HIP17 - 12th International conference on Hot Isostatic Pressing

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Book of Abstracts

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Prediction of the influence of non-homogeneous powder distribution on hot isostatically pressed components combining discrete element method and finite element analysis

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The non-uniform shrinkage of the tool/canister under hot isostatic pressing (HIP) condition is influenced by many factors, among which the powder relative density distribution seems to have a strong effect. Prediction of the final tool deformation is fundamental for canister design in order to meet dimensional tolerances of final component. To this end, numerical approaches represent a promising alternative to the expensive iterative experimental trials. Researches up to date are generally based on finite element analysis where a uniform powder relative density distribution is assigned over the whole mesh domain. In this study the Discrete Element Method (DEM) has been employed to simulate Ti-6Al-4V powder filling and pre-consolidation process allowing modelling the powder as single individual entities. A Finite Element Model (FEM) has been developed to simulate the HIP process, where the relative density distribution assigned to each element has been calculated from the final powder configuration obtained by DEM. Moreover, experimental work has been carried out validating the powder filling phase in terms of filling time, angle of repose of powder and powder relative density distribution, and the influence of the initial powder distribution on the tool shrinkage. Comparison between experimental and numerical results shows the capacity of the numerical method to predict the canister shrinkage and the results strongly suggest that it is necessary to take into account the inhomogeneous powder distribution inside the canister.

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High Pressure Heat Treatment - Phase Transformation Under Isostatic Pressure in HIP

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Hot Isostatic Pressing is widely used today to eliminate internal defects in components to achieve improved material properties like ductility and fatigue. With the modern HIP systems that Quintus Technologies can offer today there are possibilities to incorporate more processes steps into the HIP process. These process steps can be stress relief, solutionizing, quenching, ageing, tempering etc. performed in the same equipment during the same cycle which makes a very effective process route.

In this paper the possibilities for different HIP and heat treatment cases will be discussed together with results from trials within the combination of HIP and heat treatment. The results are a very cost effective way to obtain a material with the desired properties.

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HIP Process

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Fabrication of diamond/SiC composites using HIP from the mixtures of diamond and Si powders

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Fabrication of diamond/SiC=75/25~50/50vol% composites have been tried using hot isostatic pressing at 1450℃ under 196 MPa for 2 h from the mixtures of diamond and Si powders. The former consisted of bimodal particle sizes Ps of 69 and 9.2 μm, and the latter average Ps of 0.60 μm. They were mixed using an alumina mortar and pestle for 30 min in ethanol thoroughly. After drying, a small amount of binder was added to the mixed powders and compacted uniaxially and isostatically (245 MPa). They were pre-heated at 950℃ for 2 h in a vacuum to be densified for easy handling. Calcined mixed powder compacts wrapped with BN powder were sealed into Pyrex glass petri dish in a vacuum. They were heated with heating rate of 300℃/h, between room temperature and around 820℃ in Ar gas atmosphere of 0.3-0.4 MPa, and from 820° to 1450℃ with increasing pressure to 196 MPa. Archimedes method to determine the bulk densities revealed that the highest density of 96.7% has been achieved at the composition of diamond/SiC =55/45vol%, in which composition the diamond content is higher than that (45 vol%) of previous works. SEM observation on the microstructure of composites showed a little amount of cleavages at grain boundaries between diamond and SiC, which might be originated from the volume reduction around 19.3% in the formation of SiC from C + Si during HIPing. However, with decreasing the content of diamond the cleavages disappeared due to the rearrangement of diamond particles less than 35vol%.

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The influence of post-HIP heat-treatments on the tensile and HCF properties of Ti6Al4V

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Samples of gas-atomisedTi6Al4V powder have been HIPped after which they were cooled at different rates in the HIP and/or subsequently heat treated in order to obtain very different microstructures. Microstructural observations have been carried out using scanning and transmission electron microscopy. The samples were tested in tension and in fatigue in order to assess the influence of the

different heat treatments on these properties. Similar heat treatments have been carried out on ingot-route Ti6Al4V and the microstructures and properties compared with those of the HIPped powder samples. Transmission electron microscopy has been used to define the influence of the different microstructures on dislocation behaviour in an attempt to understand the observed differences in properties and these results will be presented.

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Wear of PM HIP metal matrix composites – influence of carbide type

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The type of hard phase in combination with matrix material has a great influence on the wear properties of PM HIP Metal Matrix Composites. The hardness and toughness of the hard phase as well as its reaction with the matrix in combination with wear mechanism can cause significant differences in performance of the material. Three materials with the same matrix alloy but different carbide types have been studied with regard to tribological behavior in low stress abrasion, high stress abrasion and scratch testing against a quartz stylus.

In low stress abrasion testing the material has only very small differences in the performance between the materials. The materials containing crushed or spherical fused tungsten carbide had a higher initial wear that can be explained by the microstructure of the material. In the later stages of wear the three materials preform very similar.

In the scratch testing a clear difference can be observed between the materials. The material containing the fused tungsten carbide exhibits a higher degree of carbide damage at the exit side of the wear scar sliding over the carbide. This can be attributed to the much higher degree of carbide dissolution in the fused carbide compared to the macrocrystalline carbide.

The results from tribology testing are discussed and compared to wear mechanisms observed in parts that have been in service in a slurry pump and a crusher.

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Effect of Hot Isostatic Pressing (HIP) on additively manufactured Ti6Al4V microlattice structures

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The quality of additively manufactured metallic microlattice materials is reported to be dependent on process parameters. These fabricated structures have inherent defects such as micro-voids. The build angle of the part is likely to affect its microstructure and mechanical properties due to the stacking-layered-fused nature of the metal powder in Powder Bed Fusion (PBF) process, which is essentially a vertical building paradigm. In this study, two Ti6Al4V microlattice structures, one with Body Centered Cubic (BCC) and another with additional vertical pillar (BCC-Z) unit cell, were manufactured using Electron Beam Melting (EBM) method. The initial structures were examined using the Neutron imaging instrument DINGO at ANSTO, in order to detect large internal defects if possible. While the effects of build angle may be avoided only with great difficulty, Hot Isostatic Pressing (HIP) was conducted as a suitable post-processing step to mitigate these effects by removing porosity. Since both the structures are made up by interconnecting struts, representative strut-length samples were extracted before and after the HIP process and were subjected to Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS) and Electron Backscatter Diffraction (EBSD). It is observed that the HIP process was able to remove significant amount of porosity and resulted in overall coarsening of the titanium alloy microstructure.

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Toughness of duplex steel produced by PM-HIP

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Components produced by PM-HIP from corrosion resistent steels with a ferritic-austenitic duplex microstructure are widely used in offshore-applications and in the chemical industry. In most of these applications high toughness – particular at low temperatures – is a mandatory requirement. In contrast to austenitic steels, tough-ness of duplex steel shows a temperature dependent transition from ductile to britt-le behaviour. While PM-HIP duplex steels mostly have superior strength and corrosion resistance compared to conventionally produced grades, the toughness issue often leads to discussions.
In this contribution the most important influencing factors for the toughness of duplex steels will be discussed examplarily at grade AISI 2205. Focus will be given to two major aspects: the embrittlement by σ-phase and the embrittlement caused by residual argon pores. While the formation of σ-phase depends on the cooling rate in the HIP vessel, argon porosity can either be caused by insufficient evaporation prior to HIP or small leakages in the capsule. Toughness will be discussed in terms of Charpy tests, taking into account the notch radius as additional parameter. The macroscopic results will be reflected by investigations of the microstructure. Tough-ness of PM-HIP steel will be compared to appropriate conventionally produced grades.

