SUPERALLOY 718 and Derivatives

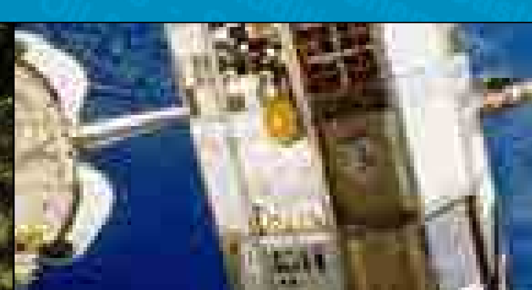
2018 SUPERALLOY 718 & DERIVATIVES: ENERGY, AEROSPACE, AND INDUSTRIAL APPLICATIONS

June 3–6, 2018 | Pittsburgh, Pennsylvania, USA

FINAL PROGRAM

www.tms.org/Superalloy718-2018





TMS

This conference is sponsored by the TMS High Temperature Alloys Committee of the Structural Materials Division (SMD).

SCHEDULE OF EVENTS

Updated May 21, 2018

Sunday, June 3	Time	Location
Registration	4:00 p.m. to 8:00 p.m.	Grand Foyer
Exhibition Set-up	4:00 p.m. to 7:00 p.m.	City Center AB
Keynote Speakers	6:30 p.m. to 7:35 p.m.	Marquis Ballroom
Welcome Reception with Posters and Exhibitors	7:35 p.m. to 8:30 p.m.	City Center AB

Monday, June 4	Time	Location
Registration	7:00 a.m. to 6:00 p.m.	Grand Foyer
Continental Breakfast	7:00 a.m. to 8:00 a.m.	Grand Ballroom
Technical Sessions	8:00 a.m. to 12:00 p.m.	Marquis Ballroom
Refreshment Break & Exhibits Open	10:00 a.m. to 10:30 a.m.	City Center AB
Conference Luncheon	Noon to 1:30 p.m.	Grand Ballroom
Technical Sessions	1:30 p.m. to 5:55 p.m.	Marquis Ballroom
Refreshment Break & Exhibits Open	3:15 p.m. to 3:45 p.m.	City Center AB

Tuesday, June 5	Time	Location
Registration	7:00 a.m. to 6:00 p.m.	Grand Foyer
Continental Breakfast	7:00 a.m. to 8:00 a.m.	Grand Ballroom
Technical Sessions	8:00 a.m. to 12:00 p.m.	Marquis Ballroom
Refreshment Break & Exhibits Open	10:00 a.m. to 10:30 a.m.	City Center AB
Conference Luncheon	Noon to 1:30 p.m.	Grand Ballroom
Technical Sessions	1:30 p.m. to 5:55 p.m.	Marquis Ballroom
Refreshment Break & Exhibits Open	3:15 p.m. to 3:45 p.m.	City Center AB
TMS High Temperature Alloys Committee Meeting	6:00 p.m. to 8:00 p.m.	The Rivers Room

Wednesday, June 6	Time	Location
Registration	7:00 a.m. to 3:30 p.m.	Grand Foyer
Continental Breakfast	7:00 a.m. to 8:00 a.m.	Grand Ballroom
Technical Sessions	8:00 a.m. to 12:00 p.m.	Marquis Ballroom
Refreshment Break & Exhibits Open	10:00 a.m. to 10:30 a.m.	City Center AB
Exhibit Dismantle	10:45 a.m. to 3:00 p.m.	City Center AB
Conference Luncheon	Noon to 1:30 p.m.	Grand Ballroom
Technical Sessions	1:30 p.m. to 3:20 p.m.	Marquis Ballroom

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CONFERENCE ORGANIZERS

CONFERENCE COMMITTEE CHAIR:

Xingbo Liu, West Virginia University, USA

ORGANIZING COMMITTEE:

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REGISTRATION

Your registration badge ensures admission to each of these events:

- Technical and poster sessions
- Sunday evening welcome reception after keynote presentation
- Refreshment breaks during session intermissions
- Daily continental breakfast
- Daily luncheons (tickets provided with badges)
- Electronic access to the conference proceedings
- Access to the conference exhibition

The registration desk will be located in the Grand Foyer on the second level of the Pittsburgh Marriott City Center.

REGISTRATION HOURS

Sunday	4:00 p.m. to 8:00 p.m.
Monday	7:00 a.m. to 6:00 p.m.
Tuesday	7:00 a.m. to 6:00 p.m.
Wednesday	7:00 a.m. to 3:30 p.m.

TECHNICAL SESSIONS

Technical sessions will be held in the Pittsburgh Marriott City Center. All oral presentations will be held in the Marquis Ballroom. All poster presentations will be held in City Center AB and Marquis Foyer. See the Technical Program on pages 12–32 for room locations.

INTERNET ACCESS

Complimentary high-speed internet access is available in all Pittsburgh Marriott City Center guest rooms. Free Wi-Fi is available in the hotel lobby and public areas.

PROCEEDINGS

All conference attendees receive free electronic access to the *Superalloy 718 & Derivatives* proceedings publication. This publication is now available for you to download as an e-book or as individual papers. Follow these easy steps for access:

1. Go to the Superalloy 718 Proceedings log in page at: www.tms.org/Superalloy718proceedings
2. Enter your order number and name. The order number can be found at the top of your registration confirmation. If you have misplaced your number, you can retrieve it through the log in link in step 1 above.
3. After clicking “Access Content” on the next page, you will be passed through to a page with free access to the e-book and individual papers.

Complimentary proceedings content **must be downloaded before June 30, 2018,** at which time standard pricing will take effect. Hard copy books and additional e-books may be purchased at www.springer.com (TMS members receive a 40% discount, plus free shipping).

EXHIBITION HOURS

The exhibition will be located in City Center AB at the Pittsburgh Marriott City Center. Exhibitors will be available at their exhibit tables at the following times:

Sunday	7:35 p.m. to 8:30 p.m.
Monday	10:00 a.m. to 10:30 a.m. and 3:15 p.m. to 3:45 p.m.
Tuesday	10:00 a.m. to 10:30 a.m. and 3:15 p.m. to 3:45 p.m.
Wednesday	10:00 a.m. to 10:30 a.m.

WELCOME RECEPTION

After the keynote session on Sunday, June 3, catch up with colleagues and exhibitors at the welcome reception from 7:35 p.m. to 8:30 p.m. in City Center AB at the Pittsburgh Marriott City Center. Don’t miss this great networking opportunity!

CONFERENCE BREAKFAST & LUNCHEONS

Your conference registration includes daily continental breakfast and luncheons, held Monday, June 4, through Wednesday, June 6, in the Grand Ballroom (Salon 1-4) at the Pittsburgh Marriott City Center. Breakfast is available from 7:00 a.m. to 8:00 a.m. Lunch is available from noon to 1:30 p.m.

PITTSBURGH MARRIOTT CITY CENTER

The Pittsburgh Marriott City Center is boldly positioned in the heart of Pittsburgh, making it simple to experience the city. The Marriott City Center is located within easy walking distance to several city landmarks, including PPG Paints Arena, PNC Park, the Pittsburgh Cultural District, and more. High-speed internet access is available in all guest rooms, and free Wi-Fi is available in the hotel lobby and public areas. Visit the hotel website at www.marriott.com/hotels/travel/pitdt-pittsburgh-marriott-city-center/ for more information on:

- A variety of local attractions and activities
- Dining options, both onsite at the hotel and located nearby
- Business services and additional hotel amenities

LOCAL ATTRACTIONS

Early June is a great time to be in Pittsburgh! From June 1 to 10, the Three Rivers Arts Festival will be held in the downtown Pittsburgh area. The festival is one of the largest and most-celebrated free arts festivals in the world and includes music, theater, dance, public art installations, gallery exhibitions, a visual artist market, creative activities, food, and more.

Consider exploring the Three Rivers Arts Festival in the evenings for dinner and live performances. For a complete schedule of events, visit https://traf.trustarts.org/.

KEYNOTE SPEAKERS

John Shingledecker, Electric Power Research Institute, USA

Presentation Title: "Age Hardenable Nickel-based Alloy Developments and Research for New High Temperature Power Cycles"

Stephen Coryell, Special Metals Corporation, USA

Presentation Title: "Superalloy 718; Evolution of the Alloy from High to Low Temperature Application"

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MONDAY MORNING BREAK SPONSOR

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TABLETOP EXHIBITORS

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Thermo-Calc Software is a leading developer of software and databases for calculations involving computational thermodynamics and diffusion controlled simulations and is widely used by commercial industry, government and academia. Thermo-Calc is a powerful tool for performing thermodynamic calculations for multicomponent systems. Calculations are based on thermodynamic databases produced by the CALPHAD method. Databases are available for steels, Ti-, Al-, Mg-, Cu-, Ni-superalloys, HEAs, refractory oxides, slags and other materials. Software Development Kits are available which enable Thermo-Calc to be called directly from in-house developed software or MatLab. DICTRA is used for accurate simulations of diffusion in multicomponent alloys; applications include: homogenization of alloys; microsegregation during solidification; coarsening of precipitates; and joining. TC-PRISMA: a tool for predictions of concurrent nucleation, growth, dissolution and coarsening of precipitate phases.

EAG Laboratories is a global scientific services company serving clients across a vast array of technology-related industries. We specialize in the determination of material identity, composition, purity, contaminant levels and crystal structure using advanced analytical techniques such as: GDMS, ICPMS, SEM, TEM, XRD, XRF, XPS, SIMS and Auger. EAG provides fast turn-around time, superior data quality and excellent results, with ISO 9001 and 17025 Certification. Our expertise in problem solving and advanced analytical methods can help you meet your goals quickly and cost-effectively. Ask EAG. We Know How.

Dynamic Systems, Inc., (DSI) located in Poestenkill, NY, near Albany, is a high-technology firm dedicated to advancing the state-of-the-art dynamic thermal-mechanical testing of materials and physical simulation of processes. DSI, since 1957 has a long history of pioneering the physical simulation of actual thermal and mechanical processes. DSI's first system christened "GLEEBLE" by one of its creators was developed to simulate the heat-affected zone of arc welding. In the metals industries and materials research DSI systems are used to optimize welding, casting, forging, and rolling processes to improve processes for new or existing materials in the laboratory while keeping production facilities producing with minimum downtime via small samples and invaluable processing maps with a force of up to 20 tons at 10,000C degrees/second. LUMet (Laser Ultrasonic Metallurgy) monitors microstructures live, real-time, in-situ, at high-temperatures on a Gleeble 3500 to study: recrystallization; grain growth; grain size; phase transformations; elastic constants; and texture to solve metallurgical problems, or processes.

MEETING POLICIES

BADGES
All attendees must wear registration badges at all times during the congress to ensure admission to events included in the paid fee, such as technical sessions, exhibition, and receptions.

REFUNDS
The deadline for all refunds was April 30, 2018. No refunds will be issued at the conference. Fees and tickets are nonrefundable.

CELL PHONE USE
In consideration of attendees and presenters, we kindly request that you minimize disturbances by setting all cell phones and other devices on “silent” while in meeting rooms.

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The Minerals, Metals & Materials Society (TMS) is committed to advancing diversity in the minerals, metals, and materials professions, and to promoting an inclusive professional culture that welcomes and engages all who seek to contribute to the field. TMS recognizes that a diverse minerals, metals, and materials workforce is critical to ensuring that all viewpoints, perspectives, and talents are brought to bear in addressing complex science and engineering challenges. To build and nurture this diverse professional community, TMS welcomes and actively engages the participation of underrepresented groups in all of its initiatives and endeavors.

EMERGENCY PROCEDURES

The chances of an emergency situation occurring at the Superalloy 718 & Derivatives conference are quite small. However, being prepared to react effectively in case of an incident is the most critical step in ensuring the health and safety of yourself and those around you. Please take a few moments to review the maps of the Pittsburgh Marriott City Center printed in this program (on the back cover). When you enter the building, familiarize yourself with the exits and the stairs leading to those exits. When you arrive at your session or event location, look for the emergency exits that are in closest proximity to you.

In case of an emergency, a horn with an automated voice system will sound to evacuate the building. The primary assembly point for evacuees is the PPG Arena parking lot on the corner of Washington Place and Centre Avenue. Emergency personnel will instruct evacuees on when it is safe to return to the building. Hotel security officers are first responders trained in first aid, CPR, and use of the AED machine.

WELCOME TO TMS

The Minerals, Metals & Materials Society

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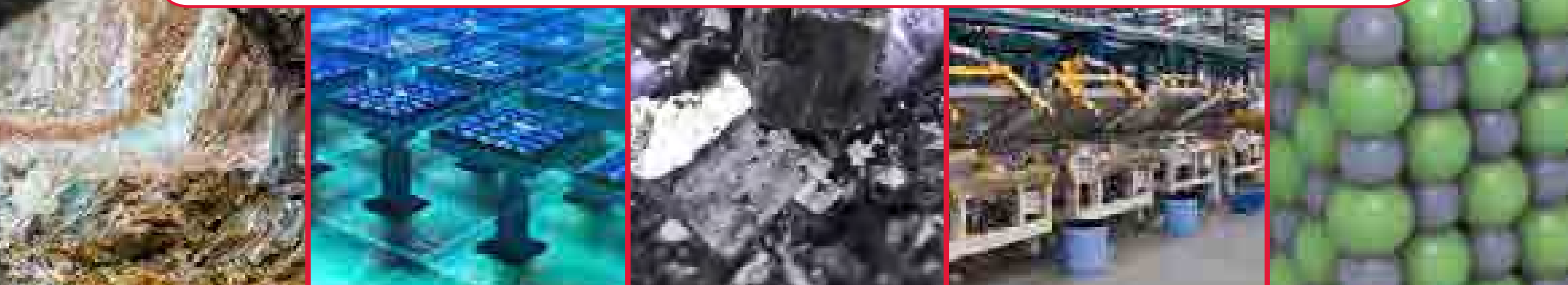

SUPERALLOY 718 and Derivatives

2018 SUPERALLOY 718 & DERIVATIVES: ENERGY, AEROSPACE, AND INDUSTRIAL APPLICATIONS

TECHNICAL PROGRAM



www.tms.org/Superalloy718-2018

Keynote Session

Sunday PM — Room: Marquis Ballroom
June 3, 2018 — Location: Marriott City Center

Session Chair: Xingbo Liu, West Virginia Univ

6:30 PM Introductory Comments

6:35 PM Keynote
Age Hardenable Nickel-based Alloy Developments and Research for New High Temperature Power Cycles: *John Shingledecker*[1]; [1]Electric Power Research Institute

Advanced Ultrasupercritical (A-USC) steam Rankine cycles and Supercritical Carbon Dioxide (sCO2) Brayton cycles are under intensive development to enable low carbon generation of electricity. These high-efficiency power cycles aimed at fossil and in some cases renewable energy require higher temperatures and pressures compared to traditional steam cycles for pressuring retaining components such as tubing, piping, heat exchangers, and turbine casings. Extensive research and development to produce and characterize age-hardenable nickel-based alloys containing Al, Ti, and Nb in judicious amounts have allowed designers to now consider supercritical fluid temperatures up to ~760°C which is much greater than today's supercritical steam technology based on steel metallurgy up to ~620°C. This paper will focus on the alloys developed around the world to enable these advanced power cycles, and a discussion on their key properties: long-term creep strength (100,000 hours+), fabricability, and weldability/weld performance. Most of these alloys contain less than 25% gamma prime, such as alloy 740, 263, and 282, due to the need for heavy section weldability which is unique to these applications. While welding processes have now been developed for many of these alloys using a variety of filler metals and processes, key research questions still remain on the applicability of processes to field power plant erection, the potential for cracking to occur during service, and the long-term weld creep and creep-fatigue performance.

