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POSTER SESSION

POWER GENERATION APPLICATIONS (1)

SEPTEMBER 12, 2022

PM-HIP Developments for Nuclear Pressure Vessels

John Sulley, Dave Stewart

Rolls-Royce

This presentation presents the work conducted by Rolls-Royce to develop a PM-HIP method of manufacture for nuclear standard Low Alloy Steel (LAS) pressure vessels. It covers material property and geometric assessments. Rolls-Royce has shown it is possible to achieve enhanced tensile properties compared to wrought equivalent material, and to meet the specified Charpy impact toughness requirements. However, under certain conditions, i.e., relatively high oxygen levels in the HIP powder, the Charpy impact toughness was found to be 66% of typical wrought material at room temperature. This presentation covers the material development and latest material property results. It also presents the latest HIP vessel demonstrator work that Rolls-Royce has conducted to assess the viability of the technology to achieve large-scale vessel geometries without the need for excessive machining.

Optimisation of PM-HIP SA508 Grade 3 for Reactor Pressure Vessels

James Connell[1], Will J. Kyffin[1], Thomas Dutilleul[1], David Gandy[2]

[1]Nuclear AMRC, [2]Electric Power Research Institute

Nuclear AMRC and the Electric Power Research Institute are collaborating on a Department of Energy funded project to exploit the near-net shape possibilities afforded by PM-HIP to reduce the cost and lead time for manufacture of complex-geometry nuclear power plant components: specifically, the pressure vessel of a small modular reactor.

The atomisation process can impair the properties of certain materials compared with wrought equivalents. This must be mitigated to realise the benefits of PM-HIP and supplant the conventional forging route - the material and process must be optimised to achieve the necessary service performance.

The toughness of PM-HIP SA508 Grade has been incrementally improved through modification of composition, atomisation, heat treatment and HIP processing, to give the necessary performance demanded of nuclear components. Further, application of electron beam welding for single-pass thick section joining of PM-HIP Grade 3 is described.

Latest Developments in PM HIP for Nuclear Power Generation

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Hot Isostatic Pressing (HIP) has been used in the production of powder metallurgy components (PM HIP) for the last 50 years. Demands for near net shape components have been focused on corrosion resistant environments predominantly in the energy sector, with a heavy focus on the offshore industry and nuclear power generation segment. The development of small modular reactor concepts and advanced modular reactors have identified challenges in the supply chain with respect to flexible production of pressure vessel components, particularly in the limitations of forging processing. The Atlas project in USA, pioneered by EPRI (Electric Power Research Institute), has been investigating the opportunity to develop large scale production of PM HIP components as an alternative to traditional production processes. In this paper, PM HIP production will be presented, along with recent developments in equipment design to product large near net shape components.

Joining Ferritic SA508 Low Alloy Steel to Austenitic 316L Stainless Steel by Powder Metallurgy Hot Isostatic Pressing

Xiaoyuan Lou[1], Josh Le[1], Houshang Yin[1], Victor Samarov[2], David Gandy[3]

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Dissimilar metal joint between ferritic steel and austenitic stainless steel represents one of the most common and complex manufacturing operations to produce large-size pressure retaining components for nuclear reactors. It is conventionally done by arc welding with complex transition structure. This approach often results in the increased cost, reduced inspectability, and unwanted metallurgical features that influence the component’s reliability. In recent years, progress has been made to manufacture large reactor structures by powder metallurgy hot isostatic pressing (PM-HIP). Integrating dissimilar metal joining into PM-HIP process is desired to simplify the overall manufacturing. This study evaluates the feasibility of joining two solid components (SA508 low alloy steel to 316L stainless steel) by PM-HIP a powder-based transition layer in between (either SA508 or 316L). The success of this design highly depends on the mechanical properties of dissimilar metal interfaces, either powder SA508/solid 316L (P508/S316L) or solid SA508/powder 316L (S508/P316L). The material properties at the dissimilar metal interfaces, including microstructure, chemical inhomogeneity, mechanical properties and sensitization, are characterized as the function of the joint design and heat treatment. While all designs presented satisfied tensile responses at the dissimilar metal interfaces, both P508/S316L and S508/P316L designs showed a significant reduction in Charpy impact toughness. The formation of oxides and carbides during PM-HIP and post HIP heat treatment are identified as the key cause to the toughness reduction. The potential remedy to improve the interfacial toughness will be also discussed.

POWER GENERATION APPLICATIONS (2)

SEPTEMBER 12, 2022

Optimized Low Alloy Steel Powders via Vacuum Annealing

David Gandy[1], Victor Samarov[2], Stephen Tate[1], Marc Albert[1]

[1]EPRI, [2]Synertech PM

Under the US DOE program on SMR Pressure Vessel Manufacturing and Fabrication Technology Development (DE-NE0008629), EPRI and Synertech-PM are looking to produce 2/3-scale reactor heads using the powder metallurgy-hot isostatic processing (PM-HIP) method. Considerable laboratory and shop investigation has been performed to scale the technology such that optimized tensile and toughness properties can be produced using A508 low alloy steel powders. This paper focuses on a method to produce pristine powders using vacuum annealing practices. More specifically, vacuum annealing is applied to a large capsule (can) that has already been filled with powder and then is vacuum annealed to remove oxygen and other residual gases from the powder. The paper will discuss vacuum annealing methodologies and mechanical and microstructural properties produced via the HIP and heat treatment processes.

Advanced Plasma Atomization – Mass Production of High-Quality Powder

Frederic Marion

AP&C, a GE Additive company

The advanced plasma atomization process developed by AP&C, a GE Additive company, provides premium quality spherical powders of reactive and high melting point materials. Over the last 15 years, their mass production facilities have demonstrated the ability to provide large quantities of spherical powder with precise control over the powder properties necessary to satisfy the fast-growing demand of additive manufacturing and other powder metallurgy processes. In fact, AP&C's titanium is now the largest titanium powder product used in additive manufacturing and its nickel and aluminum plasma atomized powders are recognized as premium choice for processes requiring stringent powder requirements. But the powder low porosity, high packing density and high purity was also shown to be an ideal fit for PM HIP applications. We will review here the details of this unique atomization process and go over the benefits and drawbacks of this process compared to the more classical powder production methods.

Irradiation Behavior of PM-HIP Nuclear Structural Alloys

Janelle P. Wharry[1], Caleb D. Clement[1], S. Sowmya Panuganti[1], Yangyang Zhao[1], Yu Lu[2], Yaqiao Wu[2], Donna P. Guillen[3], David W. Gandy[4]

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This talk will summarize current understanding of irradiation effects on the microstructure and mechanical properties of nuclear structural alloys fabricated by powder metallurgy with hot isostatic pressing (PM-HIP). The nuclear industry has growing interest in replacing castings and forgings with PM-HIP components due to their near-net shape production, microstructural uniformity, and reduced reliance on machining and welding. Here, we directly compare PM-HIP alloys to their cast/forged counterparts through an Advanced Test Reactor (ATR) neutron irradiation campaign to 1 and 3 displacements per atom (dpa) at 300-400°C. We focus on Ni-base Alloy 625, Grade 91 steel, and SA508 pressure vessel steel. Uniaxial tensile testing reveals consistent irradiation hardening and embrittlement between PM-HIP and cast/forged alloys. Dislocation loop, nanocluster, and void evolution are also relatively consistent between PM-HIP and cast/forged materials but are mainly dependent upon the initial microstructure. Results show promise for code qualification of PM-HIP structural materials.

Considerations for HIP use in Radioactive Environments

Salvatore A. Moricca[1], Martin W.A. Stewart[1], Cliff Orcutt[2], Abhi Basu[3], Reggie Persaud[2]

[1]GeoRoc International Inc, [2]American Isostatic Presses Inc., [3]Gravitas Technologies Pty. Ltd.

The industrial maturation in size, reliability, throughput, performance, and safety of Hot-isostatic Pressing (HIPing) since the early 1950s work at Battelle has led to it becoming a viable alternative for the treatment of legacy and future radioactive wastes. Some misconceptions remain about the safety, throughput and cost of HIPing. Design input to process and safety assessments for the employing HIP in hot-cells and gloveboxes reveal key considerations for HIP systems such as: passive safety, contamination control, waste volume reduction and consistency of product. HIP unit designs have been thermo-mechanically modelled and various safety features incorporated into HIP systems to ensure safe operations that meet and exceed ASME pressure vessel code requirements. The HIP process also includes the front-end operations prior to the HIP unit and these too must also be designed and integrated into the process. This paper will discuss key considerations of HIP use in a radioactive setting.

