

Article

Engineering and Process of Investment Casting for Pump Impellers

Arif Dermawan¹, Agus Edy Pramono^{2*}

¹ Program studi perancangan, Jurusan Teknik Mesin, Politeknik Negeri Jakarta, Jl. Prof. G. A. Siwabessy, Kampus UI, Depok 16425, Indonesia

² Program studi Magister Terapan Rekayasa Teknologi Manufaktur Politeknik Negeri Jakarta, Jl. Prof. G. A. Siwabessy, Kampus UI, Depok 16425, Indonesia

* Correspondence: agus.edypramono@mesin.pnj.ac.id

Abstract: This article explains the investment casting process for manufacturing pump impellers. Investment casting is a metal casting process that utilizes ceramic molds. This system is employed to produce precise components compared to sand casting processes.

The fabrication of the metal pattern involves machining with dimensional adjustments. The dimensions are determined by adding the dimensional sizes, accounting for SS316L material shrinkage (2.5~3.5%), wax shrinkage (1%), and machining (5mm). The subsequent steps include wax injection to create wax patterns, the creation of a gating system, and ceramic sintering for molding. Wax patterns are produced separately for each part of the impeller and then assembled into a complete wax pattern that matches the impeller's geometry, including the gating system.

The wax patterns undergo multiple dipping cycles into slurry and stucco solutions, forming a thick ceramic layer around the wax impeller patterns. After the wax is melted from the ceramic mold, cavities are formed according to the impeller's geometry. Sintering the ceramic mold impeller at 1000°C results in a hard ceramic mold with cavities prepared to receive the molten metal.

The investment casting process for the pump impeller is now complete, and the pump impeller is further processed with precision machining to meet the specified dimensions, features, and geometry.

Keywords: Investment casting shell; pattern wax; ceramic shell; de-waxing; ceramic mold sintering

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1. Introduction

The purpose of this article is to elucidate the fabrication process and design of pump impellers through the utilization of the investment casting method.

Investment casting, a technique and process, offers an alternative to sand casting. Sand casting is a proficient method for rapid production, boasting low tooling costs and high design flexibility. However, it is imperative to take into consideration factors such as dimensional accuracy, surface quality, and specific defects within this process.

Investment casting serves as a method used to manufacture highly intricate and complex components or parts that are not feasible through other means. Investment casting has the capacity to produce components with precise dimensions, ideal for the manufacturing of extremely thin-sectioned parts. These parts exhibit a smooth final surface, negating the necessity for further finishing.

The investment casting technique has made significant contributions to transforming and modernizing the culture of ancient civilizations.

Investment casting played a pivotal role in technological evolution during World War II in the United States, as traditional machining processes couldn't meet the growing demand for wartime equipment. Investment casting was utilized to produce turbine blades and aircraft engines. The investment casting process has evolved from being a niche sector specializing in casting activities into a distinct industry [1].

This article aims to outline the steps involved in investment casting for the manufacturing of a pump impeller. It will also make reference to various articles that elucidate this process for comparative purposes.

In this study, Al₂O₃ powder with varying particle sizes was utilized as the matrix material. The creation of Ceramic-Inorganic Hybrid Composites (CIHCs) with different diameters involved the processes of stereolithography and gelcasting. Catalyst and initiator were introduced in the form of ammonium persulfate and N,N,N',N'-tetramethyl ethylenediamine, respectively. The monomer, crosslinker, and dispersant employed included acrylamide, N,N'-methylenebisacrylamide, and sodium polyacrylate. Vacuum impregnation was carried out using a SiO₂ solution, and deionized water was used to prepare the solutions in the experiments. Sodium alginate served as the thickening agent, while calcium phosphate, sodium hexametaphosphate, tribasic ammonium citrate, and hexane dioic acid were utilized for thickening Na-alginate [2].

In this study, Stereolithography (SL) and gel casting processes were utilized to create integral ceramic molds. SL prototypes were manufactured using photosensitive resin, and an alumina ceramic solution was prepared for the gel casting process. The ceramic solution was poured into the SL prototype and then polymerized to produce a green body. After the freezing, pre-curing, and post-treatment stages, the integral ceramic mold was successfully generated [3].

