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HIP Activities for Turbopump Components of Korea Space Launch Vehicle

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

Introduction

There is a series of space launch vehicle programs in Korea and they are named KSLV (Korea Space Launch Vehicle) programs [1]. The first program, KSLV-I was successfully launched in Jan. 2013 after two launch failures. The first stage of KSLV-I was developed in Russia and the upper stage was covered in Korea. Now KSLV-II program is in progress and the launch is scheduled in 2020. The vehicle is composed of three stages, the first stage with four 75 ton thrust engines, the second stage with a single 75 ton thrust engine, and the third one with a 7 ton thrust engine [2]. All of the vehicles are under development by Korea Aerospace Research Institute (KARI) in Korea, requiring precedent development of 75 ton thrust and 7 ton thrust liquid engines. The both engines employ pump-fed gas generator cycle with kerosene/LOx, and the turbopump consists of single-stage centrifugal pumps for each propellant and a single-stage impulse turbine in one axis. An Inter-Propellant-Separator (IPS) is installed between the oxidizer pump and the kerosene pump to avoid any interaction between propellants [3]. Fig. 1 shows 75 ton and 7 ton turbopumps under development in KARI. They completed performance tests and were assembled to engines, now the engines are undergoing ground performance tests.

Various materials are utilized to fabricate turbopumps. Especially heat resistant nickel alloys are widely used in oxidizer pump and turbines due to their excellent mechanical properties at extremely low or high temperature condition. These superalloys usually have poor machinability so that casting and powder sintering methods are known to be suitable fabrication methods. In the turbopumps of KSLV-II, the impeller of the oxidizer pump is of Inconel 718 alloy, and is manufactured by machining and brazing process. Also the turbine blisk is of the same material and is manufactured by electric discharge machining and turning operation. In this paper manufacturing of these items with hot isostatic pressing was investigated. For the turbine blisk, near-net shape processing with hot isostatic pressing was tried on the billets. And for the

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impeller, consumable cores with low carbon steel were used to make fluid passages through leaching process.

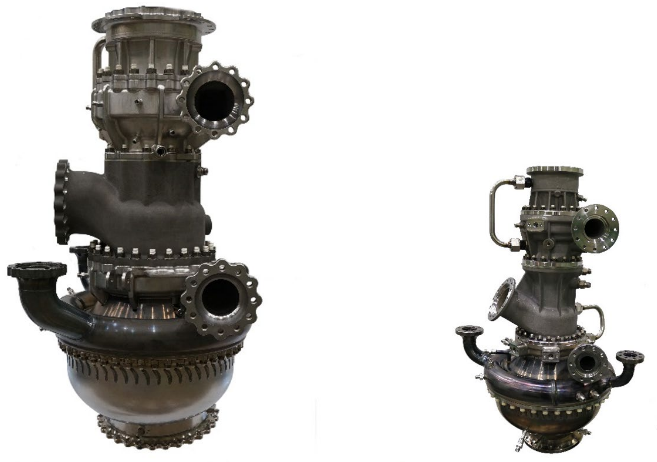

Fig. 1: 75 ton and 7 ton turbopumps developed by KARI

Manufacture of HIP billets for turbine blisk

The first step of introducing HIP process in the KSLV turbopump was manufacture of HIP billets for turbine blisk. Before that the blisk was made by cutting/turning and EDM machining from a forged Inconel 718 billet, and the mechanical machining processes were time consuming steps. Therefore near-net shape process with HIP operation was tried to minimize mechanical machining steps, leaving only EDM and final machining process.

Fig. 2: Canned metal powder before HIP(left), after HIP(center) and machined disk(right)

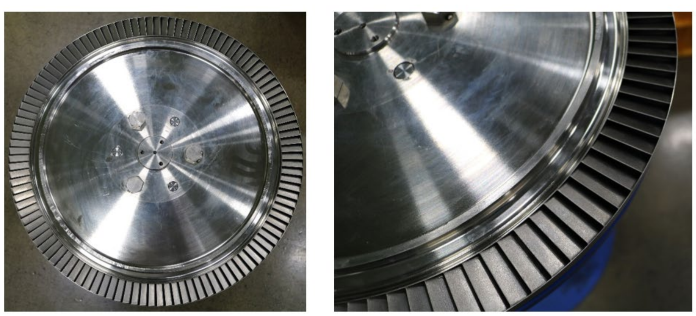

Fig. 3: Blades and shroud made by EDM machining

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Fig. 2 shows HIP process to make a billet for turbine blisk. After a blisk is obtained by HIP, EDM machining is applied from the both sides to implement blades and shroud as shown in Fig. 3. In the beginning, manufacturing billets of plain cylindrical disk was the main focus so that substantial amount of post process machining was required before the EDM process. Nowadays initial can shapes are being optimized to minimize subsequent machining.

Manufacture of Impellers

Impellers for oxidizer pump are also made from Inconel 718 due to its excellent cryogenic properties. Conventionally machining/brazing or casting methods are applied to these parts. Fig. 4 shows two impellers made with machining/brazing and investment casting.

Fig. 4: Machined/brazed impeller (left) and investment casted impeller (right)

It is well known that consumable, sacrificial metal core has to be used for HIP manufacture of shrouded impellers [4, 5]. At first step, fabricating simplified sample was tried with low carbon steel and nitric acid. The core and the sample are shown in Fig. 5.

