. Now we are able to offer rolls with improved properties. We produced mostly rolls with flat barrel but now we produce rolls with calibers as well. Main change was to adopt shape of forge to be closer to the final shape (near calibres). Using this technology "calibre contour forging" we are able to form the celibres without cutting the natural grain flow in addition to

high inner consistency provided by the 80MN forging press. Then we carry out Heat Treatment process after machined rolls with optimum allowances. Thereby we are able to obtain a layer with the best properties on celibres with the heaviest loads.
These are the benefits which we can obtain using this technology: efficient heat treatment , better hardness on calibres' surface, better resistance of calibres' during rolling and longer lifetime.
Furthermore, our engineers developed special grades, called CERLO, which are used to produce calibrated rolls for our clients. Hardness can achieve 375HB but tensile strength even 1100MPa with bainite tempered structure.

Advanced and new forging materials / 29

EVALUATION OF MAXIMUM THICKNESS FOR FORGED SUPER DUPLEX STAINLESS STEEL PRODUCTS BY USING FEM ANALYSIS

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Our company manufactures forged duplex and super duplex stainless steel products. These materials are called ASTM A182 F51, F53 and F55. These have high strength and high corrosion resistance. Super duplex stainless steels (SDSS) are by definition a duplex stainless steel with a pitting corrosion equivalent (PRE) > 40, where PRE = %Cr + 3.3x %Mo + 16x %N. So these are used injection pumps with oil and gas plant. Steel forgings have proof strength higher than cast steel and are able to increase in thickness. Therefore, these are used to drill for deep area oil. We supply forged SDSS products over 200 mm thickness. But these materials have critical thickness. Because SDSS precipitate sigma phase that is detrimental intermetallic phase with decreasing cooling rate. It causes of fragile material and could cause a problem of crack. We tested to decide critical thickness for forged SDSS. The forgings materials are thicken more and more. And test is stopped critical thickness that is crack exist. And thermal stress is analyzed by FEM. We compared difference result of analysis of existing crack thickness with no crack thickness and consider mechanism of crack for SDSS. As a result, we found critical thickness line. And in FEM analysis, we understand a difference in hydrostatic stress, maximum principal stress and trial stress state by some test thickness that is related cooling rate. In case of large thickness that is exist crack, it has high hydrostatic stress and doesn't satisfy von Mises yield criterion. And it reaches the critical thickness after slight plastic deformation from elastic deformation. In conclusion, we understand maximum thickness of SDSS that is no existing crack thickness and relation of thermal stress and thickness of its material. We could manufacture thicker products and more multiple figure products.

Advanced and new forging materials / 30

Development of material manufacturing technology and welding rods for spent nuclear fuel shipping cask

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The objective of this study is to develop the spent nuclear fuel shipping cask shell material and welding rods with high toughness at very low temperature. Recently, in Korea, The demand of shipping cask has been increased to transfer spent nuclear fuel and nuclear waste to an interim

facility and store safely due to the limitation of the storage space inside nuclear power plant. The shipping cask is required to have excellent toughness for ensuring structural integrity even against hypothetical free dropping accident during transportation. In particular, in Korea, the shipping cask shell material and its weldment should be satisfied with the strict additional design requirement of Reference Temperature for Nil-Ductility Transition (RTNDT) of colder than -105oC to verify safety even in very low temperature environment. For SA350 LF3 low alloy steel using several small blocks, optimum alloy design has been performed through the optimization of chemical compositions such as C, Al and addition of boron. Also, optimum heat treatment process has been set up to get fine ferrite and austenite microstructure for improving toughness. Through the manufacture of the 30 ton cask shell forging with diameter of 1,900mm and wall thickness of 540mm, we can confirm that the cask material have excellent toughness satisfied with material specification of SA350 LF3 and RTNDT design requirement. Also, welding rods satisfied with RTNDT criteria of -105oC for GTAW, GMAW and SAW process have successfully developed through the alloy design and optimum welding heat input. Through this research, we can obtain the manufacturing technology of spent nuclear fuel shipping cask for Korean nuclear industry.

Poster / Exhibition / 31

Development of back up roll for skin pass mill with high performance by optimization of processes and alloy

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Recently, we have developed an advanced skin pass mill back up roll (SPM BUR) which is one of the most essential elements in the manufacture of flat products of metals. In this paper, the alloy design concept and the excellent properties of the developed SPM BUR was introduced. In order to optimize chemical composition and manufacturing process, the following procedures were adopted. First, the experimental specimens with different alloy elements were chosen as 5 candidate materials in total. Secondly, the high temperature compression, the dilatation tests and hardness, impact tests with respect to the different heat treatment condition were carried out to find the optimized condition for the manufacturing processes such as forging, normalizing, quenching and tempering. Thirdly, the disc to disc tests for the wear resistance of the candidate materials were carried out under the conditions of 1,470MPa test stress and emulsion lubricant of 3% mineral oil emulsion type and the wear resistance was discussed by correlation between the disc surface morphologies and the microstructures of the candidate materials. With increasing the alloying element, the candidate material deteriorates became slower under the condition of lubrication. The experimental results were used to find new material for prolonging the service life of the SPM BUR. Fourthly, the hardened surface parts would be obtained by induction hardening heat treatment were simulated using heat transfer coefficient and with continuous cooling behavior of the material. The simulation results were beneficial for the prediction of the effective hardened depth from the roll surface under the effective cooling system. Finally, the optimized alloy design based on the experimental data and simulation results, but also the cutting-edge process technologies, e. g. induction hardening, were applied for the manufacture of the forged SPM BUR. The developed SPM BUR was mounted in the POSCO roll manufacture and proved to have superior performance compared to the previous SPM BUR in the term of the surface machining rate in operation

Advanced and new forging materials / 32

Development of 2%CrMoV Steel Rotor Forging for Geothermal Power Generation

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In recent years, as part of measures against global warming, utilization of renewable energy has been increasing to reduce CO2 emission. Especially, geothermal power generation, which can supply large scale power steadily, has been being developed around the world, and there is a growing demand for large rotor forgings for large scale geothermal power generation. Japan Casting & Forging Corporation has been manufacturing rotor forgings of geothermal power generation for Fuji Electric, and the diameter of the rotor forgings for geothermal power plants has gotten larger and larger to increase power output and improve thermal efficiency. Therefore, a new steel was desired for such large diameter rotor forgings from the viewpoints of hardenability and cost-effectiveness. Fuji Electric and JCFC have jointly developed a new 2%CrMoV steel for rotor forgings for geothermal power generation, which has good mechanical properties, corrosion resistance and cost-effectiveness. This paper describes the verification results in laboratory testings and the manufacturing results of the actual rotor forging using the new steel.

Numerical analysis and simulation / 33

DEVELOPMENT OF A HIGH FIDELITY COMPUTER MODEL OF QUENCHING OF LARGE NUCLEAR FORGINGS

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The potential consequences of failure within a nuclear reactor means components are designed with a high level of reliability and large margins for error. In a pressurised water reactor, this design criteria is most relevant to parts contained within the reactor coolant system. Amongst others, this includes a number of pressure vessels, each constructed from several forged sections. To ensure structural integrity and the desired safety margins during operation, mechanical properties such as tensile strength and impact toughness are maximised. These properties are a function of the steel grade and manufacturing processes utilised. As a consequence of the conservatism within the nuclear industry there is little motivation to modify the chemistry of tried and tested alloys. Thus attention must be given to the optimisation and design of manufacturing processes, particularly heat treatments. Due to the size, bespoke nature and cost of each forging, empirical investigations are considered infeasible. Therefore computational modelling is a powerful tool when assessing and optimising industrial practices. The aim of this work was to develop a high fidelity computer model capable of predicting accurate cooling data during quenching.
Representing scientific phenomena and the quality of input data is key to the accuracy of any model. The paper explains how the latent heat of transformation was established in the form of an effective specific heat capacity using differential scanning calorimetry. These values were then incorporated by a user defined routine in a commercially available finite element modelling software. The paper also describes how values of heat transfer coefficient were established using inverse analysis. This was based upon a production scale heat treatment trial performed by Sheffield Foragemasters international. Finally the completed model was validated and utilised as part of an investigation into the use of welded thermal buffers during quenching. Simulated data produced by the model reinforced a limited set of empirical results, thus helping to qualify a new welding procedure and build confidence when using welded thermal buffers in production.

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Effect of the slag composition and a protective atmosphere on chemical reactions and non-metallic inclusions during electro slag remelting of a hot-work tool steel

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The remelting behavior of the hot-work tool steel X37CrMoV5-1 / H11, was investigated with several experimental melts on a lab-scale ESR-plant. The investigated parameters comprised a variation of the slag compositions and the use of a protective nitrogen atmosphere. Variations of the slag composition included slags with different contents of CaF2, CaO and Al2O3 as well as a variation of the SiO2-content in the slag. The remelted ingots were forged and analyzed regarding their chemical composition as well as their distribution and composition of the non-metallic inclusions (NMI) by automated SEM-EDX method. The chemical composition of the slag after remelting was analyzed as well. The results clearly show a clear relationship mainly of Si and Al in the steel with SiO2 and Al2O3 in the slag as well as the effect of oxygen in open ESR operation. Associated with these reactions are changes in the oxygen content. NMI changed in their total amount and size distribution as well as in the chemical composition. The SiO2-content of the NMI is significantly affected by the SiO2-content of the slag. The protective atmosphere reduced the Si-losses during remelting, but changed the composition of the NMI only slightly. The majority of the NMI were of the MA-spinel type. Variations of the CaO- and MgO-content of the slag shifted the composition towards Al2O3- or MgO-typ-inclusions. In General Remelting leads to an almost complete removal of sulfides, a reduction of oxisulfides and a slight increase of oxides.

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DEVELOPMENT OF SIC HEAT STORAGE MEDIA AND IMPROVEMENT OF THE COMBUSTION EFFICIENCY FOR HEATING FURNACES

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ABSTRACT In recent years, regenerative burner is adopted to improve the combustion efficiency for heating furnaces. Typically, the heat storage media for this burner have the shape of ball or honeycomb, and are made from alumina or cordierite. TYK focuses on Silicon Carbide (SiC) for heat storage media. It is because SiC has lower thermal expansion, higher strength, higher thermal conductivity, and higher chemical resistance as heat storage media than alumina. We optimized the shape in media in terms of thermal conductivity and heat capacity and filling rate. As a result, the SiC performance was better than the alumina one. We applied the new developed SiC heat storage media to heating furnace with regenerative burner. Consequently, the combustion efficiency of furnaces has improved significantly. Therefore, fuel consumption ratio has been much reduced. We confirmed that the application of SiC brought the decrease of temperature tolerance and raising time during heating, and that there was not influence on quality of work pieces, as a result of having evaluated some characteristic. It will be reported for the evaluation of the life time of SiC media by actual operation.

Keywords: Heating furnace; Regenerative burner; Heat storage media; Silicon Carbide (SiC); Combustion efficiency; Fuel consumption ratio

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Power on Demand for Forging Presses

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Continuous demand for improvements in the forging industry makes life-cycle-cost of industrial equipment an essential focus for the plant operator. As the forging process by nature is an extremely energy consuming process, one of the biggest parts of the operating costs are energy costs.
In conventional hydraulic press drives for forging presses the pumps are running on fixed speed and the major energy consumers in the system are the main and boost pumps. After the Fast Forging Valve introduced by Oilgear some years ago, the “Power on Demand” (POD) systems architecture is the new and innovative solution in forging press drives for the future. It is based on the highly reliable and ultra-efficient Oilgear FCS pump design on the one hand, on the other hand it relies on efficient electric motors and todays easily available large variable frequency drives.
Utilizing the proven track record and references in the forging industry, Oilgear provides an integrated and tailor made energy saving POD press drive for new equipment and retrofit projects. Thanks to the unique combination of Oilgear capabilities – efficient hydraulics components, dedicated forging software algorithms, engineering, manufacturing and assembly facilities – a POD drive for forging presses saves at least 25% of energy compared to a standard drive in open die applications.
At this year’s IFM, Oilgear will showcase the different aspects of its POD systems architecture with detailed elements, including industrial references.

Advanced and new forging materials / 37

Study about re-crystallization behavior of new Ni-base super-alloy under sub-solvus forging process

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A digital engineering system using finite element (FE) analysis was developed in order to optimized forging and rolling process for obtaining an adequate microstructure in large-scale forged and rolled products. For precise prediction of changes in microstructure during forging and rolling, the re-crystallization behavior should be investigate carefully. Ni-based super alloys are usually required fine grain microstructure in order to enhance high performance mechanical properties at high temperature. So it is very important to control the microstructure in forging, rolling and heat treatment process. In conventional studies, there were some procedures of forming a fine grain microstructure. For example, they are promotion of dynamic re-crystallization with high plastic strain at super-solvus temperature and keeping grain growth with pining effect of delta phase at sub-solvus temperature in case of Alloy 718. Then new studies about re-crystallization behavior with coarse gamma prime are reported. However, there are a little reports about it right now. In this study, the re-crystallization behavior of a new Ni-based super alloy with coarse gamma prime at sub-solvus temperature was investigated experimentally. Investigation of re-crystallization rate

and grain growth behavior was carried out by a Rastegaev compression test. Figure 1 shows microstructures of austenite grain, gamma prime and crystallographic orientation distribution (KAM value using EBSD). It was confirmed that the coarse gamma prime was remained at low temperature forging, and the static re-crystallization increasing new fine grain was promoted after heat treatment. As the result of analysis of KAM value by using EBSD, the low crystallographic orientation distribution was remained in old austenite grain without recovery. It was indicated that the phenomenon had a relationship to promotion of static re-crystallization.

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Improvement on the quality of Vacuum Casting Ingots by applying the Multiple Layered Refractory and the Various Sensing Equipments

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In vacuum ingot casting, molten steel stream is dropletized and degassed in the vacuum tank, since this process is one of the effective methods to obtain good internal quality and large ingots. There are cases that the large inclusions are observed in the vacuum casting ingots at the bottom part, which consist of SiO2, SiO2-MnO, and Al2O3-SiO2-MnO. As a result of the verification experiment with VIF, it is concluded that these inclusions are derived from the thermal insulating board which is set at the hot-top. Although this problem can be solved by replacing this board with firebrick, there is possibility of the decline in thermal insulation. Generally, macro segregation in ingot casting depends on a thermal insulation. To prevent deterioration of the macro segregation, the multiple layered refractory for the hot-top which consists of insulating brick and firebrick is developed. As a result of the application of this refractory to the hot-top, these inclusions are suppressed and center segregation is reduced.
In addition, to improve the quality of vacuum casting ingots, the new vacuum tank with various sensing equipments is installed. As the operating factors, which are related to the quality of ingots, are quantified and visualized by these equipments, quality and workability are improved.

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Manufacturing technology development of the large forgings for replacement nuclear power plant

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It is important to deliver integrated forgings for elimination of in-service-inspection and improvement of quality of large forgings. Integrated forgings could be manufactured by integration of head with various nozzles by removing weld seams which is located between two parts. This manufacturing technology should be adequately designed to ensure accurate final dimension, internal material quality and required material properties such as tensile and impact properties. In general, finite element analyses can be carried out to obtain the adequate forging process on the various kinds of forgings for nuclear power plant. The analysis results were effective to get a superior quality and to reduce the trial and error time during making the large forgings. This paper introduces the development experiences of Doosan heavy industries for replacement nuclear power plant. Computer simulation, 1/30 scale lead test, 1/5 scale prototype test and 1/1 scale mockup test were carried out to develop proper forging process. Then, manufactured integrated forgings were successfully delivered to commercial nuclear power plant of USA for fabrication.