A ceramic mold, shaped like a shell, was prepared using filler materials, binders, anti-foaming agents, and moisturizing agents. These components included cobalt aluminate CA68 (C) as well as Zircon (-200#) (Z) and mullite (-200#) (M) as fillers. Two colloidal silica binders (SP 30 and SP ultra, referred to as binder A and binder B) were employed as binding agents. For mold creation, eight different types of ceramic solutions (MA, MA-C, MB, MB-C, ZA, ZA-C, ZB, and ZB-C) were formulated with the same composition. Solutions containing mullite filler and colloidal silica binders A and B were labeled as MA and MB, while those containing cobalt aluminate were denoted as MA-C and MB-C [4].

In this research, two shell molds (one from shell system I and one from shell system II) were utilized to produce LPT blades. The casting process was executed using a specialized solution under identical conditions. After the shell formation process, drying, wax removal, and heating procedures were carried out to enhance the strength of the shells. The melting and casting processes took place in a vacuum induction melting furnace, employing a nickel-based superalloy. The entire process was conducted within a controlled environment with a vacuum atmosphere. The end results comprised the shell molds and LPT blade components from both shell systems I and II [5].

This research involved the production of AlSi7Mg test blades through a combination of low-pressure die casting and ultrasonic refinement. This integrated technique yielded cast samples that were free from gas porosity and solidification defects, while also improving the mechanical properties of the alloy. The study indicates that the porosity observed is primarily a result of shrinkage, as evidenced by its irregular shape and its location among dendrites. The size of this porosity varies considerably. Round gas porosities were not detected, affirming the high effectiveness of ultrasonic degassing. Notably, the ultrasonic treatment significantly enhanced the mechanical properties of the alloy, particularly in terms of ductility. It is clear that the ultimate tensile strength, yield strength, and elongation experienced significant increases due to ultrasonic processing [6].

The existing stent manufacturing process is costly and encounters thermal challenges during laser cutting. There is a need to develop a new alternative for stent production,

especially when using magnesium alloys. In this study, a hybrid approach involving additional manufacturing techniques and investment casting within ceramic molds is utilized to efficiently and economically produce stents made of magnesium alloys [7].

In this study, the injection molding method is utilized to produce high-precision cores. This process comprises four stages: raw material preparation, element formation, adhesive removal, and sintering. The powder composition and particle size distribution are optimized to ensure the desired density after sintering. The primary raw material is liquid silica glass or quartz glass, known for its excellent thermal properties. Boron glass is introduced to enhance core sintering. Additional materials like ZrSiO_4 and Al_2O_3 are employed to reduce sintering shrinkage and enhance the core's dimensional stability during casting with liquid metal. Sintering is carried out at a maximum temperature of 1250 °C, with a temperature rise rate of 50 °C/hour and cooling at 100 °C/hour [8].

Deformation in hollow turbine castings is influenced by various interrelated factors. Turbine geometry can be determined through measurements or by using solidification simulation software. Geometric data can be represented in STL format for rapid prototyping and computer-aided manufacturing [9].

This research explores thermal resistance at the casting-mold interface to advance technology and reduce defects in investment casting. In this study, an analysis of thermal resistance at the casting-mold interface was conducted using the inverse heat conduction method. It was found that the heat transfer coefficient at the casting-mold interface is highest when the alloy is in the liquid state and then decreases significantly during solidification. A proposed mechanism for the formation of gaps between the ceramic mold and the casting is based on the formation of mixed oxide layers at the interface. Based on numerical simulations, it was determined that this heat transfer coefficient has a smaller impact on the cooling rate of the casting compared to mold thickness, thermal conductivity, and emissivity [10].

In this research, recycled foundry sand (WFS) is used to prepare insulating refractory materials. Additional ingredients such as kyanite, alumina, and plastic clay are incorporated to improve the refractory properties. The inclusion of wood powder is intended to create pores and enhance the material's porosity [11].

Porous ceramics have gained attention due to their lightweight properties, low thermal conductivity, high porosity, large surface area, and resistance to thermal shock. In this study, cornstarch is introduced into a suspension containing Al_2O_3 , SiO_2 , and MgO powders to create a homogeneous ceramic powder mixture. The primary material used is α - Al_2O_3 powder, with silica and MgO powders serving as sintering aids. Cornstarch functions as both a pore-forming agent and a binder, while an adhesive is created using a polyvinyl alcohol solution [12].