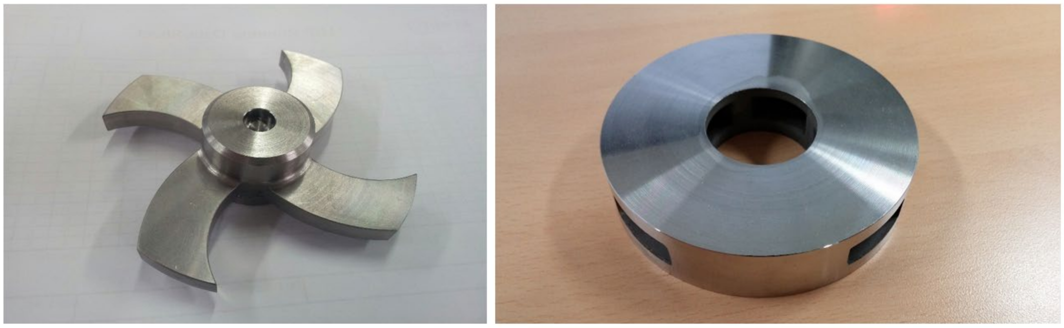

Fig. 5: Simplified, low carbon steel core and sample specimen

After sample trial, impeller of the oxidizer pump was selected as the next target. The fluid passage between blades has complex three-dimensional shape and that core making should start from the 3D modelling of it, as represented in Fig. 6. After the modelling process, a five-axis machining center was used to machine the core. As for the cans, they are of axisymmetric shape and can be machined by plain tuning operation. Plain low carbon steel was used for the core material, and STS 316 alloy for the cans.

Machined core and cans before HIP process are shown in Fig. 7.

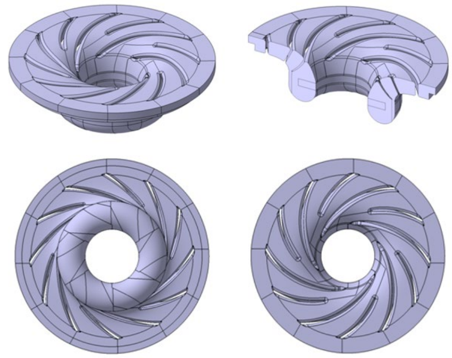

Fig. 6: 3D model of the consumable core

Fig. 7: Machined core and cans

After core and cans are assembled, Inconel 718 powder was filled up, and then the assembly was welded and evacuated before entering into the HIP furnace. HIP was done under temperature of 1160°C and pressure of 100 MPa for 4 hours. After HIP process the low carbon steel core was leached using nitric acid. The rest processes are final machining and coating to complete the impeller, as shown in Fig. 8.

Fig. 8: Core leached and machined impeller

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It is also known that carbon is diffused from the core to the impeller surface due to highly different carbon contents between low carbon steel and nickel base heat resistant alloys. Therefore it is recommended to remove a few microns of diffusion layer with some removal processes, such as chemical milling.

Fig. 9: Cut and leached impeller for inspection

Manufactured impellers were cut and inspected as shown in Fig. 10. The impeller was cut between hub and shroud, before leaching process. After leaching, blade and hub profiles were measured using a 3D coordinate measuring machine. Several cycles of trial and error for core design were necessary until satisfactory results were obtained.

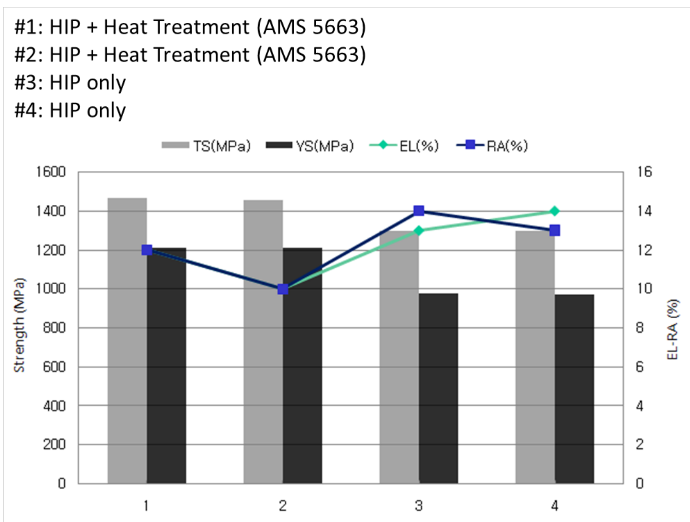

Fig. 10: Mechanical properties of HIP Inconel 718 specimens

Mechanical properties of HIP Inconel 718 specimens were measured using a tensile testing machine. The results are shown in Fig. 10, which complied with the AMS 5663 specification.

Conclusion

Manufacture of the billets for turbopump turbine blisk was performed using Inconel 718 powder. In the beginning a bulk cylindrical disk was manufactured, but can shapes are being optimized to minimize subsequent machining process. With the billets obtained, EDM and final machining were applied to complete the manufacture of the turbine blisk.

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Besides the turbine blisk, impellers for oxidizer pump were tried using leaching process of consumable core. Low carbon steel core was modeled, machined and then inserted into cans for HIP process. HIP was performed with Inconel 718 powder and with the core, which was later leached by nitric acid to implement blades and shroud of the impeller. The impellers were cut through the blades for inspection and measure, several cycles of core modeling and HIP were necessary to achieve satisfactory dimensional accuracy. Also HIP Inconel 718 specimens were prepared to measure the mechanical properties. They showed good strength and toughness results, in compliance with the AMS 5663 specification.

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