

AN INDEPENDENT STUDY

Can HIP'ing Restore And Strengthen Mechanical Properties Of Engine Run Gas Turbine Components, And Components Produced By Additive Manufacturing.

BY WARREN MIGLIETTI, PH.D., FALL 2020

2020 HIP'ing Study

INTRODUCTION

The technology of Hot Isostatic Pressing (HIP'ing) has been around for decades and was used to consolidate powder particles together to produce powder metallurgy components. Later this technology was utilized to consolidate porosity in investment casting. Investment castings have typically replaced many components fabricated by the powder metallurgy (PM) route.

Figure 1 shows a microstructure (left hand side) of an investment cast component exhibiting high or unacceptable porosity and the same figure shows a microstructure (right hand side) of the absence/collapse of the micro pores as a result of the HIP'ing process, which is performed at high temperatures (e.g. 2150—2250°F) at high argon pressures of 15ksi – 25ksi and for 2 – 4 hours for Nickel base superalloy material. — continued on page 2

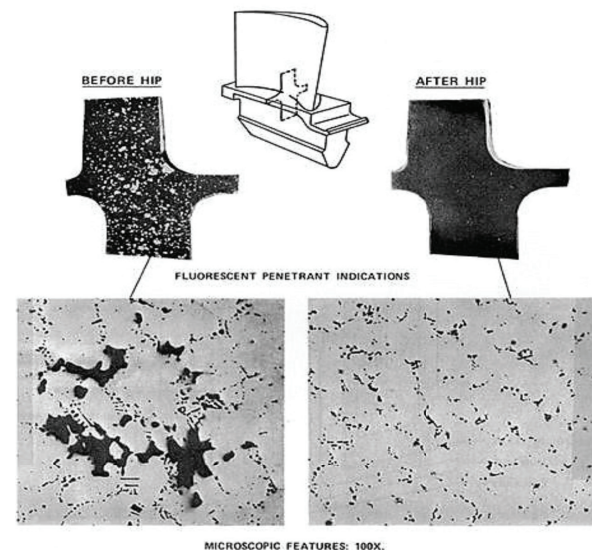


Figure 1: Collapse of microporosity as a result of the HIP (Hot Isostatic Press) process/technology

Today, HIP'ing is utilized not only in the investment casting industry to reduce porosity, it is utilized in the repair process to rejuvenate the base metal of Ni-base superalloy gas turbine engine components, so that these expensive components can operate beyond the OEM design limits. The gas turbine engine components are extremely expensive (a set of blades/buckets can easily be over a \$1Million) so the User or Operator of the gas turbine engine wants to operate these components for as long as possible to get the best return on their investment.

The latest trend nowadays is to use the HIP'ing process to consolidate the microstructure of components fabricated via the Additive Manufacturing (AM) Process. The AM process needs no introduction as this field of technology is in rapid development and utilization.

THE SYNOPSIS

For those not familiar with how gas turbine components operate, simplistically a User or Operator of a gas turbine engine, be it for power/electrical generation via an Industrial Gas Turbine (IGT) engine or for flight/aviation via a jet engine, purchases the engine new. Then the engine is operated for a period of time, e.g. for an industrial gas turbine engine it may be 24,000 hours or 3 years. After operating a service interval, the components are repaired and put back into service for another “tour of duty”/operating interval. In the IGT industry there is no regulatory body such as the Federal Aviation Authority (FAA) for the aviation industry, resulting in no 2 companies repairing the hot section IGT turbine components the same way. After a period of time, usually after 9 years, the User or Operator has to decide on whether to purchase new components or rejuvenate the material of the existing cast components and try get an additional service interval. The resulting 5 cases in this study will demonstrate how the HIP process is utilized to extend the life of these expensive hot section engine components to operate an additional service interval, sometimes even doubling the life of the components. — continued on page 3

The objective and goal of these case studies is to quantitatively highlight the use of HIP'ing in the following two industries:

GAS TURBINE INDUSTRY:

To repair expensive Ni-base superalloy gas turbine components to rejuvenate the base metal and extend their life.

ADDITIVE MATERIALS (AM) INDUSTRY:

To consolidate the microstructure of AM components to enhance their mechanical properties.

Subsequent cases for both industries will be released over the coming months this year or can be downloaded now on our website.

HOW THE ASSESSMENT WAS PERFORMED

The life assessment was performed to determine if the component can be operated for an additional service interval or whether the component should be scrapped, and new ones purchased?

Figure 2 below shows a scrapped engine run Fr7FA.03, stage 1 bucket. There are 92 of these 1st stage buckets in an engine set. Based on careful evaluation, a minimum of the worst 2 are removed from the engine test for metallurgical and destructive testing, the latter involving tensile testing and stress rupture testing of the engine run material.

The airfoil of the bucket is divided into 3 equal areas as shown in **figure 2**, at approximately 33% span, 66% span and removed at the platform fillet region.

Once the section of airfoil materials are removed as shown in **figure 3**, the goal is to try remove/excise a minimum of 2 specimens from the pressure side/concave side of the airfoil. The pressure side of the airfoil is the side where the writing is shown in **figure 3**. The back wall is the suction side, also referred to as the convex side. A minimum of 2 specimens are also removed from the suction side wall of the scrapped bucket.

