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Development and Manufacturing Technology of Prototype Monoblock Low Pressure Rotor Shaft by 650ton Large Ingot

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1. Introduction

With increasing demands of power generation efficiency and capacity in nuclear power plants up to about 1700 MW, the size of forged low pressure (LP) rotor shaft become gradually larger[1-3]. In Doosan Heavy Industries & Construction (DHI), large size of rotor shafts such as LP, high pressure(HP) and generator rotors have manufactured with 220 ~ 510 ton ingots for nuclear power plant by using 13,000 ton press. However, to meet increasing demands of nuclear power plant with high capacity, the technology for manufacturing over 600 ton of large ingot is necessary. Therefore, DHI has produced 650 ton ingot for a prototype monoblock rotor shaft in 2014, which has a maximum diameter of φ 2,800 mm, and investigated various properties such as mechanical properties, segregation of chemical composition, non-metallic inclusion and internal quality etc. The overall results were met in General Electric (GE) Specification for the properties of monoblock rotor shaft required. In this paper, the development and manufacturing technology of 650 ton large ingot with the internal quality and mechanical properties is described.

2. Manufacturing Processes

2.1 Design of 650 ton Ingot Mold

Generally, technology for manufacturing large ingot is very important with increasing the ingot size to control the shrinkage and segregation at the center and top of the ingot and non-metallic inclusions at the bottom of the ingot. Therefore, DHI has simulated by using MAGMASOFT® [4] and designed the shape of 650 ton ingot as shown in Figure 1. In this result, finally solidified region was sufficiently higher than the boundary between body and hot top of the ingot. This result is indicated that the internal defects of the ingot can be improved.

2.2 Production of 650ton Ingot

The 650 ton large ingot was produced by an optimized design of mold and refining process based on our know-how gained via previous experiences. In using electric arc furnace with the maximum capacity of 155 ton, the steel scrap was melted with five times and transferred to ladle refining process in each ladle. The chemical composition and temperature were separately controlled at ladle refining furnace in accordance with the vacuum pouring sequence. Table 1 shows the chemical composition of 650 ton ingot and this material is widely used in LP rotor shaft by GE specification. Figure 2 shows the multi-pouring process under vacuum atmosphere and the shape of 650 ton ingot after stripping.

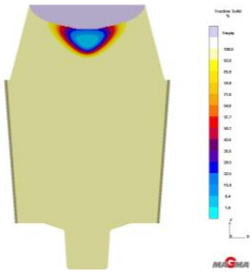

Figure 1 The simulation results of 650 ton ingot.

Table 1 Chemical Composition of 650 ton ingot (wt%)

C	Si	Mn	P	S	Ni	Cr	Mo	V
0.22	0.03	0.29	0.004	0.0009	3.6	1.7	0.4	0.08

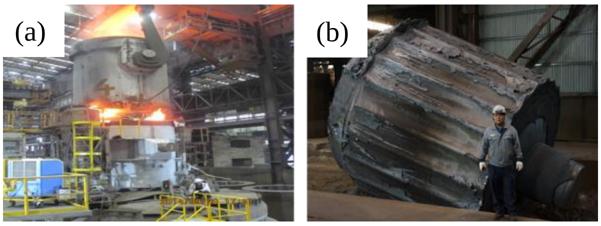

Figure 2 Ingot casting process (a) multi-pouring with vacuum system and (b) appearance of 650 ton ingot.

2.3 Forging Process

The 650 ton ingot was forged with cogging process by 13,000 ton open die press. To give sufficient forging effect for improving the micro structure and micro porosities, the Free from Mannesmann’s effect (FM) forging process was applied. The maximum body diameter of φ 2,800 mm was produced. To minimize the metal flow at top and bottom of the ingot, the ingot was divided into 3 blocks of top, middle and bottom. Figure 3 show the photograph of final forging operation.

2.4 Heat treatment

After forging process, the prototype monoblock LP rotor shaft blocks were carried out the preliminary heat treatment for the grain refinement and softening using horizontal gas furnace, which applied triple normalizing at the temperature of 870 ~ 995℃.

Figure 3 Appearance of prototype monoblock LP rotor shaft with φ 2,800 mm at finishing forging stage.

After that, quality heat treatment consisting of quenching and tempering, as shown in Figure 4, was carried out using vertical electric furnace and water tank. The tempering condition was controlled to meet mechanical properties required in GE specification based on our previous experience.