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Experience in HIP Diffusion Welding of Dissimilar Metals and Alloys

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HIP solid-state diffusion welding is a controlled process during all stages of technological process. Unlike other known solid-state welding techniques the HIP allows to provide strong and dense welded joint with stability properties irrespective of the sizes and a configuration of welded materials contact surfaces.
Here we present some special pilot examples of HIP diffusion welding of dissimilar metals and alloys: steel XM19 to steel 316L, bronze Cu-Cr-Zr to steel 316L, copper M1 to steel Fe-18Cr-10Ni-Ti-C, titanium alloy Ti-6Al-4V to steel Fe-18Cr-10Ni-Ti-C, single-crystal molybdenum to polycrystal molybdenum.

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Large-scale and industrialized HIP equipment for the densification of additive manufactured parts

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Additive manufacturing technology has significant advantages in fabricating parts with complex shape, but the internal defects, such as residual stress, pores and microcracks, would result in fatal problems under certain circumstances. To meet the requirement of HIP treatment on additive manufactured parts, we studied the thermodynamic behavior of the gas medium under high temperature and high pressure conditions, explored the deformation discipline of the thin-walled parts and the boundary conditions of controlling deformation, and optimized the process of eliminating residual stress. Based on the above work, series of HIP equipment were specially designed for the treatment on additive manufactured parts, which could provide solid support for the development of additive manufacturing technology.

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Advances in HIP Equipment with the Tie-Rod and Quick Can Approaches

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Through the last 30 years, Isostatic Forging International Ltd (IFI) has developed innovative concepts of HIP equipment that shows great promise for the full range of HIP processing from the very smallest (and fastest) units to the units of unprecedented size and capability.

With all advances of the precision casting and PM technologies the sizes of the large components are limited only by the size of the HIP systems. Moreover, the cost of the largest PM parts often exceeds the cost of the HIP cycles.
The larger the HIP, the more requirements are imposed on the safety of the operations. Therefore the damage tolerance of the HIP equipment and the cost efficiency of making parts through HIP become the factors of the major importance.

The IFI Tie-Rod Pressure Containment System (PCS) is a robust pressure vessel substitute that is extremely damage tolerant with a design that is analysis and inspection friendly. The design does not depend upon statically indeterminate factors (such as pre-stress and friction). Furthermore it can be disassembled and inspected equivalent to the original build. An advanced design of the Tie-Rod PCS done through modern techniques of fracture mechanics enables to reliably scale up the system with practically no limits

The Quick Can technique enables an access to the interior of a HIP can during the HIPing procedure so that the integrity of the HIP can be monitored and controlled through the whole process, hot outgassing can be substantially enhanced and reactive refining of the powder surface performed.

This presentation will review our work to date and the promise for future development as well as formulate detailed requirements to the design of the HIP System from the point of view of the manufacturer of large scale parts.
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Tailoring HIP Equipment and Protocols for the Unique Features of MIM

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Precise prediction of near net shape HIP components through DEM and FEM modelling

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In Hot Isostatic Pressing (HIP) of metal powder, anisotropic shrinkage of the capsule induced by inhomogeneity of the initial powder filling density determines the reproducible realization of small geometrical allowances. This becomes a detrimental factor in the manufacturing of near-net-shape components due to their high requirements of the final shape accuracy. This challenge can be solved by precisely predicting and controlling the shrinkage with respect to the filling density via numerical simulation. Using a Discrete-Element-Method (DEM) script, a two-dimensional initial powder density distribution on the component cross section is simulated. After being validated by experimental results from metallographic examination, the calculated powder density distribution is assigned as the initial relative densities in a Finite-Element (FE) model. An in-house developed user defined material model Subroutine (UMAT), which considers both instantaneous plasticity at lower temperatures and rate dependent plasticity at higher temperatures, is utilized in the frame of ABAQUS for the simulation. In addition, both the gravity and the friction between the capsule and the support are also taken into account in the simulation, as these two factors are not negligible in an industrial-scale HIP-process. The preliminary experimental validation using pre-prototype component reveals that the shrinkage induced shape changes during HIP can be accurately predicted by several virtual iterative simulations. Furthermore, the influences of local density distribution, gravity and friction force during HIP are also investigated. In summary, the developed simulation method demonstrates high accuracy in HIP component shape prediction and can be easily applied to design HIP capsules for large and complex components.

Innovative Aspects:

•The DEM simulation shows the feasibility to simulate the powder distribution inside a capsule taking into account the individual filling configurations and procedures.

•The FE-Model is improved with the addition of gravity and friction forces to the driving force for deformation during HIP.

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HIP technology enable ceramic manufacturers to control material properties and increase productivity.

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Hot isostatic pressing (HIP) technology has been known for more than 50 years, and is considered today as being a standard production route for many applications. The HIP process applies high pressure (50-200 MPa) and high temperature (400-2,000℃) to the exterior surface of parts via an inert gas (e.g., argon or nitrogen). The elevated temperature and pressure cause sub-surface voids to be eliminated through a combination of plastic flow and diffusion. The challenge is to reach the highest possible theoretical density while maintaining productivity goals.

Uniform rapid cooling is a process by which thin-walled pre-stressed wire-wound HIP units increase productivity up to 70% compared with natural cooling, and increase the density to ~ 100% of theoretical density for many alloys. The added cost to reach this density is around $0.20-0.30/kg for a large production HIP system, depending on the material.

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Hot Isostatic Pressing of Radioactive Nuclear Waste: The Calcine at INL

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Hot Isostatic Pressing (HIP) is a method to consolidate dry metal and ceramic powders by increasing the temperature up to the sintering threshold and applying high pressure, typically 15-30 ksi in an inert Argon atmosphere.

This work presents the results performed together with Quintus Technologies and Department of Energy's Idaho Site contractors to significantly reduce the volume of dry calcine radioactive nuclear waste by HIP where the radioactive waste will be contained in a collapsible canister, heat treated in the HIP to solidify it so that zero emissions of radioactive isotopes are expected from the glassy end product.
The glassified end-product is then ready for transport to a repository for final disposal when available.

To be shown in the presentation is the cost ratio for HIP vs Vitrification is 1:1.74, and the volume reduction 20-70%, while vitrification increases the volume with 100%.

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Hot Isostatic Pressing (HIP) of Castings to Improve Quality and Material Properties

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Hot Isostatic Pressing, HIP, is a method to apply a high pressure, typically 7,500 – 30,000 psi, at elevated temperatures, typically 700F up to 4000F, to eliminated voids in the material, like pores

and gas bubbles, for increased material properties, i.e fatigue, tensile strength and elongation, and remove cracks and to reduce scrap.

Another advantage with HIP is the heat treatment that can be performed at high pressure, compared with traditional sintering and annealing methods where you either have lowered pressure in vacuum sintering or annealing furnaces where you operate at 1 atm. Even furnaces with slightly increased pressure like sinter-HIPs, the applied pressure is typically 700 psi, the advantages reached at higher pressures are far better.

For example, the scatter of data is dramatically reduced, the rapid quenching in a HIP gives less distortion and lowers residual stresses so the material can be machined without intermediate stress relief heat treatment.