Reference studies indicate that most casting processes are conducted for aluminum materials. In this study, the closed pump impeller processed through investment casting is made of SS316L.

This article provides an in-depth exploration of the engineering and investment casting process for pump impellers, with a primary emphasis on the investment casting procedure. The manufacturing of the closed impeller is accomplished through investment casting, adhering to the API 610 standards.

2. Materials and Experiment Methods

The investment casting process is often used to create complex metal products, details and smooth surfaces. Such as engine parts, turbines, impellers and so on.

The general steps in the investment casting process are explained as follows:

1. Making dies from machining aluminium material
2. Making patterns or models of impeller products from wax materials. The pattern or model follows the size, shape and details of the final product impeller
3. Dipping or dyeing wax patterns in ceramic slurry liquid until the formation of ceramic molding

4. De-waxing or melting wax with a boiler from inside the ceramic molding, leaving empty space or cavity or cavity impeller shape like wax pattern
5. Ceramic sintering molding to dry it and harden the ceramic cavity mold
6. Pouring molten metal into a hard ceramic cavity and waiting for the metal to solidify
7. Release of impeller product casting objects from ceramic molding
8. Finishing and machining impeller products into impeller products according to design.

The impeller investment casting process follows the flowchart shown in Figure 1.

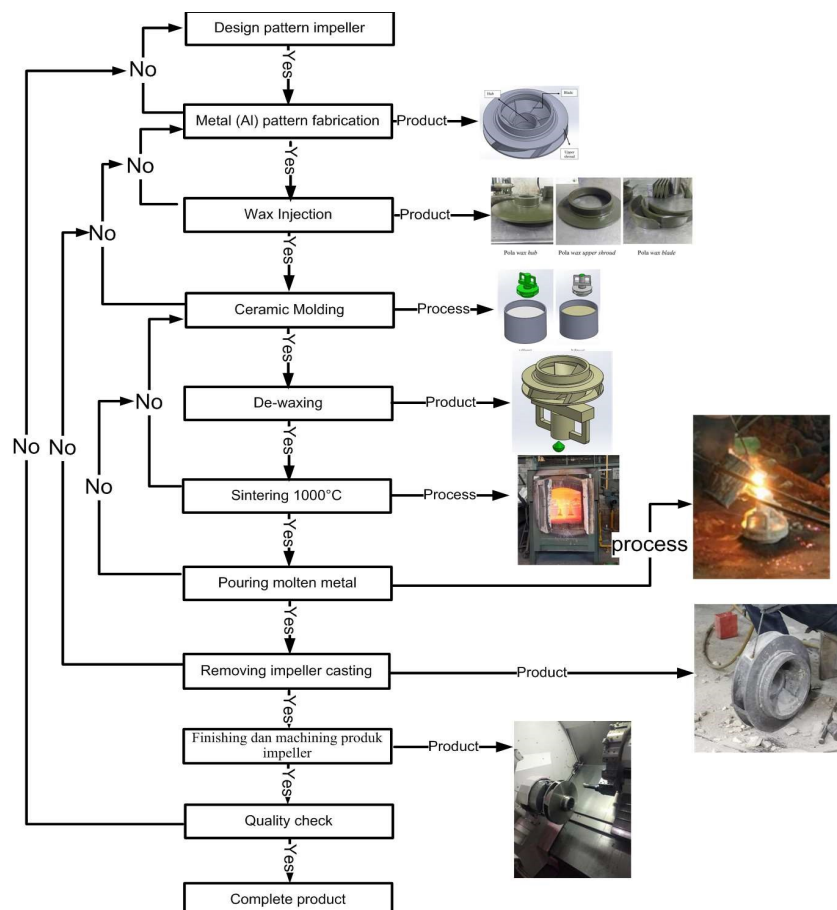


Figure 1. Investment casting fabrication process of pump impeller

3. Results and Discussion

3.1 Paternt fabrication or Impeller closed pattern

The closed impeller is a design type used in BB3 3-stage centrifugal pumps. The closed impeller features blades that fully cover its backside. This means that the fluid entering the impeller cannot flow back towards the source or the pump's suction side.