Once the section of airfoil is removed, one can send the material to approved NADCAP or ISO certified laboratories throughout the United States, or if one has an in-house laboratory, the machining of sub-size tensile and stress rupture specimens can be performed as shown schematically in **figure 4**. Not only are samples removed from the airfoil, which see high temperature exposure and high levels of stress/strain, samples are also removed from the root of the blade, which are not exposed to high temperature and have minimal microstructure degradation. — continued on page 4



Figure 2: Scrapped Fr7FA.03, stage 1 bucket after 3 engine service (hot gas path) intervals



Figure 3: Section of the airfoil removed by water-jet cutting for destructive analysis



Figure 4: Schematic of removing tensile and stress rupture specimen from the airfoils.

HOW THE ASSESSMENT WAS PERFORMED

The goal is to obtain many sub-size specimens from the airfoil and root of the blades/buckets. There are approved sub-size specimens as designated by the ASTM standards.

Other sections of the bucket/blade may be cut up as shown schematically in **figure 5**, to perform metallurgical evaluations of the base metal on the optical or scanning electron microscopes.

A Life Assessment involves performing a full metallurgical evaluation of the blade representative of an engine set. In most cases at least 2 blades/buckets have to be sacrificed, i.e. totally destroyed. A sectioning plan for each component type is based on experience and is very important to determine local effects of:

- **Temperature**
- **Stress**
- **Oxidation**
- **Corrosion**
- **Erosion**
- **ETC.**

For the Additive Manufactured (AM) tensile specimen/samples, they were produced by the laser powder bed fusion process as schematically shown in **figure 6**, and thereafter the specimens were subjected to different heat treatments inclusive of the HIP'ing process. Thereafter tensile tests were undertaken as per the ASTM E8 specification and the results reported in each case study.

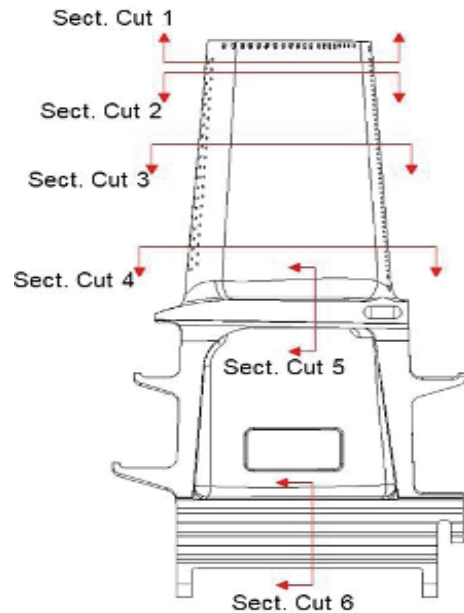


Figure 5: Schematic plan of where a blade/bucket may be sectioned to perform either metallurgical evaluations or mechanical property evaluations.



Figure 6: Tensile specimens produced in different orientations by the laser powder bed fusion AM process.

Now Introducing HIP'ing Services in our South Carolina Location

Accurate Brazing is a full-service vacuum brazing and heat treating enterprise with over 30 years in the business. Over that time, we've become adept at heat treating materials that include stainless steel, super alloys, copper, and refractory materials. Unlike competitors, Accurate Brazing has the unique expertise, capacity, and equipment to take new programs and get them into production quickly.

Due to an increasing need for perfect parts for demanding industries such as aerospace, medical, and casting, Accurate Brazing has recently invested in Quintus Hot Isostatic Pressing (HIP) Technology in our Nadcap certified facility in South Carolina. This will assist our customers with the need to get their components quicker and cheaper.



About the Author

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Dr. Miglietti is currently the President and Principal Metallurgical Consultant of Miglietti and Associates, LLC, a consultancy company based in Kansas City, Missouri. Prior to this he was Director of Repair Technology at ProEnergy and worked for 7 years at PSM-An Alstom Company. In addition he worked for 5 years at GE's Repair Development Center and 5 years for Sermatech International as a process repair engineer and as a component repair engineer respectively. His principal responsibility was the development of novel repair techniques and processes for components, operating in advanced land-based gas turbine engines, such as the Frame 7FA.03, GT24/26 and W501F/M501F engines. He has over 30 years of experience

and expertise in the Welding (GTAW and Laser), Brazing (Narrow and Wide Gap Diffusion), FIC, Acid Stripping and Heat Treatment of Ni and Co-base superalloys. Dr. Miglietti is the outgoing chairman of the Commission XVII – "Brazing and Diffusion Bonding" of the International Institute of Welding (IIW) and was past chairman of the Manufacturing, Materials and Metallurgy Committee of IGTI, an affiliate of ASME. He has authored or co-authored 47 technical papers and has 13 repair technology patents. Today, he has a strong focus on assisting clients with materials characterization and mechanical property evaluation of Additive Manufactured/3D printed components, as well as providing heat treatment information for these components.

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for Brazing, Heat
Treating, and Now,
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RAPID COOL

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HIP AND HEAT TREATMENT CAPABILITIES

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- Max Temperature: 2,282 F
- Max Cooling Rate: 390 F
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