7:05 PM Keynote
Superalloy 718; Evolution of the Alloy from High to Low Temperature Application: Shailesh Patel[1]; John deBarbadillo[1]; *Stephen Coryell*[1]; [1]Special Metals Corporation

Alloy 718 (UNS N07718) was the culmination of a research project started in the mid-1950s to develop a stronger pipe alloy for coal-fired power plants. It was never used for that application, but it was quickly adopted for aircraft turbine engines because of its very high strength, thermal stability, formability and weldability compared to the γ'- strengthened alloys available in the 1960s. Alloy 718 derives its unique combination of strength and fabricability from a coherent ordered tetragonal phase γ" and the slow diffusion rate of its main constituent, niobium. Very early in its commercial life, alloy 718 was recognized as having attributes for both ambient and cryogenic temperature uses as well. Impact toughness, aqueous corrosion resistance, and non-ferromagnetic properties were important attributes. Alloy 718 replaced established age-hardened iron/nickel-base alloys such as A-286, K-500 and X-750 as well as martensitic steels in a wide range of components in the space launch, oil and gas, marine, nuclear and superconducting magnet industries. As the applications became more specialized, so did the heat treatments and microstructures to accentuate specific properties. A common thread through these low temperature applications has been hydrogen embrittlement and a substantial body of literature documents our increasing awareness of its role in service performance. In recent decades, new alloys based on alloy 718 and the γ" strengthening phase have been introduced, especially for oil and gas production equipment. This paper describes the early development of alloy 718 for these important applications, along with alloy, microstructure and heat-treatment evolution and current status.

Poster Session

Sunday PM — Room: City Center AB
June 3, 2018 — Location: Marriott City Center

Microstructural Characterization and Mechanical Properties of Rene 65 Precipitates: *Christina Katsari*[1]; Hanqing Che[1]; Denzel Guye[1]; Andrew Wessman[2]; Stephen Yue[1]; [1]McGill University; [2]GE Additive

Nickel based superalloys are used in the aerospace industry as turbine rotor material due to their high strength and excellent fatigue resistance at high temperature. High strength is required for the high stress and high temperature environments in which these alloys operate. This is achieved by their microstructure of gamma matrix/gamma prime precipitates. The latter can cause thermomechanical processing issues since they can make the material extremely hard. The purpose of this work is to characterize the gamma prime precipitates which are present in Rene 65, a newly developed cast and wrought nickel-based superalloy by General Electric and ATI. The main precipitate that was examined was the gamma prime phase [Ni3 (Al,Ti)], which largely determines the mechanical properties of the alloy. The gamma prime in this particular alloy was found to form in three different sizes; primary, secondary and tertiary. After various heat treatments, the differences in the volume fraction and morphology of each precipitate type is described and the effect of the precipitates on hardness is determined.

Shear Spinning of Nickelbased Superalloy 718: *Fredrik Niklasson*[1]; [1]GKN

Manufacturing of aerospace engine components by very high straining methods require knowledge of the material response to solution heat treatment. This paper presents evaluation of the shear-spinning forming process by experimenting with different heat treatment temperatures and time at temperature to increase knowledge of re-crystallisation of the strained grains. Spinning and shear-spinning has the potential to replace conventional sheet metal forming methods for small to medium volumes by reducing cost, increase flexibility, lower forming forces and reduced development time. The shear spinning performed resulted in an engineering strain of 176% in the axial direction and -55% in the sheet thickness direction. The hardness increased from HV1.0kg 228 to HV1.0kg 446. The heat treatment experiments showed that the lower end solution treatment is sufficient to reach full re-crystallisation in Alloy 718 even at a time as low as 20min. Low to medium temperatures resulted in significant grain size reduction due to re-crystallisation. Using the higher end of the temperature range the original grain size and hardness could be re-established. Low solution temperature resulted in an increase of delta phase in the grain boundaries and inside the grains.

The Abnormal Dynamic Recrystallization Behavior of Alloy 706 for Large Size Disc: *Shuo Huang*[1]; Beijiang Zhang[1]; Wenyun Zhang[1]; Guangpu Zhao[1]; Zhanfu Qi[2]; [1]China Iron & Steel Research Institute; [2]Deyang Wanhang Die Forging Co. Ltd., China National Erzhong Group Co.

The development of equipment and technology makes it possible to manufacture the F2000 mm alloy 706 disc forged by 800MN hydraulic press in China. Generally, high temperature or low strain rate is recommended during forging process to lower the requirement for press capacity, However, it will leave the microstructure with coarse grains which is not beneficial for mechanical properties. In the investigation of hot deformation behavior of alloy 706, it is found that abnormal dynamic recrystallization (DRX) behavior occurs in high temperature and low strain rate condition. The EBSD investigation indicates that the fraction of twin boundaries in the abnormal microstructure is 80% lower than that in the normal microstructure with apparent characteristics of recrystallization texture. Subscale disc forging experiment are carried out to investigate the effects of abnormal microstructure on the mechanical properties of alloy 706. The evolution mechanism of abnormal DRX is validated and the influence on mechanical properties is discussed.

Analysis of Microporosity-dependent Fatigue Crack Behavior in Alloy 718 by using Synchronic Radiation X-ray CT and FEM: Yahui Liu[1]; Maodong Kang[1]; Yun Wu[1]; Mengmeng Wang[1]; Haiyan Gao[1]; *Jun Wang*[1]; [1]Shanghai Jiao Tong University

Influence of microporosity on the mechanical properties of superalloy have been studied by numerical and experimental methods for long time. In this paper, the real morphology of microporosity in polycrystalline Alloy 718 specimens was inspected by synchronization radiation X-ray micron computerized tomography (µCT) and 3D model was reconstructed for the numerical simulation based on finite element method (FEM). Fatigue testing of the heat treated samples and heat isostatic pressured samples were conducted to verify the numerical analysis. Response surface analysis based on FEM was used to establish the linear function relationship between fatigue life and factors including of porosity, pre-deformation and residual stress. The simulation results showed that the interdendritic region on the surface of microporosity was the place of stress concentration in metal and the crack site of fatigue failure. Experimentally, heat treated sample fractured at microporosity, while the HIPed samples disrupted due to the matrix ductile fracture. The good agreement was obtained between the simulation and experimental results.

Constrained Lattice Misfit Measurement in Bulk Inconel 718 Using High Resolution Neutron Diffraction: *Ruiyao Zhang*[1]; Zhongnan Bi[2]; Hailong Qin[2]; Ji Zhang[2]; Hongbiao Dong[1]; [1]University of Leicester; [2]Central Iron and Steel Research Institute

Lattice misfit is important in Inconel 718 (IN718) as coherency strain strengthening from γ” precipitates is the principal source of strengthening in this alloy. The value of lattice misfit is defined by the difference in lattice parameter between each phase. In this study, high resolution time-of-flight (TOF) neutron diffraction has been used to measure the constrained lattice parameters and lattice misfits of a bulk IN718 sample. Thanks to the high resolution of the diffractometer, overlapped diffraction peaks are successfully deconvoluted, and the lattice parameters of different phases and lattice misfits are determined. The measured constrained lattice parameters of γ” phase are much less than the reported unconstrained lattice parameters measured from extracted γ” precipitates. The lattice misfit between γ”/γ phases along c-axis of γ” phase is -0.015% indicating the γ” precipitates are largely constrained and highly coherent with γ matrix in bulk IN718.

Dependence of Creep Strength on Cooling Rate after Subsolvus Solution Treatment in Wrought Alloy 718: *Satoru Kobayashi*[1]; Chuuya Aoki[2]; Tomonori Ueno[2]; Masao Takeyama[1]; [1]Tokyo Institute of Technology; [2]Hitachi Metals, Ltd

It was recently found that the creep strength and creep life of wrought alloy 718 samples showed an interesting dependence on the cooling rate from a standard subsolvus solution temperature: the time to 0.2% creep strain varies from 5 to 400h depending on the cooling rate between 1 and ~200 degree C/min with a maximum value at an intermediate cooling rate of 50 degree C/min under a high stress creep condition. In the present paper, the dependence of the creep strength of wrought alloy 718 samples on the cooling rate has been investigated through microstructural observations for samples after creep deformation to 0.2% creep strain. The microstructural observations using field emission type scanning electron microscope and transmission electron microscope showed that the size of coherent gamma”/gamma’ particles in grains decreased and the number density increased with increasing the cooling rate but they saturated around the cooling rate at which the creep strength was maximized. A careful microstructural observation revealed the precipitation of delta phase platelets along grain boundaries and incoherent twin boundaries but also that of fine gamma” phase particles along grain boundaries and coherent twin boundaries. The precipitation of the phases along grain/twin boundaries was less pronounced as the cooling rate increased. These microstructural features suggest that the maximum creep strength obtained at an intermediate cooling rate is related to a pronounced precipitation of gamma”/gamma’ particles along grain/twin boundaries as well as a high number density (fine size) of fine gamma”/gamma’ particles in grain interiors.

Effect of Homogenization on Creep of Additive Manufactured Inconel 718: Tomoki Otsuka[1]; Hideki Wakabayashi[1]; Daisuke Igarashi[1]; Achmad Ariaseta[1]; Yuting Wang[2]; Shinya Imano[2]; Satoru Kobayashi[1]; *Masao Takeyama*[1]; [1]Tokyo Institute of Technology; [2]MHPS, Ltd.

Creep of additive manufactured (AM) alloy IN718 has been examined in order to understand the difference in nature between the AM and wrought alloy. Three types of homogenizations, 982°C (sub-solvus: SUB), 1060°C (super-solvus: SUP) and 1200°C (ultra super-solvus: USS) for 2 hours, were employed, prior to the standard aging treatment (760°C/10h + 650°C/8h AC) known as super-solves homogenization in the wrought alloy. Note that, unlike the wrought alloy, precipitates still exist even after the USS treatment and all specimens exhibit the same hardness of 500 Hv after the aging. Creep test was conducted at 650°C under constant stress of 630MPa in air, and the creep rate was monitored by extensometer through linear valuable differential transducer (LVDT). The creep rate (e.) in transient stage becomes smaller with increasing the homogenization temperature, and the minimum creep rate ($e._{m}$) of USS at 0.5% creep strain is an order of magnitude smaller than that of SUB at 0.8% strain. However, in accelerating stage, e. at 2.5 % strain becomes same among the three specimens. Eventually the rupture time (t_r) increases with increasing the homogenization temperature, and they are 282h, 822h and 1005h for SUB, SUP and USS specimens respectively. These values are almost comparable to those of the wrought alloy. However, the rupture elongation (e_r) is limited to less than 5 %, which is the highest for USS specimen. The difference in creep among the specimens and also between the AM and wrought specimens will be discussed, in conjunction with nature of the AM microstructures.

Effect of Homogenization Temperature on Microstructures of IN718C Alloy with Different Solidification Cooling Rates: Xiaofei Yuan[1]; Fanguo Meng[1]; *Qiang Zeng*[1]; Wei Li[1]; Shengguo Kong[1]; JIANTAO WU[1]; Ping Yan[1]; Juntao Li[1]; [1]Central Iron and Steel Research Institute

In order to reduce the porosity and improve the performance stability of IN718C alloy castings, hot isostatic pressing (HIP) process are usually conducted. Due to the different solidification conditions, the segregation and microstructure present various features in different positions of castings, especially for castings showing large difference in wall thickness. The above mentioned factors can influence the effect of HIP, cause incipient melting of low melting point phase, such as Laves phase, then induce the scrapping of castings eventually. So it is necessary to conduct homogenization treatment for the castings with large differences in solidification conditions before HIP process. In this article, the as-cast microstructures of IN718C alloy with different solidification cooling rates were studied, including segregation, phase constitution, etc. Then the microstructures of samples after homogenization treatment from 1075 °C to 1125 °C were analyzed. The effect of homogenization temperature on the elimination of segregation and dissolution behaviour of different phases were also investigated. Some relationships about homogenization temperatures, microstructures and solidification cooling rates for IN718C alloy have been determined. They can be used to choose homogenization temperature for IN718C investment castings with complex shapes before HIP process.

Effect of Novel Heat Treatment on Properties of the Highly Alloyed C&W Ni-based Superalloy: *Wenyun Zhang*[1]; Beijiang Zhang[1]; Shuo Huan[1]; Qiang Tian[1]; Guohua Xu[1]; Heyong Qing[1]; Guangpu Zhao[1]; [1]China Iron & Steel Research Institute Group

By special thermomechanical processing, the highly alloyed Ni-based superalloy (the γ' volume fractions >40%, or Tγ' solvus>1100 °C) was successfully converted into billets with the fine γ+γ' duplex structure. Compared with γ' dispersion structure, the fine γ+γ' duplex structure can promote the plasticity, and maintain superplastictiy at industrial strain rate (between 0.01-1 s-1). According to the benefit of the fine γ+γ' duplex, the highly alloyed Ni-based superalloys was possible to deform in industrial scale with acceptable yield ratio, then the supersolvus or subsolvus heat treatment was selected depending on desired microstructure and properties. The specify cooling regime was built to control the morphology and distribution of γ', also the condition of grain boundary during supersolvus or subsolvus heat treatment. During the novel heat treatment, the solution cooling process was divided into three stages by temperature, and controlled with molded thermo couples, cooling curve was also simulated. GH4065(Tγ' solvus =1110 °C) GH4175(Tγ' solvus =1185 °C)and GH4975(Tγ'solvus =1195 °C)disks with average grain size finer than ASTM 10 were heattreated in novel cooling regime, the γ' with desired size and quantity were obtained and mechanical properties were also invested. The results show that the highly alloyed Ni-Based superalloy can obtained balanced mechanical properties through the novel heat treatment.

Effect of Strain Ratio on Low Cycle Fatigue of Superalloy 718 at 650°C: *A Sridhar*[1]; [1]Defence Metallurgical Research Laboratory

Rotating components generally encounter variable amplitude cyclic loading involving varying mean stress (σ_m) and strain ratio, R_ε ($\varepsilon_{min}/\varepsilon_{max}$) during service life. The objective of this study is to investigate the effect of R_ε on the low cycle fatigue (LCF) behavior of a Fe-Ni base superalloy 718 in standard heat treatment condition. Axial LCF tests were conducted under strain control with four R_ε = -1, 0, 0.5 and 0.9 at 650 °C on smooth specimens using a triangular waveform with a frequency of 0.3 Hz. LCF tests were conducted at a maximum strain of 0.9, 1.2, 1.5 and 1.8%. Results revealed that the fatigue lives increased with an increasing R_ε. Lowest fatigue lives were noticed for completely reversed loading and increased with increasing R_ε. Variation of stress range ($\Delta\sigma$) with total strain range ($\Delta\varepsilon_t$) as a function of R_ε illustrated that maximum stress range is achieved for R_ε=-1, and decreased with increasing R_ε. The $\Delta\sigma$ was found to be increasing with increasing $\Delta\varepsilon_t$ for all R_ε. It is noticed that the mean stress (σ_m) is nearly zero for R_ε = -1 and decreased with increasing R_ε and increasing ε_{max}. Plastic strain amplitude ($\Delta\varepsilon_p/2$) increased with increasing $\Delta\varepsilon_t$ for a given Rε. Maximum values of $\Delta\varepsilon_p/2$ were noticed for R_ε = -1 and decreased with increasing R_ε. A combination of increasing stress range, decrease in $\Delta\varepsilon_p/2$ with increasing R_ε and the resulting decrease in σ_m led to an increase in fatigue lives.

Effects of Phosphorus Addition on Creep Properties of Wrought Gamma-Prime Strengthened Ni-based Superalloy: Satoru Ohsaki[1]; *Yusaku Hasebe*[1]; [1]The Japan Steel Works, LTD.