The blades close completely, the fluid is forced to move in the outward direction with a slight leak into the suction side. This results in a higher pressure at the pump output, which is useful in overcoming greater system pressures or pumping fluid to higher altitudes. The geometric impeller is shown in Figure 2.

In the impeller casting process, as shown in Figure 2, the impeller's geometry is created as a pattern and divided into three parts to form a wax replica of the impeller. These parts include the hub (as depicted in Figure 3), the upper shroud (as shown in Figure 4), and the wax mold for the impeller blades (illustrated in Figure 5).

The metal patterns, as shown in Figures 3, 4, and 5, are created with larger dimensions, considering the material shrinkage percentage, wax shrinkage percentage, and machining allowances. Therefore, the size of these metal patterns consists of the impeller size + material shrinkage percentage of the impeller + wax shrinkage percentage + the additional dimensions for further machining processes. Dimensions of the impeller are adjusted by adding material shrinkage following ASTM A-743 CF3M (SS316L) standard, wax shrinkage, and machining allowances. Shrinkage values: SS316L material = 2.5~3.5%, wax = 1%, and machining allowance = 5 mm.

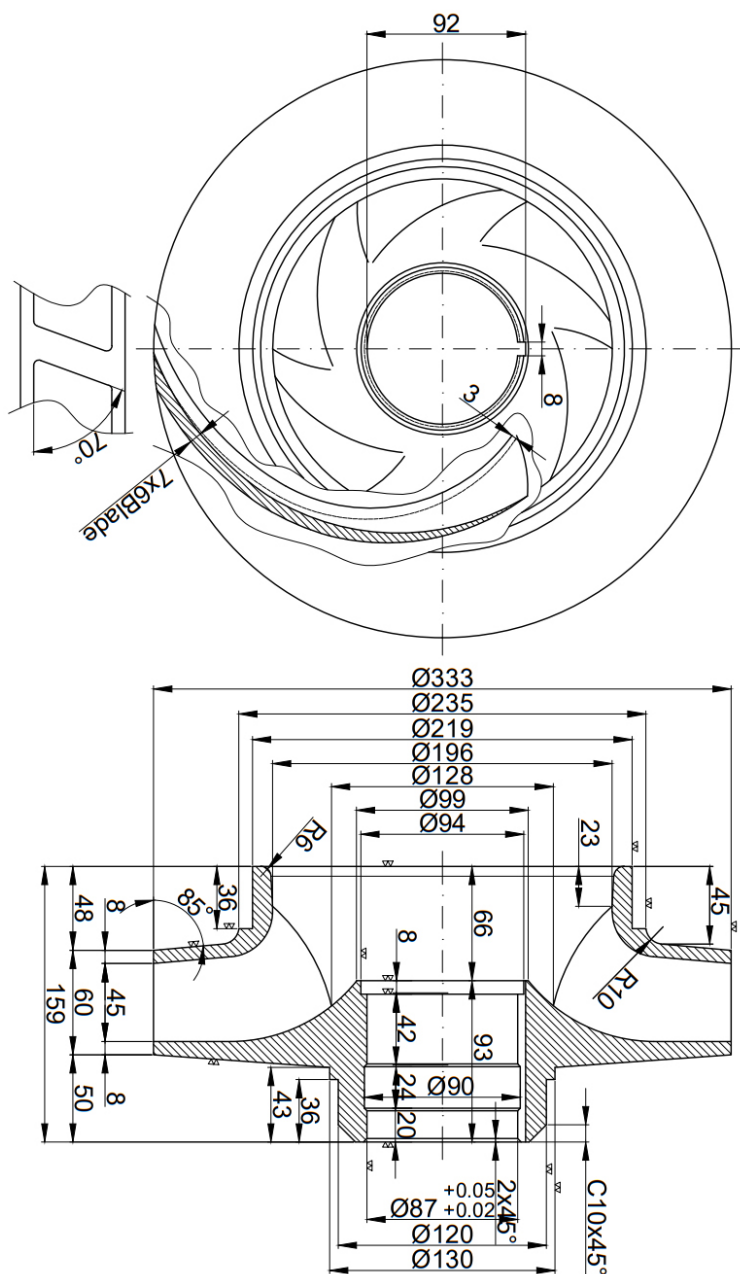


Figure 2. Impeller closed geometric

