A Novel Approach for Quantifying the Effect of Residual Stresses on High Cycle Fatigue (HCF) and the Importance of Incorporating Residual Stresses Evolution in Life Prediction Models

ID: 72273
Type: Contributed

Speaker: Daniel Paquet, Hydro-Quebec, Canada
Author(s): D. Paquet, J. Lanteigne

Reliability of turbine runners depends on the design, the welds quality and the operating conditions. Applied stresses consist of external loads and fabrication/repair internal residual stresses (RS). Quantifying the influence of RS on fatigue life is not straightforward because their effect cannot be easily isolated from those of the applied loads, the geometry, the properties and microstructure of weld metals, and the overall quality of welds. High frequency induction heating was used to introduce RS in standard stainless steel fatigue specimens while preserving their surface finish and microstructure. The influence of surface tensile RS on high cycle fatigue life of the specimens was then studied. Surprisingly, an improved life was obtained. Experimental and numerical studies were undertaken to rationalize this experimental result. The improved fatigue life of specimens was found to result from RS evolution during the fatigue tests, leading to a build up of compressive RS beneath their surface.

An Experimentally Assisted Numerical Simulation of Metal Forming for Thick and Heavy Plates by Line Heating

ID: 73136
Type: Contributed

Speaker: Guillaume Pradinc, Ecole de technologie superieure, Canada
Author(s): G. Pradinc, X. Pham, X. Cao, J. Fihey, L. Mathieu

Hydro turbine runner blades are fabricated by either machining cast parts or forming steel plates between two matrices. This paper explores an alternative, the forming of plates by line heating. This process allows bending a metal plate using thermal stresses generated by a line heating source. The technologies currently used are limited to a thickness smaller than 25 mm. However, the manufacturing of runners requires the use of steel plates thicker than 100 mm. In this study, the experimental data of both temperatures and deformations obtained from laser, induction and oxy-acetylene line heating of 6 mm thick 304L stainless steel plates have been used to validate the results of numerical simulations. Then, a series of extrapolated numerical simulations with 2D and 3D virtual heat sources have been carried out for thicker plates up to 35 mm. Results showed that 3D heat sources can build larger deformation at a lower temperature.

Analyses of Pressing Process for Francis Turbines Blades of Hydropower Plants

ID: 73488
Type: Contributed

Speaker: Zhengkun Feng, École de technologie supérieure, Canada
Author(s): Z. Feng, H. Champliaud, L. Mathieu, M. Sabourin

Hot pressing process is widely used in many industries. This process has advantages over casting process that may cause defects due to metal contraction and trapped gas during cooling and solidification. In this paper, a pressing process with reconfigurable punch and die is proposed. Both punch and die of the process are made of matrices of poles with semi-spherical ends. The process is characterized by thermo-mechanical behaviors, three-dimensional unsteady deformation and high nonlinearity. The process analysis is based on finite element method under ANSYS/LSDYNA platform to get better understanding of the process mechanism. The analysis of the influences of process parameters on the pressing forces, the distribution and maximal value of residual stress is carried out. These parameters include the blade geometry, the shape and total number of the poles. The analysis attempts to find the minimization of pressing power, total number of poles and more uniform residual stress distribution.
Cavitation Erosion of Francis Turbines: Follow-up of Degradation with Vibratory Detection
ID: 73386
Type: Contributed
Speaker: François Lafleur, IREQ, Canada
Author(s): F. Lafleur
A vibratory detection system for cavitation erosion was developed and provides information on the state of the turbine. This system is based on vibration measurements at the guide bearing. Two types of measures are described: first, measures of cavitation erosion (signature of cavitation) depending on operating conditions and absolute measurements (Kg/1000 hours) continuous monitoring of cavitation erosion. These assessments of cavitation erosion are made by:- Analysis of the Value Mean Square (RMS) modulation of the lower guide bearing vibration at high frequency (between 5 and 15 kHz). -Calculation of aggressiveness requires the analysis spectral envelopes to look at the blade passing frequency or guidelines and identification number of the software harmonic side lobes to be used for analysis. A rating of degradation is calculated on a regular basis to allow the operator to obtain the state of degradation of the group in relation to cavitation erosion.