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Direct quenching after forging and inductive re-heating - a new efficient process technology

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The biggest challenges for forgemasters are currently the general economic situation and the increasing demands arising from the environmental protection. Thus an efficient process flow with the use of process heat is increasingly indispensable for the economic continuity. One possibility is the combination of forging and quenching, the so-called quenching from forging heat. For more than ten years, this process has been established at BGH for the quenched and tempered steel grades. This method cannot be used for all steel grades as the forging temperature is below the quenching temperature, so it cannot be used for duplex and austenitic stainless steels due to the high solution annealing temperatures. In order to use this procedure for these grades as well, the process has been extended with the possibility of inductive reheating. After forging, it is possible to raise the temperature to a required value to quench the material. This process is significantly faster and more effective than in a standard furnace or batch furnace. This procedure results in several advantages regarding the cost, the environment and the product: e.g. mechanical properties and residual stress. The paper gives an overview of industrial installation of the new plant. Production results of duplex and austenitic grades will be presented as well.

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DEVELOPMENT OF A NITROGEN ADDITION METHOD IN ESR PROCESS

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Nitrogen is needed for high Cr steel to improve corrosion-resistant and heat-resistant. In generally, nitrogen adjust method in ESR is addition of nitride briquette. However, in this method, nitride does not melt and might remain in an ESR ingot as inclusions. On the other hand, the addition of powder nitride isn't suitable because yield for this method is too low. In this study, we investigated a new nitrogen addition method during the ESR melting. As a new nitrogen addition method, the nitride powder cored wire was welded to an electrode and was melted together. Fe-N-Mn and Fe-N-Cr were used as a nitride powder. As a result, it was confirmed that nitrogen increased the both ESR ingots. The electrode welded the Fe-N-Cr powder cored wire was higher in nitrogen yield. It seemed that this cause is difference in slag dipping depth by a melting point of nitride. A tendency about the nitrogen increment was higher from center to surface in middle part of the ingot. It seemed that this cause is difference of metal pool temperature. However, the difference in nitrogen increment of the diameter direction is not fatal. These results suggest that nitrogen addition method using nitride powder cored wire is effective.

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Energy Savings and Maintenance Friendliness in Special Machinery for Open Die as well as Closed Die Forging Plants

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A key point to satisfaction in the industrial sector is energy savings as well as maintenance friendliness as far as vital part of a production is concerned. DANGO & DIENENTHAL has proven over decades to be ahead in this field. All machinery is customized and of modular design. This ensures a most compact and flexible solution, which in turn generates the least-expensive operating cost in the market. This, of course, does gives a real advantage to the user of such equipment not before long. The return of investment is seen within the shortest possible period of time since the speed, the working accuracy as well as the maintenance cost are merit points versus other solutions. This paper describes in short the most recent developments according to real customer requirements with a lot of examples. The world market is different and many different machine types are required for forging plants in different countries. We focus here on some of the more interesting ones generated in the recent past.

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Automated Handling Systems for modern Heat Treatment Plants including flexible Quenching Pools with efficient Agitation

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There are three important points in heat treatment: agitation – agitation – agitation ! However, the speed in handling plays an important role in such a plant as well. The necessity to change the product range and sometimes also the layout of a plant some times, generated an idea of a movable tank in a self supporting structure with an integrated handling system to quench the material in less time. Reproducibility as well as speed in quenching are decisive factors of a modern plant. Inourdays Nowadays a lot of factories are required to deliver products with a constant and equal quenching pattern in order to keep the quality level high and stable. Aerospace industries require small thresholds and permanent documentation of all the important parameters during the process of heat treatment. This paper gives an overview of most modern plants in operation as well as some detail results compared to simulations done prior to the engineering of the plant.

Recent Developments in the forging industry / 44

South Korea's strongest Open Die Forging Plant from Planning to Commissioning

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It has been a long time since the tragic accident in Fukoshima. Immediately all large projects went 'on hold' for an 'X' amount of time, since nuclear power was in question instantly. The skepticism proved to be wrong, since this world needs more energy soon. One efficient possibility is nuclear power, for which many large size forgings are needed. Large presses have been available already during the last century. With turn to 21st century forge masters have decided to use more and more large scale forging manipulators in order to make the production of such large

size forgings even more efficient, safe cost and heats. This paper gives some insight to another successful collaboration between plant engineering companies as well as one of the most respected forging units within Asia. Some large size forgings are being discussed and compared to other routes of manufacturing – from forging with a mandrel only, forging with one huge manipulator up to forging with two very large size manipulators at one press.

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SOLUTIONS ON TECHNOLOGICAL FORGING TOOLS FOR A MODERN OPEN DIE PRESS

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Danieli's mission is to provide the most technologically advanced Forging plants available in terms of machinery and production processes in order to meet market challenges. The value in Danieli FORGING TOOLS technology is to enable the processing of materials at technological limits, execute automatic forging sequences, guarantee process repeatability, higher productivity and ultimately offer improved and uniform final product quality Additionally, with our plants, Danieli Breda forging technology helps to define and optimize forging parameters, minimizing operator intervention during the forging sequence through using suitable tools and devices in order to optimize production. Increase product capacity and possibilities also for existing installations. To be able increase, through the use of particular equipment, the capacity 'of the existing plant is one of the goals more' challengers for the Danieli forging Technological tools. In this forging tools you can see: -Movable piercer inside die -flat/round/ "V" Shape or equipment in order to forge bar, shaft, ring or disk -Pop up table from 1 to 120 ton. -turn table from 1 to 150 ton. -Top die rotating table -centering device and many other equipment in order to forge from Ingot to very close shape of final product. In this direction such as the most challenging is surely to give our customers the opportunity 'to increase horizontal daylights of the press without replace parts of the old plant, but by inserting a special tool that we will call: widening of horizontal day light. This allow forge pieces more bigger than nominal distance of column

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DEEP COGGING AND HIGH PACE RATE RADIAL FORGING IN ONE EQUIPMENT: DANIELI BREDA RF2

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High pace rate progressive reduction is the core of traditional radial forging process. Design based on eccentric shafts or crankshafts with mechanical synchronization of the 4 hammers has no equal in terms of precision, rigidity, speed. However, each single deformation is short and typically does not allow the plastic field to reach the center of the work piece. Therefore, unless hollow shapes are processed, the traditional hammering of solid pieces usually requires a previous deep forging stage, with a number of heats and additional open die forging facility. Danieli Breda has developed a new hybrid machine, called RF2, which couples in one equipment the advantages of hydraulic forging with 2 or 4 hammers and the high speed and precision of mechanical hammering. By means of a patented principle, the machine is automatically switched from one mode to the latter in a few seconds within the working cycle, allowing the piece to be fully processed in one heat with the best possible quality results both in terms of minimum FBH in the center and surface finishing. An advanced process control system precisely coordinate the press with the manipulators, managing the full working cycle in automatic, manual or semi-automatic mode. The best forging cycles for each product and material are provided by an offline calculation

software developed with Danieli R&D department, which capitalizes the extensive experience in all the hot working fields of steel.

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Macro cleanliness of big forging ingots – influence of casting parameters

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Steel cleanliness is an important quality characteristic, which becomes more and more important since the invention of secondary metallurgy in the most steel mills. The question is: What are the main influencing parameters? This paper describes several influences on the macro cleanliness of big forging ingots. Some of them like the runner system refractory, the mould powder, ladle refractory are directly linked to the macro cleanliness. Others like the cast iron parts, pouring rate, casting temperature, hot top treatment and argon shrouding representing the process parameters. A third group is maybe not directly connected to the ingot but shows also significant importance. For example staff training, the teeming equipment and data recording belong to this group. Referring to the mentioned parameters a quality inspection of all used materials, processes and standards are essential for good macro cleanliness. With numerous projects and improvements over the last ten years Breitenfeld Edelstahl generated the knowledge to produce ingots for the highest technical requirements. The results of more than 6000 metallurgical investigated ingots lead to the answer: Pay attention to every individual parameter for ideal results in macro cleanliness.

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Manufacturing of High Strength and Toughness Steel for Offshore Structure

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Offshore structure is the large installation to facilitate drilling, refining, saving, and producing oil and gas. Hence, offshore structure should maintain long term safety of structure against severe external environments such as storm waves and low temperature. Therefore, heavy thick steel plates required with high strength and toughness in low temperature have been needed as the engineering applicable materials for offshore structure. Especially, offshore structures are being changed toward to the trend of large size by multipurpose in recent years so that high strength of structures is getting important for weight reduction. The purpose of this paper is to report the development of heavy thick steel plate with an high strength and high toughness at low temperature. In more detail, the product is welded element for jack up offshore plant, composing of the rack & the chord plates. It is required to high technology in all processes including steel making, forging, forming, heat treatment and welding. Optimum manufacturing condition including forming, flame cutting and welding was investigated to develop the heavy thick steel plate with high strength and excellent toughness in low temperature for offshore plants. After making ingot, it was subjected to manufacture a slab type shape with open die forging and then, control a final plate shape with rolling. The rack plate of 210mm thickness and chord plate of 120mm thickness was produced. Weldabilty tests were also performed about rack and chord materials. After heat treatment, the rack plate was conducted by flame cutting and the chord plate was deformed by hot or cold bending and then, both products of the flame cut rack plate and the deformed chord plate were welded each other using approved Welding Procedure Specification(WPS) by Submerged Arc Welding(SAW). The plates were tested mechanical properties including tensile, impact properties, and high cycle fatigue, etc, and the

welded element was subject to test non-destructive inspection. Classification class qualified the properties of the plates and the welded element, and approved all manufacturing process.

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The Manufacture and Properties of Forged Combination Main Stop Valve / Control valve for Thermal Power Plant

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Our company always works on changing the casting to the forging. Particularly, we produce forging valves for thermal power generation. The materials support with low alloy steel, high Cr steel, stainless steel to a thermal condition widely. From the situation in the world, the demand for the thermal power generation increases recently. About the materials such as turbine casings, upsizing and integration are demanded in that. We have worked on the development of the production technology in order to meet short delivery date, the demand of the price reduction. In the case beyond 40 tons, we have conventionally forged the upper-room and lower-room and were connected by welding. We succeeded in the forging integration of the valve that forging weight exceeded 40tons in CrMoV steel and the direction of the steam inlet pipe was at right angles to the steam outlet pipe. In addition, the examination was carried out in each part and the good mechanical characteristic was provided. In this report, we explain the production result and characteristics.

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Development of a low thermal expansion superalloy for large forgings

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Low thermal expansion superalloys are thought to be candidates to reduce the clearance between some parts in turbo machines in order to improve the efficiency. Alloy903, Alloy909, HRA9291), etc. which were previously developed are well known as commercial low thermal expansion superalloys. The low thermal expansion properties of these alloys are obtained by the mechanism to control the thermal expansion by magnetro-striction in Fe-Ni-Co austenite matrix. On the other hand, the high temperature strengths of these alloys are obtained by the precipitation strengthening mechanism by adding Al, Ti, and Nb. These alloys, however, have not been applied for large turbo machine parts because it is difficult to produce large ingots without freckle segregations of these alloys. In this study, the effect of chemical compositions in HRA929 on the tendency to cause freckle segregations was investigated by thermodynamic calculation, and then small samples of some alloys selected by the calculation were made in a laboratory and cold and hot deformability, thermal expansion property, mechanical properties, oxidation resistance, etc. were investigated in order to produce large products of a low thermal expansion superalloy. As a result, the chemical compositions were optimized and a modified alloy, HRA929M, was developed. Finally, a trial production of HRA929M was demonstrated and a three-ton class forging was successfully produced.
*HRA is a trade mark of Hitachi Metals, Ltd. registered in Japan.
1) K. Sato, T. Ohno ; Superalloys1992(conference proceedings), TMS-AIME (1992), p.247.

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Development of Forging Shape Evaluation in Open Die Forging

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Evaluation of dimension and shape measurement during hot forging is an important process in open die forging. Correct dimension and shape evaluation reduces the risk of producing defective products and contributes to cost reduction, providing satisfactory yield. We have developed our own system for measuring hot dimension and shape during open die forging and put it into practical use. The system is equipped with a line laser and camera that can measure dimension and shape during hot forging in a relatively short time. In addition, automatic checking of image shapes makes it possible to get instantaneous judgment. This has eliminated problems of operation adjacent to hot materials using traditional gauges and measurement variation by operator, as well as achieving a higher percentage of good products and yield. Introduction of this system has improved workability of forging of different shapes (e.g. curved flat square shapes) and evaluation accuracy of hot dimension and shape. In addition, application of future material prediction (process modeling) can be anticipated.

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Open Die Forging- Indian Scenario

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This paper gives a brief update on manufacturing capabilities of Indian Forgemasters. Indian economy has seen significant growth since 2014. Positive movements are being witnessed in industrial sector as a result of initiatives like “Make in India” from Indian Government. Many big stalled projects have received green signal. A brief on facility addition/Upgradation resulted in extended product range is also discussed.

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New forging drive system for radial forging based on double stroke mechanism

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A new type of stroke-limited forging drive system was developed by GFM for its radial forging machines. As opposed to eccentric shaft machines this new drive creates two strokes per shaft revolution. Hence the stroke rates are doubled and allow for distinctive higher throughput and tighter tolerances. A prototype with eight synchronously working tools was built in house for proving the concept and to run trials. The machine is designed and dedicated mainly for forging of thin walled tubes. The results reveal that the ratio of outer diameter to wall thickness may be heavily increased so that this eight tool forging machine will broaden the product range of seamless tubes that are covered by a machine size. The paper will present the various trials, its results and the consequences of process advancments based on this new machine concept for the forging market.

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IMPROVEMENT OF FATIGUE PERFORMANCES ON WELDED STRUCTUAL FRAMES OF FORGING PRESS

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Main structural frames of Danieli Breda forging presses are made by welded parts. The design of their fatigue life is based upon an expected service loadtable, and on recognized international standards that provide database for evaluation of fatigue performances of each type of welded joint. All the available recognised standards are based on experimental tests from civil structures, or from oil-and-gas\naval engineering, thus covering joints whose tickness is very small compared with the ones existing in a frame of a large forging press. Additional corrections coefficients are provided for accounting of higher thickness joints. From experiences derived by many forging plants delivered in the years by Danieli Breda, it appears that such correction for high thickness plates are quite conservative. A numerical investigation on this point has been developed, followed by experimental activities on typical joints executed according to Danieli procedures, to find out the actual fatigue performances of large weldings. Even a limited upgrade, in the resulting S-N curves for this kind of weldings, has an appreciable impact on the design and economical approach of both the construction and operative service of a forging press. In the design step, once given a loadtable, it is possible to reduce the weight and the dimensions of the structural frames of the press, so reducing its dimensions (mainly its heigth), thus weight and costs. For presses already in service, it is possible to extend their expected service life and rescheduling the stops of the plant for periodical NDT ispections

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Challenges during Ultrasonic Examination of High thickness Austenitic Stainless Steel Forgings for Critical applications

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The Ultrasonic Examination of Austenitic Stainless Steel (A.S.S.) Forgings for critical application is a challenge, due to high thickness, isolated coarse grain structure and its complex configurations. To detect and characterize defects in these A.S.S. forgings, we at L&T Special Steels and Heavy Forgings (LTSSHF) have done study for ultrasonic examination technique based on stringent acceptance and reporting criteria by conventional manual scanning for thickness ranging from 350mm to 900mm.
This paper gives details of Demonstration, Reference UT Blocks, Equipment, Search Unit, Couplant used and Extent of Examination with respect to complex configuration of the forgings.

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Study on enhancement of Mechanical Properties in Thick Carbon Manganese Steel Forgings by Optimization of accelerated cooling Methodology.