POWER GENERATION APPLICATIONS (3)

SEPTEMBER 13, 2022

Near-Net-Shape HIP Manufacturing for SCo2 Turbomachinery Cost Reduction

Shenyan Huang[1], Victor Samarov[2], Jason Mortzheim[1], Tim Hanlon[1], Evgeny Khomyakov[2]

[1]GE Research, [2]Synertech PM

sCO2 turbomachinery that operates >650C requires the use of gamma prime strengthened Ni-based superalloys, leading to high cost and barrier of market adoption. Near-net-shape (NNS) HIP manufacturing with HA282 powder is being developed for sCO2 turbine components, with the estimated cost reduction of >50%. Tensile, creep, low-cycle fatigue properties of argon gas atomized and plasma atomized HA282 powder were evaluated and compared to sand cast HA282. While tensile strength and fatigue life outperformed sand cast material, a 10~25% debit in the creep stress capability was observed. Finite element model calibrated by HA282 properties accurately predicted the nonuniform shrinkage during HIP, providing HIP tooling design to achieve the target dimension. A 20 lbs. turbine nozzle ring was successfully demonstrated within 0.01'' dimensional tolerance at the vanes. A 1700lbs turbine casing with complex internal struts was fabricated. Key technical progress together with technoeconomic analysis of NNS HIP manufacturing will be presented.

Manufacturing of Compact Heat Exchangers by HIP

Emmanuel Rigal[1], Isabelle Moro-Le Gall[1], Sebastien Chomette[1], Lionel Cachon[2], Sebastien Vincent[2]

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Compact heat exchangers are made of grooved plates stacked and joined together. Among joining processes, diffusion welding is the only process that allows joining the core of the modules without filler material (e.g., braze). However, several challenges must be met to achieve such components, including management of deformation of channels, soundness of joints, non-destructive controllability and so on. The achievements made in the frame of the development of the sodium-gas heat exchanger modules of the ASTRID prototype of 4th generation nuclear reactors will be reviewed in this presentation, focusing on process modeling and experimental validation with 316L steel.

Hot Isostatic Pressing - An Omnivorous Process for the Treatment of Radioactive Waste

Sebastian M Lawson[1], Martin W. A. Stewart[1,2], Sam Moricca[2]

[1]GeoRoc International (GRI) Ltd., [2]GRI Inc.

Hot-isostatic Pressing (HIPing) has been used within nuclear processes since the treatment of fuel cladding in the 1950s. Further nuclear applications in the treatment of radioactive waste received significant interest into the 2000s, however, the technology readiness level (TRL) of HIP has previously been perceived as too immature. GeoRoc International (GRI) are reviving this technology and rapidly increasing its TRL using matured industrial processing technologies and state-of-the-art innovations to treat a variety of existing and future waste streams. HIP produces nuclear waste forms with extreme durability and < 80% waste volume reduction via an energy efficient and minimum footprint process. GRI's designs allow for the treatment of various waste streams using HIP as an "omnivorous" process. Within this paper recent advances in HIP technology for numerous wastes are discussed, including options for magnesium-rich sludges, surplus plutonium stockpiles and high-level wastes from the reprocessing of nuclear fuels.

Dissolvable HIP Apace-holders Enabling More Cost Effective and Sustainable Manufacture of Hydrogen Electrolysers

Iain Berment-Parr, Charley R Carpenter,

Manufacturing Technology Centre

Polymer Electrolyte Membrane (PEM) electrolysers are key to the future of global hydrogen production. However, these electrolysers rely on rolled titanium sheet to form their core components, which are manufactured through energy and resource intensive processes. The MTC has developed streamlined solid-state manufacturing routes to form these titanium components. MTC's proposed manufacturing routes employ circular economy principles including: (1) use of waste stream materials, titanium sponge fines and subtractive machining products (2) application of material efficient net shape manufacturing (3) streamlining a large number of processing stages within the existing supply chain. The MTC's first application of this concept has been the production of intricate titanium electrolyser plates with integrated porous surfaces. In order to assess the environmental impact of the proposed manufacturing route an embodied carbon analysis was conducted comparing the emissions potentially generated via this powder process versus the traditional cast and wrought titanium manufacturing supply chain.

OIL, GAS AND NAVAL APPLICATIONS

SEPTEMBER 12, 2022

Application Of HIP-NNS To Large Complex Products Using Super Duplex Stainless Steel Powder

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In recent years, the productivity of Off-shore plants has been improved and the field of production from shallow water to deep sea has been expanded. Along with this, it is required that the plant equipment be upsized and maintenance-free. The conventional manufacturing method for duplex stainless steel parts such as valves for plant equipment was mainly hot / cold forging. There is a problem though, that it is difficult to obtain homogeneity with the physical characteristics.
One solution to this problem is powder sintering using HIPed Near Net Shaped (HIP-NNS) products. However, near-net manufacturing requires advanced capsule design and powder filling control. In this paper, we will report the results of the HIP-NNS method when manufacturing a large-sized complex-shaped powder sintered product using the world's largest HIP device.

The Pathology of PM HIP Duplex Stainless Steels

Tomas Berglund, Björn-Olof Bengtsson, Jan-Olof Nilsson

MTC Powder Solutions

Tests were conducted to simulate possible issues in manufacturing of Powder Metallurgical HIPed Duplex Stainless Steels. Root causes, and consequences are analyzed and discussed from a manufacturing, metallurgical and properties point of view. The results highlight the importance of material understanding and good process control when manufacturing these alloys. While some issues are unique to PM HIP material, many of them can also be found in conventional wrought materials e.g., sigma and nitride precipitation.

In addition, the findings in this study puts into question limitations stated in some specifications for this process and alloys. The findings show the importance of staying within these limitations but also show that some aspects are not as critical. The majority of these specifications are based on more well-known forging specifications that might result in unnecessary limitations on the PM HIP process and materials. This while not necessarily ensuring material quality or possibly limiting material use.

Powder Metallurgy HIP for Naval Nuclear Applications - Trends in Process and Property Development

Colin Ridgeway, Terrance Nolan, Paul Pica, Kevin Fisher

Naval Nuclear Laboratory

Powder Metallurgy HIP (PM-HIP) is considered a key technology for component fabrication. By offering near-net shape forming, long lead-time components can be delivered quicker and more efficiently, ultimately supporting on-time construction of nuclear components and structures. To this end, ferrous (A508 Grade 4N) and nickel-base alloys (A600) have been examined in the consolidated PM-HIP condition to assess the mechanical behavior as well as similarity to their wrought/forged counterparts. In this study, various aspects of the PM-HIP process were explored from the powder production to the consolidated material and eventual heat treatment to develop a greater understanding of optimized mechanical properties of PM-HIP material. Trends in processing conditions and various heat treatments were correlated to the performance of each material and related to the wrought counterpart.

MATERIALS AND MATERIALS SCIENCE (1)

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Wear Resistance of PM-HIP Alloys and Metal Matrix Composites

Tomas Berglund

MTC Powder Solutions

The abrasive wear resistance of several Powder Metallurgical wear resistant alloys and Metal Matrix Composites have been investigated. The results show that the wear resistance of most alloys can be increased significantly by adding a hard phase of suitable type, size and amount. However, the addition of a less suitable hard phase like titanium carbide, can drastically lower the wear resistance of an alloy. In general, a hard phase that has a positive effect on wear resistance shows an increased wear resistance with increasing amounts of hard phase. A less suitable hard phase instead drastically lowers the wear resistance of the alloys and higher amounts further reduces the wear resistance. PM HIP offers possibilities to manufacture unique materials that are very difficult or even impossible to manufacture using conventional metallurgy. This study highlights the importance of proper alloy and hard phase selection to achieve a material with excellent wear resistance.