This paper will present the results from HIPing and heat treatment of Aluminium castings, where the material properties are significantly improved

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Heat Treatment of PM parts by Hot Isostatic Pressing

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Powder Metallurgy is a competitive method vs forgings and castings, when it comes to cost effectiveness manufacturing of complex parts or alloy systems prone to cracking during heat treatment. By applying a Heat Treatment step in the HIP, due to the use of high pressure during the HT-step, it opens up new possibilities for to improve the strength, ductility and especially the fatigue properties of the material and residual stresses will also be eliminated.

Today, it is possible to combine HIPing and heat treatment in a specifically designed HIP equipped with Uniform Rapid Quenching (URQ®) or Uniform Rapid Cooling (URC®). This paper will describe the process and benefits of HIP of PM parts together with the possibilities and advantages of combining the HIP process and heat treatment in a Rapid Cool HIP.

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Heat Treatment of MIM parts by Hot Isostatic Pressing

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MIM is an excellent process to produce smaller parts in large numbers for many industries, i.e. Automotive, Medical, Dental and Aerospace.

However, even after the final sintering residual pores exist within the material. To remove these pores, Hot Isostatic Pressing or HIP is the obvious choice. By applying a HIP step, pores will be eliminated and the density will increase to virtually 100% of theoretical density. This pore elimination will improve the strength, ductility and especially the fatigue properties of the material and residual stresses will also be eliminated.

Today, it is possible to combine HIPing and heat treatment in a specifically designed HIP equipped with Uniform Rapid Quenching (URQ®) or Uniform Rapid Cooling (URC®). This paper will describe the process and benefits of HIP of MIM parts together with the possibilities and advantages of combining the HIP process and heat treatment in a Rapid Cool HIP.

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HIP Process

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HIP for AM - Optimized material properties by HIP

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Additive Manufacturing (or 3D-printing) is the newest technology to mass produce small to medium-size parts with high tolerances and quality for many industries, i.e. Automotive, Medical, Dental and Aerospace.

However, even after the final sintering residual pores exist within the material. To remove these pores, Hot Isostatic Pressing or HIP is the obvious choice. By applying a HIP step, pores will be eliminated and the density will increase to virtually 100% of theoretical density. This pore elimination will improve the strength, ductility and especially the fatigue properties of the material and residual stresses will also be eliminated.

Today, it is possible to combine HIPing and heat treatment in a specifically designed HIP equipped with Uniform Rapid Quenching (URQ®) or Uniform Rapid Cooling (URC®). This paper will describe the process and benefits of HIP of 3D-printed parts together with the possibilities and advantages of combining the HIP process and heat treatment in a Rapid Cool HIP.

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How to Avoid Coloring of Parts in Hot Isostatic Pressing

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A common problem in the HIP industry is discoloring of parts with high Chromium content, like for Stainless Steel or Cobalt-Chromium-alloys that turns out green, for Ti-alloys that turns out blue or yellow, and for Cu-alloys that can have a black surface.

HIP users use different methods to avoid the coloring, like having different kind of getters, i.e. Titanium sponge. They wrap parts in foils from Molybdenum, Titanium and Stainless steel, which is a tedious and from time to time not effective.

This work will show the way forward how to avoid discoloring of HIPed parts. The use of a graphite furnace in combination with an optimised HIP cycle gives clean and spotless parts ready for use without any post-processing like polishing, brushing, etc.

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TeraPi - A 3.5 meter diameter hot zone HIP unit enables HIP:ing of large components

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The largest HIP unit operated in the world today has a hot zone diameter of 2.05 meters which is very big. However, there are even bigger components produced that would benefit from a HIP process but which can't be HIP:ed today because of the size. These components could be large pump house castings for nuclear power plants or large circular components for aerospace engines for example.

This presentation will cover which types of components and markets that can benefit from this size of HIP. It will also be explained how it is possible operate a monster HIP like the TeraPi and and the technical concept together with performance details

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Expanding HIP Applications as a Manufacturing Process by Overcoming the Long Existing Technical Barriers

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Recently, a Center of Excellence (CoE) in Hot Isostatic Pressing (HIP) has been established at the Ohio State University tasked with overcoming the long existing technical barriers to the use of HIP for critical applications and exploiting fully the advantages afforded by powder metallurgy processing. In particular the current research has been aimed at minimizing the influence of prior particle boundaries (PPBs) in Ni-base superalloys and obviating the deficit in fatigue properties in PM HIPed Ti-6Al-4V.
The main tasks of the COE are: i) the development of quantitative cost models; ii) the development of a physics-based computational modeling scheme that will permit the accurate prediction of the shape of tooling that will result in a given near-net shape of a component; iii) the development of an understanding of the variation in mechanical properties; iv) the development of solutions to technical barriers that limit the use of HIP for rotating components; v) development of techniques to permit the enhancement of local properties in components; and vi) the development of transfer functions that that allow properties obtained from sub-scale parts to predict accurately those of large components. The paper presents and discusses the solutions achieved.

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Increasing the cost efficiency of hot isostatic pressing for near net-shape processing of titanium alloy components

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The advent and enthusiasm for additive manufacturing (AM) has increased significantly the use of titanium alloy powders. For most of the powder-based AM processing techniques, there is a requirement for the fine powders of narrow size range. Since most of the atomizing techniques produce a range of sizes, with a more or less Gaussian distribution, this means that after delivering powders for AM, there is a considerable quantity of powders left seeking application. In consequence, the price of this powder is often very much reduced, for example, the price of Ti alloy powder may be decreased several times. Hot Isostatic Pressing (HIP) does not place such a stringent requirement on powder size (provided the tap density is not strongly impacted), and there is, therefore, a tremendous potential cost advantage for HIP of these coarser powders were to be used. The research described here involves a study of the microstructure, response to heat-treatment, and mechanical properties of samples of Ti-6Al-4V produced by HIP'ing such coarser powders. These results are compared with those of conventionally wrought Ti 6-4, and the differences are analyzed and contrasted.

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HIP Processing of Improved Tooling Materials for High-Productivity Hot Metal Forming Processes

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Much work has been carried out in the last decade on the development of high performance alloys to reduce vehicle weight. These alloys are often characterized by low room-temperature formability. A variety of hot forming processes (hot stamping, hot extrusion and high-pressure die casting) are thus being used or adapted for these alloys. The final mechanical properties, shape complexity and production cost of parts made using these processes will be closely related to mold/die thermal and mechanical performance.

Hot work tool steels generally have the required mechanical properties and durability to meet hot-processing requirements but have low thermal conductivity. The stringent low processing cost and high-volume production requirements of the automotive industry compel part producers to find ways to shorten unit production times at equivalent product quality. In order to meet the processing requirements of advanced alloys and transfer heat more rapidly, the tooling should thus have a higher thermal conductivity than the standard tool steel dies currently in use.

The aim of this work is to optimize die properties to improve heat transfer kinetics during part shaping, thus providing an increase in efficiency and productivity for automotive metal part manufacturing. Hot Isostatic Pressing (HIP) has been used to clad a conformal-cooled copper core with a layer of either a hot-work tool steel or a High-Thermal Conductivity (HTC) composite material designed at NRC. Properties and performance of these systems are compared with those of standard tool materials to demonstrate the practical potential for future development and optimization of advanced tooling.