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Thick Carbon – Manganese steel Forgings of grades like SA266 Gr 2, SA 350 LF2 & SA 765 Gr 2 are preferred as pressure boundary parts (Tubesheets, Flanges and nozzles) in the design of pressure vessels and heat exchangers used in hydrocarbon and fertilizer production process equipment. In recent times equipment manufacturers and process licensors are demanding more and more stringent simulation PWHT requirements from these forgings which has to be met in Normalized / Normalized and Tempered condition.
It has been well established that increasing the cooling rates results into finer grain structure ultimately resulting in higher tensile as well as impact toughness properties in such grades. The increase in cooling severity can be achieved in two conventional ways, either by quenching in water or by performing accelerated cooling from normalizing heat treatment. This paper focuses on study done on the optimization of cooling severity by forced air cooling to enhance the mechanical properties in thick forgings at L&T Special Steels Heavy Forgings. Actual Quantitative data of cooling rates experienced by the samples was captured using "Reference Quench Probe Analyser" equipment. Cooling rates experienced in different parts of the forgings was also measured. Optimization of cooling severity for enhancement of mechanical properties was established by performing a DOE in lab conditions at LTSSHF. It was found that accelerated cooling from austenizing temperature increases the Ultimate tensile strength and impact toughness in these grades. A critical section thickness, Carbon Equivalent and therefore a critical cooling rate at the intended sampling location in a thick forging was also determined based on the results of the DOE, beyond which no further enhancement in mechanical properties was possible by means of accelerated cooling. The findings were supported by Microstructural and grain size determination. This paper highlights the effects of accelerated cooling in enhancement of mechanical properties in these grades.

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Comparison between Four Die Forging Device and Conventional Forging Processes of Cold Work Tool Steel

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Four Die Forging Device (4DFD) is a known equipment to improve the productivity at the forging shop when compared with conventional forging process. Despite the improvement of productivity it is supposed that the quality should be at least similar. In fact, previous finite element simulation showed the forging process using 4DFD produces less effective strain in the forged bar due to less forging passes than the conventional forging process with two dies. However, the amount of shear strain obtained with 4DFD should improve the forged bar microstructure quality. To corroborate that scenario, the following study compared the metallurgical quality based on carbide distribution between 4DFD and conventional forging processes. Experiments were conducted in order to obtain round bars from cold work tool steel forging ingots. The carbide distribution at the final product was analyzed for both forging processes. In parallel, finite element simulations were performed to analyze the strain components, e.g. normal and shear, and to correlate with the microstructure obtained in the real process, supporting the comparison analysis. The results showed that 4DFD process promotes a similar or better carbide distribution around the cross section area, depending on the applied process.

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The Effect of Forging Temperature on the Mechanical Properties of AISI 4130 Engineering Steel

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Forging temperature is an important parameter to be defined in the forging process planning, because the final mechanical properties are directly influenced by this process temperature. In this study the AISI 4130 engineering steel, used for flexible tubes connectors in oil and gas industry, was investigated concerning the forging and heat treatment processes. Ingots up to 18 ton were forged in the 50 MN hydraulic open die press using different initial temperatures. Then the forged bars were heat treated following the same process of normalizing, quenching and tempering. The products were compared in terms of grain size and microstructure for the as forged and heat treated conditions. The mechanical properties, as tensile strength, yield strength, elongation, reduction of area and impact toughness, were analyzed for the heat treated condition only. The results showed better mechanical properties to lower temperatures.

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INTEGRATED RAILWAY AXLE COMPLEX

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Danieli Breda (DB) is one of his own business units, based in Milan, Italy, for over 50 years has been a leading in design, manufacture and supply of integrated plants for processing ferrous and non-ferrous metals in open die forging. In 2015 Danieli Breda started complete integrated Open Die Forging plant to produce rough axles for Railways. The Forging Complex, based on a high dynamic PFC 11MN Open Die Forging press, fully integrated with #2 rail-bound manipulators 2/4tons, is equipped with the most up-to-date and advanced features for automatic axles forging, recently developed by Danieli Breda. Technological equipment is sourced by Danieli Group, including: - Entry section area with automatic in-line log cutting and baking - Re-Heating and Heat Treatment area - Straightening, End cutting, UT testing and Shot Blasting - Handling of products fully automatic - Laboratory for the analysis & certification according to on-going standards. - The plant is fully automatically managed by Danieli Automation system, including advanced product tracking, in order to reach the ambitious production target of 50.000 marketable black axles in a year. The Plant produces in a completely automatic mode and has obtained the necessary certification of quality ‘on the final product. Following main benefits of Danieli supply: 1. No restriction on source as Continuous Cast or Rolled billet can be processed. 2. No restriction on shape as round/square/rectangular billet can be processed. 3. Finish product shape is almost round and smooth, dimensions are real time checked. 4. Process guarantee better metallurgical properties such as sound-centering, grain flow uniformity and microstructure throughout the length and section of the axle. 5. Improved fatigue and tensile strength is observed. 6. Restrained Electrical power Installed in order to reduce operating costs 7. Civil works less impacting on total CAPEX 8. 100\% DANIELI “one hundred year proven” quality and reliability!

Plant engineering and equipment / 60

TAILOR MADE DESIGN FOR FORGING PRESS

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Danieli’s mission is to provide the most technologically advanced Forging plants with new installation and with appropriate modernization using parts of existing plants. Increase, the capacity ’of the existing plant is one of the goals more’ challengers for the Danieli Team. In this direction such as the most challenging is surely the opportunity ’to increase in existing plants: -1) forging force -2) vertical and horizontal day light - 3) vertical stroke. in 2015 we achieved the revamping of a 4-column , 2,000 USTon push down forging press replacing major parts, adapting to the space available, by placing a 2-column 4000 USTon push down forging press and re-using

same floor level as reference for the die. The increase of force and vertical light, together with the increase of the stroke , was made considering the same dimensions of the old plant. Plant was equipped with a water crane in a fixed position in order to help manipulator with maximum Ingot and moment, and than was not possible increase vertical dimension. For this reason main part as baseplate, fix traverse, movable crosshead , and main cylinder was realize with “tailor made design” and special material. Existing main slide with frame and bottom device for die in forging direction it was refurbished, but basically re used with consequent benefits for total cost of revamping.

Environmental management / 61

Recent Advances of Furnace and Regenerative Combustion System Design in Large Open Die Forging Applications

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High temperature furnaces are an integral part of the open die forging process and a sizable portion of capital expense for a new press project. What is most important to the production managers, finance department, HSE managers, and maintenance group must be considered. Conflicting furnace attributes such as energy efficiency, production, emissions and temperature uniformity make these considerations difficult. The Fives North American Combustion (FNAC) design strives to promote synergies between these attributes, easing the difficult decision making process. The most important issue to end users is operating their equipment to optimize overall economic performance.
Three FNAC Regenerative Furnaces were recently installed at North American Forgemasters in New Castle, Pennsylvania to support the new 90 MN/10,121 ton open die press. The furnaces and accompanying combustion technology were tailored for the large ingots North American Forgemasters is producing. The combustion technology coupled with full furnace integration allows for significant fuel savings, improved temperature uniformity, reduced emissions and enhanced production. These in turn result in minimized carbon dioxide production, reducing the forge facilities’ total carbon footprint and impact on Eco-System Quality, while maximizing the production capability of the facility.
Results are presented detailing the efficiency and enhanced uniformity of the North American Forge Furnace. Comparisons are made to competing technologies and industry standards, highlighting the efficiency of these furnaces for large ingot forging and heat treatment. Compared to other technologies and offerings, the FNAC furnaces at North American Forgemasters have less hardware, increasing its ease of use and decreasing maintenance. Aspects of furnace design and control systems will be emphasized and the advantages and disadvantages of certain design choices will be explained.

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Ni-Base Forgings from Large Remelted Ingots

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The weight of ingots from Ni-Base alloys has steadily increased over the last years. One of the drivers was the development of advanced ultra supercritical fossil power plants requiring steam temperatures well above 630°C. Ni-Base alloys proved to have promising properties for steam

temperatures of 700 °C and above. Whereas smaller parts are needed for the boiler side, some turbine designs requires forgings with weights at the limit of experience. Regarding cost and manufacturing challenges Ni-Base material is not used for the complete turbine shaft, but only for the hottest part. Therefore, the design for turbine shaft is a welded construction of a Ni-Base part combined with steel shaft parts. With a diameter of about 1100 mm, the weight of the Ni-Base forging is in the range of 10 t to 15 t. After developments in the past focused on Alloy 617 and modification TOS1-X as well as Alloy 625, Saarschmiede has manufactured a full scale forging from the precipitation hardening Alloy 263 using a triple melt ingot (VIM / ESR / VAR) of ˜23 t, which is the largest ever produced worldwide. The paper reports on ingot making, forging and properties of the Alloy 263 part as well as on TOS1X manufacture.
For mechanical engineering Saarschmiede has remelted ESR ingots in Alloy 600 from EAF electrodes. Using a crucible of 1300 mm diameter, weights of up to 70 t have been achieved, which is the biggest ingot ever remelted worldwide from that alloy. Beneath cost saving effects by using one ingot for several forgings, this ingot is a milestone for even larger ingots. The paper reports on remelting and forging challenges as well as on achieved basic properties.

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Manufacture of large disc and ring forgings in Alloy 600

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For many years Saarschmiede has focused on the development of large remelted Ni-based alloy forgings typically used for research and development projects in the field of the power generation industry and for the nuclear industry too. Across these industrial sectors, there is a drive towards larger forgings with consistent mechanical properties, low levels of chemical segregation, more complex alloy chemistries and high requirements on the ultrasonic testability too. In light of this, Saarschmiede has focused on improving the maximum ingot sizes, ingot yield, hot working processes and also the heat treatment cycles to meet the requirements of these highly regulated industries.
Over the last three years Saarschmiede has manufactured several large disc and ring forgings from Alloy 600 with a maximum forging weight of approximately 30 tons. These forgings were manufactured from several ESR ingots with a diameter of 1300 mm. The maximal ingot weight that has been produced for a single ingot was 70 to. This is accordingly to our knowledge the worldwide biggest ingot in this grade ever produced.
This paper will discuss the manufacturing route, the mechanical properties, the microstructure, and the Non-Destructive Evaluation (NDE) for these disc and rings. It will also include a customer perspective on product quality.

Advanced and new forging materials / 64

Production and Evaluation of 10-ton Class A-USC Turbine Rotor of Ni-Base Superalloy LTES700R

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Ni-base superalloy LTES700R turbine rotors for advanced-ultra supercritical (A-USC) power generation was produced, and their microstructure, tensile, impact, and creep properties were

evaluated. 10-ton class rotor forging was successfully produced through the double melting technique, which is the vacuum induction melting (VIM) followed by the electroslag remelting (ESR), and free forging with a 14,000 ton hydraulic press. Fine grain microstructure of which grain size number was approximately 3 to 4 at the surface and the center of the rotor, this result indicated that the conditions of the forging and solution heat treatment were appropriate. Fine grain microstructure improved the permeability of the ultrasonic wave in the ultrasonic inspection test, resulting in small minimum detectable flaw size (MDFS) of under 1.6mm. The tensile strength at 700 °C was adequate, without large difference among the position of the rotor. The creep test at 700 °C revealed that the 105 h rupture stress at 700 °C was estimated to be sufficiently higher than 100 MPa, which is thought as an industrial target in service. The results of the present production expressly demonstrated that it is possible to manufacture 10-ton class A-USC turbine rotors of LTES700R with excellent mechanical properties and good permeability of the ultrasonic wave.

Advanced and new forging materials / 65

New Material and Manufacturing Developments for USC Steam Turbine Rotor Forgings

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The most significant outcome of the European COST programs (1983 – 2009) was the development of creep resistant 9-10%-Cr-steels for 600°C and 620°C application temperature. COST FB2 steel alloyed with boron is currently the best available material for turbine shafts subjected to steam temperatures up to 620°C and meanwhile introduced in production for application in commercial power plants. Currently several development programs are running to develop materials for further increase of application temperature up to 650°C. For realization of a 325 bar/650°C power plant doubling of strength compared to FB2 steel is necessary, but also resistance against steam oxidation must be improved by increase of Cr content up to 11-12%. In the past all attempts to develop stable creep resistant martensitic 11-12% Cr steels for 650°C have failed due to breakdown in long-term creep strength. Therefore new alloy concepts have been developed by replacing the fine (V, Nb) Carbonitrides strengthening particles by controlled and accelerated precipitation of the thermodynamically stable Z phase (Cr(V, Nb)N). Within the 7th Framework program of the European Union the project “Z-Ultra” was launched for further development and manufacturing of large components in this new alloy type. Saarschmiede has manufactured a full scale turbine rotor forging from the Z-phase steel ZU1 using an ESR ingot of ca. 23 t. The ingot was forged, machined and heat treated to a rotor part of 1100mm final diameter and a weight of ca. 12t. The paper reports on remelting, forging and heat treatment as well as on testing and achieved properties of the full scale forging.

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Development of High- and Intermediate-Pressure Steam Turbine Rotors for Efficient Fossil Power Generation Technology

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In terms of increasing power demand in the world and a problem of global warming, high-efficient thermal power plant has been desired. A rise in steam temperature is an effective way for

improvement of power generation efficiency, therefore a number of high temperature materials and components for USC/A-USC pressure turbine have been developed for many years. JSW began manufacturing conventional 12Cr rotors containing Ta or Nb in 1971, and then has developed advanced 12Cr steels and new 12Cr steels containing Co and B for turbine rotors in collaboration with turbine manufacturers in 1980's and 1990's respectively. These results greatly contributed to the increase in capacity and efficiency of fossil power generation, related to reduce the emission of greenhouse gases. Aiming at further high efficiency, we have developed high Cr ferritic steels for USC turbine rotors which are available at 630 degree C and manufacturing processes for Ni based super alloys for A-USC turbine rotors since 2000. Above-mentioned history of the development and the manufacturing of the high-intermediate pressure turbine rotors in JSW will be reviewed with a focus on 12Cr steels.

Testing and QM / 67

Experimental Determination of Fracture Toughness of RPV Steel by Master Curve Method

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The RPV plays a critical role in safety of a nuclear reactor, and the materials used must be able to contain the typically elevated temperatures and pressures[1]. The body usually comprises of a low-alloyed Mn-Mo-Ni ferritic steel forging, attractive for this purpose due to its high thermal conductivity, low thermal expansion, good strength, high toughness and its low tendency for irradiation embrittlement.
Toughness, however, is a closely monitored property in RPV forgings as unusually severe conditions can cause an embrittled vessel to crack and even fail. Various design and regulatory codes, such as the ASME Section III Appendix G - "Fracture Toughness Criteria for Protection against Failure", have included rules to ensure low tendency to brittle failure.
The Master Curve approach for assessing the fracture toughness of ferritic steels has been gaining acceptance throughout the world. Indirect and correlative methods used in the past, such as the Charpy V-notch impact test, have consistently been shown to be conservative relative to measurement of actual fracture toughness[2].
This paper describes the development of the equipment for sub-zero fracture crack propagation testing at temperatures up to -100[U+25E6]C, the test methods (based on ASTM E1921) and the results of fracture toughness testing of a large RPV-grade forging using the master curve approach. Effects of sample orientation and heat treatment on the fracture toughness are also studied.
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MODELLING OF HYDROGEN REMOVAL FROM MOLTEN STEEL IN A VACUUM ARC DEGASSER

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"A mathematical model for hydrogen degassing of molten steel in an argon-stirred ladle has been developed and implemented using ANSYS Fluent. Hydrogen removal has been predicted for a range of argon injection flowrates and validated with industrial data from a full-scale vacuum arc degasser. The effect of nozzle arrangement, ladle aspect ratio and the physical properties of the slag layer on degas rate were quantified. By predicting hydrogen removal rate for a given set of conditions, this model may be used as predictive tool to optimise hydrogen degassing efficiency through appropriate design of the ladle and selection of operating parameters."