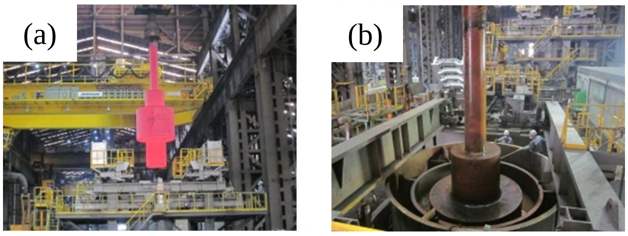

Figure 4 Heat treatment of prototype monoblock LP rotor shaft, (a) Quenching and (b) tempering.

3. Results

3.1 Mechanical Properties

The mechanical property tests of prototype monoblock LP rotor shaft were carried out at the surface and the center of the body block. Figure 5 shows the sampling positions and the results of tensile and yield strength at the surface and the center. They met the requirements of B50A375 in GE specification and also other properties such as sharpy impact, elongation, reduction of area and fracture appearance transition temperature (FATT) were in the range of the target.

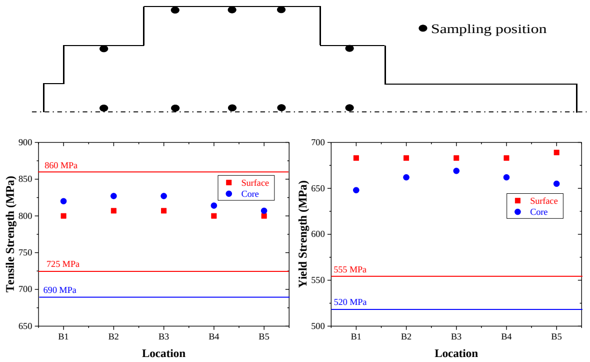

Figure 5 Mechanical properties of prototype monoblock rotor shaft.

3.2 Metallurgical Investigation

Chemical analysis was carried out at the center of each block by using spectrometer. Figure 6 shows the results of carbon concentration from the ingot bottom to the top. The carbon concentration increased slightly from the bottom to the top of the ingot in the ranges of 0.21~0.30%. The result met a target required in GE specification. The cleanliness was measured in accordance with JIS G0553. Figure 7 shows the results of cleanliness from the bottom to the top of the ingot and its rate was from 0.0029% to 0.0085% (Ave. 0.0049%) at each sampling point. These results indicated that the cleanliness was high throughout the 650 ton ingot.

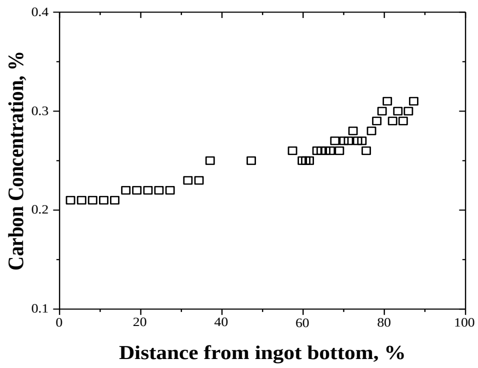

Figure 6 Results of carbon concentration.

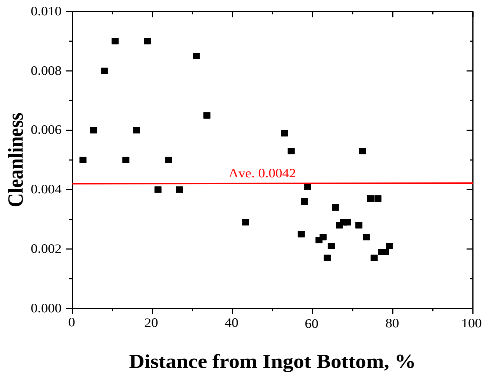

Figure 7 Cleanliness of prototype monoblock LP rotor shaft.

3.3 UT Inspection

After the quality heat treatment and the surface machining of prototype monoblock LP rotor shaft, the internal quality was inspected via an ultrasonic test in accordance with P3C-AL-2214-Rev. D. The minimum detectable defect size (MDDS) was 1.3 mm at the main body section. As the results of UT inspection, no indication was found and met the requirements.

4. Conclusions and Future Plans

In order to establish the manufacturing technology for monoblock LP rotor shaft, DHI has produced the prototype monoblock LP rotor shaft with a maximum diameter of φ 2,800 mm using 650 ton ingot and investigated the mechanical properties and the internal quality of the ingot. As a result, the quality and mechanical properties required the large rotor shaft for nuclear power plant met a target. These results indicate that DHI can be contributed to increasing demands with high efficiency and capacity at the nuclear power plant.

Additionally, some tests such as high cycle fatigue (HCF), low cycle fatigue (LCF), fracture toughness (K_{1C}/J_{1C}) and dynamic crack propagation velocity (da/dN) are in progress.

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