Large and reliable components by wrought gamma-prime strengthened Ni and Ni-Fe based superalloy are strongly demanded for advanced ultra-supercritical (A-USC) power generation, which is one of the efficient technologies with steam temperature of above 700 °C. Although trace elements are usually eliminated as low as possible in the melting process in the large components, some previous studies reported that phosphorus has beneficial effects in improving creep properties of Ni-Fe based superalloys. The purpose of this work is to investigate the effect of phosphorus on the creep properties and microstructure of wrought gamma-prime strengthened Ni-based superalloy (Haynes282), one potential candidate for components of 750 °C class A-USC power plants, focus on effects of carbides. In an alloy with phosphorus content of 8ppm, precipitation of M23C6 carbides was observed both in grain boundaries (GB) and grain interior prior to the creep tests. GB coverage by carbide increased until the phosphorus content up to about 30ppm. On the other hand, the amount of M23C6 in grain interior decreased with increasing phosphorus content. Results of the creep tests revealed that relationship between the time to rupture and the GB coverage by carbide. Microstructure of the crept specimen showed existence of misorientation at the vicinity of GB without carbides by means of an electron backscattered diffraction analysis. These results suggest that the improvement of the time to rupture is due to the GB precipitation strengthening mechanism by GB carbides and phosphorus content would affect precipitation behavior of M23C6 carbides in grain interior and GBs.

Evaluation of Mechanical Properties and Fretting Wear Resistance of Inconel 690 Alloy with Stable Gradient Nanostructures: *Auezhan Amanov*[1]; Rakhmatjon Umarov[1]; Young-Sik Pyun[1]; [1]Sun Moon University

In this study, an ultrasonic nanocrystal surface modification (UNSM) method was used to generate a stable gradient nanostructure in Inconel 690 alloy. The surface hardness of the as-received, UNSM-treated at room temperature and UNSM-treated at high temperatures of 100 and 700 0C was found to be 21, 39, 46 and 49 HRC, respectively. The mechanical properties of as-received, UNSM-treated at a temperature of 25 0C, and at temperatures of 100 and 700 0C Inconel 690 alloy samples were investigated using a tensile stress test. It was found that the stress-strain curve of the UNSM-treated at a temperature of 25 0C exhibited better mechanical characteristics in comparison with the as-received one. Moreover, the samples treated at high temperatures of 100 and 700 0C exhibited better results in terms of strain, but there was no significant difference in stress. The UNSM treated sample at a temperature of 100 0C had better results in comparison with other samples. In addition, the fretting wear resistance of those samples was assessed using a ball-on-disk fretting wear tester at temperatures of 25, 100 and 200 0C. The fretting wear resistance of Inconel 690 alloy was also increased by thermal-mechanical surface modification treatment, which may be attributed to the increase in mechanical properties and presence of stable gradient nanostructure. Hence, Inconel 690 alloy with the increased hardness and fretting wear resistance by thermal-mechanical surface modification could be beneficial for energy and aerospace applications.

Kinetics Study of Denitrogenation from Liquid Inconel 718 during Vacuum Induction Melting: *Bo Chen*[1]; Long Zhang[1]; Zhanhui Du[1]; Kui Liu[1]; [1]Institute of metal research, CAS

The kinetic studies of the nitrogen desorption from the molten Inconel 718 were investigated. The effects of initial nitrogen concentration, [C]+[O]=CO(g) reaction, intensity of induction stirring and Al, Ti addition have been considered at 1500\176C -1650\176C temperature range. At different melting conditions, the mass transfer coefficients have been measured and ultimate nitrogen contents were compared with the solubilities of nitrogen calculated theoretically. Experimental results indicated the release rates were first order with respect to nitrogen content in the melt, and the rate determining step of nitrogen was controlled by nitrogen transfer in liquid diffusion layer. Moreover, the denitrogenation reaction could be accelerated when the [C]+[O]=CO(g) reaction exist in melt, and denitrogenation rates were decreased with the reduced melt internal stirring. It was also founded that Al, Ti contents in melt impacted on denotrogenation rate.

Novel Fractgraphy of Ni-based Alloy by SEM/EBSD Method: *Keiji Kubushiro*[1]; Yutaro Ota[1]; Yohei Sakakibara[1]; Hitoshi Okada[1]; [1]IHI Corporation

Ni-based alloys have been used for blade of air craft jet engine and gas turbine. The failures of these parts derive from fatigue and creep, but it is difficult to estimate applied stress from observation of damaged samples. Oxidation and crush on fracture surfaces prevent from the estimation by fractgraphy especially. Therefore, we developed the novel observation of the microstructure on the cross section beneath cracks by using EBSD and ECCI. Tensile test, fatigue test and creep test were performed, and the change in dislocation density and the difference of strain contour of these specimens were specified by the new method. Finally the applied stress could be estimated and the test temperature could be also estimated.

Pitting Behavior of Thermally Aged Inconel 625 Weld Claddings Made Using SMAW and GMAW Process: *Amandeep Shahi*[1]; Sandeep Sandhu[2]; [1]SLIET University (Sant Longowal Institute of Engineering and Technology); [2]Quest Group of Institutions

Comparative investigations were carried out where multipass multilayers of Inconel 625 (UNS N06625) weld claddings were overlaid on 12 mm thick austenitic stainless steel plates (AISI 304L) using SMAW (shielded metal arc welding process) and GMAW (gas metal arc welding) process. The specimens extracted from the cladded plates were subjected to four different post weld thermal aging treatments (650°C/10 hours, 650°C/100 hours, 850°C/10 hours and 850°C/100 hours).The pitting corrosion of Inconel 625 clads was evaluated using PAP (Potentiodynamic anodic polarization) technique and the results were generated in the form of pitting curves. Pitting potential (Epitt) for these welds varied from 31.77 to 922.7 mV. Under all conditions, the GMA welds showed better pitting performance than the SMA welds. Aging treatment of 650°C/10hrs improved the pitting resistance of both the welds, as pitting potential of 922.7 mV (which was recorded as the highest value of Epitt among all the welds) was observed in case of GMA weld and 384 mV for the SMA weld. Precipitation strengthening occurred under this aging condition which was attributable to the presence of Laves phase, ’ and ”-phase, besides carbides in Inconel 625 weld/clad metal. However, a loss of pitting resistance was observed under aging conditions 850°C /10 hrs and 100 hrs, which could be attributed to the segregation behavior of alloying elements as well as the formation of delta phase which promoted the tendencies for pit nucleation and their subsequent growth in the matrix of the weld metal.

Research of Twin Induced LCF Cracking for 718 Alloy Using In-Situ Observation: *Xudong Lu*[1]; Du Jinhui[1]; Deng Qun[1]; Wang Minqing[1]; Bi Zhongnan[1]; [1]China Iron & Steel Research Institute Group

The 718 alloy possesses excellent mechanical properties at high temperatures, good process ability, therefore, it has been widely used in aero engine turbine disks, compressor disks, and power turbine shafts (i.e., rotating components). The fatigue properties of the 718 alloy are a key factor that determines the safety and reliability of the engine. In this paper, the fatigue properties of the 718 alloy are investigated under high temperature conditions at 455 oC and 600 oC. The initiation of fatigue cracks, and the relationship between fatigue life and grain size are discussed. The results show that the twin boundaries in large grains and carbides are acting as a crack initiation site for plate specimens, and string-type or heap-type carbides distribution promotes crack propagation and shortens fatigue life. Carbides respond as a crack initiation site for cylindrical specimens. The grain size is smaller, and the low cycle fatigue properties of the alloy are improved.

The Effect of Grain Size on the Dwell Fatigue Crack Growth Rate of Alloy 718Plus: *Minqing Wang*[1]; Jinhui Du[1]; Qun Deng[1]; Xudong Lv[1]; Chengbin Yang[1]; Jianxin Dong[1]; [1]Central Iron and Steel Research Institute

Grain size optimization is an important method to improve the fatigue crack growth resistance of superalloys. For ATI 718Plus® alloy, the effect of grain size on the fatigue crack growth rate (FCGR) is more complex, because of the complex effects of ç-Ni3Al0.5Nb0.5 precipitated at the grain boundaries. In the past, the fine-grain ATI 718Plus® alloy was found to exhibit better dwell fatigue crack growth rate (DFCGR) resistance than that of the coarse-grain alloy at high temperature. An attempt to explain this phenomenon was based on the grain boundary oxygen diffusion/oxidation viewpoint; however, the mechanism remained unclear until now. Based on this, we investigated the relationship between the grain size and the DFCGR of ATI 718Plus® alloy. The DFCGR of ATI 718Plus® alloys with different grain sizes were tested in air at 704 °C. Furthermore, the microstructures and crack growth paths were analyzed, and the plastic zone near the crack tip was calculated for specimens with different grain sizes. The better effect fine grain ATI 718Plus® has on DFCGR is related to more ç-Ni3Al0.5Nb0.5 phase precipitation and reduced oxygen diffusion along grain boundaries, as well as the reduction of the plastic zone near the crack tip and the increase in secondary cracking with decreasing grain size.

Thermal Processing Design of Cast INCONEL® Alloy 740H for Improved Mechanical Performance: *Martin Detrois*[1]; Kyle Rozman[1]; Paul Jablonski[1]; Jeffrey Hawk[1]; [1]National Energy Technology Laboratory

The increasing operating temperatures of turbine designs for power generation applications present challenges in selecting materials. With steam temperatures above 750°C, ferritic or martensitic steels are inadequate. Ni-based superalloys perform much better under these conditions and possess mechanical properties suitable for turbine and boiler applications. However, only limited Ni-based superalloys are available for large turbine castings where a combination of high-temperature strength (in particular yield stress), long-term creep resistance, ductility and weldability are essential properties. Research was undertaken at the National Energy Technology Laboratory to produce a cast INCONEL® 740H alloy with mechanical properties comparable to those of the wrought product. Since thermo-mechanical processing is not an option in castings, aging trials were performed to alter the grain boundary morphology following a computationally designed homogenization heat treatment. Thermodynamic simulations were used throughout to produce various grain boundary microstructures. Early investigations on cast INCONEL® 740/740H revealed poor ductility. The modified microstructures altered the tensile and creep properties and reinforced the possible use of cast INCONEL® 740H in power plants. The benefits associated with the alternate heat treatments were found to originate from the grain boundary phases present in the alloy controlled through the targeted aging treatments. Those results and the relations between thermal processing, microstructure, mechanical properties and failure mechanisms of cast INCONEL® 740H will be discussed.

Isothermal Oxidation Behavior of EBM-additive Manufactured Alloy 718: Esmaeil Sadeghimeresht[1]; Paria Karimi[1]; Pimin Zhang[2]; Ru Peng[2]; *Joel Andersson*[1]; Lars Pejryd[3]; Shrikant Joshi[1]; [1]University West; [2]Linkoping University; [3]Orebro University

Oxidation of Alloy 718 manufactured by electron beam melting (EBM) process has been undertaken in ambient air at 650, 700, and 800 °C up to 168 h. At 800 °C, a continuous external chromia oxide enriched in (Cr, Ti, Mn, Ni) and an internal oxide that was branched structure of alumina formed, whereas at 650 and 700 °C, a continuous, thin and protective chromia layer was detected. The oxidation kinetics of the exposed EBM Alloy 718 followed the parabolic rate law with an effective activation energy of ~248 ± 22 kJ/mol in good agreement with values in the literature for conventionally processed, chromia-forming Ni-based superalloys. The oxide scale formed on the surface perpendicular to the build direction was slightly thicker, and more adherent compared to the scale formed on the surface along the build direction, attributed to the varied grain texture in the two directions of the EBM-manufactured specimens. The increased oxygen diffusion and high Cr depletion found on the surface along the build direction were attributed to the fine grains and formation of vacancies/voids along this grain orientation.

Effect of Grain-Boundary Fe2Nb Phase on Stress-assisted Grain-Boundary Oxidation Behavior in Novel Austenitic Heat-resistant Steel of Fe-20Cr-35Ni-2.5Nb: *Yuichiro Sueishi*[1]; Masao Takeyama[2]; Hideshi Tezuka[1]; [1]Tokyo Electric Power Company Holdings, Inc.; [2]Tokyo Institute of Technology

Many Ni-base superalloys are susceptible to intergranular brittle fracture during holding under high stresses at relatively low temperatures, known as stress-assisted grain boundary oxidation (SAGBO). These superalloys are strengthened by geometrically close-packed precipitates such as Ni3Al (L12) and Ni3Nb (D022) within grain interiors, whereas role of grain-boundary precipitates in strengthening of the alloys is limited. It is thus interesting to know how the presence of grain-boundary precipitates affects the SAGBO behavior. Recently Takeyama et al. has developed a novel austenitic heat-resistant steel Fe-20Cr-35Ni-2.5Nb(at.%) strengthened by intermetallic phases of topologically close-packed Fe2Nb Laves precipitated at grain boundaries, together with Ni3Nb within grain interiors. The creep rupture strength of the steel at 800°C is comparable to Ni-base alloys, and the higher the area fraction of the grain boundaries covered by the Laves phase, the lower the creep rate, thereby leading to the superior strength. This strengthening mechanism is called *"Grain-boundary Precipitation Strengthening (GBPS)"*. In this study, the relationship between the GBPS and SAGBO behavior has been investigated using the novel steels based on Fe-20Cr-35Ni-2.5Nb. Two specimens with similar strength but different values were prepared. Constant-load tests were conducted at 90% of the yield stress and 600°C in air. Rupture time and rupture elongation become larger in high specimen. Ductile morphologies were observed on the fracture surfaces in the high specimen, whereas intergranular surfaces were more obvious in the low specimen. The results clearly demonstrate that GBPS is effective in suppressing susceptibility to SAGBO under high load condition.

Development of New Alloy 718 with Super Machinability: *Chihiro Furusho*[1]; Yuya Kousai[1]; Mototsugu Osaki[1]; Koichi Uno[1]; [1]Daido Steel

Alloy 718 has been applied in a lot of applications such as aerospace, power generation plant, automotive and Oil&Gas. Most products of Alloy 718 are finally produced by machining because there are a lot of complex product shapes. Therefore, improvement of the machinability can contribute to the manufacturability. One of the important factors for the machinability is large carbide because carbide has very high hardness. Distribution and size of carbides strongly influence on cutting tool life. New developed Alloy 718 has low carbon content to suppress the formation of NbC type carbides. Developed alloy extremely improves turning tool life in comparison with conventional Alloy 718. Moreover, developed alloy satisfies chemical compositions and mechanical properties of AMS 5663N and API 6ACRA.

Effect of Solutionizing Temperature on the Hot Flow Behavior of Inconel 718Plus: *Utkudeniz Ozturk*[1]; [1]UPC, Polytechnic University of Catalonia

Inconel 718Plus has been a successful alloy since 2003 owing to its moderate cost, good formability and weldability, and its higher maximum service temperature compared to its ancestor, Inconel 718. The service performance and hot-flow characteristics of this alloy are strongly dependent on the microstructure, particularly the grain size. The grain boundary delta (by some referred to as delta and eta [1]) precipitation in Inconel 718Plus impedes the grain growth and mostly wanted in the microstructure to have more control on the grain size of the alloy. In addition to this, the precipitation behavior of this phase heavily depends on the solutionizing treatment history of the alloy [2]. Here we study the effect of the solutionizing temperature on the grain boundary delta precipitation and overall hot flow behavior. To this end, different sets of cylindrical samples, solutionized at different temperatures were subject to compression tests with same deformation parameters. The hot flow behavior is modeled through previously given constitutive approaches [3] and obtained materials constants are compared. Furthermore, the changes in material constants are correlated with the microstructural evolution presented by different sets of samples. Finally, highlights are given on the grain size evolution as a function of delta structure prior to the deformation and its concurrent evolution during the deformation.REF1) Pickering et al. 2012. Acta Materialia, 60(6), pp. 2757–2769. REF2) J. Andersson Master's thesis, The Royal Institute of Technology, Stockholm, Sweden, 2006. REF3) Ozturk Journal of Engineering for Gas Turbines and Power, 139(3), 032101.