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Potential Detrimental Consequences of Stringent PWHT on Pressure Vessel Steel Forgings

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Pressure Vessel components, during manufacturing, undergo several heat Treatments that aim to confer the required properties on the entire equipment, including welds and base metal. Quality Heat Treatments (QHT) typically comprise of normalizing and tempering, or hardening and tempering, as per customer requirements. Usually, these QHTs are followed by Post weld heat treatments (PWHT). The aim of a PWHT is to ensure good behaviour of welded zones in terms of residual stresses and properties such as toughness.
In view of enhanced customer demands, increasingly stringent requirements are now encountered often, which stipulate higher tempering temperatures followed by very high PWHT's. Such high PWHT requirements, for increasing the toughness in the weld metal, leads to deterioration in the properties of the base metal.
This paper presents the study carried out on forgings of two grades of pressure vessel steel and the resulting data. The cumulative time-temperature effect of various heat treatments have been made comparable using the Larson-Miller tempering Parameter. The corresponding effect on the steel has been measured via standard Tensile and Charpy V-notch tests. The data shows a decline in properties beyond a point, as one progresses to higher Larsen Miller Tempering Parameters.

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Study of thick 1 1/4Cr- $\frac{1}{2}$ Mo Steel Forgings for Heavy Wall Pressure Vessel applications using Design of Experiments

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11/4Cr- $\frac{1}{2}$ Mo steels are designed for critical applications in heavy wall pressure vessels operating below 441°C. API recommended practice: API 934-C states that beyond a thickness of 100 mm, this material shows difficulty in meeting sub-zero impact toughness and percentage shear requirements at the mid-thickness, which is required by API 934 – C. API recommends the use of a higher alloyed grade, i.e. 21/4Cr-1Mo to fulfil these requirements.

With increasingly challenging market demands and customer expectations, in terms of higher tempering temperatures and Post Weld Heat Treatments, it is now required to meet the above mentioned mechanical property requirements for heavy forgings thicker than the recommended 100 mm limit.
To meet this demand and to understand the limitations of this material, an extensive study was carried out using the Design of Experiments (DoE) methodology to improve the Heat Treatment. The experiments were carried out on full thickness blocks (215mm) and the tensile and impact properties tested. The results were correlated to the input parameters using ANOVA. The deterioration of sub – zero impact values were also correlated with microstructural characteristics. This paper describes the DoE methodology, the experimental methods and the results of this study, illustrating the limits of this material.

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The forging method of high chromium steel to achieve both forming and forging in 3,000Ton vertical press

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Osaka Steel Works(OSW) manufactures the high-chromium steel products,e.g. pipe used in power plant, which are forged in open-die 3,000Ton vertical press. In OSW, forging temperature must be applied to 1250[U+2103] or higher for being loadable in press and deformable for high-chromium steel. NDT were carried out in shipping inspection, although, in some case the defects were found in the products. So that, the better methods of forging condition were required, which were able to measure both press ability and metallurgical to form. In this paper, examinations were shown about calarification of the behavior of defect using micro observation which were connected with phase transformation or mechanical property etc., and discussed about better method of forging in 3,000Ton vertical press.

Recent Developments in the forging industry / 72

the world's first super large ring rolling machine is gonna located at Shandong Iraeta Heavy Industry of China

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The main technical parameters, design features, accuracy control, etc. of the ring rolling machine of RAW2500/1250-16000/3000 designed and manufactured by German SMS Group, to highlight the leading status in the world of this ring rolling machine. Introduce briefly on the application field and market demand of large rolling rings and technical advantage of this ring rolling machine on the production of ring forgings. It can serve to wind power, hydropower, nuclear power, aerospace, pressure vessel, engineering machinery, bearing, petrochemical pipeline, military and many other industries. It will satisfy the production demands of large ring forgings and barrel forgings of stainless steel, low alloy steel, non-ferrous metals and other different materials. The ring rolling machine of RAW2500/1250-16000/3000 is expected to be put into use in Shandong Iraeta Heavy Industry Stock Co., Ltd. at the end of 2017. Shandong Iraeta is a professional manufacturer of ring forgings. Introduce briefly on the history of Shandong Iraeta, main products and main performances. Welcome the people from all walks of life to visit Shandong Iraeta to create more cooperation opportunities and better play the ability of the ring rolling machine of RAW2500/1250-16000/3000 to serve all walks of life.

Submitted by Companies[U+FF1A] Shandong Iraeta Heavy Industry Stock Co.,Ltd.1 SMS group GmbH2

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ESTABLISHMENT OF CRITICAL PRODUCTION FORGING PROCESSES FOR MAKING HEAVY FORGINGS

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During the IFM 2014 in Japan L&T special steels and heavy forgings presented about its integrated facility for making heavy forgings for various applications. At that time the plant was in its initial phase of production. This study elaborates accomplishments of LTSSHF in making critical forgings of various grades on its 70/90MN open die hydraulic press. The wide range of critical products are manufactured comprises of high thickness/diameter shells (up to 6.3 meter diameter and 5.5 meter length), tube sheet/discs of diameter up to 5.3 meter, Stainless steel plates of high thickness up to 900mm, dish ends and profile forgings & multi-step shafts etc. Given the criticality in process of these forgings and being the first mover in manufacturing of such products in India, it had been a challenge perfectly overcome by innovative & exemplary methodologies used during forging process, developing unique in house tools/ dies & skilled man power. By evolving continuously LTSSHF has developed diversified products for sectors such as hydrocarbon, nuclear, oil & gas, process plants, steel & Power.

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ESTABLISHMENT OF ULTRA-MODERN QUENCHING SYSTEM & STUDY OF COOLING RATES OF HEAVY FORGINGS

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L&T Special steels and heavy forgings private limited is India's one of the largest forging plant with integrated steel melting facility which started its operation in 2012.It has got all associated facilities to deliver finish forged products up to 150 MT. This paper explains the process of establishing ultra-modern agitation system in quenching tank with specialized headers and nozzles. The reason for installation is to get effective cooling rate which is one of the most critical parameter in heat treatment process that governs achieving required mechanical properties & metallurgical structure. In quenching operation, agitation system and quenching media physical conditions directly influences cooling rates of heavy forgings which are of extreme important to get desired properties. Due to heavy thickness of forgings, there always been a large difference in cooling rates from the surface to center of forged product which results in different microstructure at different depths. In this paper we have also included study of the cooling rates at various depths for various profiles of different forged thickness & grades of steel forgings. A Comparative study is also carried out between various tanks with different quenchant volume for analyzing quenchant effect.

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ESR PROCESS AS ADDITIVE MANUFACTURINGTECHNIQUE FOR HEAVY INGOTS AND METAMATERIALS: EXPERIENCE AND PROSPECTS

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Todays fashion Additive Manufactruring (AM) in the case of metal production integrates the achievements of 3D modeling and well-known methods of powder metallurgy (hereinafter - PM) in so-called printing. However, the very process of powders production brings a number of quality problems for PM product, as well as both the productivity and efficiency of the technological cycle of PM/AM manufacturing (forming and sintering) are significantly inferior to the performances of production technologies using a liquid metal. Own experience in producing of macro and micro-heterogeneous composite materials with a metal matrix by electroslag technologies shows their wide prospects. This presentation will outline the theoretical considerations, calculations and practical results that justify the possibility of electroslag processes in the production of heavy ingots of high homogeneity of chemical compound and metal properties due to the suppression of segregation due to solidification control. Besides the principles of creation and experimental results of new electroslag technologies with the input of various inoculators and processes operation at ultra-low rates for the embedding of a non-metal particles in order to obtain metamaterials and metal-ceramic composites with high resistance to wear and corrosion, effective absorption of neutrons, etc., which are in demand for various critical applications. The findings of this research expand nowadays assumptions of electroslag technologies as viable options (both technically and economically) for Additive Manufacturing, allowing a reasonable production productivity of highly homogeneous large ingots and macro- and micro-composites with a given heterogeneity for different properties.

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Advanced Teeming System – Development, design and operational experience with a new high performance ingot casting system

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In 2012 Buderus Edelstahl decided to modernise its steel plant in Germany. Among others there was the request to implement a new ingot casting area to improve productivity, quality and workplace safety. The Advanced Teeming System ATS a high performance teeming system showing a high level of mechanisation and automisation of the casting process. At Buderus it is specially designed for casting rolling and small forging ingots with focus on throughput and increased operational safety. This paper gives an overview about the ATS itself, related developments, design considerations and operational experience after a few months of successful operation.

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Application of PAUT technique for flaw detection on large casting

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Identifying exact location to be repair for flaw rejected by radiography examination of large casting is important step to optimize production process, since repeated repair process consequent in longer production time and increased cost. Accuracy of flaw location measured by conventional ultrasonic technique is very dependent on inspector's skill, consequently has considerable human error. Applying phased array ultrasonic technique definitely has possibility to enhance measurement accuracy, however complex shape of casting product limits proper contact of phased array probe which is essential for valid ultrasonic coupling. In this study, application process of flexible phased array for measuring flaw location was optimized. The result shows considerable possibility to enhance the accuracy of defect location measurement, and to reduce repeating repair process.

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Development and application of automated periphery UT system for rotor forgings

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New AUT (automatic ultrasonic testing) system having capacity to inspect rotor forging of 300 metric ton was developed and successfully deployed to forged rotor manufacturing process. Mock-up test result and product examination experience using new AUT system shows that the system has detectability and sizing accuracy meeting industrial standards; The system can detect 1.6mm FBH (flat bottomed hole). Comparison of sizing result for real defect detected during product examination with manual examination technique shows good agreement. The system is being used as primary examination technique replacing manual technique to enhance the integrity of final ultrasonic examination result of products.

Numerical analysis and simulation / 79

Increasing of steel making capacity and solidification simulation with upsizing of the steel ingot

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We reinforced steel plants newly and started the production of the large steel ingot of 100 tons in December, 2016. (The maximum size of the conventional steel ingot was approximately 75 tons.) The larger steel ingots manufactured in the bottom casting, and the larger ingots were forged in the 8000 tons press machine. The method to produce the high quality of steel ingot was studied by using the simulation software CPRO (Casting Professional), and we tested the simulation result with the steel ingot. As the results of the simulation, the distribution of carbon concentration in the 100 tons ingot was similar that in the 70 tons ingot.

Recent Developments in the forging industry / 81

Latest developments in the SMX hydraulic radial forging machine

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The SMX hydraulic radial forging machine from the SMS group is a market success world-wide. SMX hydraulic radial forging machines are to be found on practically every continent. The characteristics of a hydraulic radial forging machine are the high productivity combined with very close tolerances, irrespective of the material grade and dimensions of the feed stock and finished product. In many cases the high productivity allows forging operations to be carried out in just one heat.
SMS is continuously developing the SMX hydraulic radial forging machine in order to further increase productivity. One aspect is the development of an automatic tool shifting device integrated into the SMX. Another aspect is the development of an energy saving concept resulting in a significantly reduced energy consumption of the hydraulic radial forging machine.
The automatic tool shifting device allows forging of a wide diameter range without time-consuming tool changes. The reduction in energy consumption is achieved through a new press cylinder design. The developments are described and presented in detail in the paper.

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Application of Processing Map to Hot Forging in Duplex Stainless Steel

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Duplex stainless steels are in good combination with strength, ductility and corrosion resistance. For this reason, duplex stainless steels are considered as excellent choices for various industrial applications such as oil extraction, paper manufacturing and other chemical industries. From the industrial point of view, the hot deformation of these steels has drawn much attention due to cracks if hot working parameters are not adequate conditions during hot deformation. In this work, in order to manufacture bulk type hot forgings of UNS No. S32205 duplex stainless steel, the hot deformation characteristics of UNS No. S32205 duplex stainless steel were analyzed by processing map obtained from Gleeble thermal-mechanical simulator and microstructure observations. The cylindrical billets with the height of 15mm and with the diameter of 10mm were prepared. The cylindrical billets were heated to 1250oC. Then, the hot compression tests were carried out at temperature ranges of 800-1200oC, strain rates of 0.001-1.0s-1and strain of 50%. In processing map, temperature ranges from 950 to 1200oC regardless of strain rates are found to be stable hot working regimes, in which the instability parameter ξ is positive and the microstructures exhibit dynamic recovery and recrystallization without cracks. However, temperature ranges less than 950oC regardless of strain rates are unstable hot working regimes, in which the instability parameter ξ is negative and/or much closed to zero and wedge cracks are observed at austenite/ferrite grain boundaries due to sigma phase formed during hot compression tests. From the result, the obtained processing map is applied to manufacturing of hot forgings; i.e., round bars with the diameters of 260mm and 360mm respectively to prevent cracks.

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Development and Manufacturing of Monoblock Low Pressure Rotor Shaft Forged from 650 Ton Ingot

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Monoblock LP (Low Pressure) rotor shaft becomes larger with increasing the capacity and the efficiency of nuclear power plants. In addition, the size of ingot is required over 600 ton. With increasing the size of ingot, the high internal quality is very important to minimize the segregation of chemical compositions, non-metallic inclusions, micro porosities and so on. Therefore, to meet these demands, DHI has simulated by using MAGMASOFT® and designed the shape of the ingot mold. The 650 ton large ingot was produced by an optimized mold design and steelmaking processes based on our previous technologies. The steel scrap was melted with five times by using electro arc furnace and finally adjusted the chemical compositions and temperature in ladle refining furnace. The liquid metal was separately poured into the ingot mold under vacuum atmosphere. After solidifying, the ingot was stripped and transferred to forging and heat treatment shop immediately. The 650 ton ingot was forged by using 1,3000 ton press and manufactured the monoblock rotor shaft with a maximum diameter of 2,800 mm. After the heat treatment and UT inspection, the samples for the mechanical and metallurgical investigation were taken at the center and the surface at each of the blocks and evaluated. The overall results of the monoblock rotor shaft were obtained with the high quality thoroughly and met the requirements.

Products for industries / 86

Development of high performance tool steel for hot stamping and die casting of automotive parts

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The application of ultra high strength steels and advanced high strength steels at automobile industry is currently increasing for weight reduction and crash safety. The growing use of HSS results in decreasing tool life and productivity in manufacturing. The aim of this study is a development of high performance tool steel in hot work. Both the durability and high thermal conductivity are important factor for the performance. For the alloy design, the single and combined effects of alloy element of C, B, Si, Ni, V, Mo at mechanical properties were delicately studied and thermodynamic calculation and simulation with commericial databases of steel products were applied. For determining optimum heat treatment condition, continuous cooling transition diagrams are tested and the microstructure and precipitations are observed by transmission electron microscopy depending on heat treatment condition. The developed material has optimum combination of strength and toughness that shows extended life at simulated work enviornment in laboratory scale and much higher thermal conductivity compare with tranditionally used too steel.