Laminated Structures of Titanium-Based Composites Made Using Hot Isostatic Pressing (HIP) Treatment

Sergey V. Prikhodko[1], Pavlo E. Markovsky[2], Orest M. Ivasishin[2], Dmytro G. Savvakin[2], Oleksandr O. Stasiuk[2], Vianey Ellison[1]

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Three-layer laminated plate structures of Ti-6Al-4V alloy composites reinforced with TiC or TiB particles were diffusion bond using hot isostatic pressing (HIP) at 900 °C, 100 MPa for 3 hours. Starting plates 85x85x12 mm were made using blended elemental powder metallurgy, where the amount of reinforcement varied in order to build layered triplets with TiC or TiB where the particles content gradually changed in the order 10, 20, 40% (wt.%). When the macro-deformation at the interface is absent or very small and the material compositions are similar, the porosity of the bonded materials likely leads to micro-deformations at each point of the interface and can promote diffusion bonding. HIP bonded structures were tested for ballistic response and compared to uniform titanium alloys as well as layered alloy/composite structures made by press and sinter powder metallurgy. Micro-structure and of material properties were analyzed to understand the contribution of HIP processing to the ballistic performance of laminates.

Influence Of Reinforcement Type and Volume Fraction on Mechanical and Tribological Properties of PM HIP Ni-Based MMCs

Raja Khan[1], Alessandri Sergi[1], Martina Meisnar[2], Advenit Makaya[2], Moataz Attallah[3]

[1]TWI Ltd., [2]European Space Agency, [3]University of Birmingham

Materials used in space structures such as satellites, depending on their location within the satellite structure, are subjected to several degradation mechanisms. In recent years, there has been increasing interest in developing powder metallurgy hot isostatic pressing (PM HIP) parts due to ease of manufacturability, reduced buy-to-fly ratio, shorter supply chain length and superior mechanical & tribological properties. Metal Matrix Composites (MMCs) are a class of materials that can potentially have better wear properties compared to the traditional metallic alloys, and therefore, are of particular interest. In this study, we report our findings on the development of Inconel (IN) 625 base MMCs materials using PM HIP technique for the mechanical gas seal component for space application. Fine ceramic powders such as silicon carbide (SiC) and titanium diboride (TiB2) in IN625 matrix powders, were blended and HIP consolidated. In-situ reactions occurred between the metal and ceramic phases in the MMC powders during consolidation, which resulted in the bulk specimens containing complex microstructures. The microhardness test data revealed a strong dependency on the volume fraction of reinforcement particles. It was also found that the use of ceramic reinforcement plays an important role in increasing the tribological properties of the IN625 base material by reducing both abrasive and adhesive wear mechanisms.

PM HIP Of Pure Nb And C-103 Alloy for Space Application: Influence of Powder Characteristics on Mechanical Properties

Alessandro Sergi[1], Raja Khan[1], Martina Meisnar[2], Advenit Makaya[3], Moataz Attallah[4]

[1]TWI Ltd., [2]European Space Agency, [3]European Space Research and Technology Centre, [4]University of Birmingham

This work focuses in finding pure Nb as a possible alternative to C-103 Nb-Hf alloy for the manufacture of thrust combustion chamber. The HIP response of three pure Nb powders (fine, mid-range and coarse) particle sizes were analysed and results compared with as-HIPed C-103. The chemical composition for Nb powders revealed the differences in oxygen levels along with the particle size range. As-HIPed microstructure of pure Nb and C-103 was near to fully dense. EBSD analysis revealed the influence of particle size range on as-HIPed grain size. Microhardness data showed that oxygen content in the powder has a direct impact on the hardness and strength of pure Nb material. Moreover, tensile tests were performed on Nb mid-range and Nb mid-range sieved powders, demonstrating that a simple sieve operation was effective in increasing the oxygen level and consequently improving the tensile strength of the material, while maintaining good levels of elongation.

MATERIALS AND MATERIALS SCIENCE (2)

SEPTEMBER 12, 2022

Maximizing Productivity Of L-PBF Printing in Ti-6Al-4v Using Build Strategies and HIP Consolidation

Kirk A Rogers[1], Anton Du Plessis[2], Christian Fischer[3], James Miller[3], Chad Beamer[4], Eric MacDonald[5], Johan Els[6]

[1]The Barnes Global Advisors, [2]Stellenbosch University, [3]Scientific Forming Technologies, [4]Quintus Technologies, [5]University of Texas at El Paso, [6]Central U. of Tech., Bloemfontei

In laser powder bed fusion (L-PBF), the mechanical performance of fabricated parts is significantly improved by hot isostatic pressing (HIP) as the density increases (pores are closed) and the microstructure improves. By confining the laser melting to only the outer shell (contour) of the structure, L-PBF production times can be dramatically reduced. A subsequent HIP cycle, which may be mandatory for reliability reasons, and therefore does not add additional costs, is then used to densify the entire structure. Production rates and energy efficiencies be improved dramatically. Designs in this new paradigm must include compensation for the unavoidable shrinkage as the interior powder is consolidated. Furthermore, as Argon is also trapped in the intentionally unmelted powder during laser fusion of the shell, additional techniques are explored in which a port is introduced into the structure to evacuate the powder and is later welded closed to improve the quality of the internal structure. Results are included in which the shrinkage can be compensated for during design, by way of a bloated geometry which collapses to a nominal geometry after HIP. The mechanical evaluation of the consolidated shelled parts indicates that their performance is equivalent to those observed on fully dense printed parts. Up to an order of magnitude faster build rates are possible and any resulting shrinkage or distortion can be offset at design.

Development and Manufacture of Innovative Toughened Fine-Grained Recrystallized Tungsten Alloy

Koichi Niikura[1], Masahiro Onoi[1], Hunchea Jung[1], Shunsuke Makimura[2], Hiroaki Kurishita[2], Yasuhiro Matsumoto[3], Masashi Inotsume[3]

[1]Metal Technology Co. Ltd., [2](KEK) University, [3]Sunric Co. Ltd.

Tungsten (W) exhibits excellent thermal properties such as the highest melting point among the metallic elements, however, its engineering usefulness is limited due to the recrystallization embrittlement. Aiming at solving the recrystallization embrittlement, TFGR (Toughened Fine-Grained Recrystallized) W-1.1TiC that exhibits high bending strength of 3.2~4.4 GPa and appreciable bend ductility at room temperature was developed. In collaboration with KEK and Sunric Co. Ltd., MTC is promoting the development of TFGR W-1.1TiC to increase the manufacturable size, to achieve mass-production, and to improve heat resistance and toughness. Decrement of gas-impurity such as oxygen and nitrogen is one of the essential factors in the manufacturing process. In this presentation, the fundamental study to understand outgassing behavior inside the HIP vessel will be introduced.

Comparison Of HIP Composite and Individual Materials with Solid Metallurgy

Alexander Ernst[1], Aaron Schütz1, Adem Altay[1], Dr. Michael Hamentgen[1], Beat Hofer[2]

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The production of composite materials using HIP technology is finding more and more applications. Composite parts for co-rotating twin screw extruders have been introduced in practice for years and are indispensable. Further applications in the roller sector for the processing of high-quality sheet metal and wood pellet production contribute to quality improvement and life extension and can be tailored precisely to the requirements. Composite material is particularly advantageous for large dimensions. Requirements such as high hardness in the edge area and high strength in the load-bearing core can be combined with different materials. In the present work, HIP composite materials and HIP solid materials were compared with melt-metallurgically produced solid materials. The differences in hardness and strengths in the edge area and in the core after heat treatment are presented, showing the advantages and disadvantages of both systems. The choice of composite material depends on the requirements and can cover contrary needs such as corrosion, wear resistance and high strength.

Optimization of HIP Cycle for Co-Cr-W based Alloy 6

Tomas Berglund[1], Ralf Carlström[2], Denis Oshchepkov[2], James Shipley[3], Johannes Gårdstam[3]

[1]MTC Powder Solutions, [2]Höganäs AB, [3]Quintus Technologies AB

Near-net-shape hot isostatic pressing (HIP) is established technology in oil and gas, nuclear, aerospace and other demanding industrial sectors. Co-Cr-W alloy family is widely used in oil and gas industry for the applications requiring combination of high strength, wear and corrosion resistance. The use of Co-Cr-W alloys in powder based HIP technology is however limited for the moment. The purpose of this investigation was to optimize HIP cycle for one of the most popular Co-Cr-W alloys - Alloy 6. Relationships between the microstructure, mechanical properties and HIP temperature was established. HIP cycle, optimized for the highest strength provided Tensile strength of 1400MPa combined with Yield strength 930MPa and Elongation of 3%. It is shown that mechanical properties of HIP powder based Alloy 6 are considerably higher compare with the cast version.