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Influence of rapid cooling rates for hot isostatic pressing on mechanical and corrosion properties of UNS S32205

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The formation of undesirable intermetallic phases affected by low cooling rates of HIP-manufactured components made of duplex stainless steels requires a conventional heat treatment combined with quenching in a water bath. From a technical point of view, this thermal post-treatment is energy-intensive as well as time-intensive. An approach to avoid these disadvantages is the application of an internal cooling system in the HIP facility to achieve high cooling rates. The influence on the metallurgical structure, the mechanical properties and the corrosion resistance is discussed for a 2205 duplex stainless steel. For this purpose, conventional heat treated components are compared with fast cooled components with the same material.

Metallographic investigations show a clear influence of the cooling rate and wall thickness on grain size, austenite/ferrite ratio as well as the number and the expression of intermetallic phases. The

mechanical properties are determined according to notch impact test ISO 148-1 and tensile test ISO 6892-1. The corrosion resistance was measured according ASTM G150-13. Technical opportunities and economic aspects for the production of thick-walled components are discussed.

Please choose topic:

HIP Process

Materials / 38

Hot Isostatic Pressing of the Water Atomized Steel Powder Prealloyed with Chromium

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Typically gas atomized powder grades are used for hot isostatic pressing. Gas atomization provides spherical powder with the high purity that is required for HIP. Water atomized steel powder is significantly cheaper but has some drawbacks when it comes to the powder purity, irregular powder surface, difficulty to produce high alloyed materials, etc.
Recent advancement in the water atomization allows manufacturing of iron and low-alloyed steel powder with the purity close to gas atomized powder from the surface oxide composition point of view. Hence, HIPing of industrially water atomized steel powder, prealloyed with 3 wt.% Cr and 0.5 wt.% Mo is performed in this study. Graphite powder is admixed to the base powder (0.4 wt.%) in order to achieve required steel composition and further HIPed as well. Oxide transformation in the system is discussed based on the initial powder surface oxide analysis and analysis of the fracture surface of the HIPed components. These are studied by X-ray photoelectron spectroscopy (XPS) and high-resolution scanning electron microscopy (HR SEM) combined with EDX. The mechanical properties of the HIPed material are evaluated and results are discussed with regard to the influence of residual surface oxides and microstructure. Full density components were obtained in case of both, pure powder and powder admixed with graphite. Mechanical properties were on the level expected for the fully dense material, indicating potential of HIPing of water atomized powder. Further efforts to improve powder filling are necessary to get full advantage of the HIPing of water atomized powders.

Please choose topic:

Materials

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Surface Chemistry of Steel Powder and its Changes during HIP Processing

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Metal powders are characterized by the large surface area that results in high surface reactivity of the powder. This is especially important in case of complex alloys containing elements with high sensitivity to oxygen (Cr, Mn, Si, V, Zr, etc.) such as tool steels, Ni-base super-alloys, stainless steels, etc. The residual surface oxides hinder the metallic bonding between the powder particles and remain as crack propagation sites. Therefore, knowledge concerning initial state of the powder before HIP as well as oxide transformation during HIP process is of vital importance to assure defect-free manufacturing of HIP components.
In this study the effect of the surface oxide composition in high alloyed steels such as austenitic steel E316L and two tool steels (X40CrMoV5-1 and HS6-5-3) are being examined. The oxides present on the initial powder surface are examined by means of X-ray photoelectron spectroscopy (XPS) and high-resolution scanning electron microscopy (HRSEM+EDX). Results indicate that the base powder is covered by a heterogeneous surface oxide layer, formed by thin iron oxide layer (<5 nm) with the presence of fine particulates of thermodynamically stable (Cr, Mn, V, Si-rich) oxides, sizing about 30 nm, that also form larger agglomerates in some sites. The mechanical properties of the HIPed material are studied and the results are discussed with regard to the influence of residual surface oxides on the mechanical behavior. Based on the experimental finding and thermodynamic simulation of the oxide stability, a generic model of the oxide distribution and its changes during HIP processing is developed.

Please choose topic:

Materials

Materials / **45**

Precipitation of Y-Ti-O nanoparticles during the HIP consolidation of gas atomised powders

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The increase in the operational temperature range of structural materials plays an important role in most demanding energy generation sources and in certain industrial processes since it enhances the efficiency and promotes a reduction of the environmental pollution. In this sense, oxide dispersion strengthened ferritic stainless steels (ODS FS) are candidate materials for structural components in future fusion and fission reactors, concentrated solar power plants, chemical reactors or advanced coal fired plants. Their high strength and creep resistance at elevated temperatures, and good resistance to neutron radiation damage is obtained through a high density of nanometric complex oxides, generally rich in yttrium and titanium, very stable thermodynamically.
In this work, the powder metallurgy route named STARS (Surface Treatments of gas Atomized powder followed by Reactive Synthesis) is applied to produce ODS FS with composition Fe-14Cr-2W-0.3Ti-0.3Y2O3 (wt.%). The gas atomized powders already contain the oxide-dispersion formers, so mechanical alloying is no necessary to dissolve yttrium in the ferritic matrix. Then, a metastable oxide layer, mainly consisting of Cr2O3 and Fe2O3, develops at the surface of powder particles. Consolidation by HIP at high temperature promotes the dissociation of the metastable oxides, the subsequent oxygen diffusion towards the interior of the particles and the final precipitation of Y-Ti-O nanoparticles. The process finishes with a thermo-mechanical treatment performed to refine and

homogenize the microstructure and improve the mechanical properties
Microstructural characterization of powders and consolidated and thermo-mechanically treated samples performed by XPS, SEM, TEM, and X-ray absorption spectroscopy (XAS) is presented and correlated with manufacturing parameters.

Please choose topic:

Materials

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The effect of element Hafnium on the microstructure and mechanical properties of as-HIPed FGH4097 PM superalloy

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FGH4097 is a new type of powder metallurgy (PM) superalloy developed in China. It is mainly used as the key hot end components for the advanced aero-engines, for instance the turbine disc and compressor disk etc. Powders of FGH4097 alloy were produced by plasma rotating electrode process (PREP) firstly, and then consolidated into billets with a size of Φ80*135mm by hot isostatic pressing (HIP). The size of FGH4097 alloy powder canned is +50 -150μm. The HIPed condition is 1180~1220℃/130MPa/4h. The billet is heat treated by solid solution, and then aged three times. The influence of element Hafnium with different content on the grain size, γ′ phase, MC carbide in as-HIPed FGH4097 alloy was studied by means of metallurgical microscope, scanning electron microscope and physiochemical phase analysis. And the major mechanical properties of each PM superalloy were investigated, such as tensile properties, stress rupture properties, and fatigue crack propagation rate. The results showed that Hf had no effect on the grain size, the size of γ′ phase, and the size and morphology of MC carbide. But Hf promoted the precipitation of γ′ phase and MC carbide, and changed the chemical compositon of γ′ phase and MC carbide, and accelerated the splitting of γ′ phase from one instable cubic γ′ particle to stable octet of cubes. Appropriate Hf content was helpful for improving mechanical properties, such as impact ductility, tensile plasticity, stress rupture life, and fatigue crack propagation resistance. FGH4097 PM superalloy containing 0.30% Hf presented the best comprehensive mechanical properties.