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Optimizing Ultrasonic Forgings Inspection by exploiting Pulse-Compression technique and multi-frequency AVG analysis

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Ultrasonic Nondestructive Testing (UT-NDT) is the only technique that allows the inspection of the entire volume of large forgings. For this reason, improvements of the UT-NDT sensitivity are a key goal for the forging industry. Pulse-Echo (PuE) is the reference method for which all the Standards and evaluation procedures have been developed so far, and it is effective in most of the situations. Nevertheless, in the presence of high attenuation (e.g. in austenitic samples) and-or large dimensions of the forgings, the PuE method could not guarantee an adequate signal to noise ratio (SNR) and sensitivity as requested by the Standards or by customers. It is therefore of utmost importance to develop procedures able to outperform the PuE in those critical applications requiring a high sensitivity, as happens with very weak signals or high noise. Fortunately, suitable signal processing protocols can be exploited to enhance the SNR of the procedure. Recently the authors proposed to exploit Pulse Compression (PuC) techniques in combination with the use of two separate transducers, one transmitter -Tx- and one receiver -Rx-, to increase the SNR of the measurement and thus reducing the dimension of the minimum detectable defect. In the present work, the method is further developed and improved by introducing two fundamental improvements: (1) a tool for calculating the AVG curves for an arbitrary Tx-Rx configuration has been developed; (2) a multi-frequency AVG analysis relying on a broadband chirp signal excitation that acts as coded waveform for the PuC procedure. The contextual implementation of (1) and (2) allows the inspection sensitivity to be optimized "depth-by-depth". In the full paper, details on the experimental procedure, on the digital signals processing and on the AVG calculation will be given and an extensive comparison between PuC and PuE methods will be carried out on various forgings to validate the technique. [1] Ricci, M., et al. "Pulse-compression ultrasonic technique for the inspection of forged steel with high attenuation." Insight-Non-Destructive Testing and Condition Monitoring 54.2 (2012): 91-95.

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Automated Forging And Utilization of 3D Visualization in Forging Process

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The open-die forging unit consists of a respective forging press with hydraulic drive and one or two forging manipulators. A properly conceived manipulator increases productivity and quality in the sphere of open-die forging significantly. In addition to the proces of manipulation with ingot and forging throughout the forging operation, the manipulators are included in the integrated forging unit. Here, they are able to ensure program-based forging of entire series of products with maximum accuracy of manufacture. In view of the required productivity, the recent developments require the full automation of the forging process using high performance equipment starting with the forging press and ending with transfer elements of new generation with using quick and easily controllable drives. The use of two manipulators is advantageous because of the possibility to forge without the need to turn the forging between the operations (alternate holding of the forging). In case of longer forgings, the system of double-sided holding of the forging is used advantageously in order to avoid deflection of the forging. It is also possible to use double-sided holding of the forging and simultaneous synchronization of the manipulator in the final processing of the forging (so called planishing). The automated control of this forging unit also uses the full synchronization of both manipulators, synchronized transfer of the forging between manipulators, control according to preselected algorithms, database system handling, data collection and processing for higher (master) level of control. In the field of operator-machine communication in the future, there is a solution of control and monitoring of machines using 3D visualization processes having indisputable advantages such as even better operator prompting during control of production processes, clearer and logically designed diagnostics, the possibility of extension with production process animation etc.

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Integrated Forging and Life-time Computational Simulation for Aerospace Parts – Developed for International Sourcing of Various Manufacturing Bases

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Points of Classification and a Short Abstract

The target was to analyze the complete forging process from raw material to finished forged parts. The presentation is based on a best practice example considering growing forging sources from Asia.

In a first step, all relevant parameters for the whole process needed to be defined. This analysis phase was done at international suppliers on site. We noticed well equipped and modern forging sources suitable for the aerospace industry in the Asian region. By experience, the demand of service support for forging design development, dies and toolings is high, especially for high sophisticated applications.

During this project a new supplier for aerospace parts was developed which finally was able to submit the total approval for new forged parts in aerospace. In addition, to guarantee a stable serial production process combined with high cost efficiency, the development is supported by Low-Cycle-Fatigue Finite-Element-Analysis to calculate part and die life-time including crack propagation.

The total development process is based on a highly connected collaboration of the integrated computational simulation and the process management work.

This presentation will show all technical aspects and will give an overview of entering and developing new markets for forged parts with special focus on the aerospace industry.

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ON THE INTERMEDIATE HEAT TREATMENT OF THE FORGED WHITE CAST IRON ROLL

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High Carbon Forged White Cast Iron Rolls are manufactured using a hot stage of as cast ingot till final forging shapes in order to avoid a brittle fracture of this material. The Forgings should be cooled for the first time to RT through a spheroidal heat treatment. During a continuous forging process carbides grow alone grain boundary and inside of grains. The special carbides are formed rod or disc and grow to bigger size as the Widmanstätten Carbide. The structure with grown disc like cementite indicates the weakness on impact properties. Therefore, rolls with over 2.2%C are not manufactured depending on existence of the uncontrolled this structure. In order to achieve a good wear resistance of high carbon level forged roll, the method how to erase this carbide structure was investigated in the 2.2%C NT roll and others. The Widmanstätten cementite grows only in the special thermal gradient that carbide embryo should be located in austenite matrix alone grain boundary or beside of ledeburite in the forging process. If the generating condition and growth condition of carbide nucleus are removed, the Widmanstätten cementite will be disappeared. The heat treatment for this purpose is pearlite treatment. In this treatment, cementite embryos are located of great number in grain. Forging and re-heating of

forging process, return to austenite always remains the cluster of carbon, then in case of cooling cementite grain will be grown always. Pearlite transformation is the key technology to disappear the Widmanstätten carbide. Adopting the internal heat treatment, we are succeeded in making the large size of high C% NT rolls in manufacturing process and in applications.
END

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The Application of Low Frequency Melt Power in the Production of Large Scale Electro-slag Re-melted Ingots

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In recent years, the power generation industry has demanded forged parts of increasingly high quality to meet the requirements of increased operating temperatures and pressures. This has pushed metals suppliers to utilize Electro-slag Re-melt (ESR) technology to produce such large ingots. Single-phase, line frequency power supplies have traditionally been used to economically and reliably provide the melting power for these ESR furnaces. As long as the power supply line capacity was sufficiently large compared to the melt power requirement, the single-phase nature of the load was not a major concern. Likewise, the harmonic generation characteristic of saturable reactor power supply technology was also masked by a sufficiently robust power line. But, as ESR furnaces have grown in size, the unbalanced single-phase load and harmonic generation has become increasingly unacceptable. In addition, the use of line frequency power in melting requires ever higher voltages to overcome the inductive voltage drop component which decreases energy efficiency and poses a hazard to operators.
The solution is to use a power supply that produces a low frequency output current from a three-phase AC source. Many technologies may be considered that meet this requirement. This paper will examine the use of an AC thyristor controlled cycloconverter to economically and reliably produce a variable low frequency current. Varying frequencies from DC up to 5 Hz can have a significant effect on pool depth and solidification structures, so the ability of this power supply to produce output frequencies up to 2.5 Hz is a major benefit. Detailed computational modeling of the effects of low frequency current on slag, melt pool dynamics including flow patterns, Lorentz forces, temperature distribution, pool depth, and the associated metallurgical effects will be discussed.

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"High end descaling in forging"

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Continuous development in materials, processing and joining technology opens up new possibilities for the application and optimization of forged parts with more complex structures. In particular, extrusion processes and the use of higher-alloyed, or micro-alloyed steels, which are becoming increasingly important in the production of high-quality forgings, present challenges for the established descaling processes. Even high forming rates and the close to finish shaping requires a clean surface of the forging before the first upsetting. Therefore, the number of installed high-end descaling systems in forging is steadily increasing - even in applications for which hydraulic descaling has not yet been established, for example for the descaling of small forging in the automotive industry with extremely short cycle times. These systems not only achieve clean part surfaces, moreover they offer new possibilities for the efficient production of high-quality forgings with low water requirements, minimum temperature drops and low energy requirements. Modern high-end descaling systems make it possible to keep the temperature control constant

within narrow limits during the process and achieve a temperature drop of only 5 to 10 ° C during descaling - an effect which is of decisive importance for the production of high-quality forging products. The increased adhesion of the scale of modern alloys also places high demands on descaling systems. Hydraulic high-end systems meet them with the precise control of the individual process parameters when applying the force of the water. Apart from the actual descaling process, also the individual parts and process handlings are often the focus. The Presentation " High end descaling in forging "provides an insight into the process of hydraulic descaling, and represents the state of the art. In addition to current methods for the high-end descaling of medium heavy and heavy forging blocks, the newly developed MicrolineDescaling System is used for lighter automotive applications. . It significantly reduces the time for descaling and is also used in processes where hydraulic descaling had not been established.

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Ultrasonic Computed Tomography – Pushing the Boundaries of the Ultrasonic Inspection of Forgings

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Forgings, being usually one of the most critical components (like in power generation machinery), require intensive volumetric inspection to guarantee a sufficient lifetime. This is usually accomplished by manual or automated ultrasonic testing. We are reporting about a game changer in ultrasonic testing: Ultrasonic Computed Tomography uses analytics to reconstruct the volume (a linearized diffraction tomographic approach for the solution of the inverse problem). This improves the SNR allowing an increase of sensitivity by up to an order of magnitude and to displays indications spatially and visually correct in the 3D volume. The method is an imaging algorithm, based on the Synthetic Aperture Focussing Technique (SAFT). The applied software is a brand new implementation of SAFT with a strong focus for a large scale industrial application: the complete 2D as well as 3D imaging of ultrasonic inspections of heavy rotor forgings. This paper shows the working principle of the method along with the first results and computation times. Ultrasonic Computed Tomography was also awarded by the Werner von Siemens Award as one of the Top 15 ingenuity programs.

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Induction and Conduction Thermography: A new Surface Inspection Method Suited for the Forging Industry

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Active thermography, using electromagnetic excitation, is a non-contacting, non-destructive evaluation method with a wide range of applications. It allows detecting inhomogenities, like cracks, at or close to the surface of metallic components fast and reliable utilizing infrared imaging. Electric current can be used in two ways for thermography: In induction thermography a current is coupled to the component by passing an AC current through a coil which is in close proximity to the component inspected, while in conduction thermography the current is coupled directly

into the component. In this paper we present the basics of this new NDE method, along with several component examples and how to build systems for the inspection. Active thermography using electromagnetic excitation and in particular induction thermography is a method which can be highly automated and is therefore an ideal tool for the inspection of forgings. Examples will be shown for crack testing of various forged steel parts with typical surface defects. The detectability of covered defects will be discussed as well as the reliability of the method and the prospects for automation.

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Production Advantages Through the Use of the Electroslag Remelting Process

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While the historical use of remelting equipment has, in large part, been about improving the cleanliness and internal structure of the ingot, recent pushes to increased forging weights have opened up new possibilities for the utilization of Electroslag Remelting furnaces (ESR) at a variety of sizes. It is not only the largest ESR furnaces that can improve the production from a forging shop, but the properly sized furnace relative to what a given shop can produce. An ESR furnace can increase the maximum forging weight output from a shop just through the yield improvement inherent in the process as compared to an air cast ingot.
This paper explores the literature and customer case studies to present how the use of an ESR furnace can improve the production from a shop beyond the typical cleanliness, structure, and other quality measures. Yields from different ingot production process routes are examined, as well as potential advantages from moving away from round ingots to slab remelting and other non-traditional production forms.

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Ultrasonic attenuation in a medium carbon forged component as a function of microstructure

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The ultrasonic technique is the main non-destructive testing (NDT) method for the inspection of large forgings. With this technique, it is also possible to obtain information about microstructural features, which is very important because it gives the possibility to easily check the quality of processes during all the production cycle.
In this paper, the relationship between some microstructural features of a medium carbon steel for forged components and the propagation of ultrasonic waves within the material is analyzed. The work focuses on the study of the relation between ultrasonic attenuation and mean grain dimension: this topic has attracted in the last years a renewed research interest since more accurate and fast measurements can be realized due to the evolution of digital instrumentation in the field of ultrasonic NDT [1-3]. In this paper, we compare different methods based on the use of linear and non-linear chirp signals, which allow an easy and fast analysis of the attenuation data. Moreover, by proper chirp design, also the non-linear ultrasonic response of the material can be analyzed [4].

Different microstructures obtained by means of different heat treatments were firstly realized on a pilot scale and characterized by means of light microscopy (LM). Afterwards, the ultrasonic attenuation of the various samples was measured in a wide range of frequencies by applying several measurement techniques and signal processing. In the full paper, a thorough analysis of these results will be given.

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New design solutions of four-die forging devices (FDFD) and open-die forging technologies

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Operation of four-die forging devices (FDFD) under various operational conditions and on various hydraulic presses, which differ in their design concepts and degree of automation, showed that in every application case an individual approach should be used to select optimized design concept and forging technology depending upon actual production objectives. With a view of above, introduced in this paper are various design concepts of FDFD and various forging technologies applicable for these devices. The main selection criteria both for the design concept and for the forging technology are: high production output which must be significantly higher than that of the replaced production process, higher metal quality and forged parts quality (in terms of dimensional accuracy and surface quality), shortened production cycle due to a shorter forging cycle, reduced reheating requirements and shortened non-production time, and also higher good metal yield. Presented in this paper are the ways of meeting these criteria for solution of various technological tasks and also some specific modifications of existing technology and existing press design which may occasionally appear to be necessary in order to gain maximum value from utilization of a FDFD.

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Analysis of two-die and four-die forging processes implemented on hydraulic forging presses and RFM

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Presented in this paper is a comparative analysis performed by means of technology simulation based on FEM method using DEFORM 3D tool.
The following processes were analyzed:

- forging on a hydraulic press between two dies according to conventional technology;

- forging on a four-die radial forging machine (RFM);
- forging on a forging press in a four-die forging device (FDFD) according to five different technologies;
- combined forging on a forging press consisting of two-die forging and four-die forging in a FDFD.

The presented analysis shows that the forging process performed in a FDFD in comparison to two-die forging on a press and to forging on a RFM results in a much better effect on distribution of stress, strain and temperature in a workpiece; it further contributes to elimination of metallurgical defects, makes it possible to forge low-ductility material and thus finally provides a better quality, higher good metal yield and increased production output.
Comparison of the discussed technologies in terms of production output proved that the production output in case of forging in a FDFD at various forging modes is 1.6 to 3.0 times higher as compared to two-die forging process and also higher than the forging output of a RFM.

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Forged ingot casting process simulation with a powerful 3D thermo-mechanical fluid/structure numerical model

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A non-neglecting percentage of the final quality of forged pieces is originally depending on the ingot parts from which they are made. It is well known that the ingot defects like hot tears or cracks are rooted at the first beginning of the solid shell birth. Damages result from the competition between hydrostatic pressure within the turbulent flow of the liquid zone and the solidifying skin under tensile stresses and strains state. In addition, the thermal energy extracted from the cast product by the mold has huge impact of the thickness of the shell. Among other parameters, it depends on the air gap growth issued from the shrinkage of the solidifying metal together with the deformation of the mold components. Numerically speaking, the method able at taking all that complex and coupled phenomena into account through an accurate way is a fluid/structure model. Indeed, a standard CFD method does not represent the solid behavior, so that the stresses, strains, air gap evolution due to the shrinkage of the shell are not reachable. In that paper, a new 3D fluid/structure model involving the turbulent fluid flow and the solid constitutive equation is described. The management of the dedicated “liquid time step” allowing high velocity motion into the liquid phase of the alloy coupled with the “solid time step” dealing with the solid phase and the corresponding slow motion, is described. An application on an ingot casting process considering the coupling with the deformation of the mold is presented. Moreover, based on that model, the segregation within the ingot is tracked. Grain structure resulting from a CAFE method coupled with the cooling of the ingot is also performed and shown. In addition, the top powder is accounted as deformable body following the shrinkage of the top surface of the ingot. The exothermic reaction is considered as well in order to estimate its impact on the cooling time and the final quality of the cast product. This one can be therefore transferred to a forging code for a complete simulation of the fabrication of the forged piece.