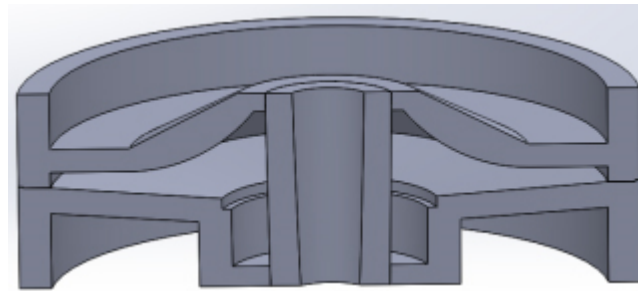


Figure 3. Hub impeller dies

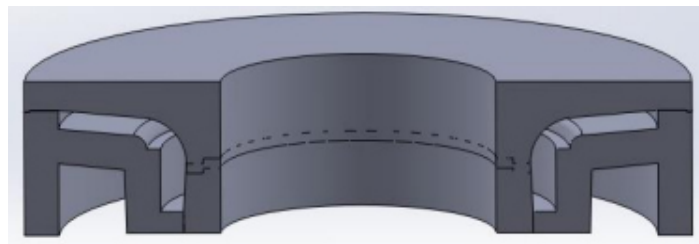


Figure 4. Upper shroud of impeller

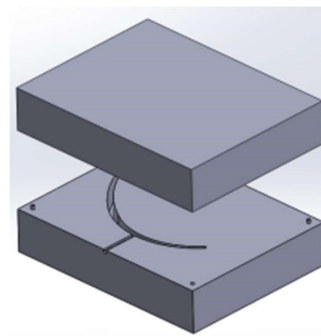


Figure 5. Blade impeller dies

3. 2 Impeller replica fabrication

The wax pattern replicas are created by injecting PARAMELT CERITA 996C AS wax into designated aluminium dies, as shown in Figures 3, 4, and 5. The molten wax, at a temperature of 80°C, is injected into the aluminium impeller mold through an injection nozzle at a temperature of 60 - 70°C from the injection machine, at an injection pressure of 10 – 70 kg/cm². The wax replicas resulting from the injection process are removed from the metal impeller mold. The dimensions of the wax replica impeller are measured to ensure that they match the intended dimensions of the impeller to be produced. The outcomes of the injection for forming the impeller parts are illustrated in Figure 6.

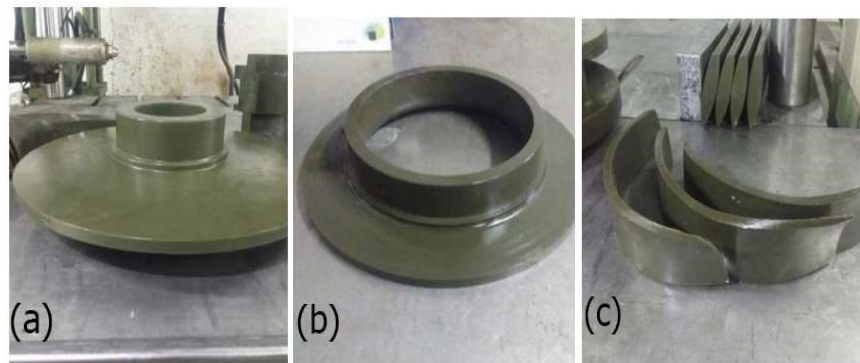


Figure 6. Wax pattern of impeller, (a) Hub, (b) Upper shroud, (c) Blade

3. 3 Sistem gating fabrication

The gating system, or runner system, serves the purpose of directing molten metal into the mold cavity. Figure 7 illustrates the geometric design of the gating system for molding the impeller, which consists of three parts: the pouring cup, runner, and gas vent.