Cavitation Resistance of ASP Coatings, Ultrasonic Testings and Francis Runner Field Performance Comparison
ID: 72574
Type: Poster
Speaker: Anderson Pukasiewicz, Technological Federal University of Paraná, Brazil
Author(s): A. Pukasiewicz, A. Capra, R. Vaz
Cavitation erosion frequently occurs in hydraulic equipments like: hydraulic turbines, valves, pumps and ship propellers. The Arc Thermal Spray Process has a possibility to recover hydraulic blade runners without tensile residual stress development. Fe-Cr-Mn-Si is a cavitation resistance class of steel with high concentration of oxide formers elements, which can be important for arc thermally sprayed coatings. The main goal of this article is analyze the results obtained in ultrasonic cavitation tests and the results obtained in field application in francis hydraulic turbine runners. It was observed better performances for Fe-Mn-Cr-Si alloys than austenitic and martensitic commercial alloys, in laboratory tests. In field tests, after more than 2,000 operation hours, it was verified that the cavitated areas recovered with Fe-Mn-Cr-Si alloys presented only a small amount of eroded areas. The areas recovered with commercial alloys showed coating detachment of large areas, exposing the substrate surface.

Chip Formation Analyses of Single Grit Cutting Action in Grinding Processes
ID: 73618
Type: Student
Speaker: Amir Masoud Tahvilian, École de technologie supérieure/University of Quebec, Canada
Author(s): A. Tahvilian, H. Champliaud, Z. Liu, B. Hazel
In machining simulations, large deformation and moving boundaries are two important characteristics to consider in chip formation mechanism. These aspects become more critical for FE simulation of this highly nonlinear process when a negative rake angle tool is used. In this study, FE models using Arbitrary Lagrangian Eulerian (ALE) and Lagrangian formulation with element deletion damage law are developed and simulation results obtained from different formulations are compared with experimental results. The aim of this study is to determine the efficient and reliable formulation suitable for chip formation simulation involving negative rake angle tools. The results will be used to build a FE model of single grit cutting action to study the process forces and to optimize other parameters. The final model will be adjusted and applied to a grinding process conducted using a flexible robotic system named SCOMPI dedicated to in situ maintenance of large hydro turbine runners.
Considerations Regarding Cavitation Erosion Behavior of Hydraulic Turbine Runners Steels
ID: 72153
Type: Contributed
Speaker: Laurent Tôn-Thât, Hydro-Québec research institute, Canada
Author(s): L. Tôn-Thât

Cavitation erosion is still one of the most important degradation modes in hydraulic turbine. Part of researches focuses on finding new materials exhibiting high resistance. In this study, cavitation erosion behavior of high strength steels is investigated. This paper states a two-sided approach which has been used to get an advanced understanding of behavior regarding cavitation phenomenon. First, the four-stage behavior is determined using a cavitating liquid jet to determine the cavitation erosion resistance. Moreover, 20 kHz vibratory test has been performed to study the incubation period to get evidence of the degradation mechanisms. In both cases, mass losses have been followed during the exposure time. A particular effort has been implemented to determine the evolution of surface damages in terms of pitting, surface cracking and material removal. For this, 3D optical profilometry as well as scanning electron microscopy have been used to link microstructure to degradation mechanisms.

Development of an Inverse Method for Material Characterization
ID: 72454
Type: Student
Speaker: Mehdi Saboori, École de technologie supérieure (ÉTS), Canada
Author(s): M. Saboori, H. Champliaud, J. Gholipour Baradari, A. Gakwaya, J. Savoie, P. Wanjara

Conventional analysis involves the determination of material properties under uniaxial loading conditions. The flow curves generated through this way were used in finite element modeling of different forming processes. However, this method is valid up to the onset of instability; after this point the errors between finite element simulations and experimental results are significant. By using an inverse identification method the material behavior parameters after the instability were determined using its measured response to the loading condition. A new hardening equation for predicting material behavior after the instability was used for 6.2 mm thick stainless steel 321. A finite-element-based inverse method has been devised with the aim of determining the properties of isotropic materials after instability. The method was implemented into the LS-DYNA code to facilitate the process of material characterization. The procedure was used to predict the flow behavior for thicker materials in lieu of performing the experiments.

Effect of Electron Beam Process Parameters on Weld Characteristics of CA6NM
ID: 70280
Type: Student
Speaker: Sheida Sarafan, École de technologie supérieure (ÉTS), Canada
Author(s): S. Sarafan, P. Wanjara, H. Champliaud, L. Mathieu, J. Lanteigne