Novel Design Approaches Using TCP Phases for Heat Resistant Materials: *Masao Takeyama*[1]; [1]Tokyo Institute of Technology

Topologically close-packed (TCP) phases consisting of transition metal (M) elements, such as Laves and Sigma phases, are commonly observed but exclusively avoided for high-temperature alloy design, because of their brittle nature. Is this concept true? If yes, how about transition metal carbides, such as $M_{23}C_6$ and MC? Do they deform? These carbides are even harder than TCP phases but commonly used as strengthening species in heat-resistant steels and alloys. TCP phase are implicitly believed to deteriorate the mechanical properties, but this thought is not necessarily true, and TCP phases can be rather promising if their precipitation morphology can be controlled. In this talk, a novel design concept for development of a new class of austenitic steels strengthened by TCP Laves phase is presented based on thermodynamics and precipitation kinetics at elevated temperatures. The carbon free model steel of Fe-20Cr-35Ni-2.5Nb (at.%) exhibits excellent creep properties at 1073 K, equivalent to Ni-based alloys. This superior creep strength is caused by precipitation of Fe_2Nb Laves phase at the grain boundaries. The higher the fraction of grain-boundaries covered by the Laves phase (ρ), the lower the creep rate (ε.), with following relationship: $\varepsilon.=\varepsilon._0(1-\rho)$, leading to longer rupture life. This strengthening method, named "*Grain-boundary precipitation strengthening* (GBPS)", is effective in ρ;>80% under low stress levels. Details of the creep behavior and GBPS mechanism of the novel steels, morphology control of the Laves phase and sigma phase, and evolution of this design approach to Ni-base alloys will also be presented.

Manufacturing of IN718 Aero Engine Components by Smart Powder Based Directed Energy Deposition Process: *Pedro Alvarez*[1]; Fidel Zubiri[1]; María Sierra[2]; Javier Díaz[2]; [1]IK4-LORTEK; [2]ITP

Additive Manufacturing technologies can greatly reduce manufacturing and delivery times and costs of weldable nickel superalloys. In this work a smart additive manufacturing process has been developed and applied to the manufacturing of aeroengine components made of IN718. This process is based on Directed Energy Deposition (DED) in which a laser is used as heat source and metallic powder as feedstock. Initially a process parameter optimization was completed with the aim of optimizing deposition rate while keeping good balance with geometrical accuracy and internal quality. This optimization implies the use of external contour tracks with different process parameters compared with internal overlapping tracks. Microstructural characterization and mechanical tests at room and high temperature (600ºC) were completed in samples that were machined both in the horizontal and vertical directions. Results show that mechanical properties of parts built by DED are between 80-90% of the equivalent forged parts and exceed those of casting parts.The influence of powder physical properties, i.e., grain size morphology and internally embedded porosity, on final density was analyzed. Since the presence of internal defects, especially lack of fusion defects, can jeopardize fatigue performance, an analysis of the internal defects on manufactured parts was performed. Moreover, process monitoring based on real time temperature and pool size measurement was developed. It was concluded that controlling the physical characteristics of the powder, applying suitable scanning strategies and real time monitoring system, it is possible to manufacture and repair components meeting current quality specifications that are required by aero engine manufacturers.

The Effect of Additive Manufacturing Growth Direction on the Thermomechanical Deformation Behaviour of IN718 Components: *Chrysanthi Papadaki*[1]; Alexander Korsusnky[1]; [1]University of Oxford

The recent developments in Additive Manufacturing (AM), Selective Laser Melting (SLM) can be used to fabricate complex shaped components, obviating the high expense and geometrical restrictions imposed by conventional machining. Alongside the evident advantages of SLM, additional care must be taken due to the anisotropy of the arising mechanical properties: previous studies have shown that crystals tend to grow in preferred directions, leading to characteristic grain morphology and texture. To elucidate the nature of the correlation between texture due to SLM process and the mechanical properties, in situ neutron diffraction texture and deformation analysis was performed. In situ tensile experiments on SLM Inconel 718 samples fabricated by AM in different orientations were carried out at operation temperatures. Detailed microstructural characterisation and diffraction data analysis were carried out, providing quantitative information about the average elastic lattice strains in groups of grains of certain crystallographic orientation. The result of the interpretation will shed light on the influence of texture and morphology on the onset of plasticity and damage, thereby guiding the optimization of SLM manufacturing for best performance of components and assemblies.

Expanding the Usability of an Existing Thermodynamic Database, TCNI, by Adding Sulphur: *Reza Naraghi*; Andreas Markström[1]; Lina Kjellqvist[1]; Qing Chen[1]; Paul Mason[2]; [1]Thermo-Calc Software AB; [2]Thermo-Calc Software Inc

Computational thermodynamics has shown to be a very powerful tool for alloy design and it has been extensively used for several decades. The development and implementation of new materials can be accelerated by gaining a deeper insight into underlying behaviors based on scientific models and databases. The predictive power is dependent on the thermodynamic database that is used. For Ni-Base superalloys several commercial databases exists that can successfully be used for prediction of phase fractions, phase composition, gamma-prime-solvus, solidus, liquidus, oxidation/de-oxidation, carburization etc. However, no database can handle sulphidation/de-sulphidation of Ni-base superalloys. For such calculations important sulphur-containing systems needs to be assessed and added to the existing thermodynamic databases. In this work we demonstrate how to add sulphur to an existing thermodynamic database for Ni-base superalloys, TCNI, and validate it against experimental information. Several examples will also demonstrate the expanded usability of the thermodynamic database after the addition of sulphur.

LUMet – Laser-Ultrasonic Sensor for In-Situ Metallurgical Studies: *Michael Hudack*[1]; [1]Dynamic Systems, Inc.

Laser-ultrasonics enables non-contact ultrasonic measurements, using lasers to generate and detect ultrasound pulses. Unlike other ultrasonic technologies, it can be used on hot materials up to any temperature because there is no physical contact. Therefore, it is ideally suited for in-situ studies of solid metallic or ceramic materials up to their melting point. Although the “laser” aspect of laser-ultrasonics is the most visible one, the “ultrasonics” aspect is where the real interest lies. This is because ultrasound is one of only three techniques that can probe the deep interior of opaque materials such as metals and is sensitive enough for measurements of elasticity, internal microstructure, phases, crystallographic texture, grain size, and more. When used with the Gleeble 3500 or 3800 from Dynamic Systems Inc., these measurements can be done in situ, in real time, during thermomechanical processing. Our poster describes 1) Laser-ultrasound, LUMet technology, and how it works to generate and detect ultrasound, 2) The principles of materials characterization using ultrasound, and 3) Demonstrated applications to in-situ characterization with the Gleeble using a LUMet system.

Wrought Processing

Monday AM	Room: Marquis Ballroom
June 4, 2018	Location: Marriott City Center

Session Chair: Ian Dempster, Wyman Gordon /PPC

8:00 AM Introductory Comments

8:05 AM Invited
The High-Temperature Bauschinger Effect in Alloy 718: *Lee Semiatin*[1]; Patrick Fagin[2]; Brian Streich[3]; Robert Goetz[4]; Vasisht Venkatesh[4]; [1]US Air Force Research Laboratory; [2]UES Inc; [3]Honeywell; [4]Pratt & Whitney

The final heat treatment of large aerospace components of alloy 718 typically comprises solution treatment followed by water quenching and aging. Such operations give rise to small, but non-uniform plastic strains that can produce significant levels of residual stress. During water quenching, in particular, material elements may undergo not only concurrent cooling and straining, but also reversed-plastic flow. Therefore, constitutive relations for the simulation of residual-stress evolution should include a description of such transient phenomena. To meet this need, a series of experiments involving reversed straining of short-gage-length samples of 718 was performed at various temperatures and strain rates. These experiments revealed a noticeable Bauschinger effect over a range of temperatures. The temperature at which the BE disappeared was a function of the applied strain rate. A similar BE was also observed in experiments involving both reversed straining and continuous cooling.

8:30 AM Invited

The Case for Physical Experiments in a Digital Age: *Erin McDevitt*[1]; Ramesh Minisandram[2]; Debdutta Roy[2]; Matias Garcia-Avila[2]; [1]ATI Specialty Materials; [2]ATI Specialty Materials

Casting and solidification simulations, heat transfer models, hot isostatic press consolidation simulations, hot working simulations, phase equilibrium calculations… the list is quite long of digital technologies embraced by ATI and other producers of specialty materials and components. Through virtual experimentation, product development cycle time and cost is reduced, the potential impact of process upsets can be determined without testing, and sensitivity to process variation can be assessed prior to ever making any metal, among other efficiency and cost benefits. Still effective, efficient development of superalloys manufacturing processes require careful physical experiments at the pilot scale in order to manage risk and expense of scale-up. Pilot scale development provides critical insight into factors not easily computed, such as the integrity of a VIM cast electrode, the variation in segregation during VAR melting, and cracking due to grain structure or surface condition during hot working. ATI integrates use of physical experiments conducted in pilot research facilities and computational methods to facilitate both new product development and development of the manufacturing method. Such an approach has been instrumental in the development of ATI 718Plus® alloy and Rene 65 alloy and an array of new products including cast-and-wrought, powder, and titanium alloys and components. This paper will discuss the advantages of using physical experiments to streamline the development of new products and manufacturing methods and some of the ways ATI capitalizes on the combined approach.

8:55 AM

Ring Rolling of IN718 for Critical Engine Applications: *Markus Buescher*[1]; Thomas Witulski[1]; [1]Otto Fuchs KG

Critical engine disks are typically die forged products due to the high demand on quality and reproducibility. Therefore, it is state of the art that the die forging process is well controlled by close loop controlled hydraulic press combined with a tight monitoring of process parameters, e.g. deformation velocity, press load, transfer time etc. Based on the geometry of the disk, for example in case of low pressure turbine disks that have a large inner diameter, die forging is not always the most cost efficient process. In these circumstances, ring rolling of a preshape for final die forging or direct ring rolling of the disk by using contoured rolls can result in a much higher material yield and reduced production costs and time. For critical components, that require a fine and homogeneous microstructure to fulfill the required mechanical properties, ring rolling has not been used due to the lack of process control and the difficulties to simulate the process. By using an improved process control of the ring rolling mill in combination of an enhanced process monitoring a suitable microstructure can be achieved during ring rolling. Results of rolled rings with rectangular and shaped contours made from IN718 and Allvac718Plus™ will be presented and the necessary process control and process monitoring will be described. In addition, microstructure results from rolled rings will be compared with simulation results.

9:15 AM

Microstructure Controlling of U720-typed Superalloys to Improve a Hot and Cold Workability by Using Incoherent Gamma Prime: *Atsuo Ota*[1]; Nobuhumi Ueshima[2]; Katsunari Oikawa[2]; Shinya Imano[1]; [1]Mitsubishi Hitachi Power Systems, LTD.; [2]Tohoku University

For high performance air craft engine disks, high-performance Ni-based wrought superalloys (e.g. U720LiTM, AD730TM) with over 40vol% of the γ' phase at 600-700 °C have been developed. Applying them to gas turbines is expected to improve the efficiency. However, due to their low workability, it is difficult to make large size components. We have developed a new innovative process (the MH process) to improve the workability of high-performance Ni-based wrought superalloys. The strengthening mechanism of these γ' precipitation-typed superalloys is widely known to be enhanced by the coherent interface between the γ phase and γ' phase. We focused on the incoherent γ' phase that precipitated on the γ phase grain boundary during forging and it was found that the incoherent boundary shows no strengthening effect. Formation of γ/ incoherent γ' two-phase microstructure would dramatically improve their workability. Cold working was achieved by applying the MH process to the U720-typed alloy AD730. The cold working made it possible to fabricate cold rolled sheets, cold drawn wires and the forged turbine blades. It also exhibited excellent ductility at high temperature; we obtained 99% reduction of area at over 920 °C and 500% elongation at 950 °C by applying the MH process. It was demonstrated that U720Li can be processed by die forging at low temperature and high strain rate without using superplastic forming. In this study, we investigated how the heat treatment condition affects the formation of unique microstructures with good hot and cold workability.

9:35 AM

Influence of Temperature and Strain Rate during Rolling of René 65 Bar: *Oscar Terrazas*[1]; Mark Zaun[1]; Ramesh Minisadram[1]; Michael Lasonde[1]; [1]ATI Specialty Materials

The requirements for rotating jet engine components have placed increasing demands on materials suppliers in the aerospace industry. Higher temperature demands of blade and rotor disk applications in the compressor section have led to a need for alloys with properties superior to ATI 718Plus®™ while retaining the ability to be processed by the conventional cast plus wrought process. René 65 was developed for rotor disk applications. The alloy's property capability also makes it an excellent candidate for compressor blade applications. Processing parameters become critical throughout different stages for this alloy. This study is focused on the hot rolling process of René 65 for blade applications, with rolling temperature and strain rate as the parameters of interest. The results show the significant influence of starting temperature and strain rate for hot rolling of René 65 bar when processing through a continuous rolling mill. Slight changes in rolling temperature and strain rate could ultimately have a major impact on resulting microstructure and mechanical properties.

9:55 AM Break

Melting and Casting

Monday AM
June 4, 2018

Room: Marquis Ballroom
Location: Marriott City Center

Session Chair: Paul Jablonski, DOE/NETL

10:30 AM Introductory Comments

10:35 AM Invited
A Computational Model of the Electroslag Remelting (ESR) Process and Its Application to an Industrial Process for a Large Diameter Superalloy Ingot: *Kanchan Kelkar*[1]; Corey O'Connell[2]; [1]Innovative Research, LLC; [2]Special Metals Corporation

This paper presents a comprehensive computational model for the prediction of the transient Electroslag Remelting (ESR) process for cylindrical ingots based on a two-dimensional axisymmetric analysis. The model analyzes the behavior of the slag and growing ingot during the entire ESR process involving a hot-slag start with an initial transient, near-steady melting, hot-topping and subsequent solidification of the slag and ingot after melting ends. The results of model application to an industrial ESR process for a 1.12 m diameter nickel-iron-chromium superalloy and its validation are presented. They demonstrate the comprehensive capabilities of the model in predicting the behavior of the ingot and slag during the entire process and properties of the final ingot produced. Such analysis provides significant benefits for the optimization of existing process schedules and design of new processes for different alloys and ingot sizes.

11:00 AM
Melt Parameters and Resulting Characteristics in Laboratory-Scale Electroslag Remelting: *Martin Detrois*[1]; Paul Jablonski[1]; [1]National Energy Technology Laboratory

Vacuum induction melting (VIM) and electro-slag remelting (ESR) are techniques used to produce ingots of alloys with complex chemistries while lowering the amount of defects, inclusions or extent of elemental segregation. Those practices are widely employed in aerospace applications and more recently in fossil-fueled power plants due to the increasingly demanding operating conditions. Consequently, research is ongoing to improve and control the melting of commercially available alloys for optimal performance in service. In this investigation, a laboratory-scale (200 mm – 200 kg) ESR furnace was used to remelt various alloys with a focus on the ingot quality. Several approaches were considered to study and improve the melting characteristics. Targeted additions of minor elements in master alloys were found to improve the melt range which affected the melt pool volume and subsequently increased the remelting efficiency. Furthermore, the melt parameters during ESR of some select alloys were modified to improve the melting characteristics. Finally, the influence of the size of the ESR electrode was observed and provided a better understanding of the mixing mechanisms in the slag region and their effect on the voltage swing and melt rate. The results will be discussed using a combination of experimental and computational (thermodynamic and CFD-based) data.

11:20 AM
Production of Nitride-free 718 by the VIM-VAR Processing Route: *Kleber Sernik*[1]; Iona Leonardo[2]; Claudio da Hora[2]; Mariana dos Reis Silva[2]; [1]Strategy Consulting; [2]CBMM

The current state of the art of superalloys manufacturing process makes possible to obtain materials substantially clean of oxides associated with a fine grain structure. However, little progress happened in the elimination of nitrides from the Cr-Nb-Ti containing superalloys. The nitrogen is mostly carried into the melt by chromium and niobium master alloys, associate with leaks in the melt chamber. The present development obtained by CBMM`s materials and processing research program provides a process for the manufacturing of material above mentioned in which the precipitation of nitrides during the solidification can be essentially eliminated. This is done by a two-step melting process. In the first one the nitrogen is taken out a bath formed with the non-reactive metals (Ni, Fe, Mo) by a controlled carbon-boil. Subsequently Cr and Nb bearing master alloys with extra-low nitrogen content (produced by a special smelting process developed by the company) are added to the bath, together with Ti, Al and B. The VIM furnace utilized is designed in a way that it is virtually atmospheric leak-free. That will result in an ingot whose nitrogen content is below the limit for the TiN precipitation during the solidification of alloy 718.