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NEW GENERATION FATIGUE ENHANCED CRANKSHAFTS

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Current requirements for internal combustion engines are becoming more and more demanding. Therefore, new generation of crankshafts needs to reduce in size and sustain higher loads. This dramatically increases the stresses in the components, making the fatigue strength enhancement a necessity. Sidenor understands that this improvement should arrive as a result of the combination of two different lines which have proved to be efficient separately: applying surface treatments (such as deep rolling) and improving material cleanliness.
Deep rolling has been developed for fillet areas in solid-forged crankshafts for marine and energy applications. In addition to the elimination of micro notches and improvement of surface roughness quality, this cold deformation process produces a deep layer of compressive residual stress in the surface of the component, which behaves as a natural barrier for crack propagation.
The other upgrade, seizing the advantage of a process integrated plant, consists of achieving extremely high cleanliness in the steel for these applications. By having less and smaller non-metallic inclusions, a higher fatigue strength is obtained.
In order to confirm the superior behavior of material treated according to mentioned techniques, several tests have been performed, from which it has been shown the great advantage that combining them would imply, so that engine manufacturers may continue with their size reduction process.

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A novel method for manufacturing qualified special steel by Forging Solidifying Metal

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Anenergy efficient methodcalled Forging Solidifying Metal (FSM) in two phase region, which applied for manufacturing special steel was proposed based on semi-solid forming technology (SSF).To verify its feasibility, the effects of deformation temperature and deformation methodson the microstructure of H13 were investigated experimentally.The bulky dendrites structure and shrinkage cavities can be eliminated when deformed at 1350[U+2103] (0.1/s 50% compression).Microsegregationon the grains boundaries can be eliminated and the microstructure isrefined when deformation were carried out at 1350[U+2103] (0.1/s 30% compression) following with0.1/s 30% compression at 1100[U+2103]. Therefore, the proposed method in this study would be a great breakthrough to manufacture qualified special steel with high efficient and low cost.

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A NOVEL MANUFACTURING PROCESS FOR HEAVY FORGINGS: ADDITIVE FORGING

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Segregation, shrinkage porosity, and coarse dendrite are main problems in heavy forgings due to the ultra-slow solidification process in heavy ingot. Researchers and engineers have put a lot of effort on improving the solidification microstructure but harvest little. If we jump out of the mind of manufacturing heavy forging by heavy ingot, the solution may be found on the continuous slab,

which has finer microstructure and less metallurgy defect compared to ingot. In current study, we have proposed a novel method of manufacturing heavy forgings by first building several slabs to a cuboid, and then forging these slabs under vacuum environment into an integrated billet. Finally, the billet is forged into final product. This method propose a novel way of manufacturing heavy forging with less segregation, shrinkage porosity. Several products, such as rotator for nuclear power station, main journal for hydropower station have been produced by such novel method, homogeneous microstructure and uniform mechanical properties have been obtained.

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Study on the multi-ram forging technology of the high temperature-pressure valve body

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Abstract[U+FF1A]The study on the multi-ram forging of the high temperature-pressure valve body is intended to meet the technical requirements for the valve body sustaining high steam parameters in thermal power generation units. The multi-ram forging of a 3-inch gate valve body was used as an example to demonstrate the features of the multi-ram forging, in which principles and methods of multi-ram forging was elaborated through the die design of the 3-inch gate valve body. Numerical simulation was used to investigate the influence of the tool's movement sequence on the forming load, clamping force, the horizontal punch load, the vertical punch load and the temperature distribution on the tools. The experiment on a 40MN multi-ram hydraulic press produced a 3-inch gate valve body forging with required dimensions. In compliance with national technical requirements, mechanical properties test and the forging flow line observation were done with the multi-ram forged valve body, which indicate that: the multi-ram forged valve body achieved better technical qualities than those required by the national standard.
Keywords[U+FF1A]multi-ram forging[U+FF1B]high temperature-pressure valve[U+FF1B]plastic forming; numerical calculation

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Effects of solid-liquid fraction on microstructure and mechanical properties of SKD 61 under ultra-high temperature forging

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Because tool steels are widely employed in industrial as machining tools and dies. Excellent mechanical properties, such as hardness, toughness and strength, are the most important criteria in evaluating tool steels. As a coarse dendritic structure with bulk precipitates owing to segregation causing embrittlement in the interdendritic regions, grain refinement and the uniform distribution of fine precipitates are necessary to improve the microstructure and optimize mechanical properties. The conventional manufacturing for tool steels, which include high-temperature homogenization treatment for 1 day and nearly 20 passes of hot rolling (such as SKD 61), consumes large amounts of energy and time and results in a long process chain for the manufacture of products. ...

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Development of mono-bloc nozzle shell for CAP1400 RPV

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The mono-bloc nozzle shell for CAP1400 RPV is a combined component of Vessel flange [U+FF0C] Nozzle shell course, inlet and outlet nozzles, safety injection nozzles. The mono-bloc nozzle shell manufacturing is technically challenging for hot working technique due to its complex shape and large size. In order to realize the dream of eliminating both U-shaped and circular welding seams, a series of research work by numerical simulation has been carried out. A final development has been adopted by using melting technique with low Si and controlled Al to cast a 700 ton super clean ingot, forging the nozzle shell by profile-modeling forging technique, that is pressing the nozzle plum blossom-protrusion like and then extruding to form the nozzle, and uniform cooling the large and complex shaped forging by swim-immersion into the water . A proportional experiment has been performed to verify the development. At last, the mono-bloc nozzle shell for CAP1400 RPV was successfully developed on the basis of optimization of the development. Key words: mono-bloc nozzle shell, plum blossom-protrusion, swim-immersion

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Research on the near net shape forging technology for CAP1400 main pipe

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It has been widely focused because of its complex integral-structure and strict technical requirement since AP1000 main pipe appeared, which is made by 316LN stainless steel. After ten years of effort and exploring, excellent forging suppliers from all over the world agree that 316LN heavy forgings including AP1000 only can be formed by relatively simple solid forging technology though it cannot meet the initial design requirement of ASTM level-4. The design concept of CAP1400 main pipe is the same as AP1000, in which the straight part, curving part and branch nozzle should be an integrated structure manufactured by 316LN steel. But due to larger dimension and higher requirement for technology, the manufacturing of CAP1400 is more difficult. In order to realize the near net shape manufacturing of CAP1400 main pipe, we invent a green manufacturing technology with highly asymmetrical nozzle for stainless steel main pipe hollow forgings, We have successfully manufactured a stainless hollow forgings using a 78t ESR ingot with nozzle height of 400mm, wall thickness of 160mm, total length of 9000mm, and ASTM level 4-6 of grain size for each part. Keywords: hollow forgings, near net shape manufacturing, grain size

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STUDY ON THE KEY TECHNOLOGY & THE ROUTINE OF INTELLEGENT MANUFACTURING FOR OPEN DIE FORGING PLANTS

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Intelligent Manufacturing (IM) technology belongs to the advanced & the new production technologies. Recent years, China government published several policies to support the discrete

production type industry including open die forging industry to develop IM. However, there is few of the open die forging plants responding actively. Comparison with the volume production type industry, the open die forging plants is facing greater difficulty and challenge in developing IM technology. In this paper, the main difficulties and the reasons are analyzed based on the production characteristics, the technology foundation and the existed realistic situation in the open die forging plants. The inherent meaning of IM and the necessary to develop IM for open die forging industry are studied based on the economic profit data and the background investigation, statistics and analysis. The urgent problems to be solved first and the priority to be done by IM for the open die forging industry is proposed based on the actual requirements of the open die forging industry and the manufactures,. Considering the combining the basic survival needs and the necessary foundation of developing IM for open die plants, 6 techniques or research achievements are proposed by this paper based on many year continuous studies. Those technical achievements construct the basis to develop the advanced IM in Chinese open die forging industry. Based on the above technical achievements, the basic progress routine map for Chinese open die forging plants to develop and realize IM is given generally. The study may attract more researchers to study on the IM for open die forging industry, it may provide reference idea for the open die plants to develop IM in order to realizing transforming & upgrading, it may also have certain valuable for software and hardware suppliers of the open die forging plants to adjust and to improve their future products and services. Keywords: Open die forging; Intelligent manufacturing; Key technology; Development; Routine; Study

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Microstructure Prediction of Nuclear Grade 316LN Austenitic Stainless Steel

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316LN stainless steel is selected as the material for forgings in the nuclear power plant owing to its better mechanical properties and excellent corrosion resistance. In this paper, the strain stress behavior and microstructure evolution of nuclear grade 316LN austenitic stainless steel under different conditions were investigated by several thermal simulation compression tests. Based on the test result, the recrystallization mechanism of the steel were studied. Through linear regression of the experimental data, microstructure prediction models of 316LN related to temperature, strain and strain rate were established. Then the accuracy and effectiveness of these models were validated in real experiments with large size billets. The result show that these prediction models have high reliabilities and could meet the requirement of practical work.

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On the deformation of dead metal zones at ingots' ends areas during upsetting

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Upsetting is a basic operation of greatest importance, which is commonly used in heavy forging process. Slowness in research on upsetting impeded the development of technologies for heavy forgings making. Upsetting deformation is determined by the billet's internal velocity fields (or displacement fields), therefore, the key to the research on the upsetting deformation is to get its

true velocity field (or displacement field). To that end, variational principles for plastic mechanics was employed to study upsetting. Based on the upsetting deformation's fundamental rules that were achieved from experiments and shop-floor production, kinematically permissible velocity fields were assumed and hence, the strain rate fields were obtained. Finally, the first variational principle for rigid-plastic materials was used to acquire the mathematical expression of the true velocity field. To verify their correctness, investigations on upsetting cases with end face friction factors of 0, 0.25, 0.5 and 0.75 were carried out. The calculations show reasonable results. Further comparisons between the analytical results and numerically simulated results indicate they agree well with each other. The conclusion can be drawn that the mathematical expressions achieved for the true velocity fields of upsetting are correct. The true velocity filed for ingot upsetting was established to analyze the Dead Metal Zones (DMZ) during ingot upsetting, which provides reliable reference for heavy forging makings. Keywords: upsetting; rigid-plastic materials; theories of plasticity; variational principles

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On the multi-ram forging for large marine crankthrows

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a marine crankshaft is the key component for large ships' power transmission. One of the critical techniques for the marine crankshaft manufacturing is the forging of its crankthrows. Existing forging techniques for marine crankthrows have limitations such as low material utilization, complex operations with multiple heatings, discontinuous material flowlines and cumbersome removal from dies. A multi-ram forging technique was developed to produce marine crankthrows based on numerical simulations and physical modelling. The technique makes use of the structural advantages such that, with only two heatings, the crankpin and the web end can be formed, into shapes as close to the required dimensions as possible. Hence, machining allowances can be greatly reduced and the weight ratio of the crankthrow forging to its machined final part can reach 1.6:1. Thanks to the high material utilization, small allowances, this technique avoids torch cutting, reduces both machining work hours and energy consumption. Compared with other techniques, this technique is easy to operate, more efficient and lowers costs. More importantly, the crankthrows produced with this technique have continuous material flowline, fine structures, which ensures high-quality of crankthrows and their longer service life.
Keywords[U+FF1A]multi-ram forging; marine crankthrow; numerical simulation; material flowline

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The Hot Ring Rolling Process for manufacturing Large Rings with As-cast Ring-shaped Billets

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The hot ring rolling process with as-forged ring-shaped billets is designed conventionally for forming the accurate size and configuration of all kinds of ring components. However, when the ring-shaped billet is prepared by casting, the hot ring rolling process have be designed not only

to form the accurate size and shape of ring parts but also to transform as-cast microstructures into the as-forged at the same time to meet the final microstructure and mechanical property requirements of rings, especially for large rings. In this investigation, an as-cast ring-shaped billet of 42CrMo was prepared and its microstructure and mechanical properties were tested firstly. Then, the hot ring rolling process with an as-cast ring-shaped billet was designed by analyzing the hot deformation behavior and microstructure evolution of as-cast 42CrMo by thermo-mechanical experiments and microstructure examination, and simulated by DEFORM software. Finally, the hot ring rolling process with the as-cast ring-shaped billet was carried out and its microstructure and mechanical properties were examined. The results show that the designed ring rolling process for the as-cast ring-shaped billet can improve casting structures mainly including removing casting pores and porosity defects and refining casting coarse grains. The microstructure and mechanical properties of the ring manufactured by the designed ring rolling process for the as-cast ring-shaped billet can meet the requirements of ring parts. Keywords: Large rings; Hot ring rolling; Simulation; Microstructure; Mechanical properties

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Development of complete equipment for 125 MN double column open-die forging hydraulic press

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It was described the development necessity of complete equipment for large forging hydraulic press. The general scheme of complete equipment consisting of 125MN double column open-die forging hydraulic press, and 1800kN/4000kN-m rail bound forging manipulator was proposed. A series of advanced design methods and key technologies were presented, such as digital prototype, co-simulation, visual platform, and so on. The integrated innovation has realized based on the construction, driven model, control strategy of complete equipment for forging hydraulic press, providing high forging precision and fast response speed under different technological parameters. Application results show the complete equipment can well satisfy the process requirements, and its overall performance parameters reach the international advanced level. Keywords: double column; complete equipment for open-die forging hydraulic press; digital prototype

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Steel 4.0: An application of the Industry 4.0 concepts to the real-time prediction of microstructural evolution during hot rolling of long products

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In cold forging of parts with relatively complex geometries forging pressures are highly dependent on the ductility of the steel grade applied. Grain refinement is the only mechanism that simultaneously increases strength, toughness and ductility. Thermomechanical rolling process (TMP) can improve strength-ductility balance of steel grade towards optimization of the properties by means of controlling of the grain size and precipitation behavior. Such process could reduce the cost of steel manufacturing by minimizing or even eliminating the heat treatment after the rolling process. A connection between processing parameters, microstructure and mechanical properties of the final product is the fundamental issue. To gain information into deformation behavior during the rolling process a coupled finite element method has been adapted. The 2D rigid-plastic FEM, used for generalized plane strain condition, which results in the reduction of the amount of computational time required without losing much of the accuracy has been applied. Based on the

phenomenological models which are supported by the process parameters, the model is able to calculate the temperature and mass flow distribution over the cross section of the rolled bar. A hybrid model for determining properties of rolled bars which combines technological capability of a process model with learning ability of Machine learning technology has been developed. An Industry 4.0 concept has been developed to pave the way toward connections of embedded system production technologies and smart production processes. This paper addresses development of a fully integrated system for real-time prediction of material properties with emphasis on the thermomechanical rolling process and its application within an Industry 4.0 framework.

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Development and Manufacturing of Wrought Co-Ni-Al-W-Cr Alloy "COWALOY" with High Temperature Strength and High Hot Workability.

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Recently, Co-Al-W alloys with a new γ' phase consisting of Co3(Al,W) have been found. Since the Co-Al-W-based alloys show the γ/γ' microstructure similar to the Ni-based superalloys and flow stress anomaly, it is expected that the Co3(Al,W) strengthening Co-based superalloys would be able to be applied to higher temperature applications. However, the hot workability is one of the main concerns that should be addressed. In this work, we optimized the chemical compositions to improve the hot workability without deteriorating the high-temperature strength at service temperatures. Finally, Co-Ni-Al-W-Cr alloys was determined for wrought materials. Developed alloy COWALOY(Co-47.5%Ni-3.7%Al-16%W-15%Cr-0.01%C(mass%)) achieved excellent high temperature strength and superior hot workability than Alloy520(Ni-14%Cr-12%Co-6%Mo-3%Ti-2%Al-1W-0.05%C(mass%)) which is known well as a forging Ni-based superalloy with high temperature strength. In the trial production of COWALOY, VIM-ESR process was applied to homogenize the compositions in the ingot. Subsequently, a radial forging machine (12MN) was used for forging to make a billet of 95 mm in square. Moreover, the forged billet was rolled into a wire rod of 5.5 mm in diameter and the rolled wire was wire drawn to fine wire to approximately 1mm in diameter successfully. As the result of trial, it was confirmed that the common manufacturing process for Ni-based alloys can be applied for COWALOY without additional special process. It is expected that COWALOY can be applied in a wide range of high temperature applications such as exhaust valves in automobile, heat resistant wires and plant parts.