In this study, the viability of thick-gauge section assembly for hydroelectric turbine manufacture was considered by electron beam welding CA6NM martensitic stainless steel, a widely utilized hydro-turbine cast material. Particularly, bead-on-plate trials on 60 mm-thick CA6NM plates were carried out using a 42 kW high vacuum electron beam welding system. The influence of the heat input, beam position, beam oscillation (XSF-YSF), and in-situ pre-heating conditions on the characteristics of the weldments, such as the bead geometry, weld integrity, fusion zone and HAZ microstructures and hardness were evaluated. A relationship between the welding parameters and the resulting depth of penetration was established. A methodology for in-situ heating of the thick-gauge section prior to welding was developed and evaluated for reducing welding defects in CA6NM. Key words: Electron beam welding, thick gauge section, cast CA6NM martensitic stainless steel, in-situ pre-heating
Effect of isothermal and isochronal austenitization treatments on the size of the microstructure of cast martensitic stainless steels (13wt. %Cr-4wt. %Ni)
ID: 72247
Type: Contributed
Speaker: Aziz Akhiate, École Polytechnique de Montréal, Canada
Author(s): A. Akhiate
Isothermal and isochronal austenitization treatments have been conducted for four martensitic stainless steels, used for hydraulic turbines manufacturing, containing different carbon contents from 0.02 wt.% to 0.06 wt.%.
Observations indicate that a one hour austenitization causes an initial size reduction of prior austenitic grain and packet. It is observed that, for all alloys, increasing the austenitization time and temperature favors the growth of austenite grains resulting in coarser martensitic packets as could be predicted by a typical diffusion kinetics relationship. On the other hand, the carbon content and the chemical composition of the alloys have an influence on the parameters of the proposed relationship. In addition, results analysis indicates that there exists a linear relationship between the size of the prior austenitic grain and the size of the martensitic packets.

Effect of Isothermal and Isochronal Austenitization Treatments on the Size of the Microstructure of Cast Martensitic Stainless Steels (13wt. %Cr-4wt. %Ni)
ID: 72251
Type: StudentPoster
Speaker: Aziz Akhiate, École Polytechnique de Montréal, Canada
Author(s): A. Akhiate, J. Chaix, D. Thibault, M. Brochu
Isothermal and isochronal austenitization treatments have been conducted for four martensitic stainless steels, used for hydraulic turbines manufacturing, containing different carbon contents from 0.02 wt.% to 0.06 wt.%.
Observations indicate that a one hour austenitization causes an initial size reduction of prior austenitic grain and packet. It is observed that, for all alloys, increasing the austenitization time and temperature favors the growth of austenite grains resulting in coarser martensitic packets as could be predicted by a typical diffusion kinetics relationship. On the other hand, the carbon content and the chemical composition of the alloys have an influence on the parameters of the proposed relationship. In addition, results analysis indicates that there exists a linear relationship between the size of the prior austenitic grain and the size of the martensitic packets.

Electron Beam Bead-On-Plate Welding Process for Thick Gauge Section Martensitic Stainless Steels
ID: 70204
Type: StudentPoster
Speaker: Sheida Sarafan, École de technologie supérieure (ÉTS), Canada
Author(s): S. Sarafan, P. Wanjara, H. Chapilaud, L. Mathieu, J. Lanteigne
Sustainable manufacturing for assembly of turbines used in hydropower generation systems is driving the development of advanced technologies targeted to reduce life-cycle costs whilst assuring high performance over the prolonged product lifespan. The turbinerunner, a critical component in hydro power generation systems, requires weld assembly between the crown, band and blade subcomponents. With due consideration of the thick-gauge sections involved, design and fabrication of a turbine runner that integrates a high energy density technology for assembly, such as vacuum electron beam welding (EBW), has marked potential to achieve deeppenetration with a low heat input, thereby rendering a
weldment with narrow heat-affected zones (HAZ) and low distortion. The purpose of this study is to evaluate the influences of electron beam welding parameters on microstructural characteristics of thick CA6NM’s plates.

**Exploratory Work on the Statistical Modeling of Cavitation Erosion within the Operation Parameters of a Hydraulic Turbine.**

*ID: 73535 |
Type: Student |
Speaker: Paule Bodson-Clermont, Institut de recherche d'Hydro-Québec, Canada |
Author(s): P. Bodson-Clermont, J. Guidi, G. Hamel, F. Lafleur, Y. Mossoba, L. Perreault, M. Soares, D. Thibault, J. Angers*

Cavitation resulting from the implosion of vapor cavities leads to severe erosion of the materials that compose hydraulic turbines. A system to detect erosion using vibration measurements has been installed on 4 hydropower units and the data was collected. One of the aspects of the work done at IREQ is to study the behavior of cavitation based on operating variables and to build a statistical model. The availability of data, the identification of key variables and the prospect of links between the different variables will be presented, as well as some preliminary results such as the heterogeneity of the phenomenon. Indeed, changes in the relationship between cavitation and various operating variables were observed and could be due to a seasonal behavior or different operating conditions. These types of heterogeneous phenomena can be formally represented using mixture models. Parameter estimation will be implemented with the EM-algorithm.