11:40 AM CANCELLED
Grain Refinement on Microstructure and Mechanical Properties of IN718 Superalloy: *Taiwen Huang*[1]; Ziqi Jie[1]; Jun Zhang; [1]Northwestern Polytechnical University,china

The mixed refiner of Co3FeNb2 and CrFeNb ternary intermetallic compounds and melt superheating treatment under the modified thermally-controlled solidification (TCS) process have been designed to achieve grain refinement and further improve mechanical properties of IN718 superalloy. It is found that the refinement effect of addition grain refiners under TCS process is quite superior to that by convention casting (CC) process with refiner, as experiment results show that the grain size is refined from 3340 μm to 126 μm and greatly reduce the amount of porosity, during the refinement process. In addition, the applied melt treatment can refine grain size from 6420 μm to 89 μm and greatly reduce the amount of porosity. Meanwhile, after grain refinement, the stress rupture property under 650 °C/620 MPa is significantly improved. Grain refinement mechanisms are also discussed.

Welding and Joining

Monday PM
June 4, 2018

Room: Marquis Ballroom
Location: Marriott City Center

Session Chair: Zhongnan Bi, Central Iron And Steel Research Institut

1:30 PM Introductory Comments

1:35 PM
Review of Weldability of Precipitation Hardening Ni- and Fe-Ni-based Superalloys: *Joel Andersson*[1]; [1]University West - Sweden

Fabrication and welding of structural components for the hot section of aero engines continues to be of high importance to the manufacturing industry of aero engines. This paper discuss and review the literature on hot cracking and strain age cracking, cracking phenomenon that can occur during welding or subsequent heat treatment of precipitation hardening Ni- and Fe-Ni- based superalloys. The influence of chemical composition in terms of i.e. hardening elements and impurities, microstructure of base material and weld zone, together with welding processes and corresponding parameters and heat input are discussed and related to the cracking susceptibility of different nickel based superalloys.

1:55 PM

A Simplified Varestraint Test for Analyzing Weldability of Fe-Ni based Superalloys: *Pedro Alvarez*[1]; Lexuri Vázquez[1]; Pedro Pablo Rodríguez[2]; Ana Magaña[3]; Fernando Santos[3]; Pedro Manuel García-Riesco[1]; [1]IK4-Lortek; [2]Alfa Investigación Desarrollo e Innovación; [3]IK4-Azterlan

High temperature Ni-based superalloys are largely used in components of aircraft engines which are subjected to high thermal (above 700ºC) and structural loads. Investment casting has been traditionally implemented for the manufacturing of these components with different levels of complexity and size. However, investment casting of large and complex parts can entail some difficulties which lead to higher casting defect ratios and the need of repairing. Therefore, it is essential to develop easy to repair Ni-based superalloys castings, i.e., castings with an enhanced weldability or reduced weld cracking susceptibility. Improvement of weldability will also enable the combination of small size castings with forged and rolled components in welded structures reducing overall manufacturing costs and foundry capacity requirements. Cracking susceptibility of Ni-based superalloy castings is much greater in comparison with equivalent wrought components due to coarser and non-homogeneous microstructures, grain boundary segregations and particular chemistry which promote several cracking mechanisms during welding. A methodology based on Varestraint test (hot cracking test) is introduced to evaluate cracking susceptibility of Ni-based superalloys with a reduced number of samples. This reduction is particularly important when considering castings since practical conclusions can be drawn with minimum material usage. Influence of Varestraint testing parameters, machine performance and total crack length (TCL) measurement procedure on scattering of results are assessed. Conditions to reduce scattering and improve repeatability as well as reproducibility of results are defined, which are essential to compare weldability performance between different alloys and microstructures.

2:15 PM

Varestraint Weldability Testing of ATI 718Plus® - Influence of Eta Phase: *Sukhdeep Singh*[1]; William Fransson[2]; Joel Andersson[2]; Anssi Brederholm[3]; Hannu Hänninen[3]; [1]Chalmers University of Technology; [2]University West; [3]Aalto University School of Engineering

This study investigates the effect of eta phase on hot cracking susceptibility of ATI 718Plus®. Two heat treatment conditions of 950°C/1 h and 950°C/15 h having different amounts of eta phase were tested by longitudinal Varestraint testing method. The heat treatment at 950°C/15 h exhibited the highest amount of cracking. This was related to the higher amount of eta phase precipitation during the long dwell heat treatment which aided to extensive liquation during welding.

2:35 PM

The Influence of Base Metal Microstructure on Weld Cracking in Manually GTA Repair Welded Cast ATI 718Plus®: *Fabian Hanning*[1]; Joel Andersson[2]; [1]Chalmers University of Technology; [2]University West

The effect of base metal conditions on the weld cracking response of cast ATI 718Plus® was investigated in this study, comparing as cast microstructure with pseudo hot isostatic pressing (HIP) heat treatments at 1120, 1160 and 1190°C for dwell times of 4 and 24 hours. Linear grooves have been filled using multipass manual gas tungsten arc welding (GTAW) to simulate repair welding conditions. Metallographic investigation revealed cracks in both base metal heat affected zone and fusion zone layers. The heat treatment temperatures chosen below, at and above incipient laves melting temperature of ATI 718Plus® were found to have an effect on weld cracking behaviour, with an increased average total crack length in the base metal heat affected zone for both 1160 and 1190°C as compared to the as cast condition and the 1120°C homogenization treatment. The increase in cracking susceptibility shows a correlation with the amount of Nb-rich secondary phases, with lower amounts leading to crack concentration to solidification grain boundaries present from the casting process, increasing the average crack length.

2:55 PM

Fracture Toughness and Fatigue Behaviour of Variably Precipitated Inconel 625/AISI 304L Welds: *Sandeep Singh Sandhu*[1]; Amandeep Shahi[1]; [1]Quest Engineering College

Nickel based superalloy Inconel 625 welds were fabricated by depositing its filler in AISI 304L substrate using a single-V groove configuration and employing SMAW (Shielded metal arc welding) as well as GMAW (gas metal arc welding) process. Fatigue crack growth and fracture toughness characteristics of SMA weld Inconel 625 compact tension specimens of thickness 25mm in as welded and after post weld thermal aging treatments(temperatures ranging from 650°C to 850°C and duration of 10 and 100 hours) were investigated on the basis of curves plotted between crack length and number of cycles. Fatigue crack growth rate was examined in delta k range of 21-39 MPavm. Varying degree of precipitation in these welds was observed due to thermal aging which influenced their fracture toughness significantly. The fracture toughness values for SMA weld Inconel 625specimens in as welded condition was found to be Jmax (213.183 kJ/sq-m) and JQ (5.618 kJ/sq-m) Whereas, the treatment (650°C/100 hours) specimen exhibited stable crack growth during the J-integral test and Jmax increased to (221.58 kJ/sq-m) and JQ (12.56 kJ/sq-m).

3:15 PM Break

Microstructure I: Structure-Property Relationships

Monday PM — Room: Marquis Ballroom
June 4, 2018 — Location: Marriott City Center

Session Chair: Kevin Bockenstedt, ATI Specialty Materials

3:45 PM Introductory Comments

3:50 PM Invited
Microstructure Dependence of Dynamic Impact Behaviour of ATI 718Plus Superalloy: *Gbenga Asala*[1]; Joel Andersson[2]; Olanrewaju Ojo[1]; [1]University of Manitoba; [2]University West

ATI 718Plus is a γ'-strengthened nickel-based superalloy developed to substitute the widely used IN 718 in aero-engine applications. This newer superalloy is a candidate material for aero-engine turbine casing, with the requirement to withstand impact loading occurring at high strain rates during turbine blade out events. Furthermore, the understanding of the high strain rate response of ATI 718Plus is important in optimising its machinability during cutting operations. To predict and model the behaviour of ATI 718Plus during these events and in other dynamic impact applications, proper understanding of the high strain rate behaviour of the alloy is important, but not presently available. Therefore, in this work, the influence of microstructural condition, in term of the presence of γ' precipitates, and strain rates on dynamic impact behaviour of ATI 718Plus, using a modified version of direct impact Hopkinson bar, is investigated. It is observed that the presence of γ' precipitates in the microstructure significantly reduced the strain hardening and strain rate hardening sensitivity of the alloy, compared to its γ'-free microstructure. Moreover, microstructural examination of the deformed samples shows that the formation of adiabatic shear bands, which usually serve as damage nucleation site, is substantially suppressed in the γ'-free specimen, while the γ'-bearing microstructure exhibits high propensity to form localised shear bands.

4:15 PM
Strain Controlled Low Cycle Fatigue Behaviors of U720Li Disk Superalloy above 700 °C: *Fei Sun*[1]; Yuefeng Gu[1]; Kyoko Kawagishi[1]; Hideyuki Murakami[1]; Yoko Yamabe-Mitarai[1]; [1]National Institute for Materials Science

The low cycle fatigue behaviors of Udimet 720Li (U720Li) and the related microstructure evolution have been investigated at 725 °C under strain control tests. The interrelationships between microstructure factors and properties were analyzed using transmission electron backscatter diffraction (t-EBSD) in scanning electron microscopy (SEM) and transmission electron microscopy (TEM). For comparison, LCF behaviors at 650 °C were also presented to find the inferior aspects of U720Li alloy at relatively higher service temperatures. The results show that recrystallization occurs during the LCF testing at 725 °C. The extent of recrystallization increases with the strain. The LCF property at 725 °C is weakened to a large extent after recrystallization, which could be the significant factor that causes LCF degradation. Combination t-EBSD and TEM are beneficial for characterizing and analyzing the microstructure evolution in terms of primary \947:' precipitates and dislocations, proposing that gliding dislocations could concentrate into walls to form sub-grain boundaries, with the combination of primary \947:' precipitates to form sub-grains.

4:35 PM
Mechanical Performance of Various INCONEL® 740/740H Alloy Compositions for Use in A-USC Castings: *Kyle Rozman*[1]; Martin Detrois[1]; Paul Jablonski[2]; Jeffrey Hawk[2]; [1]ORISE; [2]National Energy Technology Laboratory

The use of Ni-based superalloys as structural components of advanced ultra-supercritical steam and CO2 turbines is becoming necessary due to the increasing performance requirements of future power plant designs. Although numerous Ni-based superalloys can respond to the demanding mechanical performance, very few present a combination of high-strength and creep resistance while maintaining good ductility and weldability. Furthermore, the improved performance is often associated with wrought alloys while the fabrication of large castings is the primary target for those applications. With the comparatively lower mechanical properties of cast alloys, new designs based on compositional changes are necessary to allow for the use of Ni-based superalloys in A-USC castings. This lack of performance is primarily associated with the large and inhomogeneous grain size as well as elemental segregation and other casting anomalies. This investigation presents various alloys with compositions within the range of INCONEL® 740/740H designed to overcome the issues associated with the use of Ni-base superalloys in A-USC castings. Modifications to the chemistry were based on thermodynamic simulations and experimental results. Particular attention was given to reactive element additions, element partitioning, \947:' precipitate phase promoting elements and grain boundary carbides. The effects of the various compositional changes on the tensile and creep properties of INCONEL® 740/740H will be discussed.

4:55 PM
Effect of Heat Treatment on Microstructure and Mechanical Properties of VDM Alloy 780 Premium: *Martin Bergner*[1]; Joachim Rösler[1]; Bodo Gehrmann[2]; Jutta Klöwer[2]; [1]Technische Universität Braunschweig; [2]VDM Metals GmbH

VDM Alloy 780 Premium is a new 718-type superalloy recently developed by Technical University Braunschweig and VDM Metals GmbH. It contains the γ'-phase for strengthening in addition to a second phase, in the following referred to as δ-phase. As in alloy 718, the δ-phase may be used for grain refinement and strengthening of grain boundaries upon creep loading. Most important differences in chemical composition compared to Alloy 718 are the essential replacement of Fe by about 25% Co and a higher Al-content (about 2%) in combination with a lower Ti-content (about 0.3%). Firstly, these measures stabilize the strengthening phase and allow for application temperatures of up to 750°C. Secondly, the δ-phase is preserved despite the relatively high aluminum content. To make best use of Alloy 780, the precipitation kinetics of both phases along with the concurrent evolution of microstructure and mechanical properties must be understood. Consequently, this article deals with the influence of heat treatments on the phase kinetics, microstructure evolution and mechanical properties. Firstly, it will be demonstrated that proper control of the heat treatment parameters allows for a distribution of the δ-phase as in Alloy 718. Secondly, Vickers hardness testing along with creep rupture experiments will be presented, revealing interdependencies between heat treatment strategies and mechanical properties. At ambient temperature, the strength of the new alloy meets or exceeds that of Alloy 718 despite absence of the 947;"-phase, while its creep strength is far superior.

5:15 PM
Computed Tomography as an Alternative Method to Measure Crack Growth in Non-conventional Geometries: *Adrian Loghin*[1]; Vipul Gupta[2]; Anjali Singhal[2]; Albert Cerrone[2]; [1]Simmetrix Inc.; [2]General Electric

The computed tomography (CT) application presented herein aims at measuring cracks three dimensionally in a non-traditional fracture mechanics Superalloy 718 specimen exposed to supercritical CO2 (sCO2). Superalloy 718 is one material of choice for manufacturing components for Concentrated Solar Plant (CSP) units using sCO2 power cycle. To quantify the low cycle fatigue (LCF) capability of the Superalloy 718 material exposed to sCO2, at 550 C, 200 bar internal pressure, hollow tensile specimens were designed and LCF experiments at different loading levels were conducted. The same hollow specimen was considered to monitor fatigue crack growth (FCG) while the crack surface is exposed to sCO2 environment. By interrupting the LCF test procedure and conducting ex-situ volumetric CT scans, the location, size and shape of several cracks were identified and, incremental crack advancement was measured.

5:35 PM
Evaluation of the Stress-Strain State in Alloy 718 after Hydrogen Charging: *Ekaterina Alekseeva*[1]; Sergey Kolesov[2]; [1]Peter The Great St. Petersburg Polytechnic University; [2]Weatherford, Materials department

The changes in the stress-strain state as a result of hydrogen saturation of alloy 718 produced via traditional and 3D metal printing routes was studied. The stress-strain state of the material after electrochemical hydrogen charging was measured by X-ray technique techniques using diffractometers with two power levels to obtain the information from different depths from the surface. It was found that most of the hydrogen accumulated in the thin surface layer. It was found that the microstrains and sub-microstrains change up to 35% in a depth of ~5-30 microns as a result of electrochemical hydrogen charging. Changes in the residual stress (macrostress) as a result of cathodic charging were not detected in the studied materials. As a result of hydrogen desorption at 200-800 °C the stress-strain state of the investigated alloy returns to its initial state for traditional made material. The bulk of hydrogen after cathodic charging is removed at 300 °C.

Microstructure II: Advanced Characterization

Tuesday AM — Room: Marquis Ballroom
June 5, 2018 — Location: Marriott City Center

Session Chair: Max Kaplan, Pratt & Whitney

8:00 AM Introductory Comments

8:05 AM Invited
Characterization of Nano-Scale γ' Phase in HPT-Disk P/M Superalloys HGN300 by Small-Angle X-ray Scattering: *Masato Ohnuma*[1]; Takuya Yoshioka[1]; Toshinori Ishida[1]; Motoki Okuno[2]; Daisuke Nagahama[1]; [1]Hokkaido University; [2]Honda R&D Co., Ltd.