Please choose topic:

Materials

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The effect of HIP treatment on mechanical properties of titanium aluminide additively manufactured by EBM

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Titanium aluminide, one of important next generation high temperature materials, attracts intense R&D interests, and the application for aeronautics and space fields is seriously studied. TiAl components additively manufactured by us possesses more than 99% density and good mechanical properties, however residual voids are problematic in the area where cyclic properties are important, therefore HIP treatment is necessary. In this study, the effect of HIP treatment on the lamellar structure of TiAl alloy which showed excellent tensile ductility is investigated.

Please choose topic:

HIP Process

Oil & Gas / **25**

Exhaust valve spindles for marine diesel engines manufactured by hot isostatic pressing

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The exhaust valve spindle is one of the most challenging components in the marine two-stroke diesel engine. It has to withstand high mechanical loads, thermal cycling, surface temperatures beyond 700 °C, and molten salt induced corrosion.

Powder metallurgy gives the opportunity of improving the component using materials not applicable by welding or forging. Therefore exhaust valve spindles have been produced by Hot Isostatic Pressing (HIP) with a spindle disc coating of a Ni-Cr-Nb alloy that cannot be manufactured by welding or forging.

This paper presents the service experience gathered by MAN Diesel & Turbo in a number of service tests on ships (up to 18000 running hours): corrosion and degradation phenomena in the spindles produce by HIP are presented and compared with the performance of state-of-the-art exhaust valve spindles.

The macroscopic geometrical changes experienced by the spindles are studied by means of Finite Element Method (FEM) calculations and strategies for further development of the component are outlined.

Please choose topic:

Power Generation

Materials / **17**

Production of Intermetallic Alloys by Powder Metallurgy: the Distinguishing Features of the Hot Isostatic Pressing

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We have proposed a following approach to determine the parameters of hot isostatic pressing (HIP) intend for consolidation of the powders from intermetallic alloys with a large prone to embrittlement at ambient temperatures. We analyze a temperature dependence of the mechanical properties (0.02 proof stress, σ0.02) and diffusion characteristics (the diffusion coefficients in the bulk and along interfaces) of the alloy and use the following manner to a choice of the HIP parameters (the temperature THIP and the pressure PHIP). If one needs to conserve a small-grained microstructure in the compacted state after HIP, PHIP pressure at a given temperature has to be smaller than σ0.02 and a condition of the large diffusion path of vacancies in the microstructure has to be fulfiled. When a significant coarsening of the microstructure under HIP is acceptable, PHIP pressure has to be larger than σ0.02 without a control of diffusivity.
An ability of HIP to form differend kinds of microstructures is especially important in a case of treating the materials having a large tendency to embrittlement at ambient temperatures. Here we have used such an approach to consolidation of the powders from intermetallic Ni3Al-base alloy and presented the data deal with microstructure and mechanical properties of this alloy.

Please choose topic:

Materials

HIP Process / 20

The Pros and Cons of HIPping of Ti-based Alloys to Near Net Shape

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It is widely accepted that Near Net Shape HIP (NNSHIP) has many advantages over alternative process-routes for the production of some types of components, but as with all process-routes there are disadvantages. This process-route now has competition from additive manufacturing, which is being used to produce components such as engine casings, but the various technologies of additive manufacturing also have their disadvantages. It is important that the pros and cons of all process-routes, including of course conventional thermo-mechanical processing, are considered so that the optimum process-route is selected for different types of components. In this paper the advantages and the disadvantages of NNSHIP will be discussed together with progress in overcoming them, where that is seen as feasible. The work will be illustrated by work on HIPping of beta Ti alloys, since these are in many ways the most interesting because their microstructures and thus properties are sensitive functions of the thermal history.

Please choose topic:

HIP Process

Materials / 12

Development of constructive and technological solutions for the manufacture of blisks turbine by connecting the disk with shrouded blades under hot isostatic pressing

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In order increasing the gas-dynamic and strength characteristics of the turbine wheel gas turbine engines and reducing their weight the bimetallic turbine blisk with shrouded blades was engineered. To connect the separately cast shrouded blades nickel superalloy with disc of heat-resistant alloy powder is suggested a method of hot isostatic pressing (HIP). The complexity of the problem of connecting is caused by the presence of the shrouds on the periphery of the blades. These should provide a good contact on the working faces of the shrouds into the operation condition. To solve this problem a process flow diagram with the calculation of forming a capsule during hot isostatic pressing and a capsule for manufacturing disk piece were developed.

Please choose topic:

Aerospace

Materials / **46**

Oxygen content in PM HIP 625 and its effect on toughness

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Oxygen control during powder manufacturing and handling is crucial when manufacturing HIPed parts. The influence of elevated oxygen content on mechanical properties is something that has been debated and investigated for many years. The general consensus in the industry is that oxygen has a very detrimental effect on the toughness of the material if present in excessive amounts.

The detrimental effect of oxygen content on the impact toughness of the material has resulted in HIPed specifications, both existing and under development, with limits on the oxygen content in the material. Many specify a relatively low limit on oxygen content at e.g. 120 ppm which can have adverse effects on yield in powder manufacturing which might increase costs without accomplishing the desired effect of ensuring sufficient toughness. As this study show, oxygen content and chemistry alone is not enough to describe the effect of oxygen content on the HIPed material. Setting a limit at e.g. 120 ppm will not guarantee that one gets better properties or even reaches the desired properties of the material. The study show it is important where the oxygen is located in the powder and to separate bulk oxygen content and the surface oxygen content, where the latter has a more pronounced effect on toughness. In the study four batches of alloy 625 have been investigated, all with only relatively small variations in oxygen content but with drastically different toughness and differences in how oxygen is distributed in the material.

Please choose topic:

Materials

Aerospace / **53**

Net Shape HIP Process for the Parts of Rocket Engine Turbopump

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Net Shape HIP (NSHIP) process is a suitable approach for both high performance and cost reduction compared to the castings and the machining of forged materials. We have developed the NSHIP technology in order to utilize for the LE-9 engine turbopump of H3 rocket which is under development by JAXA.
In this paper, we show the verification result of our modified FEM analysis model which predicts a dimensional change under the HIP sintering process. With this FEM analysis tool, we have established the high quality and stable process of manufacturing the LE-9 fuel turbopump turbine nozzle. We also confirmed that the NSHIP turbine nozzle have excellent material properties to meet requirements for the turbopump.
From these results, we determined to proceed to the next phase of the NSHIP part development, the engine testing which is currently performed.

Please choose topic:

Aerospace

Materials / **43**

Post-HIPing of Transparent Polycrystalline Alumina Ceramics Prepared by Pulsed Electric Current Sintering

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Transparent polycrystalline alumina (TPA) ceramics have been used in optical devices such as optical windows and high efficiency lumps. They have been produced with sintering process with advanced fine alumina powder. Pulsed electric current sintering (PECS), which is also so-called spark plasma sintering (SPS), is useful for producing TPA ceramics. However, transparency of TPA ceramics produced by using PECS is still lower than the single crystalline alumina. As well, carbon contamination in TPA ceramics makes darker in color. Heat treatments in air for TPA ceramics decreases their transparency. This phenomenon is explained as formation of microscopic cracks by heat treatments. Because hot isostatic process (HIP) is useful to remove fine closed pores in sintered materials with closed pores, HIP may be effective to increase transparency of TPA produced by PECS. In the present report, post-HIPing process of TPA ceramics produced with PECS was described.

Please choose topic:

Materials

Nuclear / **83**

ANM/SyMo Facility

HIP Process / 61

Controlled uniform load cooling in production scale HIP equipment

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Several aspects of load cooling in a production HIP unit have been widely tackled in the last 40 years.