**Fatigue Crack Growth Behavior of Hydraulic Turbine Runner Welded Joints: Residual Stress and Microstructural Effects**

*ID: 73923 |
Type: Poster |
Speaker: Alexandre Trudel, École Polytechnique de Montréal, Canada |
Author(s): A. Trudel, M. Brochu*

The fatigue crack growth behavior of a stainless steel alloy CA6NM weld was investigated. The effects of residual stresses, as well as of microstructural features are discussed. Constant stress intensity factor range fatigue tests and residual stress measurements using the contour method were realized on as-welded and tempered compact tension specimens with the crack growing perpendicular to the weld. Tensile residual stresses were found at the crack tip, and are believed to inhibit closure mechanisms. Despite the crack being fully open, fatigue crack growth rate (FCGR) variations were found through the different zones of the weld in the as-welded specimens. Results can be rationalized by crack deflection concepts applied to the weld microstructure. In the tempered specimens, the FCGR remains constant through the weld, and decreases gradually in the base metal. This behavior is associated to the relaxation of remaining tensile residual stresses, allowing closure mechanisms to become fully active.

**Finite Element Welding Model for the Assessment of Residual Stresses and Distorsion Resulting from Hydraulic Turbine Runners Fabrication and Repair**

*ID: 73094 |
Type: Contributed |
Speaker: Jacques Lanteigne, Hydro-Quebec, Canada |
Author(s): J. Lanteigne, D. Paquet, J. Lévesque, M. Tireh Dast, H. Champliaud*

Residual stresses (RS), whether inherited from the welding assembly during fabrication or from weld repair, limit the fatigue life of turbine runners. In this context, a finite element code for weld simulation was developed at IREQ to evaluate RS resulting from the thermal gradient produced by arc welding, phase transformations resulting from thermal cycles, and prevailing clamping conditions while assembling the blades on the runner. The main objective is to optimize the
parameters of welding procedures and to minimize the RS level, thus providing a useful tool for both the manufacturer and the user. Several cases of simulation of multi-pass welding are presented for carbon steels and martensitic 13Cr-4Ni stainless steels. In the latter case, different carbon contents are considered, which significantly influences the martensitic phase transformation. The influences of preheating and interpass temperatures on the level of CR, as well as the influence of clamping are also studied.

Fracture Toughness of 13Cr4NiMo High-strength Steels Used in Hydraulic Turbine Runners
ID: 72578
Type: Contributed
Speaker: Jianqiang Chen, École Polytechnique de Montréal, Canada
Author(s): J. Chen, Y. Verreman, F. Foroozmehr, J. Lanteigne

The fracture toughness of three grades of 13Cr4NiMo steels used in hydraulic turbine runners is investigated. Two grades are cast CA-6NM steels and one grade is a wrought S415 steel. JIC tests are first conducted on one CA-6NM steel to determine the best conditions to measure the fracture toughness. Mechanical tests are carried out on both 12.7 mm and 25.4 mm thick compact tension (CT) specimens. Experimental results show that only the thicker specimen gives a valid test according to ASTM E1820 standard. However, very close JQ values are obtained at crack initiation with thinner specimens provided they are side-grooved. Thickness constraint effect is exhibited both on the J-R resistance curve and the crack front during the stable crack propagation. Fracture toughness anisotropy is examined on the wrought S415 steel which is tested in both rolling and transverse orientations. Fracture mechanisms are investigated using SEM in the crack extension region.

Influence of Hot Deformation and Heat Treatment Conditions on Microstructure Changes and Final Mechanical Properties in a Medium Carbon Low Alloy Forged Steels
ID: 73436
Type: Contributed
Speaker: Mokhtar Ben Salah, École de Technologie Superieur, Canada
Author(s): M. Ben Salah, S. Chentouf, A. Chamanfar, M. Jahazi

The influence of thermomechanical processing conditions on the microstructure and particularly the prior austenite grain size of medium carbon low alloy steel used in energy production applications are investigated. Such deformation and temperature gradients have deleterious effects on the mechanical properties of the product. Large size blocks are forged and later machined for various applications including turbine shafts. One of the main microstructural features affecting the mechanical properties of these steels is the prior austenite grain size. However, this feature is very sensitive to the précising conditions. Hence, it is very important to optimize the forging and heat treatment conditions in order to minimize prior austenite grain size variations for each processing condition. In the present study the influences of reheat temperature, holding time, and percent deformation on the evolution of prior austenite grain size are determined and the results analyzed with the view to determine the optimum processing conditions.