ADDITIVE MANUFACTURING COUPLED WITH HIP (1)

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Rapid LPBF Printing of IN718 Coupled With HIP-Quench: A Faster Approach to Combine Manufacturing and Heat Treatment in A Nickel-Based Alloy

Emilio Bassini, Giulio Marchese, Davide Grattarola, Pietro Antonio Martelli, Sara Biamino, Daniele Ugues

Politecnico di Torino - DISAT

Additive manufacturing has been attracting more and more interest in recent years. Researchers are constantly involved in enhancing component quality by tailoring the printing parameters, increasing the lead time and decreasing overall productivity. Recently, rapid printing is becoming an appealing strategy to decrease the time to complete the components manufacturing. A faster building strategy is likely to cause a higher density of internal flaws that will be healed during the HIP cycle. In this work, Inconel 718 was rapidly printed avoiding the use of any support with different strategies leading to an overall 50% printing time reduction. Using a HIP-quench approach, a further time optimization was achieved combining the HIP cycle with the heat treatment. Two different HIPping temperatures were used, and this work shows the obtained results considering the retained flaw density, final microstructures and deviation from the original 3D cad model. Finally, the microstructural degree of recrystallization was also assessed via EBSD analysis.

Use of High-Pressure Heat Treatment for L-PBF F357

Chad M Beamer[1], Andrew Wessman[2], Donald Godfrey[3]

[1]Quintus, [2]University of Arizona, [3]SLM Solutions Americas

Recent advancements in HIP equipment now offer the ability to integrate HIP and heat treatment in the HIP furnace with the aid of controllable high-speed cooling and in-HIP quenching. This approach has shown to not only offer improvement in productivity but provides a path to prevent anomalies during heat treatment including thermally induced porosity and part quench cracking or distortion. This manuscript will cover the approach of this novel concept, referred to as High Pressure Heat Treatment, applied to SLM Solutions L-PBF printed high strength aluminum alloy F357. Microstructure, tensile properties, and part distortion are evaluated. The results capture a process method making it possible to prevent hydrogen blistering, consolidate defects present in the L-PBF material, offer strength properties exceeding that of MMPDS cast properties, and minimize geometric distortion of complex part geometries.

The Critical Role of HIP in Powder-Based Manufacturing Processes at Boeing

Austin Mann, Ali Yousefiani

Boeing Research & Technology

The current state of the aerospace and defense industry is incredibly demanding of higher performance metallic material systems with improved manufacturing and lifecycle cost benefits. At the Materials & Manufacturing Technology division of Boeing Research & Technology (BR&T), we are actively involved in the maturation of novel alloys for a wide array of components in our commercial and military aircraft, satellites, spacecraft, and launch systems, reducing life cycle impact and improving energy-efficiency of manufacturing and production processes. Specifically, in the past decade we have been focused on the development of a host of advanced metallic alloys and methods of powder-based net and near net shape manufacturing. These include laser powder bed fusion, directed-energy deposition, and of course powder metallurgy methods, providing energy savings, reducing environmental impact, improving durability, while reducing end component costs. An outline of our current efforts towards achieving economic benefits needed to drive implementation of these advanced alloys and their efficient powder-based manufacturing methods will be presented, with emphasis on the critical role of HIP. Additional points of discussion will include execution and transition challenges, opportunities, barriers to entry and potential solutions.

ADDITIVE MANUFACTURING COUPLED WITH HIP (2)

SEPTEMBER 13, 2022

Synergistic Effects on Metal Additive Manufacturing Components Between Hot Isotactic Pressuring and Surface Finishing Through Chemical Polishing and Accelerated Vibratory Finishing

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[1]REM Surface Engineering, [2]Quintus Technologies, LLC

Additive manufacturing and its free-form build have opened the possibility of manufacturing highly complex components with optimized features and part consolidation for different applications. However, the technology also has significant drawbacks, often called surface-related defects (SRD), such as high surface texture, partially melted/sintered powder, deep v-notches, and near-surface porosity. Most of these SRD can be remediated via a surface finishing process; however, this post-processing step will uncover the near-surface porosity producing a heavily pitted surface. All the SRD, including near-surface and internal porosity, must be remediated to improve the mechanical performance and corrosion resistance on metal-AM components. This work will study the synergistic effects of hot isotactic pressing and surface finishing of metal AM components and their implication on mechanical and corrosion resistance performance.

Production Of Complex Near-Net-Shape Components with Wear-Resistant Layers Via The Combination of Additive Manufacturing With Hot Isostatic Pressing

Anke Kaletsch[1], Markus Mirz[1], Marie Franke-Jurisch,[2] Johannes Trapp[2], Alexander Kirchner[2], Simone Herzog[1], Yuanbin Deng[1], Thomas Weissgaerber[2], Christoph Broeckmann[1]

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Additive manufacturing (AM) is a technology with increasing importance since complex components can be manufactured easily. AM is also suitable for producing geometrically complex capsules for hot isostatic pressing (HIP). If the design of the capsules is accompanied by numerical simulations, the production of very complex near-net-shape components is made possible. Since the capsule no longer needs to be removed in case of numerical design optimization, it can remain on the component after the HIP process. There, the capsule can even become a functional layer if it is produced, for example, from wear-resistant material. This study comprises the production of complex HIP capsules made of wear-resistant cold working tool steel (AISI-A11) via electron beam melting (PBF-EB) which are filled with hot working tool steel (AISI-L6) and densified by HIP. The focus is on microstructural analyses of the interface area, hardness measurements as well as the validation of the numerical simulations.

Sintering and Hot Isostatic Pressing of Binder Jetted H13 Tool Steel

Peeyush Nandwana[1], Rangasayee Kannan[1], Kinga Unocic[1], Chad Beamer[2]

[1]*Oak Ridge National Laboratory,* [2]*Quintus Technologies, LLC*

H13 tool steel is an ideal candidate for additive manufacturing (AM) due to its extensive use in cold and hot work tooling since AM can enable the formation of intricate features such as conformal cooling channels. However, H13 has a propensity to crack when deposited via fusion-based AM, something that can be alleviated by the lower thermal gradients during sintering when fabricated using binder jet AM (BJAM). Here, we leverage supersolidus liquid phase sintering (SLPS) to densify H13 deposited via BJAM. Further densification is achieved via hot isostatic pressing. The microstructural evolution and its impact on the properties on H13 during sintering, and HIP and/or heat treatment will be presented.

Study of Hot Isostatic Pressed Ti-Al Mechanically Alloyed Powders

Le Quynh Trang Ngo[1], Dr David Wexler[2], Prof Huijun Li[2], Sam Moricca[3]

[1]*Gravitas Technologies / University of Wollongong,* [2]*University of Wollongong,* [3]*Gravitas Technologies*

Hot Isostatic Pressing (HIPing) is widely utilized for consolidation and defect removal in the production of metal castings and 3D printed components. As the material softens at high temperature, the application of isostatic pressure closes pores, removes cavities, voids, and internal cracks, thus, improving the mechanical properties of the workpieces. Sinter-HIP and HIP allow full density to be achieved at lower temperatures, compared to the traditional sintering processes. HIPing therefore offers a means to better control the microstructure of the materials. In this paper, we compare the effects of HIP, sinter-HIP and sintering of Ti-Al alloys fabricated via a powder metallurgy route. Microstructural changes and physical properties of the alloys produced are investigated and compared. The study aims to understand the fundamental variables for mechanical alloying and densification to allow for the production of high entropy alloys based on the Ti-Al system.