Quantitative evaluation of the size and volume fraction of γ' particles has been studied for the first time by Small-Angle X-ray Scattering (SAXS) in the newly developed HGN300 superalloy employing different aging conditions. In addition to γ' particles of about 20 nm in diameter formed during cooling, particles with D (diameter) < 10 nm form on aging. The average size of the γ' particles with D < 10 nm increases on prolonging the time at a fixed temperature as well as by increasing temperature for fixed lengths of time. However, their size remains in the range under 10 nm except for the highest temperature and the longest time. The γ' particle volume fraction also increase on increasing the aging time at a fixed temperature but is roughly constant after 24 h of heating, independent of temperature. Ultra Small-Angle Scattering (USAXS) reveals that the volume fraction of γ' particles in the size range from 20 to 100 nm in diameter increase in the early stage of aging, while it decreases in the late stage. These results suggest that the disappearance of the particles in the size range of 20 < D < 100 nm stimulate the formation of γ' particles with D < 10 nm in the single step aging. Comparison with Scanning Electron Microscope (SEM) images indicates that the regions with a low number density of γ' particles in the size range from 20 to 100 nm in SEM images are the sites where the particles with D < 10 nm form. An increase in the number density of γ' particles with 20 < D < 100 nm occurs in the following second step aging and cause an increase of the Vickers hardness. Consequently, statistically representative parameters obtained by SAXS in a larger sample volume than that viewed by direct observations show that the formation pathway of γ' particles with 20 < D < 100 nm after two steps aging is through the dissolution of γ' particles with 20 < D < 100 nm formed during cooling and the growth of newly formed particles with D <10 nm.

8:30 AM
Precipitation Behavior and Mechanism of Sigma Phase in Alloy 925: *Zhaoxia Shi*[1]; Xiaofeng Yan[1]; Chunhua Duan[1]; [1]China Iron & Steel Research Institute Group (CISRI)

The aim of the present work was to investigate the precipitation behavior and mechanism of the sigma (σ) phase in Alloy 925 by employing several complementary techniques of microstructural analysis and thermodynamic calculations. The thermal exposures were performed at 650 °C, 750 °C and 850 °C for different times, after which the thermally exposed specimens were studied and compared in terms of their microstructure and the micro-hardness of γ matrix. It was found that the chemical composition of σ phase in Alloy 925 could be represented as (Cr,Mo)6(Ni,Fe)5 with the lattice parameters a=0.878 nm and c=0.457 nm. Higher local concentrations of Cr and Mo in the γ matrix caused by the formation of γ' phase and η phase resulted in the formation of σ phase along the grain boundaries and in the vicinity of η phase. Higher contents of Cr, Mo, Al, Ti and Nb in the alloy could accelerate the formation of σ phase. The increase in C content could inhibit the precipitation of σ phase. The formation of σ phase most likely occurred during the thermal exposure at 750 °C. The amount of σ phase was remarkably increased with the thermal exposure time increasing, which led to the softening of γ matrix.

8:50 AM
Influence of Residual Stresses on Aging Precipitation Behavior of Alloy 718: *Hailong Qin*[1]; Zhongnan Bi[1]; Ruiyao Zhang[2]; Hongyao Yu[1]; Guang Feng[1]; Xia Guo[3]; Hai Chi[3]; Jinhui Du[1]; Ji Zhang[1]; [1]Central Iron and Steel Research Institute; [2]University of Leicester; [3]Beijing Center for Physical and Chemical Analysis

The interior residual stresses, which were generated at previous stages of forging and water quenching, exist as a pre-condition of γ" precipitation during the subsequent thermal ageing. To clarify the issue, a refine investigation for the preferentially orientation of γ" precipitates in Inconel 718 can be achieved by means of TEM, FE-SEM and small angel neutron scattering. Compared with the isotropic nucleation in the early stage of ageing, the preferential orientation during the coarsening process has a specific orientation-relationship, due to the volume diffusion of niobium atoms affected by elastic strain, with the load direction in a multiple crystal system. The inhomogeneity and anisotropy in microstructure give rise to a deterioration and anisotropy of mechanical properties.

9:10 AM
Characterisation of the Initial Stages of Dynamic Recrystallisation in ATI 718Plus®: *Christiane Kienl*[1]; Ana Casanova[1]; Olivier Messe[1]; Christos Argyrakis[1]; Catherine Rae[1]; [1]University of Cambridge

ATI 718Plus® 1 is a polycrystalline multi-phase strengthened Ni-base superalloy for turbine disc applications in aero engines. A typical turbine disc experiences temperatures in the rim up to 700ºC and stresses as high as 1000MPa in the cooler parts of the component. The manufacturing process, especially the forging and heat treatment, plays a pivotal role towards achieving the final microstructure and mechanical properties needed to withstand this harsh environment. The microstructural evolution during processes aforementioned is associated with dynamic recrystallisation. The changes occurring during the initial stages of deformation and the influences of different phases are of particular interest as partially recrystallised areas with a broad range of grain size can be detrimental for the mechanical properties of component. ATI 718Plus® has been used in this work to study grain nucleation and growth during recrystallisation. To evaluate the importance of the initial microstructure on the outcome of the forging, two sets of specimens were produced from a single ingot. Hot compression tests were performed on on Rastegaev-samples across a wide range of temperatures, strains and strain rates. In addition, the characteristics for meta-dynamic recrystallization were evaluated on a certain set of samples. The evolution of the flow curves as well as the development of the microstructure will be presented. Particular interest will be paid on the role of deformation parameters and their influence on the recrystallized fraction and grain boundary misorientation angle. 1. ATI 718Plus® is a registered trademark by ATI Allvac.

9:30 AM
On the Effect of Alloying Additions to the Ni-Cr-Al-Nb Dual-Superlattice Gamma-Gamma Prime-Gamma Double Prime Superalloys: Paul Mignanelli[1]; Nicholas Jones[2]; Mark Hardy[1]; Howard Stone[2]; *Katerina Christofidou*; [1]Rolls-Royce plc; [2]University of Cambridge

Recent work has identified a novel Ni-Cr-Al-Nb alloy capable of generating a γ -γ'-γ" dual-superlattice microstructure with excellent microstructural stability and tensile strength. In this study, we report on the effect of additions of alloying elements that traditionally partition to the ã matrix. Attention is focussed on their effects upon the microstructure, hardness and lattice misfit of dual-superlattice superalloys. The results obtained from these studies indicate that judicious alloying may further enhance the properties and stability of these dual-superlattice superalloys and that they offer the potential of greatly increased temperature capability compared to other alloys reinforced by \947:" precipitates.The authors would like to acknowledge the EPSRC/Rolls-Royce Strategic Partnership for funding (EP/M005607/1 and EP/H022309/1).

9:50 AM Break

Corrosion

Tuesday AM — Room: Marquis Ballroom
June 5, 2018 — Location: Marriott City Center

Session Chair: Jon Groh, GE Aviation

10:30 AM Introductory Comments

10:35 AM Invited
Performance of Wrought Superalloys in Extreme Environments: *Bruce Pint*[1]; [1]Oak Ridge National Laboratory

As power generation systems move towards higher efficiency operation above 700°C, wrought superalloys are the leading structural alloy candidates, including precipitation strengthened (PS) alloys 740 and 282 for the highest temperatures. To evaluate the performance of these alloys for these applications, a range of 500-5,000 h evaluations have been conducted in environments including steam, supercritical CO_2 (sCO_2) and simulated combustion exhaust with H_2O and/or SO_2 at 700°-800°C and compared to baseline exposures in laboratory air and 1 bar CO_2. These alloys primarily rely on the formation of an external Cr-rich oxide layer or scale for environmental protection and the reaction rates in all of these conditions are similar and relatively low. However, compared to a conventional solid solution strengthened alloy, like 625, the mass gains are higher for PS alloys due to the internal oxidation of the g´ forming additions, Al and Ti. Post-exposure characterization has quantified the reaction products and the depth of internal oxidation is not a concern and does not appear to increase above the baseline behavior in laboratory air. Likewise, there is no indication of internal carburization in the sCO_2 environment at 750°C/300 bar. The addition of 0.1% SO_2 in CO_2-10%H_2O at 800°C actually suppressed the internal oxidation at 1 bar but SO_2 may be a concern when the total pressure is higher. Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Solar Energy Technology Program (SunShot Initiative) and the Office of Fossil Energy, Crosscutting Research Program.

11:00 AM
Hydrogen Influence on Crack Propagation and Stress-Strain Evolution of Alloy 718: *Sergey Kolesov*[1]; Robert Badrak[1]; Aleksey Shakhmatov[1]; [1]Weatherford

Nickel base alloys such as 718 are used for many applications in the drilling, completion and production segments in the Oil & Gas Industry. The alloy selection is based on high strength levels while exhibiting resistance to embrittlement and environmental cracking. Hydrogen embrittlement can be a limiting factor to applications and this investigation was undertaken to better understand the mechanisms and characteristics of hydrogen in 718. Saluted hydrogen into metal could be presented in different conditions: diffuse-active and trapped by different defects and structure elements. Fatigue was used in current work as a tool for (1) the generation of structure defects and (2) hydrogen effects on crack growth. The following items were studied: (1) hydrogen solubility into different versions of 718 alloy; (2) effects of increased surface and volume defects density on hydrogen solubility; (3) hydrogen effects on stress-strain evolution; and (4) effects of hydrogen at different locations within the structure on crack growth rate. The specifics of each type of hydrogen location within the structure on crack propagation including diffusion-active and trapped by different defects and structure elements were discovered and presented.

11:20 AM
High Performance New Ni-base Alloy AF955 (UNS N09955) for Oil and Gas Industry: Carlo Malara[1]; Luca Foroni[1]; *Louis Lherbier*[2]; [1]Foroni SpA; [2]Lherbier Consulting

A precipitation hardened Ni-base alloy has been developed to fulfil the recent stringent requirements of the oil and gas industry. The new alloy is commercially designated as AF955 and the Unified Numbering System (UNS) assignment of N09955. The new alloy is patented and accepted for inclusion in NACE MR0175/ISO 15156. It is produced at strength levels of 827 MPa (120 ksi) 0.2% offset minimum yield strength (MYS) and 965 MPa (140 ksi) MYS with very good ductility and toughness, and with a microstructure characterized by fine γ' and γ" strengthening precipitates, uniform and equiaxed grain size distribution, minimized secondary phase precipitation and free of continuous grain boundary precipitates. It exhibits good corrosion resistance and low susceptibility to hydrogen embrittlement. These properties make alloy AF955 a very promising material for widespread applications from oil and gas industry to power generation, chemical applications and many others. Details of the manufacturing process and properties of AF955 are presented and discussed in this paper.

11:40 AM
Corrosion and Carburization Behavior of Ni-Cr-Mo-Nb Superalloys in a High Temperature Supercritical-CO2 Environment: *Sung Hwan Kim*[1]; Chaewon Kim[1]; Gokul Obulan Subramanian[1]; Changheui Jang[1]; [1]KAIST

Two Ni-Cr-Mo-Nb superalloys (Alloy 625 and Alloy 718) were corroded in high temperature supercritical-CO2 (S-CO2) at 700 oC (20 MPa) for 500 h and compared in terms of oxidation and carburization behavior. A continuous chromia (Cr2O3) layer was formed on the surface of Alloy 625, whereas Ni- and Fe-rich oxide nodules were also formed with chromia on Alloy 718. Meanwhile, the extent of carburization by formation of an amorphous C layer at the oxide/matrix interface was comparatively low for Alloy 625. This difference did not seem to stem from oxide type or underlying microstructure, and was thought to be associated with oxide properties. In terms of mechanical properties, only Alloy 625 exhibited decrease in ductility after exposure to S-CO2. This was ascribed to the microstructural evolution of the alloys during the high temperature exposure.

Application of Experimental and Modelling Methods

Tuesday PM	Room: Marquis Ballroom
June 5, 2018	Location: Marriott City Center

Session Chair: Joel Andersson, University West

1:30 PM Introductory Comments

1:35 PM
Simulation of Co-precipitation Kinetics of γ' and γ" in Superalloy 718: *Fan Zhang*[1]; Weisheng Cao[1]; Shuanglin Chen[1]; Chuan Zhang[1]; Jun Zhu[1]; Duchao Lv[1]; [1]CompuTherm, LLC

In this paper, we will study the co-precipitation kinetics of phases in Superalloy 718 using the simulation tool we have developed using the CALPHAD approach. This tool considers concurrent nucleation, growth and coarsening of these precipitates. Furthermore, it is directly integrated with thermodynamic calculation engine to obtain instant update of phase information, such as the composition of the matrix and the nucleation driving force for each precipitate. In addition to the average particle size, the more advanced KWN (Kampmann & Wagner Numerical) model was implemented to allow for predication of the full evolution of the particle size distribution (PSD). In this paper, we will perform virtual experiments using this tool to simulate the co-precipitation of the and phases under different heat treatment conditions. Simulation results, such as temporal evolution of volume fraction, number density, and mean size of the precipitates, as well as the final particle size distribution will be presented and discussed. The impact of precipitate and the initial microstructure will also be briefly discussed. These virtual experimental results can be used to understand the microstructural features of Superalloy 718 and serve as guidance for further optimization of heat treatment schedule.

1:55 PM
ICME Based Additive Manufacturing of Alloy 230 Components: *Suresh Sundarraj*[1]; Sion Pickard[1]; Alonso Peralta[1]; Anil Chaudhary[2]; David Snyder[3]; Suraj Rawal[4]; Ray Xu[5]; Sesh Tamirisakandala[6]; Albert Contreras[7]; John Meyer[8]; Andrzej Wojcieszynski[9]; Derrick Lamm[10]; Edwin Schwalbach[11]; [1]Honeywell Aerospace; [2]Applied Optimization Inc.; [3]Questek Innovation; [4]Lockheed Martin; [5]Rolls Royce Corporation; [6]Arconic; [7]Aerojet Rocketdyne; [8]Carpenter Technology Corporation; [9]ATI Corporation; [10]Northrup Grumman; [11]AFRL

Metal additive manufacturing (AM) is an innovative and enabling manufacturing technology that is also pervasive/cross cutting in terms of system applications, dual use and multiple agencies. AM technologies build near-net/net shape components, one layer at a time, using digital data from 3D CAD models. In addition, AM has the potential to enable novel product designs that could not be fabricated using conventional subtractive processes. The goal of the MAI project (HON-9 Agreement Order Number FA8650-14-2-5204) is to create a cross-functional team focused on developing the necessary integrated computational materials engineering (ICME) based framework, knowledge and supporting database to enable powder bed AM technologies to produce nickel-base superalloy aerospace and space components. An Activity Integrated Project Team (AIPT) comprising, of Honeywell Aerospace (Lead), Aerojet Rocketdyne, ATI Powder Metals, Carpenter Powder Products, Lockheed Martin, Northrop Grumman, Rolls-Royce Corporation, Arconic Inc. along with Applied Optimization and QuesTek as major subcontractors was formed. The AIPT successfully completed the concept feasibility demonstration for additively manufactured Alloy 230 components. Focused series of design of experiments (DOE) related to machine parameters and post processing operations were designed and implemented within Concept Laser M2. Empirical data collected was used to optimize process parameters, calibrate ICME models, and improve tool maturity level (TML) of ICME framework for AM. Preliminary business case was developed for parts from Honeywell Aerospace, Aerojet Rocketdyne, Rolls-Royce Corporation, Northrup Grumman and Lockheed Martin.

2:15 PM
Modeling Tensile, Compressive, and Cyclic Response of Inconel 718 Using a Crystal Plasticity Model Incorporating the Effects of Precipitates: *Marko Knezevic*[1]; Saeede Ghorbanpour[1]; [1]University of New Hampshire

A comprehensive elasto-plastic polycrystal plasticity model is developed for Ni-based superalloys. To demonstrate the microstructure sensitive predictive characteristics, the model is applied to an Inconel 718 (IN718) superalloy that was produced by additive manufacturing (AM). The model with the same set of material and physical parameters is compared against a suite of compression, tension, and large strain cyclic mechanical test data applied in different AM build directions. The model embeds the contributions of solid solution, precipitates shearing, and grain size and shape effects into the initial slip resistance. Non-Schmid effects and a backstress term are included in the driving force for slip activation. The hardening law is based on the evolution of dislocation density. It is demonstrated that the model is capable of predicting the particularities of both monotonic and cyclic deformation to large strains of the alloy including decreasing hardening rate during monotonic loading, the non-linear unloading upon the load reversal, the Bauschinger effect, the hardening rate change during loading in the reverse direction as well as anisotropy and concomitant microstructure evolution. The microstructure constituents and behavior of IN718 under these conditions is similar to other Ni-based superalloys, and therefore, it is anticipated that the general model developed here can be applied to other superalloys fabricated using AM and other approaches.