Investigation of CA6NM Runner Failure Based on Standard Tests
ID: 71647
Type: Contributed
Speaker: Serge Prigent, Alstom Hydro France, France
Author(s): S. Prigent

Submerged parts of hydro turbines are exposed to the dynamic action of flowing water. Fatigue damage is dependent on many variables such as hydraulic design, operating conditions of the turbine and material of the turbine. All these factors need to be considered when predicting life cycle and to understand the cause of most fatigue cracks. A test plan was
designed to simulate real material site solicitation. This test plan focuses on variation of mechanical properties with different sets of input parameters. The variables of the test plan are carbon content, heat treatment, casting defect and hydrogen content. The results from the test conducted on CA6NM steel will be discussed in this paper. Due to the test results, it is now possible to understand some causes of fatigue crack. This knowledge will help to improve fatigue resistance and to develop a new technology for an optimum solution.

Investigation of Thick Multicore Sandwich Constructions Under Low Velocity Impact and Static Indentation
ID: 73073
Type: Contributed
Speaker: Rim Ouadday, Polytechnique Montréal, Canada
Author(s): R. Ouadday, R. Boukhili, a. vadean
This investigation deals with the impact behavior of thick sandwich panels intended for hydroelectric turbine rehabilitation through modifications to stay vane. For the two sandwich configurations considered as extensions, the skin is made of a 4 mm thick bidirectional laminate of a glass fiber reinforced epoxy. The first sandwich configuration has a 30mm thick core made of alumina trihydrate filled epoxy E/ATH making the overall thickness 38mm. The second sandwich configuration differs from the first one only by the insertion of 100mm thick expanded polystyrene foam in its middle, making the overall thickness 138mm. The manufactured sandwich panels were subjected to drop weight impact test using various impactor diameters. Static indentation tests were performed using the same experimental setup and impactors noses as indenters. The results show a good correlation between the drop weight impact and indentation tests.

Line Heat Forming Using a Differential Geometry Formulation: Methodology and Application
ID: 73395
Type: Student
Speaker: Rafaël Bédard, École de technologie supérieure, Canada
Author(s): R. Bédard, H. Champliaud, J. Gholipour, P. Wanjara
Hydraulic turbine blades have complex shapes and are made in small quantities. Traditionally, the blades are shaped by hot stamping of thick plates, but due to the high tooling cost and low production rate, the manufacturing cost is dramatically high. On the other hand, shipbuilders have used efficiently a thermal gradient process to form hulls. This process consists of heating locally one side of a plate with a heating source to induce plastic strains in the plate. During cooling, the plate starts to deform such that the material in the heated region bends locally, and results in permanent deformation. In this article, a method is presented to effectively estimate the deformed shape of a thick plate due to line heating. Heating lines can then be combined and the final shape can be calculated. Through an optimization process, this approach allows determining the trajectories needed to shape complex geometries.

Line Heat Forming Using a Differential Geometry Formulation: Methodology and Application
ID: 73855
Type: Contributed
Speaker: Rafael Bédard, École de technologie supérieure, Canada
Author(s): R. Bédard, H. Champliaud, J. Gholipour, P. Wanjara
Shipbuilders have used efficiently a thermal gradient process to form hulls. This process consists of heating locally the plate with a heating source, such as a torch, to induce plastic strains. As such, to transfer this approach to the manufacturing of hydroelectric assemblies, researchers have worked to understand the effect of a specific heat trajectory to automate this forming process. In this article, a method is presented to effectively estimate the deformed shape of a thick plate due to line heating. The method uses a differential geometry approach. The fundamental coefficients, which represent the effect of a given heating line, are determined through experiments and/or finite element simulations to build-
up a database for generic shapes. Heating lines can then be combined in terms of these fundamental coefficients and the final shape can be calculated. Through an optimization process, this approach allows determining the trajectories needed to shape complex geometries.

**Luminescent lanthanides: past, present and future**
ID: 73174  
Type: Contributed  
Speaker: Andries Meijerink, Utrecht University, Netherlands  
Author(s): A. Meijerink

Lanthanides are found in luminescent materials now in every home, at many different places. The unique optical properties of lanthanides has led to technological developments which has promoted the widespread use of these materials. It started in 1963 with the application of Eu3+ emission in color TVs and strongly increased with the use of rare earth phosphors in (compact) fluorescent tubes. Presently, rare earth luminescence is applied in a variety of flat displays, white light LEDs, scintillators for medical imaging and homeland security, afterglow materials, laser, fiber amplifiers, anti-counterfeiting labels and more applications, e.g. in solar cells, may emerge. This presentation will start with a short historical introduction and then discuss the status of the various present applications with an outlook on the future, including new materials for spectral conversion for higher efficiency solar cells and warm white LEDs.