ADVANCES IN HIP EQUIPMENT (1)

SEPTEMBER 11, 2022

Application of Programmatic Asset Management in Hot Isostatic Presses

Daniel Peters

Structural Integrity Associates

High pressure vessels and specifically hot isostatic presses (HIPs) need asset management guidelines, including requalification and fitness for service assessments. Many applications in the HIP industry are not covered by existing standards. The paper will cover various ASME and API documents, providing overall methodology for the effective and logical implementation asset management protocols for reference. ASME discontinued publication of the High-Pressure Systems Standard (HPS-2003) in 2009. This document included vessel requalification methods. This paper will discuss the application of requalification methodology specific to a high-pressure asset management plan. API 510 covers the in-service inspection, repair, alteration, and rerating activities for pressure vessels. That document references most of the technical requirements in the ASME construction codes for design, welding, NDE, and materials as being applicable for in-service pressure vessels. This paper will discuss the use of construction codes for use in the development of comprehensive long term asset management.

Computational Fluid Dynamics (CFD) Analysis of Loss of Cooling Accidents in HIP Systems

Abheek Basu[1], Dasith Liyanage[1], Reggie Persaud[2], Sam Moricca[1]

[1]Gravitas Technology Pty Ltd., [2]American Isostatic Presses Inc.

The working fluid within Hot Isostatic Pressing (HIPing) systems operates at elevated pressures and temperatures whilst contained in a cylindrical shell. Applied external cooling keeps the shell-wall bulk temperature within safe working limits. The inherent safety of HIP systems, however, during loss of cooling accidents is of particular interest to operators in both industrial and nuclear settings. In this study, an axisymmetric computational fluid dynamics (CFD) model of a HIP unit of interest is developed to capture flow and heat transfer mechanisms. The model results agree well with physical test results under both steady state and cooling phases of the HIP cycle. The CFD model is further used to simulate loss of cooling scenarios and estimate the influence of wall thickness on the shell bulk temperature during these hypothetical events. The CFD results clearly distinguish the safety advantage of thick shell configurations in cooling mechanism failure scenarios.

Optimisation of Hot Isostatic Processes by Remote Plasma Optical Emission Spectroscopy

Erik J. Cox

Gencoa

There is an ever-growing range of sensors being applied to industrial techniques to gain greater control over process conditions. Remote plasma optical emission spectroscopy (RPOES) provides vital information on the state or condition of a process via measurement of residual gas partial pressures present in the chamber. RPOES is now a popular method of residual gas analysis as it is industrially robust compared to quadrupole mass spectrometry methods, operates from 0.5 mbar to 10-7 mbar and does not require any additional pumping or sampling equipment. This talk will present the application of RPOES for analysis of the HIPing process. This includes the monitoring and leak checking of canister degassing; sampling of gases during HIPing and delivering traceability of parts as data can be saved during all process stages. Continuous monitoring and analysis allow for the HIPing process to be optimised, leading to significant time savings and data driven quality control.

ADVANCES IN HIP EQUIPMENT (2)

SEPTEMBER 13, 2022

Opportunities Using Steered Cooling in Hot Isostatic Pressing

Anders Magnusson[1], Johannes Gårdstam[1], James Shipley[1], Chad Beamer[2]

[1]Quintus Technologies, [2]Quintus Technologies LLC

A lot of water has past under the bridge during the 70 some years since the first hot isostatic pressing, HIP, equipment was developed and put into operation to be able to manufacture materials that was previously not possible and to densify material and components to theoretical density. During the last 40 years, HIP has gradually evolved in incremental steps and has today become a fully integrated densification and heat treatment system. In the following, we display the steered cooling performance of state-of-the-art HIP equipment and explore the opportunities that this brings. Repeatability, increased HIP productivity, tailoring the microstructure of heat treatable alloys and control of stresses in thermal shock sensitive ceramics and structures are examples of how this technology is now being used in production.

Thinking and Practice of HIP Engineering

Hongxia Chen, Zhoujin Lv, Deming Zhang

CISRI HIPEX Technology Co., Ltd

HIP technology has gone through more than 70 years since its establishment. With the continuous progress of technology, more and more materials are applicable, the application field is expanding, and the requirements for HIP equipment are further improved. HIP equipment has experienced the development process from experimental type, pilot type, large type to extra-large type and specialization. At present, HIP technology has been widely used in various fields. The size, batch and scale of high-performance products produced by large HIP equipment are becoming larger and larger, and its engineering pace is accelerating. From the perspective of HIP technology, application and equipment engineering, this paper analyzes the characteristics of HIP technology, application scope, scale and equipment configuration level. The cost of HIP application and equipment has always been an important factor affecting the development of HIP. This paper also makes a preliminary discussion on the cost advantages brought by HIP engineering. This paper expounds the all-round exploration and practice of HIP technology, application and equipment for many years, and further shows that the era of HIP engineering has come.

HIP with Addition of Reactive Gases

Johannes Gårdstam[1], Hans Magnusson[2], Maheswaran Vattur Sundaram[3], Giulio Maistro[4], Alexander Angré[5]

[1]Quintus Technologies, [2]Swerim, [3]Höganäs, [4]Uddeholm, [5]Linde

The aim with the work was to increase the understanding of the material response when exposed to different atmospheres at high pressure and high temperatures. The influence of reactive gas addition, including carbon, nitrogen and hydrogen, to the argon gas, has been tested for several materials. From nearly pure iron up to high alloyed tool steels have been analyzed. The information can be used to optimize the process itself, or to create new possibilities with capsule free materials, like case hardening or nitriding. Another possibility is to investigate how minor additions of reactive gases can give neutral atmosphere and thereby avoid unwanted oxidation or carbon/nitrogen loss. After HIPing, the samples have been characterized with different techniques, like direct chemical measurements or GDOES, but also indirect measurements like hardness of quenched structures which is strongly related to carbon. By combining many different measurements, i.e., the relation between methane and carbon content (or activity via Thermo-Calc) can be derived and used to predict the response on other kind of materials as well.

Industrial Gas Supply Systems for Hot Isostatic Pressing Applications

Eduardo Cardoso, Matthias Bors, Michael Graf, Patrick Diggins, Karthi Srinivasan

Linde, Inc.

With the Hot Isostatic pressing application, the need for industrial gases is quite common. In this session, we will briefly discuss the different types of industrial gases and supply systems that are commonly used. Within the industry, there is a wide range of industrial gas requirements including storage, pressures and flows. Because of that range, there are many supply systems options currently available to help meet those needs. From small cylinders to merchant high-pressure tank systems, we will review supply system options to meet process requirements. Properly calculating the HIP system requirements and sizing the gas supply system correctly can lead to better performance, enhanced productivity, less capital costs and the system flexibility to meet today's demanding specifications and production demands.

ADVANCES IN HIP EQUIPMENT (3)

SEPTEMBER 13, 2022

Real-time HIP Container Access Technology

Robert M Conaway, Douglas Bardwell

Isostatic Forging International

A container is often used to encapsulate material to be subjected to hot isostatic pressing. The purpose is to prevent the gas to flow into a bed of powder, which otherwise would defeat consolidation. Typically, such capsules are loaded, evacuated and sealed prior to placing into the HIP chamber. IFI has developed a technique using capsules that are provided with a flow path to the exterior of the HIP Press, enabling a real-time communication with the inside of the HIP container. With such plumbing it is possible to do the following: 1) Monitor capsule integrity, 2) Evacuate dynamically during the HIP process, 3) Provide refining gases for the surfaces of components/powder within, 4) Provide reactive gas for reaction HIP consolidation, 5) Provide inert pressure to inhibit consolidation and improve heat transfer during ramp of temperature/pressure, This paper will present our experience and envisioned uses for our Container Access Technology.

Experience, Capabilities and Technical Challenges in Acid leaching of NNS PM HIPed parts

Jim Ringer, Dan Schutzer

Tech Met Inc.

Tech Met has extensive experience removing a variety of tooling alloys (primarily ferrous based) from a variety of substrate alloys. Tech Met performs traditional Tooling material removal through chemical Milling / Acid Leaching but has developed significant expertise in tailoring solutions and processes such that the amount of base alloy removed is negligible while providing the added ability of removing metallic insert. This process typically, is performed in three unique steps. Stage 1: Steel removal; gross material removal, etchant should ideally not impact substrate alloy at all Stage 2: Remnant removal; remnants passive to Stage 1 etchant, more aggressive etchant with minimal attack on substrate alloy Stage 3: Customized solution for controlled conventional chemical milling, capable of maintaining chem mill quality characteristics, typically formulated for the substrate alloy, and typically on boundary layer material. Potential 4th solution cosmetic predominantly a visual impact on substrate, should have no significant dimensional impact.