The aim of this paper is to make an overview of the required cooling types applied to typical metallurgical applications available for industrial HIP users.

Both electronic controls and furnace & heat shield design have progressed in order to fulfill this demand, while considering the economic aspects of the HIP treated products.

Please choose topic:

HIP Process

Aerospace / 49

Hot isostatic Pressing interest for Turbine parts in future Engines

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One of the main challenges for the next generation of aeronautic engines aims at reducing consumptions and environmental impact like emissions and noise, in improving at the same time the performances and efficiency. To reach these objectives, an increase of the engines internal temperature is needed.
In the turbine, increasing temperature is already possible for the discs with the use of cast and wrought superalloys like Waspaloy, U720, AD730, Rene 65 or for hottest or most solicited locations, powder metallurgy (PM) materials. Materials capable to provide highest mechanical characteristics are indeed available on the market, nevertheless their very poor workability (for PM) and the actual very expensive industrial route able to produce them limit drastically their use to simplest shapes and most critical parts.
The use of Hot Isostatic Pressing (HIP) technology to directly produce near net shape (NNS) components using powder materials is an efficient solution to propose parts with complicated shape, impossible to produce today by another way, with very high mechanical properties, and at a competitive price compared to the significant technical gains.
This paper intends to show the interest of the HIP process for parts of engines low pressure turbines,

already produced in Aubert&Duval as demonstrators in PM γ' superalloys: First, a static turbine casing in Astroloy highlighting the possibility to produce a NNS complex shape with higher mechanical properties than actual solution; Second, possibility to produce turbine parts in material N19 (Safran superalloy) allowing reaching an excellent compromise of tensile, creep, fatigue and crack growth properties.

Please choose topic:

Aerospace

Modelling / 75

Efficient modeling of very large NNS parts (up to 3 meter diameter) and key parameters to control dimensional scattering in a +-15 mm range.

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The paper addresses the challenging scientific and technological tasks of achieving limitation of over thickness to 1% of a linear dimension in HIPing Near Net shape PM Components of large size up to 3 meter diameter. To reach this goal it is necessary to increase precision of modeling which has to include thermal conductivity for large (thick) parts, especially influential at the initial stage of densification. This sounds obvious, but our analysis shows that rather than to work on constitutive equations and numerical procedures, it is more efficient to improve the material data base constituency and more particularly for the first step of HIP cycle which controls heat conductivity and the initial deformation pattern. In particular, it is shown that the initial (tap) density of powder in the capsule determines not only the integral shrinkage but also all following deformation pattern. Independently of modeling, it is necessary to control all parameters generating scattering (HIP cycle, temperature homogeneity, filling and handling of capsules…) . The paper enables to define through parametric modeling which material properties, geometrical factors and process parameters are essential for reaching the dimensional precision and what realistic tolerances can be respected.

Please choose topic:

Modellling

Materials / 70

Taylor-Made Net-Shape Composite Components by Combining Additive Manufacturing and Hot Isostatic Pressing

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A promising production route for high quality taylor-made parts can be established by combining Additive Manufacturing (AM) and Hot Isostatic Pressing (HIP): With the help of a numerical simulation routine, the geometry of the parts prior to HIP is calculated. These geometry-optimised parts

are built by Laser Beam Melting (LBM) and consolidated by HIP. After HIP they exhibit a net-shape form that requires only little or even no post-processing at all.

In this study, open thin-walled capsules are manufactured by LBM, filled conventionally with metal powder, evacuated and sealed and hot-isostatically pressed. By this processing route, it is possible to use different materials for the capsule and the powder filling. If capsule and bulk material are identical, the expensive removal of the capsule after HIP can be omitted. By using two different powders, it is possible to produce composite components with a core of high strength and toughness and a wear- or corrosion-resistant surface layer, offering an alternative and competitive production route to conventional HIP cladding.

Here three materials are investigated in different combinations: austenitic stainless steel AISI 316L (X2CrNiMo17¬ 13-3), martensitic tool steel AISI L6 (55NiCrMoV7) and the wear resistant high carbon steel X245VCrMo8-5-1. A number of technical challenges need to be addressed: the production of dense, thin-walled capsules by LBM; LBM of carbide rich steels; diffusion control between corrosion resistant steel and carbon steel; and sealing of capsules made of materials that cannot be welded.

The success of the new process route is demonstrated by metallographic and geometrical investigations.

Please choose topic:

Materials

Materials / **27**

Microstructural design of Ni-base superalloys by hot isostatic pressing

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Single crystal Ni-base Superalloys (SXs), used as blade materials, operate at temperatures close to their melting point and have to withstand mechanical and chemical degradation. Casting and extensive solution heat-treatments of such blades introduce porosity, which can only be reduced by hot isostatic pressing (HIP). Recent developments of a HIP unit with a quenching possibility allow performing heat- treatments and eliminate porosity simultaneously. This work gives an overview about the opportunities that such a unique HIP offers for the solution heat-treatment of conventionally cast SXs or directionally solidified Ni-base superalloys fabricated by selective electron beam melting (SEBM).
The influence of temperature, pressure, and cooling method on the evolution of γ/γ'-morphology and on the pore shrinkage is investigated. The cooling method has a strong impact on the γ'-particle size and shape. Slow or natural cooling lead to coarse γ'-precipitate sizes. Quenching after solutioning at 100 MPa leads to a high number density of small γ'-particles, ideal for the subsequent formation of a fine and uniform γ/γ'-microstructure after ageing. Porosity reduction was most efficient at $T > T_{\gamma'\text{-solvus}}$. Based on these findings, first, an integrated solution and aging heat treatment for an as-cast SXs is implemented into the HIP unit. Second, short HIP treatments are applied on SEBM parts, generating promising and defect free microstructures. Finally, a HIP treatment is satisfactorily used to rejuvenate the γ/γ'-microstructure of SXs after creep degradation, re-establishing the γ/γ'-microstructure without recrystallization and closing all pores and creep cavities.

Please choose topic:

Materials

Nuclear / 18

Synthesis and microstructural characteristics of simulated iodine-bearing waste formed by HIP sintering of the silver impregnated alumina sorbent

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Silver impregnated materials are widely used as an absorbent of radioactive iodine in the nuclear industry. A commercial fuel reprocessing facility of Japan will be working in shortly. The waste management for the spent alumina sorbent (AgA) to be disposed in deep underground is a challenge because iodine-129 has the extreme long-life and a mobile nature in aquifer systems. For the safety disposal, a candidate immobilization technique has been proposed, the first advantage of which is the simple hot isostatic press (HIP) process confining silver iodide (AgI) into the corundum matrix without the separation of iodine from the spent AgA to alleviate the process complications. The previous research has suggested that the densification of the waste form matrix is valid to improve the waste form performance under a repository. Here, we have examined the HIP sintering behavior of alumina matrix by adding several commercially available alumina reagents and virgin AgA in order to optimize the waste composition. After consolidation by HIPing at 175 MPa up to 1325℃ the 3-dimensional microstructure of the simulant waste form has been analyzed using the images processing technique from the data pile of scanning electron microscopy (SEM). The fine particles of AgI are confirmed to be distributed homogeneously and are separated independently by the alumina (corundum) matrix. The matrix porosity and the connected pores are negligible. The tolerance will be assessed using the standard static leaching test under an expected repository condition.