2:35 PM
3D Stochastic Modelling of Microstructure Evolution during Solidification of Alloy 718: *Laurentiu Nastac*[1]; [1]The University of Alabama

A three-dimensional (3D) stochastic model for simulating the evolution of dendritic crystals during the solidification of alloys has been developed. The model includes time-dependent computations for temperature distribution, solute redistribution in the liquid and solid phases, curvature, and growth anisotropy. The 3D model can run on PCs with reasonable amount of RAM and CPU time. 3D stochastic mesoscopic simulations at the dendrite tip length scale were done to simulate the evolution of the columnar-to-equiaxed transition and segregation patterns in alloy 718. A detailed comparison between the experimental and simulated microstructures in 3D is performed. It is shown that the present 3D model is more accurate than the previously developed 2D models for predicting the CET and the segregation behavior in alloy 718.

2:55 PM
Application of Analytical Electron Microscopy and Tomographic Techniques for Metrology and 3D Imaging of Microstructural Elements in Allvac 718Plus: *Adam Kruk*[1]; Agnieszka Wusatowska-Sarnek; [1]Pratt & Whitney

The development of innovative materials for aeronautics requires use of modern research methods to characterize their structure on the level from micro- to nanoscale. Allvac® 718Plus™ (718Plus) is a relatively new nickel-based superalloy that has high strength, is corrosion resistant and has improved higher temperature performance compared to the 718, while retaining the excellent processing characteristics of this alloy. The aim of this study was the application of analytical electron microscopy and tomographic techniques to perform the qualitative and quantitative characterization of structural elements in the wrought and cast 718Plus. Determination of crystallographic structure of selected phases was performed using electron diffraction method supported by JEMS software. 3D imaging of microstructural elements and chemical compositions of selected phases were performed using STEM-EDX tomography technique using a probe Cs corrected Titan3 G2 60-300 with ChemiSTEM™ system. Tomographic reconstruction was performed using Simultaneous Iterative Reconstruction Technique (SIRT) method on a tilt series, which allowed visualizing the three-dimensional distribution of selected elements (Al, Cr) in the analysed volume. The shape and distribution of particles in the reconstructed volume, as well as complex particle composition of -phase were analyzed using STEM-EDX and FIB-SEM tomography techniques. 3D imaging of precipitates in the interdendritic region (Laves and phases) was performed using FIB-SEM tomography technique. The 3D visualization of reconstructed space was performed using ImageJ and Avizo Fire software. The study showed that advanced microscopic techniques and test methods in conjunction with tomography technique permits to obtain complementary information about the microstructure of 718Plus superalloy.

3:15 PM Break

Microstructure III: Deformation and Properties

Tuesday PM — Room: Marquis Ballroom
June 5, 2018 — Location: Marriott City Center

Session Chair: Daisuke Nagahama, Honda R&D Co Ltd

3:45 PM Introductory Comments

3:50 PM Invited
Characterization and Modeling of Deformation Mechanisms in Ni-base Superalloy 718: Duchao Lv[1]; Yunzhi Wang[1]; Don McAllister[1]; *Michael Mills*[1]; [1]The Ohio State University

Although the relationships between processing and the resulting properties are relatively well known for alloy 718, a better understanding of the deformation mechanisms activated across its usable temperature range is needed to create more mechanistically accurate property models. In this work, direct atomic-scale imaging with high angle annular dark field scanning transmission electron microscopy has been complemented by phase field modeling informed by generalized stacking fault surface calculations using density functional theory. This coupled experiment/modeling approach has shed light on the complex shearing processes occurring in alloy 718 following a standard commercial heat treatment, which produces both monolithic γ and γ" particles, as well as composite particles. Deformation at room temperature occurs through complex shearing of γ" into intrinsic stacking fault configurations that were restricted to the precipitates. Exploration of possible shearing sequences with the aide of phase-field dislocation dynamics has revealed that precipitate shearing by motion of coupled 1/2<110> dislocations of non-parallel Burgers vectors on the {111} glide plane is the dominant deformation mechanism at lower temperature. Microscale mechanical testing is also in progress to explore the existence of an anisotropy in strength. Deformation at higher temperature (up to 650°C) revealed a distinct transition in deformation modes, including stacking faults extending into the matrix, as well as microtwinning. Notably, in this temperature regime, the yield strength becomes rate sensitive, indicting that the stacking fault and microtwinning modes are temperature and rate-dependent. The sources of the microtwins, and the possible origin of this rate dependence, will be discussed.

4:15 PM Invited
Development of an Automated Property Simulation Tool for Direct Aged Alloy 718 Engine Disk Forgings: *Martin Stockinger*[1]; Aleksandar Stanojevic[2]; Volker Wieser[3]; Peter Raninger[4]; [1]voestalpine BÖHLER Aerospace GmbH & Co KG; [2]voestalpine BÖHLER Aerospace & Co KG; [3]voestalpine BÖHLER Edelstahl GmbH & Co KG; [4]Materials Center Leoben Forschung GmbH

As the optimization of highly demanding engine parts like engine disks pushes the used materials to their limits, the estimation of the material properties becomes increasingly important. The complex interactions of strengthening mechanisms in direct aged (DA) Alloy 718 forgings demand detailed modeling of each mechanism. As some strengthening mechanisms are influenced during the billet processing it is essential to consider the forging stock manufacturing in the design process of forged engine disks. Therefore a finite element analysis of the billet processing was incorporated in an existing simulation chain of the die forging process of engine disks. It includes all thermo-mechanical operations after vacuum arc remelting, i.e. homogenization, upsetting, drawing and radial forging of the billet as well as prepressing, forging and heat treatment of a disk. In order to implement the local deviations of microstructure caused by the billet processing a newly developed grain class model was applied. Furthermore a duplex microstructure, which is often present in the surface region of the billet, was considered using the grain class model. For a sound precipitation modeling the local temperature history of the whole simulation chain was considered in the thermo-kinetic software tool MatCalc. After parametrization of the MatCalc model parameters the precipitation, solid solution and grain boundary contribution to the total yield strength was calculated. For the determination of the DA-effect a semi-empirical, deterministic model was developed. The established, automated simulation chain takes all mentioned mechanisms into account and calculates the local yield strength of the forged engine disk.

4:40 PM
Study of the Oxidation-assisted Intergranular Cracking Mechanism on a Ni-base Superalloy: *Julien Milanese*[1]; Eric Andrieu[2]; Jean-Baptiste Osio[3]; Joël Alexis[4]; Didier Bardel[5]; [1]AREVA NP/CIRIMAT; [2]CIRIMAT; [3]Midival; [4]LGP; [5]AREVA NP SAS

In order to collect accurate information about the widely reported Oxidation Assisted Intergranular Cracking (OAIC) mechanism of the superalloy 718 at 650°C in air environment, we investigated a new tensile test procedure which enables to have access to a quantitative semi-continuous assessment of the damaging process of the alloy 718 during a standard tensile test. Tensile tests were carried out on a solutionized and aged alloy 718 by varying the deformation mode of the alloy during the ongoing experiment. The semi-continuous quantification of the intergranular damage was performed after a fracture surface analysis of samples tested in both Dynamic Strain Ageing (DSA) domain and DSA-subdomain where Portevin-Le Chatelier (PLC) effect occurs. This innovative testing method allows to characterize the intergranular damage that occurs when the material is stressed with an unserrated DSA deformation mode as the alloy 718 is only sensitive to OAIC in this domain. In these conditions, the onset of the intergranular cracking process was found to be around 10% of total strain. An increase in the cracking kinetic when necking occurs was also noticed. A close connection between the intensity of the intergranular damage and the cumulated strain in DSA deformation mode before the onset of the damaging process was found. The gathered information represents a significant improvement in the understanding of still debated OAIC or Stress Corrosion Cracking (SCC) mechanisms.

5:00 PM
Optimization of the Forging Process Window in Respect of AGG, IGG and Direct Age Effect in Alloy 718 Engine Disks: *Aleksandar Stanojevic*[1]; Christian Bucher[1]; Bernd Oberwinkler[1]; Martin Stockinger[1]; Markus Gruber[2]; [1]voestalpine BÖHLER Aerospace GmbH & Co KG; [2]Research Center for Non Destructive Testing GmbH (RECENDT)

Alloy 718 is commonly used for engine disks in jet turbines for aircrafts. The very demanding loading conditions require top notch mechanical properties of the material. In order to maximize the mechanical properties a perfect use of the direct age (DA) effect is necessary. An optimal DA effect contributes approximately 150 MPa to the total yield strength. However, the effect is only present in a certain, narrow process window. It was observed that small deformations at specific local temperatures during the last forging step lead to an ideal DA-effect. As the ideal process window in respect to the DA-effect can hardly be maintained in the whole forging, regions with a decreased DA-effect occur. A connection between the regions with decreased DA-effect and abnormal respectively irregular grain growth (AGG and IGG) was analyzed based on forging simulations. Therefore, the meta-dynamic recrystallization velocity parameter v_mrx was developed for indication of AGG and IGG. A correlation of the introduced parameter and the DA-effect was found. In addition v_mrx was used for the design of solution annealed forgings containing coarse grain regions. Those forgings were manufactured and analyzed using laser ultrasonic testing (LUS) and metallography on cut-ups. The occurrence of ALA grains was identified but no white spots (light etch indications) were found.

5:20 PM
Stress Relaxation Behavior Comparison of Typical Nickel-base Superalloys for Fasteners: *He Jiang*[1]; Jing Yang[1]; Jianxin Dong[1]; Maicang Zhang[1]; Zhihao Yao[1]; Xishan Xie[1]; [1]University of Science and Technology Beijing

In the present work, stress relaxation behavior of three typical nickel-base Superalloys: Alloy 718, Waspaloy and AEREX 350, were investigated in a temperature range of 600-800 °C for up to 10 hours. The effects of stress relaxation parameters on behavior were analyzed and stress relaxation characteristics of the three superalloys are compared and mechanisms revealed by FESEM and TEM observation. The study results show that the stress relaxation property of Alloy 718 is very sensitive to temperature. It is very stable at 650 °C, but decreases extremely with temperature increasing to 750 °C as a result of serious microstructure degeneration. Moreover, stress relaxation stability is related with initial stress, and appropriate increase of initial stress under normal service temperature can increase the stress relaxation limit of Alloy 718. The stress relaxation resistance of Waspaloy decreases with increasing temperature. The increase of initial stress and initial strain is beneficial for stress relaxation resistance of Waspaloy, but the influencing degree is related with temperature. Furthermore, Waspaloy with heat treatment A (1020°C×4h/AC+845°C×4h/AC+760°C×16h/AC) shows better stress relaxation resistance than that with heat treatment B (1080°C×4h/AC+845°C×24h/AC+760°C×16h/AC). In addition, stress relaxation stability of AEREX 350 is the best among the three superalloys in the temperature range of 600-800°C on the whole. The combined effect of \947:' phase and η phase guarantee the stress relaxation property of AEREX 350.

5:40 PM
Enhanced Strength of Inconel 718 by High Rate Severe Plastic Deformation: *Prabhat Yadav*[1]; Shashank Shekhar[1]; [1]IIT Kanpur

Inconel 718 is Ni-based super-alloy commonly used for manufacturing engine components in aerospace industry. Nickel based super-alloys are particularly well suited for service in high temperature environment where resistance to creep, corrosion and thermal shock are primary requirements. Alloy 718 forms various nano-precipitates which endow thermal stability to the microstructure up to 650°C due to grain boundary pinning of these nano precipitate. In order to further improve the strength of the alloy at elevated temperatures, we utilized high rate severe plastic deformation (HRSPD). Machining was used to impose HRSPD on the alloy, and the chip formed was used to study the response of thermomechanical process. Machining led to significant microstructural transformation and resulted in "bi-modal" grain size distribution. Grain refinement led to significant increase in strength. Further improvement in strength was attained after extended heat-treatment at 600°C for 10hrs. This increment in strength can be attributed to the formation of nano precipitate which result in obstructing dislocations movement and pinning of grain boundaries. However, it is known that deformed microstructure with very fine grains saturated with dislocations, result in brittle behaviour of alloy rendering them unusable for most applications. In order to alleviate this problem, post-process heat treatment was designed. Three different temperatures were selected for short heat-treatment at 700°C, 800°C and 900°C for 15minutes. This short treatment resulted in varying amount of recrystallization of the matrix and precipitation and ripening of γ' and γ" phases. Transformation in microstructure and ensuing properties after thermomechanical processing are discussed in this paper.

Alternative Processes

Wednesday AM	Room: Marquis Ballroom
June 6, 2018	Location: Marriott City Center

Session Chair: Eric Ott, GE Aviation

8:00 AM Introductory Comments

8:05 AM Invited
Alloy 718: Laser Powder Bed Additive Manufacturing for Turbine Applications: *Rajendra Kelkar*[1]; Amber Andreaco; Eric Ott; Jon Groh; [1]GE Additive

Alloy 718 has been utilized successfully in both static and rotating turbo machinery applications for four decades. The combination of high strength, fatigue capability, rupture strength, corrosion and creep resistance at temperatures through 650°C are key attributes of this alloy. Conventional manufacturing routes include cast, wrought, sheet, joining and fabrication by welding and brazing, powder metallurgical processing and metal injection molding. Recent investigation of aerospace materials like Alloy 718 produced by additive manufacturing technology has provided an opportunity for disruptive component manufacturing methods, geometries, and component capabilities which expand design space for complex applications. At GE Aviation (GEA), development of laser powder bed direct metal laser melting (subsequently referred to as DMLM) Alloy 718 was a natural choice following the successful commercial application of DMLM CoCrMo in GE Aviation and Safran's LEAP platform fuel tip component and the GE90 T25 sensor part. GEA's DMLM 718 development started with demonstrator military applications, and now has expanded to include multiple commercial engine applications across the size range of the GEA product line. The additive (laser) process development for Alloy 718 involved a combination of laser processing parameter investigation and heat treatment development to produce both acceptable build geometry and metallurgical microstructures. Initial developments started with 20 microns build layer thickness, and expanded to 50 microns thicknesses for improved build productivity. From the onset, the materials engineering focus was on isotropic, fine grain, pore free and fully developed microstructures for Alloy 718 by heat treat design. Mechanical characterization included consideration of build direction, machine type, machine to machine variation and processing gas effects. This paper will discuss various metallurgical challenges and related, microstructure & mechanical characterization of DMLM Alloy 718.

8:30 AM Invited

Progress in the Processing and Understanding of Alloy 718 Fabricated through Powder Bed Additive Manufacturing Processes: *Michael Kirka*[1]; Alex Plotkosky[1]; Ryan Dehoff[1]; Suresh Babu[2]; [1]Oak Ridge National Laboratory; [2]University of Tennessee

Additive manufacturing (AM) technologies have grown in importance with their increasing maturity and understanding. Among the nickel-base superalloys that stand to benefit from the benefits of AM is Alloy 718 (718), the most widely used superalloy. While much is known about the phase kinetics and structure property relationships in traditionally processed 718; repeated thermal gyrations, rapid solidification, and high thermal gradients common to AM processes give rise to non-equilibrium phase kinetics and highly refined microstructures. To be discussed are ongoing efforts in understanding the process-structure-property relationships for 718 fabricated through both laser and electron beam powder bed processes. Specifically, the state of computational tools for predicting the process-structure-property relations in laser powder bed. Additionally, the discussion will place a special emphasis on the sensitivity of the resultant microstructure and texture in the electron beam process to process parameters and resultant influence upon high temperature properties of 718.