HIP Processes for Diffusion Bonding and Electrochemical Process for Can Removal

T.D. Hall[1], H. Garich[1], R. Radikrishnan[1], C. Beamer[2]

[1]Faraday Technology, [2]Quintus Technologies

This talk will highlight two activities undertaken by Faraday Technology.

The first will be a brief discussion of an electrochemical approach to selectively remove one metal that has been formed and pressed into another. For instance, during powder metallurgy, hot isostatic pressing (HIP) the HIP “Can” used to hold the powder during operation will become attached to the produced component. Generally, to remove the cast iron “Can” a pickling process is used to dissolve it away and leave the final component. Pickling processes are generally costly to use considering the high concentration of hazardous chemical constituents and the amount of time for material dissolution. Furthermore, pickling process have a propensity to create pits in the final components surface due to attack of the acidic solution and its dissolved constituents. In this case study we demonstrate an electrochemical method that utilizes a salt water-based electrolyte to rapidly (8 times faster) and selectively dissolve the can from the component (U.S. Patent 6,676,825).

The second study will be a discussion on the use of HIP processes to diffusion bond an electrodeposited coating to a surface. Specifically, this study will examine the effect to temperature, time and pressure on the diffusion that occurs between the coating and the substrate. We will also examine the potential corrosion resistance and adhesion enhancements offered by performing a HIP process to bond an electroplated material.

Development of the Active Furnace Isolation Chamber (AFIC) for the HIPing of Radioactive Material

Abheek Basu[1], Reggie Persaud[2], Simon Chung[1], Laura Gardner[3], Claire Corkhill[3], Sam Moricca[1]

[1]Gravitas Technology Pty Ltd, [2]American Isostatic Presses Inc., [3]The University of Sheffield

American Isostatic Presses Inc (AIP) and Gravitas Technologies Pty Ltd (Gravitas) have successfully developed and patented an “Active Furnace Isolation Chamber” (AFIC) that provides significantly increased efficiency and safety during the process of treating radioactive material via Hot Isostatic Pressing (HIPing). This paper explores the design of the AFIC and provides several case studies where the AFIC design has been customized for specific applications. Furthermore, the performance of the AFIC during the mis-operation (MISOP) of a HIP unit is presented. This review establishes the development of the AFIC as a critical stepping-stone towards realizing the full potential of HIPing as a preferred radioactive treatment process.

ADVANCES IN HIP EQUIPMENT (4)

SEPTEMBER 13, 2022

History of Kobelco HIP's Challenges and Future Prospects

Akinori Maegawa, Katsumi Watanabe

Kobe Steel, Ltd.

HIP technology has been applied not only to general applications but also to more-high pressure, temperature and special gas atmospheres for the development of new materials and products. Kobe Steel, Ltd has a history of more than 60 years as a pioneer of HIP technology in Japan. In response to these changes in the market, we have taken on the challenge of expanding the equipment specification width. In particular, regarding pressure and temperature, which are the most important parameters when using HIP technology, we have experience in making equipment with a maximum pressure of 1 GPa and with a maximum temperature of 3000 ° C. These are designed not only for mechanical structure but also for control technology of each parameter. The purpose of this presentation is to introduce the unique equipment and technology that we have been trying in the past, and future possibilities based on our experience.

Development of Tie-Rod Design HIP Presses at IFI Group

Mike Conaway[1], Steven Cotton[2], David Evans[2]

[1]Isostatic Forging International, [2]IFI Europe

The Isostatic Forging International Group (IFI) has over 25 years' experience of designing, manufacturing, installing, as well as owning and operating, HIP units of the Tie-Rod design. The well-established Tie Rod Pressure Containment System (PCS) has proved to be a reliable and cost-effective concept for production HIPs ranging from laboratory to large-scale HIPs with working dimensions of up to 1.6m. IFI has also developed high speed Tie-Rod HIPs with high productivity for automotive applications. Interest in HIP technology continues to grow, in particular for densification of powder metallurgy (PM) components. There is an international drive to design HIPs with significantly more capacity the largest currently available to enable very large PM products to be manufactured. This presentation describes the approach of IFI's HIP designs for Tie-Rod HIPs already in production and the applicability of the Tie Rod PCS concept to future HIPs with working dimensions on the order of 4.0m diameter.

Advanced NDE Techniques and Their Deployment on High Pressure Hot Isostatic Presses

Daniel T. Peters, Jeff Milligan

Structural Integrity Associates

Advances in Non-Destructive Examination (NDE) have occurred in recent years. Some are slowly migrating their way into niche industries, including high-pressure applications such as hot isostatic pressing. This includes Linear Phased Array (LPA) ultrasonic examination for volumetric examination and Eddy Current Array (ECA) technology for surface examination. Advancements in ultrasonic Guided Wave Testing (GWT) also show promise for the examination of long tubes. Effective deployment and delivery of these advanced techniques is critical to the collection and analysis of the inspection data. NDE challenges in high-pressure equipment include access issues like small diameter deep bores, large and thick section components, multiple layers and thick section welds, complex geometries, and small required detectable crack sizes. Applying modern techniques and updating of in-service inspection plans for high-pressure equipment leads more accurate assessment of the equipment's fitness for continued service, reduced maintenance costs, proper asset management of capital equipment, and reduced turn-around time.

Advances In Powder Metal HIP Processing for The Production of Large Components

Joshua Morris, Doug Puerta

Stack Metallurgical

Stack Metallurgical Group is a leading supplier of heat treating, Hot Isostatic Press (HIP), and aluminum chemical processing services. Stack operates four Nadcap-accredited facilities in the western United States and is a key supplier to a range of quality-critical industries including aerospace, medical implant, power generation, and high-end consumer products.

With the launch of Stack HIP in 2019, Stack commissioned the largest high-pressure HIP in North America. Stack has been very active in the development of PM HIP technology, and in the application of this technology to the production of large components. With demand continuing to increase and with the size of the targeted components now exceeding that of existing HIP units, Stack and a consortium of organizations have advanced a robust design for what will be the world's largest HIP unit. With continued industry support, the ATLAS HIP will be operating in North America later this decade.

MODELING FOR HIP APPLICATIONS (1)

SEPTEMBER 14, 2022

Simulation-Based Manufacturing of Near-Net-Shape Components with The Prediction of The Microstructural Evolution During Hot Isostatic Pressing

Yuanbin Deng[1], Berenice Kramer[2], Anke Kaletsch[1], Werner Theisen[2], Sebastian Weber[2], Christoph Broeckmann[1]

[1]IWM, RWTH Aachen University, [2]Ruhr-University Bochum

Following the development of hot isostatic pressing (HIP) with integrated rapid cooling technology, it is now possible to combine consolidation of encapsulated powder and subsequent heat treatment in a pressure vessel in a single step. In this study, the influences of pressure and cooling rate on the microstructural evolution of martensitic steels during the entire HIP with rapid cooling process are first clarified. Besides the standard microscopic investigations of the microstructure, a material model for finite element (FE-) simulations was developed to numerically correlate the understanding based on experiments and to predict the final shape of the HIP component. This FE-simulation was additionally employed in the capsule design to achieve net-shape production of the components with complex geometries. The comparison between experimental and simulated results validated the method to be able to ensure a near-net-shape product with target microstructure as well as to save energy and numerous resources.

Modelling of Powder Filling of HIP Canisters

Simon Chung[1], Abheek Basu[1], Kieren Irvine[1], Peter Wypych[2], David Hastie[2], Andrew Grima[2], Sam Morrica[1]

[1]Gravitas Technologies, [2]University of Wollongong

Filling a Hot-isostatic pressing can with powder is a critical aspect of the HIPing process. Improvements in powder packing will improve process efficiency and will enhance the predictability and consistency of HIP can collapse leading to less wastage. Understanding the effect of powder morphology, its properties and characteristics on the can filling process and subsequent compaction is important to optimising can design and the filling system. Conventionally, this has involved conducting numerous costly and time-consuming trial and error experiments. Computational modelling offers an alternative optimisation path. We review a discrete element method (DEM) simulation of a powder filling process developed by GRI Inc. for handling US Department of Energy radioactive Idaho Calcine powders. A comprehensive analysis of a non-radioactive simulant powder has been conducted and a DEM model developed with validation of the model against experimental data obtained from the filling system development program.