Please choose topic:

Nuclear

HIP Process / 78

60 years after Battelle: why to HIP, what to HIP and how to HIP? (Science and Technology behind the Wall of an Autoclave)

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The paper analyzes 40 years of personal experience in developments of PM HIP processes along with the general tendencies of HIP evolution from a process developed in Battelle in 1956 to solve some specific problems in nuclear technology to a world-wide technology of building new materials and structures for critical applications

Fundamental physical and technological differences of HIP from other consolidation and shaping processes are analyzed and the most important applications- outlined.

The major advances in performance of the PM HIPed parts and in PM HIP technology built on the physical principles of thermo-dynamics and heat and mass transfer, are considered through:

- development of large size complex shape components much beyond the limits of casting and forging processes,
- near-net shaping (NNS) capabilities brought by modeling and HIP tooling design;
- enhancement of the properties and performance of large parts through the use of advanced PM

alloys and powder compositions;
- radical enhancement of non-destructive inspection of HIPed materials and shapes;
- new cost efficient solutions for powders and integrated or reusable HIP tooling in conjunction with evolving Additive Manufacturing technologies;
- modeling of micro-structural evolution and formation of mechanical properties during HIP consolidation;
Technological, engineering and scientific requirements to the newly developed HIP Equipment and HIP cycles brought by the Near Net Shape PM Technology are developed and formulated

Please choose topic:

HIP Process

Oil & Gas / 14

HIP process of a valve body to Near-Net-Shape using Grade 91 powder

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Material used for steam piping of power plants is exposed to high temperatures and high pressures over long periods. As a consequence, forged Grade 91 alloy steel is commonly chosen to meet these demands. However, complicated structures such as a valve body need to be machined from large forged blocks. As a result, the machining time is long and the material weight is heavy. Therefore, by manufacturing a valve body with near net technology, both time and material weight can be reduced.
This paper will present 1) A survey of the dimensions of a near net shape valve body by HIP, 2) An investigation of the mechanical properties of NNS Grade 91, 3) A comparison of the structure of a HIP sintered product and a forged product, 4) The machining time and material weight of a near net molded product by HIP compared to a product forged from blocks. This paper will illustrate that the near net shaped product was able to reduce the machining time by 30% and the material weight by 40% than when machining from a forged product.

Please choose topic:

Power Generation

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Diffusion bonding of Al 6061and Cu by hot isostatic pressing

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In this work, diffusion bonding between Aluminum and Copper were successfully performed by hot isostatic pressing (HIP). In order to improve the strength of diffusion bonding joint, different

thickness of pure Nickel foils was used as an intermediate layer. The microstructure of the interface between Aluminum and Copper was investigated using X-ray diffraction (XRD) technique, secondary electron microscopy (SEM), and the mechanical property evacuated through nanoindentation test.

Please choose topic:

HIP Process

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Mechanical Strength Evaluation of Superconducting Magnet Structure by HIP Bonding Method

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At the previous international conference HIP '14 it was suggested that the HIP method for the fabrication of the radial plate segment, which is the structure for supporting the toroidal magnetic field coil of ITER, be used.
The purpose of this suggestion was to improve the material yield and reduce the time spent on the machining process.
In order to verify that a uniform HIP effect for a large structure, a mock-up was fabricated using diffusion bonding method.
Mechanical strength tests were performed at both room temperature and cryogenic temperature on various locations of the mock-up.
The yield strength of the bonded area was about 920 MPa at 4 K (kelvin), and it was approximately the same yield strength as the base material after HIP treatment.
However, yield strength of the base material was reduced due to heat input, decreasing by 28% at room temperature and by 8% at 4 K, comparing before and after HIP treatment.
In order to apply HIP bonding for fabrication of each part, it is necessary to obtain the optimal parameters, to achieve the best results for the bonded area and the base material.
Focusing on the HIP bonding temperature as a parameter for determining the optimal conditions for diffusion bonding, small test pieces were bonded at various temperatures by HIP treatment.
From the results of the mechanical strength and micro structure analysis of the bonded area, the optimization of the bonding condition can be estimated.

Please choose topic:

Nuclear

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Past and Present Applications of Synroc

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Since the year 2000, Synroc has evolved from the titanate full-ceramics developed in the late 1970s to a technology platform that can be applied to produce glass, glass–ceramic, and ceramic waste forms and where there are distinct advantages in terms of waste loading and suppressing volatile losses. Recent efforts have focused strongly on waste form development for plutonium-bearing wastes in the UK, for different options for the immobilization of Idaho calcines and most recently developing an engineered waste form for the intermediate level wastes arising from 99Mo production, for the Australian Nuclear Science and Technology Organisation (ANSTO). A variety of other studies are currently in progress, including engineered waste forms for spent fuel and investigating the proliferation risks for titanate-based waste forms containing highly enriched uranium or plutonium. This paper also attempts to give some perspective on Synroc waste forms and process technology development in the nuclear waste management industry.

Please choose topic:

Nuclear

Materials / **68**

Novel approaches to densify powder metallurgical materials through hot isostatic pressing

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Powder metallurgical materials usage in high performance applications is limited by the inherent porosity that contributes to the inferior properties as compared to the wrought material. Combination of powder metallurgical routes with HIP as a final processing step allows to reach fully dense material. In addition, recent development in HIP processes with integration of rapid cooling proved to be an effective in diminishing the processing time and cost. The objective of this work is to reach closed porosity through different powder metallurgy routes that can be further HIP: ed without using capsules. Powder metallurgy consolidation methods considered ensure surface densification either through one of the following approaches such as liquid phase sintering, double pressing and double sintering or cold isostatic pressing combined with high temperature sintering. All mentioned above methods bring cost-competitiveness as components can be densified without any capsules that will improve the process timing and cost. All of these methods are based on utilisation of the water atomised powder that also bring additional cost competitiveness.

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Materials

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Capsule-free HIP of Water Atomised Steel Powder through CIP

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Water-atomised powder metallurgical (PM) steels offer cost-effective solutions for structural components and are typically processed through the 'press and sinter' route. Utilizing these steels for high performance applications requires further improvement of their mechanical performance. This requires increased density as compared to that achieved via the conventional uniaxial pressing and sintering route. The present study demonstrates the prospect of employing cold isostatic pressing (CIP) to achieve enhanced densification for iron and Cr-alloyed powder grades without using lubricant. It was shown that higher green densities can be achieved after CIP in comparison with uniaxial pressing for equivalent nominal pressures for both powder grades studied; with a gain of about 0.3 g/cm3 obtained at 600 MPa. In addition, the homogeneous densification eliminates low-density (neutral) zone otherwise obtained in the centre of uniaxial compacted components with large height to diameter ratio. As a consequence, significantly larger components are supposed to be possible than by means of conventional press and sinter. The sintering of CIP compacts at 1250℃ for 1 hour resulted in surface pore closure which enabled subsequent full densification using capsule-free HIP process. The results suggest that using cost-effective water atomised powder grades and eliminating the necessity of capsule for HIP offers the potential of realizing new PM products, in particular with regards to manufacture of medium-sized net-shape PM components.