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Quality Control in Manufacturing Process of Large Forgings

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Quality control of large forgings is a manufacturing process by which entities review the quality of all factors involved in production. On one hand, this paper briefly describes the research status of large forgings with the common flaws and their solutions, such as flaw segregation, inclusions & harmful elements, shrinkage cavity & porosity, bubble, discontinuities(crack), over-heating due to

high-speed temperature raising in high-temperature sintering, uneven temperature, white spots, and uneven microstructure; On the other hand, it also describes the key quality control and the matters needing attention for each link of the manufacturing process. Aiming at the quality of large forgings, The reasons for creating all above quality problems of large forgings shall be carefully targeted, and various parameters shall be strictly controlled by each production link to reduce the flaws of the large forgings and to guarantee the quality of the products. Keywords: large forgings, quality, manufacturing process and control Company: Handan Zishan Special Steel Group Co. Ltd.

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VID – Flexibility in Refining and Integration in melt Shop

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Various routes for manufacturing of high quality steel grades at small to medium batch sizes are examined. Special attention is paid to process features with respect to refining flexibility and production costs. It will be shown how the combination of cost effective melting furnaces with subsequently performed refining processes in a Vacuum Induction Degassing (VID) unit provide means to excellent and stable product quality. Today's increasing material prices results in the use of more common less expensive scrap stock. Whereas minor quality scrap can be diluted in huge steel factories using batch weights above 50 t, smaller sized furnaces require additional features in melt treatment. High quality ingot production requires customized production lines due to material input and necessary refining steps. The VID furnace can be used as melting in or just as a refining unit whereas classical steel melting lines consists of Electric Arc Furnace (EAF), Ladle furnace (LF) and Vacuum Degassing (VD). The flexibility of a VID unit in modern steel melting shops without ladle practice will be presented. In first part of this paper an overview of refining capabilities during VID process is given. Results from decarburization and degassing routines at various batch sizes are presented. Furthermore, the impact on refining kinetics by enhanced melt bath movement will be revealed. Possible slag treatment procedures are described in detail with respect to removal of Sulphur. In second part customized design solutions to establish best means for cost effective high quality production are presented. Combinations of production routes of various melting furnaces with VID are presented and comparison of investment and operation costs among these different routes will be made.

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USE OF REGENERATIVE BURNER SYSTEMS IN BATCH-WISE FURNACE OPERATION

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This article is concerned with the application of regenerative burner systems in heating plants with **batch-wise operation**.
The use of regenerative burner heating systems in continuously operated plants in the steel and forging industries is well known and has been tested in practice over the years. Due to the enormous energy savings with correspondingly large power requirements, and the continuous mode, these systems are used very successfully.
In batch-wise operation, especially in the forging business, this system was rather uneconomical due to the batch operation and the cost situation. Due to the development of combination burner, regenerator and regulation a system was developed that in the light of rising energy prices and the demand for cumulated emission reduction allows the use in batch-wise operation.

Thanks to successful implementation by **ANDRITZ Maerz** of the regenerative burners system over the past years it could be tested in practice comprehensively.
Its significant further development made its application possible in leading forging shops worldwide.

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Temperature distribution in ESR ingot withdrawal technology

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Electroslag Remelting (ESR) furnaces with electrode exchange techniques offer the possibility to produce large-sized ingots with homogenous, dense structures, high cleanliness levels and desired mechanical properties for high quality materials. ESR units that form one large ingot from multiple electrodes require electrode exchange techniques and typically utilize an ingot withdrawal system. Compared with electrode exchange in stationary molds, the short-collar molds feature short electrode exchange times and provide more flexibility of electrode length. Modern, advanced control systems perform ingot withdrawal as well as electrode exchange in a fully automatic mode. A crucial requirement for automated ingot withdrawal is a reliable level control of the slag pool within the mold. In short-collar molds, a slag pool is established and the initial ingot section will be remelted under static mold conditions. When the slag pool reaches the desired level within the mold, the withdrawal system will start to pull the ingot out of the mold in order to keep the slag pool at a constant level within the mold. Various systems for determination of the slag level have been realised, including contact rods, radar, etc. ALD developed a modern ingot withdrawal control system utilizing temperature readings from the mold wall. This paper describes how temperature measurement of the mold can be useful to control withdrawal rates of the ingot, thereby maintaining constant heat transfer rates in an industrial ESR furnace. In addition to the level control function, this new technology allows an insight into the thermal process of the forming ingot. Results from several ingot dimensions and process settings will be presented.

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Design and Manufacturing Technology of Large Class Main Shaft for Wind Turbine

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In recent years, global wind turbine market is increasing every year and wind turbine systems are getting larger to increase efficiency of power generation. With this trend, it is essential to manufacture lightweight and cost-effective main shafts which are main components of wind turbines. In this study, an attempt to design optimal hollow shaft and forge the component was performed. The relationship between shape parameters and stress distribution was derived by finite element analysis and optimal shape was designed on the viewpoint of structural strength by optimal design technique. Weight reduction of hollow main shaft shows more than 30% compare with solid shaft. Process design was performed to manufacture sound hollow products and the part was forged by 15,000ton press. Mechanical properties and micro structures were analyzed. Fabricated hollow main shaft satisfies the components requirements specification. With the results obtained by this study, an opportunity to be a world competitive company can be provided.

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Manufacturing of Ø1,000 grade large diameter round bloom and development of cost effective hot forging process using the round bloom

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Taewoong utilized continuous cast facility consists of EAF(Electric Arc Furnace), LF(Ladle Furnace), VD(Vacuum Degassing), VOD(Vacuum Oxygen Decarburization) and CC(Continuous Casting) to manufacture Ø1,000 grade large diameter round bloom. Characteristics of utilized facility were analyzed and relationship between casting process parameters and casting defects were derived. Hot forging process design was performed to fabricate sound products with manufactured round bloom. Major working factors deeply related to defect in forging process were derived and improvement activities were carried out by finite element analysis and experimental analysis. With the results, sound forged parts were formed. Improvement of competitiveness was analyzed in the viewpoint of processing cost. Utilization of continuous cast facility and optimization of forging process increase raw material utilization ratio and decrease amount of energy use. The results show utilized continuous cast facility gives opportunity to be a world competitive company.

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Industrial implementation of ring and wheel rolling simulation

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Presented approach to simulation of the ring (or wheel) rolling technology includes modeling of the whole sequence of technological operations starting from upsetting of an ingot, then forging a blank, piercing it and finally rolling it in a stand and heat treatment. The specific feature of a ring rolling process that makes its simulation so difficult is related to big number of rotations required by the technology that causes increasing of the computational time. In QForm VX software it is compensated by implementation of the dual mesh method that is based on the use of two independent meshes based on tetrahedral finite elements. Verification of the rolling process simulation was performed using different industrial cases and they have shown good correspondence with practice in terms of the load applied to the rolls and predicted shape of the rings, flanges and wheels. The developed numerical model is available for different types of machines, i.e. single stand mill, double stand mill with different methods of process control, stands with inside and outside main rolls. They are illustrated by industrial examples of the simulation implementation.

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Understanding Macrosegregation in Ingots

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During the solidification of large ingots, fluid flow and the sedimentation of solid grains can lead to the development of inhomogeneities in chemistry over length scales of a metre or more. This chemical segregation, referred to as macrosegregation, must be understood by manufacturers if they are to produce components that are as homogeneous as possible. This paper explores our current understanding of how macrosegregation arises in large castings, and the methods by which we can predict and track segregation. Discussions make use of the measurements made on an experimental 12-tonne steel ingot, as well as observations of small-scale experiments using the transparent NH4Cl-H2O system. Simple models, such as those utilising Rayleigh numbers, are highlighted, as well more complex simulation procedures that couple together equations for a number of different phenomena. The final section of the paper describes a state-of-the art multi-phase model and its predictions.

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A New Experimental Methodology for Predicting Through Thickness Property Variation in Large Forgings

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Validating new materials and heat treatments for large forgings is often a long and iterative process, due to uncertainty of through thickness variations of microstructure and mechanical properties. Finite element modelling can provide insight into the variables that control this variation, however material characterisations remain the province of small scale experimental simulations, and/or destructive testing of component test coupons following manufacture of full scale components. In the current work, a new rapid experimental assessment method has been developed, which predicts the microstructure and mechanical properties of large forgings following quality heat treatment.
The work characterises the transformation kinetics of ASTM SA508 Grade 3 Class 1, and uses this to predict microstructure evolution of large forgings from through thickness temperature profiles. The rapid assessment method is then used to test the temperature profiles, and produce volumes of representative material from which microstructure and mechanical properties are characterised. The results are validated using existing small scale simulation methods, and show strong correlation, implying the new methodology is successful in rapidly predicting through thickness variations of microstructure and mechanical properties in large forgings.

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SUPERSIZED ESR - STRATEGIES FOR THE FURTHER OPTIMIZATION AND SIZE INCREASE OF THE PROCESS

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The ESR process has been established within the last decades as a mature, reliable and attractive production route for big forging ingots of more than 100 tons in weight. This material is further

used for hollow or solid forgings in power generation industry. Advantages in solidification structure, mechanical properties and yield of the ingot shift the ESR process more and more in the focus of modern forging companies. Today, state of the art ESR processed ingots are produced up to 250 tons as material for reactor pressure vessels, rotors, shafts etc. and a demand on a further size increase exists. INTECO permanently develops ideas and solutions for upscaling the process which leads to challenges upstream and downstream of ESR which of course need to be considered. One of these fields of interest is the production of consumable ESR electrodes focusing on a quality and yield enhancement of the entire process route. This paper explains some of these ideas and strategies and gives detailed comparisons between classical and new ways of electrode production. The newly developed segment casting process will be introduced to illustrate promising alternatives of electrode production. Finally, engineering and operational challenges related to upscaling strategies of ESR are analyzed.

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Melting and Casting Technologies for the production of 9-12% Chromium Steels for the Power Generation Industry

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Nowadays the production of 9-12% chromium steels is characterized by different metallurgical processes adjusted to the final application and customer requirements. Usually the primary melting is done in the EAF and the steel is further refined in the LF and VD/VOD respectively AOD process. In the production route a special focus lies on the casting and remelting technology. For casting the conventional ingot casting process is usually applied. Segment casting can also be utilized for casting an ingot with better product quality compared to the conventional casting process. For ingots with a weight exceeding 100 tons and for a precise control of the hydrogen content the so called VSD (vacuum stream degassing) process is used. For enhanced product quality, the 9-12% chromium steels are subsequently remelted in the ESR process before forging, heat treatment and machining. This keynote lecture covers the typical production routes and the involved processes in melting and casting 9-12% chromium steels and will also highlight the state of the art plant technology in order to produce the required quality

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INTOVAL VL 1000

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For companies it has become progressively more important to protect their employees from exposure to health hazards such as ceramic fibres. Regulators issue directives that are increasingly strict with regards to health and safety aspects and tightly control their implementation. INTOCAST has advanced in establishing new products that assist safety efforts.
A refractory concrete has been developed with insulation characteristics similar to ceramic fibres. Their product components, however, are understood to be none hazardous.
With focus on overcoming health and safety issues several of our customers have been convinced to try newly developed concrete products in operation. When intermediate repairs of fibre installations were due to be carried out INTOCAST alternatives such as INTOVAL VL 1000 HT/1 as castable product or INTOVAL GUN VL 1000 HT/1 as gunnable product version have been tested. When operating in temperature ranges for forging the INTOCAST products have demonstrated significant advantages over the very costly combination-fibre modules.
The INTOVAL VL 1000 HAT/1 solution is maintenance free and with time the customer is able to realise cost savings.

In comparison to maintenance-free INTOVAL VL 1000 HT/1 the customer installations usually suffer from fibre embrittlement after a certain time in service and resulting loss of insulation. This is where the INTOCAST products show cost saving potential way above break-even point. Compared to ceramic fibres INTOVAL VL 1000 HT/1 and INTOVAL GUN VL 1000 HT/1 exhibit the same thermal conductivity. Furthermore the refractory concrete products are more resistant towards mechanical attack and penetration as much as showing superior volume stability.

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Role of simulation in reducing the development time of Dished end forgings

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Dished end is the most critical part of pressure vessel. Based on the applications of the pressure vessel dished end can be spherical , ellipsoidal or torispherical. It can be made in a single piece or by "petal" construction. In this paper we present the development work of the die design and forged blank profile for the dished-end formation. We used 'Simufact.Forming' software package for this development work. This package uses the flow stress data and calculates the material flow pattern. Use of this package reduced the development time by two-third. Successful production forging was achieved after just two shop trials.

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Energy Saving: New Drive Concepts for Forging Presses

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The energy efficiency in forging technology is an ongoing task for the forging industry due to global challenges (resource availability, environmental impact), legislative decrees (eco-design of products) and national projects (energy transition). An eco-design of energy-using products is required as described in the European directive 2009/125/EC. As continuously rising energy prices put a significant strain on a company's profits, machinery and equipment investment decisions depend increasingly on energy consumption and energy costs. How can energy be used most efficiently? And where can resources be saved? Especially simple and low-cost solutions for improving energy efficiency for new and existing Presses are required. The purpose of this presentation is to show the technical approaches and the potentials to improve the energy efficiency of forging presses. It describes the key aspects for enhancing the energy efficiency of forging presses and problem-solving approaches of innovative hydraulic systems for presses. Maximum performance and flexibility with minimum energy consumption are not a contradiction. The on-demand delivery of hydraulic energy can be provided automatically without intervention. The implementation will be demonstrated on examples of the modular concept of EHF, an intelligent energy saving system with huge potential, developed by Schuler. "Efficient Hydraulic Forming" (EHF) can reduce energy consumption of hydraulic presses by up to 60 percent. The new technology offers energy savings in all operating phases – fully automatically, without the need for any action by the machine operator.

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Use of Feed-Forward Controlled Experiments and Trained Computations for Accurate Simulation of Heat Treatment

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During the plant operations, the process parameters are usually controlled by feed back mechanism. To operate a control system in a feedback mechanism, they have to be tuned for a specific material and conditions. In this paper we will be discussing how we used this feedback data of experiments to train the calculations (computer simulations)and turned the experiments into feed-forward controlled experiments. We implemented modern analysis techniques for optimization like Machine Learning(ML)and Artificial Neural Networks(ANN). This process involved three stages 1. Study the system 2. Predict the system 3. Control the system. This system is used to reproduce the thermal cycle recorded at the mid-thickess of shell of very high thickness on a test specimen in a lab scale furnace. This paper also explores the implementation of this system in full scale production using the plants level 2 automation data.

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Qualification of Hollow Ingot Technology in Safety Critical Forgings and Fabrications

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The use of hollow ingot technology presents may advantages in safety critical applications such as nuclear island components. Although not new technology to Sheffield Forgemasters International Ltd. (SFIL), in order to implement large-scale hollow ingots in the conservative nuclear power market, the material behaviour must be proven to be equivalent to or better than material from conventional solid ingots.
Recent collaborative work at SFIL has cast a 151t ingot of next generation nuclear alloy (NGNA) that may be forged into a variety of commercial pressure vessel geometries. In order to expand the component size and capability, whilst advancing in-house fabrication capacity, electron beam welding has been investigated as a method to join hollow ingot components. The quality heat treatment of the hollow ingot components has been scheduled after electron beam welding to re-austenitise the weld, with the aim of largely removing its influence on mechanical properties. Microstructural evolution and the resultant mechanical behaviour of heat treated electron beam welded NGNA has been evaluated and is presented. Data reveals it is possible to erase weld microstructure and dramatically improve the mechanical properties of the weld material.
Full material characterisation and mechanical testing has been carried out to demonstrate the improvement in microstructural and chemical homogeneity of hollow ingot material. Segregation mapping has been carried out through a combination of surface measurements and multiple through-wall trepanned samples. Mechanical properties have been shown to match and exceed conventionally produced ingot material.