**Materials Science and Technology in Hydroelectricity**
ID: 70911  
Type: Keynote  
Speaker: Michel Sabourin, Alstom Hydro, Canada  
Author(s): M. Sabourin

Hydroelectricity is the only renewable energy source that is flexible, predictable and reliable. From a technological perspective, hydroelectric development is well-established and mature with efficiencies exceeding 90% and an operational reliability that is practically maintenance-free. With consideration of the vast amount of hydroelectric energy available, continuous research is necessary to evaluate emerging technologies and consider their integration for improving and maintaining hydroelectric systems. In this regard, materials science research can lead to significant improvements in hydroelectric development in the following domains:• Performances• Reduction of outage times• Lifetime and reliability• Mitigation of environmental impactsPresently, research and development continue to increase the knowledge of traditional material properties such as stainless steel CA6NM. Innovative developments are being deliberated, such as in materials and manufacturing processes, including technologies to improve surface finish and weld reliability of conventional materials, as well as novel applications of composite materials.

**Metallographic Model to Evaluate the Cavitation Resistance in Austenitic Steels and Welding Filler Repair Mn Basis for Hydraulic Machinery**
ID: 73540  
Type: Contributed  
Speaker: Patricia Carrizo, Universidad Tecnológica Nacional Regional Mendoza(UTNFRM), Argentina  
Author(s): P. Carrizo, C. Bello

Abstract: The purpose of this research was to determine an evaluation model application materials to components of hydraulic machines, allowing to quickly determine its response trials using specimens subjected to cavitation. This model was applied in a study of welding filler used to repair these components and to characterize the damage by theories of non-diffusive transformations in ferrous materials. The application of this model allow to achieve a proper identification using standards metallographic techniques and low cost through a bank of ultrasonic cavitation. This model served to
verify that the welding filler used on the specimens tested, are a successful combination for repair hydraulic turbines which are built mostly with austenitic steels.

**Keywords:** ultrasonic testing, standardized specimen, model, welding, d ferrite.

**Minimize Weld Hardness in 410NiMo FCAW by Heat Treatment**

ID: 73222  
Type: Contributed  
**Speaker:** Louis Mathieu, Alstom Energie and Transport Canada Inc, Canada  
**Author(s):** L. Mathieu

Hydro turbine runners are mainly made of CA6NM and weld with homogenous filler metal 410NiMo. This paper will present the influence of heat treatment on the objective to respect the base metal maximum hardness on welds and heat affected zones. By prolongations of time at temperature the experiment will demonstrate the trends in hardness modification of filler metal and the effect on global runner stability in the aspect of geometry and base metal properties. This paper will hopefully give axes of improvement in the objective to obtain homogenous hardness in filler metal and base metal of 13-4 martensitic stainless steel considering fabrication restrictions.

**Modeling and Experimental Work on Robotic Grinding Tool Profiling and Angle Control for Repair of High Curvature Surfaces**

ID: 73371  
Type: Student  
**Speaker:** Stéphane Agnard, École de technologie supérieure, Canada  
**Author(s):** S. Agnard, Z. Liu, B. Hazel

For maintenance and repair of hydroelectric equipment, a special hemispherical tool can be used to conduct grinding work on high curvature surfaces or hard-to-access areas such as turbine blade junctions. During this process, it is important to keep the tool contour as spherical as its initial shape in order to ensure uniform ground surfaces. In this paper, we present the material removal and tool wear models developed to control the tool profile evolution caused by wear. The objective is to minimize the contact area between the tool and the workpiece throughout the process such that flat surface formation on the tool head is avoided. The solution proposed is an oscillation function of tool frontal angle controlled by the robot arm holder. Intensive experimental work has been done to validate the models and tool angle oscillation functions using grinding, laser measurement and profilometer. Various results will be presented in the paper.

**Modeling and Simulation of Hot Radial-Axial Ring Rolling Process**

ID: 73487  
Type: Contributed  
**Speaker:** Zhengkun Feng, École de technologie supérieure, Canada  
**Author(s):** Z. Feng, H. Champliaud

Hot radial-axial ring rolling process has the advantage over hot axial ring rolling in improving product quality and is widely used to produce seamless rings for critical structural components. This complex bulk forming process is characterized by high nonlinearity, unsteady and asymmetrical three-dimensional deformation, dynamic contact boundary conditions caused by the rotations of ring and rolls. In this paper, a model based on finite element approach is proposed and numerical simulations are performed. The applied forces of the process, the stress-strain distribution in the workpiece are computed. Through investigation of the process, better understanding of the mechanism of the process can be obtained.  
**Keywords:** Hot radial-axial ring rolling; Finite element analysis; Residual stress.