8:55 AM

Impact of Powder Variability on the Microstructure and Mechanical Behavior of Selective Laser Melted Alloy 718: *Chantal Sudbrack*[1]; Bradley Lerch[1]; Timothy Smith[1]; Ivan Locci[1]; David Ellis[1]; Aaron Thompson[1]; Benjamin Richards[2]; [1]NASA Glenn Research Center; [2]Northwestern University

Powder-bed additive manufacturing processes use fine powders to build parts layer-by-layer. Alloy 718 powder feedstocks for selective laser melting (SLM) additive manufacturing are produced commercially by both gas and rotary atomization and are available typically in the 10-45 or 15-45 μm size ranges. A comprehensive investigation was conducted to understand the impact of powder variability on the microstructure and mechanical behavior of SLM 718 heat treated to Aerospace Material Specification (AMS) 5664. This study included sixteen virgin powders and three once-recycled powders within the 10-45 and 15-45 μm size ranges that were obtained from seven direct source suppliers and one reseller. Although alike as highly regular spheroids, these powders showed distinct differences in composition (especially Al, C and N contents), particle size distributions, and powder features such as degree of agglomeration, fusion and surface roughness. Compositional differences expectedly had the strongest impact on microstructure. High N and C contents formed TiN-nitrides and/or (Nb,Ti,Mo)-C carbides on the grain boundaries, prevented recrystallization during heat treatment, and resulted in retained (001)-scalloped shaped grains that ranged from 19 to 41 μm in average size. In the absence of this particle pinning, the average grain size of the heat treated SLM 718 ranged from 51 μm to 90 μm. Room temperature tensile and high cycle fatigue (HCF) testing compared as-fabricated (AF) and low stress ground (LSG) surface conditions. Tensile testing revealed consistent behavior between the two surface conditions and amongst the powder lots. The finer grained SLM 718 builds displayed the lowest tensile properties. A SLM 718 build fabricated from a powder with eight times lower C content showed statistically better tensile properties presumably due to enhanced coarsening of δ-Ni3Nb precipitates. The specimens from once-recycled powders had slightly higher tensile strengths and slightly higher ductility compared to their virgin equivalents; once-recycling also did not substantially degrade the mean HCF life. The LSG fatigue lives agreed with conventionally manufactured 718 data, while AF lives exhibited a knock-down due to surface roughness. The fatigue lives of AF specimens were statistically equivalent across powder lots except for one and failures typically initiated at stress concentrators associated with SLM surface asperities. Fatigue testing of low stress ground specimens result in both transgranular and within facet crack initiations. More than half of the cracks initiated from these facets for the machined condition; however, these facets appeared to be within grains that were larger-than-average in size. A nitrogen-atomized powder with fine prior particles of TiN-nitrides and M(Ti,Nb,Mo)C carbides from atomization on powder surfaces resulted in the best fatigue performance with segregation of these particles to the SLM 718 grain boundaries leading to higher resistance to early-stage crack propagation. Typically the fine-grained builds with minor phases along the grain boundaries did not perform well in fatigue, whereas a larger-grain build with lower carbon content and coarser δ-Ni3Nb precipitates showed the next best HCF response. Further details of the build microstructure and its impact on tensile and fatigue behavior was considered.

9:15 AM

Microstructure Development in Track-by-track Melting of EBM-manufactured Alloy 718: Paria Karimi[1]; Dunyong Deng[2]; Esmaeil Sadeghimeresht[1]; Jonas Olsson[1]; *Joakim Ålgårdh*[3]; Joel Andersson[1]; [1]University West; [2]Linköping University; [3]Swerea KIMAB AB

Electron beam melting (EBM) is a powder-bed fusion process within the group of additive manufacturing (AM) technology that is used to fabricate high performance metallic parts. Iron-Nickel base superalloys, such as Alloy 718, are subjected to successive heating and cooling at temperatures in excess of 800°C during the EBM process. Characterization of the dendritic structure, carbides, Laves and d- phase were of particular interest in this study. These successive thermal cycles influence the microstructure of the material resulting in a heterogeneous structure, especially in the building direction. Hence, the aim of this study was to gain increased fundamental understanding of the relationship between the processing history and the microstructure formed within a single layer. Different numbers of tracks with equal heights were for this purpose produced, varying from one to ten tracks. All tracks used the same process parameters regardless of number and/or position. Microstructure characteristics (sub-grain structure, grain structure and phases) were analyzed by optical microscopy, scanning electron microscopy equipped with energy disperse spectroscopy and electron backscatter diffraction. The direction of dendrites changed in the overlap zones within the tracks due to re-melting of material in the overlap zone. The primary dendrites arms spacing were slightly increasing along multi-tracks owing to decreasing cooling rate by addition of next tracks. Epitaxial growth of grains were observed in all sample due to partial re-melting of grains in previous layers and surface nucleation was also found to occur in all tracks.

9:35 AM

To be anounced.

9:55 AM Break

Microstructure IV: Alloy Effect and Alloy Development

Wednesday AM	Room: Marquis Ballroom
June 6, 2018	Location: Marriott City Center

Session Chair: Chantal Sudbrack, QuesTek Innovations, LLC

10:30 AM Introductory Comments

10:35 AM

Experimental TTT Diagram of HAYNES 282 Alloy: *Michael Fahrmann*[1]; Lee Pike[1]; [1]Haynes International Inc.

HAYNES® 282® alloy was developed by Haynes International as an age-hardenable, yet fabricable, wrought Ni-base superalloy. To date, the alloy has been specified for a number of applications, most notably in the hot sections of both aero- and industrial gas turbines. A Time-Temperature-Transformation (TTT) diagram is a useful guide to assess an alloy's behavior during thermo-mechanical processing and heat treating. Starting with the (commercially relevant) 1149oC (2100oF) mill-annealed condition, a time (0.1 hours to 100 hours) - temperature (649-1121oC (1200-2050oF)) exposure matrix was executed. Precipitates, which had formed as a result of these exposures, were analyzed by light microscopy, scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS), and, in selected cases, by x-ray diffraction (XRD). Chiefly, g' and two types of carbides, Cr-rich M23C6 and Mo-rich M6C, were found. Approximate C-curves for these phases were constructed, and some implications for the alloy's processing and properties characteristics are discussed.

10:55 AM

Development of Ni-base Disk Alloy for Large-size Gas Turbines by Improving Macrosegregation Property of Alloy 718: *Takashi Shibayama*[1]; Jun Sato[1]; Naoya Sato[2]; Toshiaki Nonomura[2]; Eiji Shimohira[2]; Toshihiro Uehara[2]; Shinya Imano[1]; [1]Mitsubishi Hitachi Power Systems, LTD.; [2]Hitachi Metals, Ltd.

Alloy 718, a high-strength Ni-base superalloy, is used for the gas turbine disks of aircraft engines and thermal power generation plants. However, macrosegregation defects often form in larger ingots, making it difficult to apply Alloy 718 to large-size industrial gas turbine disks. In order to improve the macrosegregation properties of Alloy 718, the chemical composition was modified using calculation phase diagrams. The macrosegregation defect type of Alloy 718 is a sinking type. According to the difference in density $\Delta\rho$ calculated using the Scheil-Gulliver equation, it is found that W, which contributes to the same solid solution strengthening as Mo, could strongly enhance floating-type macrosegregation defects. Therefore, it is possible to suppress sinking-type macrosegregation defects by W addition. A new high-strength Ni-base superalloy (named FX550) for large-size gas turbine disks has been developed by substituting W for Mo on the basis of Alloy 718. The microstructure, mechanical properties, and macrosegregation properties of forging were investigated. According to the experimental results, the microstructure, microstructure stability, and tensile strength of FX550 were confirmed as being the same as those of Alloy 718. The macrosegregation properties of FX550 were also similar to those of Alloy 706, which is used for large-size gas turbine disks. This paper presents an alloy design method for improving the macrosegregation properties of Alloy 718. In addition, the trial status of a large-size disk is described.

11:15 AM

Depletion Induced Grain Growth in Alloy 751 after Long Term Aging and Its Effect on Fatigue: *Mark Veliz*[1]; [1]Caterpillar Inc.

Expected service lifetimes for high temperature components can be many thousands of hours, and during this time microstructural degradation including surface oxidation are major concerns for the designer. Nickel based alloy 751 in two different grain sizes was subjected to exposure at 875°C for up to 4,000 hours in air. Fatigue testing was performed at 840°C after exposure and the microstructures and fracture surfaces were characterized. Both grain sizes had similar amounts of oxide and alloy depletion, but it was found that the fine-grained material experienced significant depletion induced grain growth in the near-surface region. While 875°C is significantly below the temperatures where grain growth is active for the bulk alloy composition, the depletion of Al, Ti, and Cr in the near surface region decreased the γ' solvus and increased grain boundary mobility. Property testing was performed on the as-oxidized surfaces as well as post-machined surfaces to study the effect of this microstructural change. The experimental results show that the coarse-grained material had longer fatigue life after 4000 hours, and that surface degradation had a more significant effect on the life of the fine-grained material.

11:35 AM
Compositional Design and Mechanical Properties of INCONEL® Alloy 725 Variants: *Martin Detrois*[1]; Kyle Rozman[1]; Paul Jablonski[1]; Jeffrey Hawk[1]; [1]National Energy Technology Laboratory

With a combination of high strength, toughness and resistance to corrosion, INCONEL® alloy 725 has been widely used in marine, aerospace, and land-based power industries. Typically, the alloy presents a conventional precipitate-strengthened γ-γ/ γ" microstructure when appropriate aging treatments are employed. Although the corrosion resistance of INCONEL® alloy 725 is significant, its use is limited to relatively low temperatures when compared to other γ' precipitate-strengthened Ni-based superalloys. This can limit the use of the alloy as turbine engine components or in other power-generation applications since future engine designs suggest increases in the operating temperature. This investigation aims at modifying the composition of the alloy to assess its high-temperature mechanical properties. Variations to the Ti/Al ratio were considered with respect to the precipitate phases stability as well as additions of Ta and Nb. Thermodynamic and kinetic predictions, such as phase fraction/stability and time–temperature–transformation diagrams, were used to help in the design process and were validated experimentally. The various compositions and relative aging treatments investigated produced microstructures differing in grain boundary phases and γ' precipitate sizes and fractions. Tensile and creep testing were performed and the effect of the various compositions and microstructures on the mechanical performance of the modified INCONEL® 725 alloys was examined.

Microstructure V: Structure Development in Additive

Wednesday PM	Room: Marquis Ballroom
June 6, 2018	Location: Marriott City Center

Session Chair: Karl Heck, Carpenter Technology Corp

1:30 PM Introductory Comments

1:35 PM
Quantitative Texture Prediction of Epitaxial Columnar Grains in Inconel 718 Processed by Additive Manufacturing: *Jian Liu*[1]; Qian Chen[1]; Yunhao Zhao[1]; Wei Xiong[1]; Albert C. To[1]; [1]University of Pittsburgh

The lack of a reliable theoretical model of the processing-microstructure relationship of AM (Additive Manufacturing) material is preventing AM technology from being widely adopted by the manufacturing community. The goal of this work is to establish the link between the microstructure (texture) and the process parameters of metal AM processes. A quantitative method based on the epitaxial growth of columnar grains within and across melt pools is proposed to predict the texture formation during a metal AM process. The state-of-the-art CALPHAD-informed FEM (finite element method) simulation has been used to predict the geometry and thermal profile of the quasi-steady melt pool. The thermal gradient distribution within the 3D melt pool determines the crystallography direction and growth direction of the columnar grains within each deposited single tracks. The single tracks with the predicted geometry are amalgamated together to represent the bulk part, and the epitaxial growth of grains across the boundary of neighboring tracks are quantitatively modeled. The proposed method is calibrated and validated by experimental studies of metal AM processed Alloy 718.

1:55 PM
The Effect of Location and Post-treatment on the Microstructure of EBM-built Alloy 718: *Sneha Goel*[1]; Jonas Olsson[1]; Magnus Ahlfors[2]; Uta Klement[3]; Shrikant Joshi[1]; [1]University West; [2]Quintus Technologies AB; [3]Chalmers University of Technology

Additive manufacturing (AM) of Ni-based superalloys such as Alloy 718 may obviate the need for difficult machining and welding operations associated with geometrically intricate parts, thus potentially expanding design possibilities and facilitating cost-effective manufacture of complex components. However, processing AM builds completely free from defects, which may impair mechanical properties such as fatigue and ductility, is challenging. Anisotropic properties, microstructural heterogeneities and local formation of undesired phases are additional concerns that have motivated post-treatment of AM builds. This work investigates the microstructural changes associated with post-treatment of Alloy 718 specimens produced by Electron Beam Melting (EBM) for as-built microstructures at 3 build heights: near base plate, in the middle of build and near the top of the build. Two different post-treatment conditions, hot isostatic pressing (HIP) alone and a combined HIP with solutionising and two-step aging were examined and compared to the results for the as-built condition. The influence of various post-treatments on minor phase distributions (δ, γ", carbides), overall porosity, longitudinal grain widths and Vickers microhardness was considered. The HIP treatment led to significant reduction in overall porosity and dissolution of δ phase, which led to appreciable grain growth for both post-treatment conditions. The variation in hardness noted as a function of build height for the as-built specimens was eliminated after post-treatment. Overall, the hardness was found to decrease after HIP and increase after the full HIP, solutionising and aging treatment, which was attributed to dissolution of γ" during HIP and its re-precipitation in subsequent heat treatment steps.

2:15 PM
Oxidation-assisted Cracking at 650 °C in superalloy 718 manufactured by Laser Beam Melting: Effect of temperature and strain rate: *Alexandre Pancou*[1]; Eric Andrieu[1]; Arnaud Votié[2]; [1]CIRIMAT; [2]Fusia Groupe

Additive manufacturing of complex parts in superalloy 718 by Laser Beam Melting (LBM, also referred to Selective Laser Melting, SLM) is currently under the evaluation by the aerospace industry, due to the opportunity to combine alloy 718 excellent properties and versatility of use, with the benefits and increasing maturity of LBM technology. In this work, the interactions between fracture modes and deformation modes for LBM-manufactured 718 were studied at 20, 450 and 650 °C. Vertical and horizontal tensile specimens were fabricated, then heat-treated with two sets of standard solution-aging treatments, before being tested in air over a range of strain rate from $8.10^{-5}s^{-1}$ to $3.10^{-2}s^{-1}$. Results of these tests showed evidence of a coupling effect between oxidation and mechanical loading, resulting in oxidation-assisted cracking of LBM 718 alloy for the same temperature and strain rate conditions than conventionally-manufactured alloy 718. Also, in spite of consisting of fundamentally different microstructures, relationships between fracture modes and deformation modes for laser beam melted 718 were found to be surprisingly consistent with the ones previously established for conventional 718. These results suggests that microstructure parameters such as grain size and morphology, or phase distribution are not involved at the first order in the mechanisms controlling these interactions. To further describe these phenomena, the interactions between solute elements, mobile dislocations and interfaces must be considered.

2:35 PM
Machine learning to optimize additive manufacturing parameters for laser powder bed fusion of Inconel 718: *Branden Kappes*[1]; Senthamilaruvi Moorthy[1]; Henry Geerlings[1]; Aaron Stebner[1]; Dana Drake[1]; [1]Colorado School of Mines

Approximately 6000 samples have been printed to characterize the build parameters for SLM of Inconel 718. The tested samples connect the microstructure and mechanical properties to laser power, speed, spot size, powder size, shape and part orientation. These data serve as the basis for development of machine learning (ML) algorithms — including decision trees, scalable vector regression, random forest networks and deep learning networks — that focus on two-way modeling of process-property and process-structure relationships. Our results show how these parameters effect mechanical performance through microstructure, particularly keyhole and lack-of-fusion porosity defects. We will present on the data collection, processing, validation and distribution framework; on ML performance, accuracy and validation procedures; and conclude with a brief discussion on the extension of this model to other data input streams and materials systems.

2:55 PM Concluding Comments

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Y

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