Keywords: PM Steels, CIP, water atomised powders, capsule free HIP, full density

Please choose topic:

Materials

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RECENT DEVELOPMENTS OF HIP EQUIPMENT IN JAPAN

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The toll services have been increased in the recent Japanese HIP market. This trend leads to larger HIP equipment and shorter cycle times for productivity improvement. In addition, longer life cycle of pressure vessels are demanded to reduce the costs in conformance with the requirements of the relevant laws and regulations of Japan.
To meet such demands, the HIP equipment with a new rapid cooling system has been developed and the first product was delivered. This new cooling system ensures a rapid cooling rate while achieving the design life cycle by low design temperature of the pressure vessel.
At the development stage of the new cooling system, the numerical analysis of the heat flow during rapid cooling was conducted using new techniques including a real gas model and a new model for thermal insulator.
This article will introduce this new rapid cooling system and describe other related topics.

Please choose topic:

HIP Process

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Heat treatment inside the HIP-Unit

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The possibility to combine the densification or compaction of steel parts with a heat treatment has evolved recently by the production of HIP-Units with a rapid quenching device. Since then several studies have been performed to assess the cooling speed and show possibilities to heat treat steels. It was shown before that several alloyed steel grades can be hardened with the method of quenching inside a HIP. This study aims to characterize the impact of high isostatic pressure during austenitization and quenching on the transformation behavior and resulting microstructure of hardenable steels. In order to study the effects of the pressure during quenching two methods have been applied. The first method is to measure the latent heat during isothermal holding inside the transforming steel. The release or uptake of energy reveals information about the succession of the transformation that takes place. Secondly the electrical resistivity of a steel can be used as a sensitive indicator for the existing phases and solution state of steel during continuous cooling after austenitization. The two analytical methods both reveal that isostatic pressure of 170 MPa is sufficient to shift the transformations and hence, increase hardenability of martensitic hardenable steel.

Please choose topic:

Materials

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HIP Activities for Turbopump Components of Korea Space Launch Vehicle

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In Korea, we are developing liquid rockets for commercial launch services, and the government agency, Korea Aerospace Research Institute (KARI), is responsible for main development. Turbopump, which is a key component of liquid rocket engine, is a rotating machine that pressurizes fuel and liquid oxygen in an extreme environment and supplies them to a combustion chamber. Design requirements are very severe because it must maintain lightweight feature while outputting very large power. The HIP (Hot Isostatic Press) method is a Near-Net Shape processing, which makes it easy to mold a material that is difficult to machine, while securing quality comparable to forged products. These advantages are particularly attractive for the aerospace sector. Recently, we tried manufacture of turbopump impellers and turbine discs using HIP technology, and some of the products have been assembled in a turbopump and ground-tested. This will be described in detail in this paper.

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Aerospace

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HIP diffusion bonding of PM superalloy disk and cast superalloy blade rings for dual-alloy turbine wheels

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Dual-alloy turbine wheels produced by HIP diffusion bonding of vacuum investment cast blade rings of the cast superalloy K418B to preconsolidated powder metal hubs of the powder metallurgy(PM) superalloy FGH4091, which have the long cyclic lives characteristic of PM superalloys combined with the high creep strength and net-shape blades characteristic of cast superalloys. After machining, the consolidated hubs and blade rings are cleaned, assembled, hot degassing at about 500℃ and then sealed in vacuum less then 1.0×10-3Pa. Finally, the sealed disk and blade rings are HIPed at 1160~1200℃/130MPa/4h, so as to diffusion bonding with each other completely. The diffusion-welded joint is characterized for microstructural features, diffusion of alloying elements and tensile properties. Microstructure is investigated by scanning electron microscopy(SEM) and electron probe micro-analyzer(EPMA). The results showed that the joint is integral without any defects, such as inclusions and continuous distribution of the second precipitates. EPMA further revealed the width of diffusion zone is about 100 micrometers. The diffusion of elements Co, Ni, Al, Cr, Ti, Nb, Mo is gradually weakened, which is caused by their vary diffusion constants. Specimens showed good weld strength, all the tensile specimens are failured at the cast superalloy.

Please choose topic:

Aerospace

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Overview of properties, features and developments of PM HIP 316L and 316LN

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PM HIP 316L is an alloy that is of increased interest for nuclear applications since it´s recent ASME code case approval. Over the years comprehensive data and understanding of the properties and features have been collected and evaluated which will be summarised in this article. Since the early developments of the PM HIP technology it has been observed that PM HIP alloys generally exhibit higher yield strengths compared to their conventional counterparts, a feature that applies well for 316L. In this article this is demonstrated, both by using the Hall-Petch relationship as well as Pickering´s and Irvine´s empirically derived relationship between composition, grain size and yield strength for austenitic stainless steels. Furthermore, a mechanism generating the increased yield strength in PM HIP 316L vs conventionally manufactured 316L will be proposed. Results also show that low oxygen contents itself is not a guarantee for good or increased performance in form of mechanical properties, but that there are other features that is of similar or perhaps even higher importance in order to achieve good properties. The results of this article includes microstructural properties derived from EBSD measurements as well as tensile and impact properties in a wide range of test temperatures of PM HIP 316L from several powder batches manufactured at different locations and processed with various HIP and heat treatment procedures. Finally, some results regarding creep properties of PM HIP 316L is presented.

Please choose topic:

Materials

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Effect of processing parameters on intermetallic phase content and impact toughness for super duplex alloy PM HIP Sandvik SAF 2507™

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PM HIP is a widely applied manufacturing technology to produce thick walled and complex shaped duplex and super duplex stainless steel (DSS and SDSS) components for the petrochemical as well as the oil and gas industry. The PM HIP process offers the advantage of a fine grained microstructure which generates an increased resistance to HISC (Hydrogen Induced Stress Cracking) as well as higher yield strength. A limiting factor when producing thick walled components of DSS and SDSS alloys is the precipitation of brittle intermetallic phases which results in decreased corrosion resistance and impact toughness if high enough fractions are precipitated. The precipitation of intermetallic phases is a diffusion controlled process that may take place during quenching following solution annealing if the cooling rate is too slow. The thicker wall of the component, the slower is the cooling in the center of the wall which enables increased intermetallic phase precipitation. In this article it is shown that a coarser PM HIP microstructure results in lower contents of intermetallic phases after water quenching. However, despite of the lower intermetallic phase content the impact toughness is not improved and this is explained by the fracture mechanisms as shown by instrumented impact testing and fracture surface analysis.

Please choose topic:

Oil & Gas

Nuclear / **58**

ANSTO's Plutonium Wasteform Research

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Actinide-bearing waste streams which typically include fissile material, for example Pu-239, offer unique immobilization challenges. Key aspects to waste form design include maximizing the waste loading, producing a chemically durable product, maintaining flexibility to accommodate waste variations, a proliferation resistance to prevent theft and diversion, and appropriate process technology to produce waste forms that meet requirements for actinide waste streams.
Synroc waste forms incorporate the actinides within mineral phases, producing products which are much more durable in water than baseline borosilicate glasses. Other advantages are that the mineral phases can incorporate neutron absorbers allowing criticality control both during processing and whilst within the repository as well as high waste loadings and increased proliferation resistance. With a waste loading of 40-50 wt.%, Synroc would also be considered a strong candidate as an engineered waste form for used nuclear fuel and highly enriched uranium-rich wastes. The HIP

technology offers several advantages such as increased density, minimum grain size and removes the need for costly and bulky off-gas systems. This paper will highlight the latest developments of Synroc as an advanced waste form and technology platform for actinide bearing wastes including recent radiation damage results of high zirconolite glass-ceramic wasteforms for plutonium immobilization.

Please choose topic:

Nuclear