**On-site Post-weld Heat Treatment of Welds Made of 410NiMo Steel**
CA6NM and UNS S41500 steels are commonly used for manufacturing hydraulic runners. The blades are generally welded using 410NiMo filler. A post-weld heat treatment (PWHT) is then required to temper the brittle martensite formed in and around the weld zone. To date, such PWHT has been difficult or impossible to perform on runners installed in a power plant. If on-site repairs must be performed due to fatigue cracks or cavitation, austenitic stainless steels like 309L are used. The use of 410NiMo with no PWHT is not recommended since cold cracking and poor fatigue properties may result. A new portable heat control process using a robot and an induction source is proposed for local on-site post-weld heat treatment of welds made of 410NiMo. Tests on welded samples compare microhardness, impact properties, microstructure and residual stresses before and after simple and double PWHT. The results show the potential of the process.

Residual Stress Characterization in a 13%Cr–4%Ni stainless Steel Weld by Neutron Diffraction and the Contour Method
ID: 73831
Type: Contributed
Speaker: Michael Gharghouri, National Research Council, Canada
Author(s): D. Thibault, P. Bocher, M. Thomas, M. Gharghouri, M. Marjolaine
Neutron diffraction has been used to determine the transverse, longitudinal and normal components of stress in a 13%Cr–4%Ni weld made using 410NiMo weld filler metal. The longitudinal stress distribution was also measured by the contour method. In the as-welded condition, the last bead of the weld was found to be in a state of triaxial compression while a part of the heat-affected zone as well as a region beneath the weld were in a state of longitudinal tension. These results are rationalized on the basis of the low martensitic transformation start temperature (Ms) of the alloy. The measurements were repeated on an identical weld that had undergone post-weld heat treatment. The maximum tensile stress was reduced from 534 to 136 MPa, and the maximum compressive stress was reduced from 371 to 152 MPa as a result of the stress-relieving heat treatment.

Rubber Fiber-reinforced Composite Materials for Hydraulic Turbine
ID: 70929
Type: Contributed
Speaker: Edith Roland Fotsing, École Polytechnique de Montréal, Canada
Author(s): A. Favre, E. Fotsing, E. Ruiz, M. Levesque
Fiber-reinforced rubber composites have recently found applications in the hydro-electrical sector. Inflatable membranes can be inserted at the turbine outlet to improve its efficiency and thus reduce cost of electricity. These membranes would enable controlling of water flow without rebuilding the hydraulic dam. The aim of this study was to evaluate the long term durability of rubber composites in aquatic environment. Accelerated water aging treatment was performed on four composites made from EPDM, silicone, Neoprene and EPDM/silicone matrices and fiberglass reinforcement. Characterization procedures were developed in order to monitor the physical and mechanical properties of these materials under different aging conditions. The extent of water absorbed was measured using an absorption test. Scanning electron microscopy was used to assess the quality of fiber-matrix interface before and after aging. Finally, the evolution of mechanical properties of the reinforced membranes was followed by measuring tensile properties at different times during water aging.
Strain Variations of AISI4340 Steel Undergoing Metallurgical Transformations during Induction Hardening Heat Treatment
ID: 72787
Type: Student
Speaker: Rabih Kassab, École de technologie supérieure, Canada
Author(s): R. Kassab, H. Champliaud, P. Bocher, J. Lanteigne, V. Lê

Heat treatment of steels using Induction Hardening (IH) is done to increase the strength of the material at the outer surface while preserving intact the inner material properties i.e. tenacity. The general purpose of the research is to predict the residual stresses and deformations due to Induction Hardening of gears. The specific goal in this paper is to compute the deformation of the AISI4340 steel taking into account metallurgical transformations. During heating, temperature and time dependent austenite transformation occurs. On the other hand, during quenching instantaneous martensitic transformation happens. The occurrence of the mentioned metallurgical transformations affects the deformations and the stresses in the heat treated material. Based on the thermal cycle, the calculation of the strain variations are computed using the finite element software COMSOL®. A good match is achieved between calculated strain values and published experiments.