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Dimensional control during forging: the 3D Laser Measurement System

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In the forging sector, during the open die forging process, dimensional checks are necessary to guarantee that the final component is extracted from the forged envelope. Usually, the forged envelope needs to be enough to accommodate surface features typically associated with forging, whilst not being overly generous, as this decreases yield whilst increasing cost. Typically, forgings are measured manually during forging, these measurements are performed at very high temperature (˜1200 °C) and components are of considerable size. For this reason measurements can present health and safe challanges, only a few measurements are performed and the forging cannot be fully characterized. Moreover the quality of such measurements depends upon operator skills or experience and thus subject to variability. The solution adopted by MERMEC is the 3D Portal. This paper presents the revised and improved version of a laser measuring system capable of producing a full 3D survey of large, complex components at hot forging and ambient temperatures. The paper will describe the implementation and use of the 3D Portal, capable of measuring bulk component dimensions as well as quality parameters such as linearity/straightness, concentricity/ovality. The software used to manipulate the scanned data and allows 2D/3D visualization and comparison with CAD models of the required geometries. The analysis software includes moreover a bespoke reporting system, designed to replace manually recorded quality information.

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Hydrogen Embrittlement Mitigation Techniques in High Strength Steel Manufacture

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It is generally accepted that hydrogen is only a contributor to failure when in its monatomic form. As a result, an important measurement in determining whether hydrogen damage is present in a material is a measure of diffusible (mobile) hydrogen. This measurement cannot currently be conducted either quickly enough or reliably enough to be used during industrial steel manufacturing. Moreover, unlike most precursors to mechanical failure, hydrogen embrittlement cannot be detected by any type of industrial nondestructive evaluation. As a result, hydrogen damage must be precluded from engineering components.

To reduce the manufacturing cost and facility throughput demands associated with currently specified hydrogen soaking treatments, hydrogen mobility in high strength HY-80 steel was studied. Two heats of HY-80 were manufactured; one heat using aged lime in an induction furnace after secondary refining to create material with high diffused hydrogen, and a second heat containing high embrittling element concentrations to bound the worst case condition for the onset of temper embrittlement.

The first two strategies for reducing the cost and time of hydrogen removal treatments evaluated alternate diffusion based treatments both below and within the temper embrittlement range respectively, with post austenization and tempering to recover properties for those treatments in the embrittlement zone. The second two strategies evaluated hydrogen transport by non-equilibrium processes. Both induction and vibratory treatments were used to create a controlled directional stress wave through test materials. This was done to investigate the theory of hydrogen entrapment at dislocation cores and that these dislocations would still be mobile and therefore capable of accomplishing hydrogen transport. Results for non-equilibrium strategies were inconclusive showing marginal improvements for vibratory treatments conducted on cast blocks. However, assays conducted using traditional thermal diffusion mechanisms showed the ability to reduce required soaking times by more than 30\% via optimization of treatments below the temper embrittlement range, and by up to 90\% via soaking in the embrittlement range at 900°F followed by a subcritical anneal and re-heat treatment.

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Open die forging activities in the Voestalpine Special Steel Division

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3 production companies of Voestalpine Special Steel Division are involved in open die forging business , namly Böhler Edelstahl(Austria), Buderus Edelstahl(Germany) and Villares Metals(Brasil).Equipment, technology and typical products will be described . The transformation process to other product families due to changed global ODF markets will be discussed.

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HEAVY FORGING IN CHINA

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Introduction to Chinese economy and heavy forging industry, in which will include power station, machine building, shipbuilding, matellurgy industry and the related industries. The presentation also will focus on what happened in forging equipment made in China, technology/process applied at the moment and management situation in China; especially will display some information concerning the forging production and market. Of course, it will discuss what is the challenges existed in China forging industry and what we have to do for the brighten future. In the presentation, the related economy policy and regulation concerning manufacturing industry in 13rd Five-year Plan will be introduced.

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The South America Forging Industry

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This paper gives a brief introduction of the open die forging industry in South America. It describes the capacities and forging equipment in the major companies. Also the effects of the economy in the open die segment will be reported.
The open forging industry in South America has small influence in the global market, mainly due to the low demand when compared to others such as Europe, Asia and North America. The main companies are located in Brazil, where some investments have been made in the last 8 years, and will be presented.

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Resent Trends and Developments in the Heavy Open-Die Forging in Japan

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This paper describe the recent trends and development activity in the Japanese heavy open-die forging manufacture since the 19th International Forgemasters Meeting (IFM) held in Tokyo, Japan in 2014. In the three years since 2014, Japanese forgemasters have been developing new technologies aimed for high quality, cost reduction, greater productivity and efficiency. This paper focused on forged material production, new facilities installation and technical developments in

the manufacturing process such as steel making, forging, heat-treatment and inspection. And also review and discuss about major problems facing the industries in Japan in next several years.

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Forging Applications and Challenges in the Power Generation Industry

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Commercial activity in regions of the world driving the need for large ST and GT generator equipment are showing soft market conditions. These combined with increased competition from equipment OEMs is driving significant pressure on product cost. Techniques such as should cost modeling and partnering with key suppliers and their respective suppliers to drive cost-out initiatives down the supply chain are just a few industry wide examples. That partnership is essential to drive the identification of new ideas to improve productivity and efficiency in their factories & processes as well as the thorough evaluation of the product requirements driving costs.

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Full scale 3D simulation of the electroslag rapid remelting (ESRR) process

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In the ESRR process, a T-shaped mold is used including a graphite ring that takes major amount of current through the mold. The standard ESR process can ideally control the solidification of ingot and produce homogenous structure with minimum defects. However, the melt rate of electrode is rather low that makes the whole process uneconomical especially to produce small ingot sizes. In contrast, continuous casting is an economical process to produce small ingots such as billets at high casting speed. Unfortunately, deep liquid melt pool forms in the billet ingot of continuous casting that leads to center porosity and segregation. As such, continuous casting is not suitable to produce segregation prone alloys like tool steel or several super alloys. On the other hand, the electro slag rapid remelting (ESRR) process has advantages of both traditional ESR and continuous casting processes to produce billets. There are only a few reports available in the literature discussing about this topic. The research on the ESRR process is currently ongoing aiming to improve the design of the T-shaped mold, to decrease overall heat loss in the process, and to obtain a higher temperature at metal meniscus. In the present study, the electromagnetic, thermal, and flow fields in the whole process as well as solidification of the billet ingot (˜ 200 mm) are studied using a full scale 3D model. The main goal is to obtain some fundamental understanding of the formation of melt pool of the solidifying billet ingot in ESRR process.

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Development and Integration of Digital Technologies in Forging Processes

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The trend of Industry 4.0 shows itself as the collaboration of multidisciplinary technologies to increase efficiency and effectiveness. The cooperative use of measuring, big-data handling, modelling and controlling technologies in a production plant is usually not trivial and requires specific approaches and adaptations. This paper presents a conceptual basis concerning the comprehensive value-creation-chain of forging processes. The considered process extends from the production of raw material to the quality control after the heat treatment. The control of the process is achieved by a control-logic working on the process, workpiece and the product data. The general concept for regulation based on control-variables requires direct and/or indirect monitoring of process data and product properties including failures when possible. In this context, an inline-control is possible if and only if the workpieces are traced throughout the whole process.

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Development since 2014 in the Open Die Forging Industry in Austria, Germany, Sweden and Switzerland mainly in Association with the Steel Institute VDEH

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The paper will inform about the economical and technical development of Ingot Manufacturers and Open die forging shops mainly associated with the VDEH-Forging-Committee and about the development of energy prices in the region. Highlights based on research and development of Universities will be presented. The paper will include also general information about the development of suppliers of Equipment for steel making, forging, heat treatment and simulation software.

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Review and Recent Trends in Main Topics of IFM-Conferences 1954 - 2017 and Conclusions

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The paper describes an analysis of the main topics of all IFM-Conferences from the 1st Meeting

The focus of these main topics will be analyzed in more detail. This analysis will highl

Final conclusions will include remarks concerning economic aspects and market conditions

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Virtual Hedging of Added Value for incremental formed parts

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There is still an unbroken trend towards higher specifications and performance measures of metallic components and assemblies, no matter how they are processed.There are two major trends forcing engineers from all relevant disciplines–to continuously reach and exceed known limits of existing approaches.The lightweight idea has been establishing as an everyday business task since the last five to ten years but is still challenging engineers. Locally defined properties within given boundaries need to be guaranteed at the end of multiple stage process chains.This requires deeper insight of the interactions between process conditions, material processing and related impacts on changing properties over all measurable length-scales.This calls for new approaches and a change of mindsets from “design-oriented” thinking towards “designed as manufactured”.Additionally modern industries are dealing more and more with “Industry 4.0”.Modern engineering simulation tools play an important role in this process.They enable physical experiments to be replaced by virtual experiments.In addition to significant cost savings, this allow for faster SOP times and will make production of prototypes increasingly obsolete.Doubtless, the complete process chain has to be considered when aiming to predict final properties of the product.Finally, customers are not buying products but performances. In addition, product performances or life times are determined through their properties.Due to get deeper insights of properties and their evolution over a processing cycle detailed knowledge of the process kinematics is required.Often the process kinematics is based on “self-controlled” kinematics-numerous measured values are taken to adjust the process to control product quality and properties dynamically.The same algorithms needs to be implemented into the virtual tools due to model the process output in a reasonable manner. When doing so it must be guaranteed at the same time, that the measured values can be calculated accordingly.Realistic representation of the right parameters with appropriate accuracy levels is a key to reach this goal.Since the process-chains become more complex sophisticated controls alone will not guarantee desired process output.Rather the first initial process and parameter set-up contributes to a robust and stable process situation.One of the classics of simulation tools in this context is the virtual validation of assumed set-up variations.During processing the material undergoes elevated temperatures and work hardening which determine and trigger evolution of the micro-structure.Physical interrelations can be arbitrary complex in this case.The contribution will demonstrate a fully coupled solution to connect machine controls with a virtual simulation platform–exchange information between the different worlds-and finally supports engineering and process planning in developing initial process layout.

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RECENT CHANGES THAT HAVE OCCURRED IN THE NORTH AMERICAN OPEN DIE FORGING INDUSTRY

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There have been many changes in the North American open die forging industry since the 19th International Forgemasters Meeting (IFM) in Tokyo, Japan in 2014. By far, the most significant has been the severe decline in orders and shipments since 2014. On a shipped tonnage basis, shipments have declined each year since Tokyo and are projected to be at the lowest levels since the early 1990’s. The timing and extent of any improvement is unclear. Trends regarding raw material costs and utility costs will be reviewed. The decline in production and other problems faced by the open die forging industry along with technical developments and developments related to open die forging company facilities will also be addressed.

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ITALIAN MARKET AND INDUSTRY OVERVIEW

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Introduction of general Italian economy and forging industry with focus on changes occurred since the 19° IFM; since Tokyo, there have been 3 years of further stagnation but in spite of the resection, new investments have been completed in this time period. A review of recent developments of facilities and major changes in the Italian open die companies will be given. Presentation will display national open die forging production in terms of weight over the past IFM conferences and review major highlights of technical developments. Finally, in a scenario where the time of a consistent recovery is unclear, an outlook on what we can expect for the next future will be addressed.

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Current Developments in the UK Forging Industry

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Changes to the UK Forging Industry since the IFM 2014 in Japan will be described in full, including turnover, cost reduction, investment in plant and machinery and research & development. The future prospects of the business at Sheffield Forgemasters in the coming five years will be described.

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Open Die Forging Market and Industry Overview in Korea

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This paper updates remarkable changes in production and market trend, the status of major players, and development of new products and technologies of Korean open die forging industry since 19th IFM in Tokyo. Like many other countries, there have been heavy and intensive investments in major Korean forgemasters in early 2000's when the global economy was booming up to its peak. But global financial crunch taken place in year 2008 rapidly cooled down the market of all of the forward industries and Korean forgemasters started suffering from unbalanced demand and supply of forging products. It is already almost 10 years since global financial crisis in 2008, but the current market status keeps going slow and many Korean forgemasters had to experience financial difficulties, causing reshaping of overall forging industries in Korea including reorganization.

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Automated ultrasonic inspection system for high performance forged parts

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Forged high performance parts require efficient and exact quality assurance methods such as ultrasonic (UT) inspection. Increasing requirements on NDE from OEMs are leading to change from manual UT to automated inspection systems at the forges.
Ellwood City Forge (USA) is producing quality forged parts for different industrial use, including turbine disks and rings for various power plants. Areva GmbH delivered two (2) automated UT

inspection systems equipped with SAPHIRquantum UT device as well as customized UT data collection and data analysis software.
AREVA GmbH NDE department profits from its experience in nuclear NDE services for development of high performance automated UT inspection system through combining outstanding mechanical design with customizable UT technique. The UT software and the UT device SAPHIRquantum are in-house developments of Areva GmbH. This allows creating the most efficient inspection modes resulting in customer benefit.
In cooperation with Ellwood City Forge, this presentation will give an overview about state of the art UT inspection system and technique based on the delivered Areva GmbH turbine disk UT system.

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DEVELOPMENT AND OPTIMIZATION OF A TEST FOR DETERMINING THE FRICTION COEFFICIENT

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The present paper gives a description of a new technological test for measuring friction coefficient using a closed die forging process. The test specimen is a cylinder of pre-defined dimensions. The result is a forging whose shape reflects the magnitude of the friction coefficient. The magnitude of the friction coefficient varies with the forging temperature and the lubricant used. The test is thus suitable for obtaining direct comparison between lubricants. The friction coefficient computation is controlled by optimization tool ISIGHT. The optimization process compares results adjusted friction coefficient FEM model and final forging.

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IFM 2017 - Evolution and growth of CHW FORGE

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This paper focuses on the extent to which modernization and technological advancement have been a crucial support for CHW Forge in its efforts to embrace modern forging techniques and compete at a global level. The demand of high quality forgings in India introduced us to a newly formed niche market where factors such as quality assurance, customer service and comprehensive testing methods were not only desirable but also mandatory. The country's focus shifting towards creating its own energy (mainly via solar and wind energy) and strengthening the defense sector encouraged us to tap into the rising niche market which was marked by our rapid technological upgradation and prioritizing customer requirements.

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STUDY TO UNDERSTAND REVERSSIBLE TEMPER EMBRITTLEMENT OF HIGH STRENGTH STEEL

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During pressure test of a huge hydro power plant; embritteled weld material caused a catastrophic fracture of the closure head of a new penstock. Temper embrittlement (TE) in weldings of high strength steel type S 690.was identified as basic cause of theobserved failure. TE was caused by application of an unusual slow cooling rate during post weld heat treatment. A procedure, characterized by a short-time heating at about 600°C,recovers this embrittlement(Reversible Temper Embrittlement treatment, RTE) significantly, was developed, qualified and successfully applied to the welds in place. Basic investigations have been performed to explain the embrittlement (TE) as well as the de–embrittlement (RTE). As basic cause for the embrittlement, phosphorus segregation in the grain boundaries was identified by high resolution Atom Probe Tomography (APT). The APT results alsorevealed that by application of RTE treatment, the phosphorus segregation in the grain boundaries disappeared. According to Mc Lean, the reversal mechanism of the temper embrittlement is explained by grain boundary equilibrium segregation of phosphorous.