Computational Modeling of PM-HIP Capsule Filling and Consolidation by DEM-FEA Coupling

Samaneh Sobhani[1], David W. Gandy[2], Marc Albert[2], Ali Tabei[3], Zhaoyan Fan[3]

[1]Oregon State University / ATAMI, [2]EPRI, [3]Oregon State University

Power Metallurgy Hot Isostatic Pressing (PM-HIP) is a manufacturing process, capable of producing net shape or near net shape components with complicated geometries from materials that are difficult to deform, machine and weld. However, the acceptance of the final part geometry after HIP consolidation and amount of post HIP processing depends on the design and geometric complexity of the capsule. First-one-of-a--kind geometries often require prototype builds or additional bulk material adding expense and time to the process. Therefore, usage of computer models in order to predict parameters for an optimal capsule design and PM-HIP process the first time is extremely valuable in reducing costs and increasing industry use of PM-HIP. In this study, the pre-consolidation capsule filling process is simulated by Discrete Element Method (DEM) to capture the initial relative density. Finite element analysis (FEA) modeling of the HIP process includes a combined constitutive model based on mechanical behavior of the powder during compaction and consolidation in conjunction with the DEM results as input. Accuracy of the simulation tool created within the project was then confirmed by comparing against a corresponding physical PM capsule fabrication and HIP experiment with pre- and post-HIP 3D scanning. The result shows that consolidation occurs with negligible deviations on sharp edges. Additionally, DEM simulations were conducted to understand powder particle segregation to better in an effort to provide recommendations during capsule filling.

CALHIPSO: A French platform serving HIP and Advanced Materials

Frédéric Bernard[1], Emmanuel Rigal[2], Philippe Emonot[2], Marc Bernacki[3], Thomas Geneves[4], Jean-Philippe Chateau-Cornu[1]

[1]ICB - UMR 6303 CNRS / UBFC, [2]CEA, Liten Grenoble, [3]CEMEF, Mine Paris Tech, [4]Framatome

CALHIPSO is an ambitious research project (n°ANR-21-ESRE-0039) that aims to remove many scientific and technological obstacles in order to promote the use of HIP technology in industry. HIP which consists of compressing materials at high temperature under high pressure of inert gas allows (i) the assembly of even dissimilar materials by diffusion welding and (ii) the fully densification of powders by sintering to produce, in both cases, complex and large parts, thus allowing an increase in their performance through a fine control of their microstructure. CALHIPSO aims to offer a global approach to modeling and simulation that will make it possible to define HIP "tailor-made" solutions to produce advanced components via high-performance models. Our longer-term ambition will be to have complete models of densification and evolution of microstructures. For this, two HIP devices will be installed in France in response of a full scientific program established by the partners whose abilities are complementary.

MODELING FOR HIP APPLICATIONS (2)

SEPTEMBER 14, 2022

Identification Of Porous Materials Rheological Coefficients During HIP Using Experimental Determination of The Radial and Longitudinal Strain Rate Ratio

Gerard Raisson[1], Vassily Goloveshkin[2], Victor Samarov[3]

[1]Consultant, [2]IAM RAS, MIREA, [3]LNT PM Inc.

Traditional approach of identification of the F1 and F2 function of the Green plasticity criterion for porous materials is based on the two experiments: isostatic pressing of samples in the interrupted cycles (determining density as a function of pressure providing the F2 values) and uniaxial upsetting providing an equation for determining the F1 values responsible for the shear deformations. A new approach is suggested allowing to determine these two functions using only the deviations from the isotropic shrinkage obtained in the interrupted cycles. This anisotropy is characterized by the ψ coefficient ratio between the radial and the axial strain rate. Two experimental approaches have been studied.

- HIP dilatometry which allows a continuous determination of ψ coefficient

Close interrupted HIP cycles. If density values are close and the increments of radial and axial deformations are small, then their ratio can be considered close to the strain rate ratio ψ for a rather large density range.

A New Constitutive Modeling for Hot Isostatic Pressing of Powders

Gholamreza Aryanpour

University of Quebec

The fact that a major deformation and thus densification of powder takes place during both ramp and holding stages in the process of hot isostatic pressing, a more precise model must be applied to describe the inelastic behavior of powder. For this aim, a plastic-viscoplastic modeling is developed in this work. This modeling is based on considering two logical phenomena, one is the strain hardening of powder particles during isostatic pressing and the other one is the increase in relative density following the particle deformation. Based on these facts, the plastic-viscoplastic model is formulated for the isostatic pressing. Finally, the numerical and experimental results will be compared and discussed.

HIP Modeling and Design of Large Complex Shape Parts Close to The Size of The HIP Furnace Accounting Capsules Manufacturing Technology and Their Movement Inside It During The Cycle

Dmitry Seliverstov, Evgeny Khomyakov, Alex Bissikalov, Victor Samarov

Synertech PM

The size of the parts needed for critical applications, especially in nuclear, is growing and very often the HIP capsules become so large that they take not only the entire diameter of the HIP furnace, but almost all its entire height. Very often, these parts are heavy, weigh thousands of pounds and do not have an axial symmetry and cannot stand by themselves in the furnace requiring complex shape supporting frames.
In this case additional problems arise and need to be solved in the HIP tooling design and HIP process itself caused by:

- deformations during HIP that become really large, a 100" high non-symmetrical can moves down 12-15", maintaining dimensional accuracy becomes a challenge;
- non-uniform temperature field inside the HIP furnace during heating and ramping the pressure, that starts densifying different areas of the capsule with powder differently;
- different HIP capsule elements for such parts may have different mechanical properties due to the fabrication and deformation processes used and residual stresses remaining in the material, this can alter the deformation patterns during HIP;
- HIP capsules move inside the supporting frames that must be designed not only for filling and transportation, but also to accommodate the HIP capsule deformations during HIP.

HIP modeling allows to approach these problems. The presentation illustrates several examples of the suggested solutions allowing to produce complex shape non-symmetrical parts up to 70" in size.

POSTER SESSION

SEPTEMBER 13, 2022

Phase Field Modeling of Hot Isostatic Pressing for Joining of Dissimilar Metals

Albert C. Lin[1], Yongfeng Zhang[1], Xiaoyuan Luo[2]

[1]University of Wisconsin-Madison, [2]Purdue University

Hot isostatic pressing has been proven to manufacture components with mechanical properties matching or exceeding those created by traditional methods due to the superior microstructure formed at the interface. Here, a phase field model is constructed in the open-source MOOSE framework to simulate the interdiffusion between Fe- and Ni-based alloys. The free energy models for the ferritic and austenitic phases of steel taken from CALPHAD models, in conjunction with mobilities of alloying elements, are used to describe and predict the interdiffusion and phase evolution in the interdiffusion zone. The model is applied to interdiffusion between 316 austenitic/A508 ferritic steels and between 316 steel/Ni-based 600M alloys using a Fe-Cr-Ni ternary system to demonstrate the capabilities for concurrent diffusion and phase transformation. The generality of the MOOSE framework and the thermodynamic basis leave the model open to additional modeling of carbide phases, thermal cycling, and other critical issues of dissimilar metal joining.

Use of HIP Process in Post-Processing of Components Manufactured by SLM Technology from Magnetically Soft $FeSi_{6.5}$ Powder

Joanna Kulasa, Dariusz Kolacz, Adrian Radon, Karol Krukowski, Aleksandra Kolano-Burian

Lukasiewicz Research Network – Institute of Non-Ferrous Metals

This paper presents the influence of the HIP (Hot Isostatic Pressing) process on the structure and properties of the components printed by SLM (Selective Laser Melting) technology. The samples were manufactured by SLM (Selective Laser Melting) technology from magnetically soft FeSi6.5 alloy powder, using different SLM printing parameters. Semi-finished products were densified in Hot Isostatic Pressing process by varying its duration and isostatic pressure (HIP) value. Apparent density, hardness and microstructure were tested on the printed parts both before and after HIP densification. The application of the hot isostatic pressure densification process indicates a change in its final properties with respect to the feedstock components. The effect of varying SLM printing parameters of semi-finished parts on their quality (properties) after the HIP process was also observed.