Study on Cold Cracking Testing Methods for Low Carbon Soft-martensitic Stainless Steel Arc Welding
ID: 73464
Type: Student
Speaker: Mathieu Paquin, Ecole de technologie supérieure, Canada
Author(s): M. Paquin, D. Thibault, P. Bocher, Y. Verreman

Low carbon soft-martensitic stainless steels are widely used for hydraulic turbines manufacturing. Their good corrosion resistance, their high mechanical strength, their good cavitation erosion resistance combined with their relatively good weldability explain this success. However, because of their martensitic structure, some metallurgical phenomena bring complications during assembly, done by arc welding. In fact, in multipass situation, transverse cracks can sometimes be detected in the weld joint during inspection. The cracks appear in the melted zone, but are not propagated into the base metal. Cold cracking is the usual suspect to blame for the origin of this defect. This paper will first describe the cold cracking phenomenon followed by a brief review of cold cracking tests with precisions about their advantages and their limitations. Finally, a modification of the GBOP test (Gapped-Bead-On-Plate) is suggested in order to reproduce the behaviour of the filler material (410NiMo stainless steel), observed in industrial conditions.

Temperature Profile Optimization in a New Robotic Local Induction Heat Treatment Process
ID: 70760
Type: Student
Speaker: Mathieu Gendron, École de technologie supérieure, Canada
Author(s): M. Gendron, E. Boudreault, B. Hazel, H. Champliaud, T. Pham

Post-weld heat treatment (PWHT) restores mechanical properties and relieves internal stress after hydraulic turbine runners are assembled by welding. For many aging turbines, PWHT is needed to ensure high-quality repairs. It is not feasible, however, to dismantle such large runners and take them to a furnace. A new robotic process was thus developed to perform local induction heat treatment in situ. A critical factor in the process is to maintain a uniform temperature profile within a precise range. Heat is generated by moving an induction coil back and forth over a specific area. A method combining finite element analysis and optimization is proposed to set heating parameters. Through a series of stationary and transient thermal analysis, the heating path and parameters are optimized to achieve a uniform temperature profile. The method was tested by performing robotic post-weld heat treatment in laboratory. Results show good agreement between numerical and measured temperatures.
List of Speakers
Revised: Monday, April 22, 2013

SYMPOSIUM: Advances in Hydroelectric Turbine Manufacturing and Repair

The Contribution of Metallurgy to the Reliability of Turbine Runners
ID: 73160
Type: Contributed
Speaker: Denis Thibault, Institut de recherche d'Hydro-Québec, Canada
Author(s): D. Thibault

Failure of hydraulic turbine runners is a very rare event. So to be able to assess the reliability of these components and to predict the evolution of their degradation it is necessary to use physically-based reliability models. Using these kinds of models it is easy to illustrate how materials science and metallurgy contribute to hydraulic turbines reliability. The proposed paper will focus on fatigue of turbines to show how different metallurgical aspects can affect their reliability. Some of the aspects that will be covered are crack propagation mechanisms, transformation-induced plasticity, martensitic stainless steel microstructure, welding related cracking and post-weld heat treatment.

The Microstructure of 13Cr4Ni Multipass Weld Metal Before and After Tempering Heat Treatment
ID: 72542
Type: Student
Speaker: Mohsen Mokhtabad, École de Technologie Superieure, Canada
Author(s): M. Mokhtabad

13Cr4Ni martensitic stainless steels have lots of applications in hydroelectric industries. 410NiMo is a 13Cr4Ni weld metal electrode which is being used for fabrication and repair welding of 13Cr4Ni turbines. The 410NiMo produces a fully martensitic microstructure weld metal however the weld metal could contain up to 25% of austenite based on either a later heat treatment or heat effects of adjacent passes. This austenite improves mechanical properties of the weld. In this research, microstructure and texture of 410NiMo multipass weld metal has been studied. The heat effects of a multipass welding and effects of different heat treatments on microstructure of martensite and morphology of austenite in the weld metal have been investigated to choose a proper heat treatment for 410NiMo weld metal. It has been shown that austenite could be found in the multipass weld microstructure which means the heat effects of adjacent passes may produce austenite.

Using a Pyramidal Three-roll Bending Process to Improve the Quality of Seemed Cylinders
ID: 73483
Type: Contributed
Speaker: Zhengkun Feng, École de technologie supérieure, Canada
Author(s): Z. Feng, H. Champliaud

Mecano-welding can efficiently produce cylinders used in many industries. The pyramidal three-roll bending process is commonly used to produce a cylinder with non-seamed gap. However, there is a planar zone near the front and rear ends which will be seamed together with a welding process. This paper proposes a numerical model to simulate the roll bending process to improve the geometrical quality of the bent cylinders. Explicit and implicit solvers are applied to the numerical modeling by using ANSYS/LS-DYNA software. The numerical model provides a useful tool for design and optimization of the Mecano-welding process.