HIP Process Impact on the Elements Made of the Maraging Steel Using SLM Technology

Joanna Kulasa[1], Aleksander Kowalski[1], Wojciech Burian[1], Dariusz Kołacz[1], Paweł Płatek[2], Janusz Kluczyński[2], Szymon Łukasiewicz[2]

[1]Łukasiewicz-IMN, [2]Military University of Technology

The work presents the results of the research on the Hot Isostatic Pressing (HIP) process effectiveness in 3D printed elements. The HIP process was carried out using Isostatic Hot Press AIP8-30H by American Isostatic Presses, Inc. The process temperature was 1250°C, and three different levels of pressure were used: 100 MPa, 150 MPa, and 200 MPa. The time of the HIP process was 60 mins in the atmosphere of Argon 5.0. The tested objects made of the MS300 maraging steel were printed by means of the Selective Laser Melting (SLM) technology. The printed objects were tested by means of computer tomography (CT), and also the object geometry was analyzed using the multi-sensory measurement machine. The CT and geometry analyses were carried out both before and after the HIP process. It was revealed that the use of the HIP process allows a reduced number of pores in 3D printed elements.

Fabrication of a Three-Dimensional Flow Channel Using Stainless-Steel Flexible Tubing

Ryunosuke Kitamori, Shigeki Tsuruoka, Takuya Nagahama

Metal Technology Co. Ltd.

Aluminum is used in many products that require cooling due to its high thermal conductivity and light weight. However, the low corrosion resistance is a factor to be aware of when using cooling water. MTC manufactures various aluminum products in which stainless-steel pipes are embedded and integrated with HIP to improve corrosion resistance while maintaining a light weight. Although the demand for complex three-dimensional cooling channels is expected to increase, the complexity creates restrictions and limitations on making the cooling channels with the current methods and processes.

A three-dimensional flow path can be manufactured if bent pipes are welded together, but the assembly process for HIP is complex. Despite the current understanding that stainless-steel flexible tubes are not able to withstand the pressures during diffusion bonding, we, here at MTC, have successfully constructed an option for making inner 3D flow channels with stainless-steel flexible tubes.

Effect of Experimental Determination Process on Shear Stress Coefficient of Green Equation Describing HIP

Gerard Raisson[1], Vassily Goloveshkin[2], Evgeny Khomyakov[3], Victor Samarov[4]

[1]Consultant, [2]IAM RAS, MIREA, [3]Synertech PM Inc, [4]LNT PM Inc.

Despite the uniformity of the boundary conditions on the surface of the HIP capsule during the HIP Cycle (Pressure , Temperature) and full uniformity of stresses inside the powder material at the end of the cycle (isotropic tensor), the compressive deformation of the capsules with powder has a substantial shear component that can be described as distortion or non-uniformity. Accounting the values of shear deformation is the subject of HIP modeling and HIP tooling design.

To determine the functions that adequately describe deformation of capsules with the given powder material during HIP, it is important to carry out experiments so that the values of the deformation tensor are close to those in the powder during a real HIP process.

The adequacy of 6 deformation conditions for a combination TA6-4 powder and 304L capsule. was evaluated for the data base generation:

- HIP in capsules with different stiffness (deformation close to flat);
- Uni-directional upsetting of porous samples;
- Upsetting in a rigid die (uni-direction deformation);

After homogenization of full dense material and capsule material, coefficients of Green equation have been calculated for TA6-4 powder in a 304L capsule. Unidirectional densification and HIP dilatometer give similar results when upsetting results are apart. Analysis of results shows that, in actual conditions of HIP cycle, only a small portion of ellipsoidal plasticity surface given by Green equation is used. Unidirectional pressing and HIP dilatometer condition are on the actual portion of ellipse. Upsetting of porous material is out of the useful zone and seems not convenient to determine shear stress coefficients.

Theoretical Evaluation of the Strain Rate Hardening of the Capsule Material on Deformation During HIP

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The paper presents the results of the theoretical study of the effect of strain rate hardening (viscosity) of the capsule material on the process of hot isostatic pressing of a long cylindrical can with powder (so that the influence of lids can be neglected. Relations are obtained that make it possible to evaluate the qualitative estimations of the processes taking place at different stages of the HIP process. Calculations are made for the capsule shrinkage values.

Laminated Structures of Titanium-Based Composites Made Using Hot Isostatic Pressing (HIP) Treatment *Best Part Competition Entry

Sergey Prikhodko[1], Pavlo E. Markovsky[2], Orest M. Ivasishin[2], Dmytro G. Savvakin[2], Oleksandr O. Stasiuk[2], Vianey Ellison[1], Sergey V. Prikhodko[1]

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Three-layer laminated plate structures of Ti-6Al-4V alloy composites reinforced with TiC or TiB particles were diffusion bond using hot isostatic pressing (HIP) at 900 °C, 100 MPa for 3 hours. Starting plates 85x85x12 mm were made using blended elemental powder metallurgy, where the amount of reinforcement varied in order to build layered triplets with TiC or TiB where the particles content gradually changed in the order 10, 20, 40% (wt.%). When the macro-deformation at the interface is absent or very small and the material compositions are similar, the porosity of the bonded materials likely leads to micro-deformations at each point of the interface, and can promote diffusion bonding. HIP bonded structures were tested for ballistic response and compared to uniform titanium alloys as well as layered alloy/composite structures made by press and sinter powder metallurgy. Micro-structure and of material properties were analyzed to understand the contribution of HIP processing to the ballistic performance of laminates.

NNS HIP Demonstration of a sCO2 Turbine Casing in Plasma Atomized 282 Alloy Powder *Best Part Competition Entry

Shenyan Huang[1], Evgeny Khomyakov[2], Alex Bissikalov[2], Jason Mortzheim[1]

[1]GE Research, [2]Synertech PM

A 1700 lbs. sCO2 turbine casing with complex internal struts and manifolds was demonstrated by NNS HIP fabrication using plasma atomized 282 alloy powder. Several technical challenges were conquered in the first iteration, including HIP tooling design and fabrication, powder filling/outgassing, HIP, dimensional control, NDT inspection, de-canning by acid leaching. In addition to reaching the 100% density (confirmed by the TIP tests and microstructure), the turbine casing adequately reproduced the shape from the FEM simulation with small distortions/deviations. The dimensional analysis done after sectioning revealed a good correspondence and the possibility to reach 20~40mil tolerances for the second iteration. A significant LCOE reduction (>70% $/kW reduction) for sCO2 power cycle was estimated over the conventional manufacturing method.

Bi-metallic Shear Rams *Best Part Competition Entry

Tomas Berglund

MTC Powder Solutions

The blind shear rams are one of the most safety critical components in the Subsea Oil & Gas industry. They are the last line of safety, used in the Blow Out Preventer for cutting the pipe going into the oil well and sealing it off in case of an emergency. The newly developed bi-metallic rams are the most capable and robust rams on the market today. A bi-metallic solution means no compromise has been made on material properties in any of the areas of the rams. The cutting edge has very high strength and hardness combined with good ductility to be able to cut even the toughest pipe. The main body of the ram has high strength, high toughness, corrosion resistance and resistance to Sulfide Stress Cracking enabling it to cope with the harsh environment. All aspects of the manufacturing process have been optimized with tailored material compositions, HIP and heat treatment processes. All to meet the extremely tough requirements in all areas of the rams.

PM-HIP of NNS Components for Small Modular Reactor Applications *Best Part Competition Entry

EPRI, Synertech PM. , NAMRC, Stack Metallurgical
DOE funded Project DE-NE 0008629

Near-Net Complex Shape PM HIPed components up to 5,500 lbs., made via PM HIP provide a substantial reduction of machining costs , significantly improved inspection characteristics, homogenous micro-structure all around the part and shorter time to market over forged products. An example of development of ½ A 508 Top Head is presented