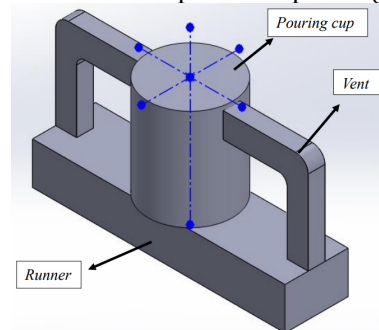


Figure 7. Gating system of impeller moulding

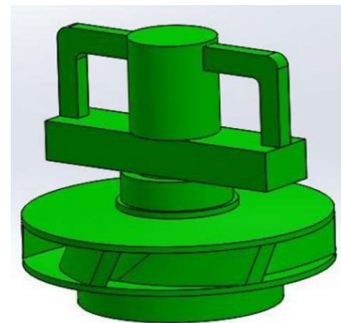


Figure 8. Form of wax pattern assembling

3. 4 Wax pattern assembly

Assembling is the process of joining or combining the pattern parts fabricated from wax to form a single unit. Assembly is performed by heating solder on the elements, then simultaneously melting the solder on the surface of the runner and the main gating (the largest module) of the workpiece and bonding them together. The assembly configuration of the wax pattern to form the molding impeller is illustrated in Figure 8.

Table 1. Ceramic forming dyeing material

Materials	Stages of Immersion						
	1	2	3	4	5	6	7
Colloidal silica, Liter	18	18	24	24	24	24	24
Wetting agent, cc	20						
Anti Foam, cc	40						
Zircon foam, kg	80						
Zircon flour, kg		80					
Sand/stucco	yes	yes	yes	yes	yes	yes	yes
Mullite sand, #200, kg			60	60	60	60	60
Viscosity, second	20-45	25-35	25-40	25-40	25-40	25-40	25-40
Drying temperature, °C	23-27	23-27	23-27	23-27	23-27	23-27	23-27
Drying time, hours	24	2 - 4	2 - 3	2 - 3	2 - 3	2 - 3	2 - 3

3. 5 Investment casting mold ceramic fabrication

The assembled wax pattern is dipped into a slurry and stucco mixture. In this process, it is dipped seven times to obtain a ceramic layer adhering to the wax pattern, with a thickness of 9 – 10.5 mm. Afterward, it is left to dry to form the cavity mold.

Slurry materials for dyeing are shown in Table 1.

3. 6 De-waxing

The wax pattern is melted and removed from the ceramic mold, leaving behind the cavity mold of the complete impeller with the gate system. The de-waxing process is carried out in an autoclave boiler. Steam is used to melt the wax, at a pressure of 8-10 kg/cm², for a duration of 10 minutes. The de-waxing process results in the formation of channels and empty spaces, forming the impeller's shape, as well as the gating system.

3. 7 Sintering ceramic mold

Sintering is the process of firing the ceramic mold in an oven at temperatures around 1000°C for approximately 4 hours, gradually. The goal is to obtain a hard and strong mold and to remove any remaining water and wax residues from the de-waxing process. During the sintering process, particles of ceramic material within the mold begin to interact chemically and physically. This results in the bonding and crystallization of particles, which helps enhance the strength and hardness of the ceramic mold.

3. 8 Molten metal pouring

The cavity of the impeller mold is now ready to be filled with molten metal. The raw material or metal to be used in this case, ASTM A-743 CF3M (SS316L), is melted using an induction furnace. The melting process reaches a temperature equal to or greater than 1500°C.

3. 9 Removing impeller casting

The removal of the casting impeller from the mold cavity is done by destroying the ceramic mold. This is followed by cleaning, trimming excess metal, and cutting off the gating system.

3. 10 Quality inspection of casting objects

The inspection is carried out visually to ensure that there are no defects or cracks of the impeller casting object. Dimensional and geometric examination of impeller casting objects, guided by impeller design drawings.

3. 11 Machining

Machining is carried out to achieve precise measurements according to the casting design drawings. The main parts of the impeller e.g. the hub that will pair with other components, for example the shaft must meet tolerances according to the impeller pair.

4. Conclusion

The fabrication and design of the pump impeller were conducted using the investment casting method. The investment casting process encompasses various stages, which include crafting a metal pattern from aluminum. The creation of the aluminum metal pattern is achieved through machining with additional dimensions. The dimensions of the metal pattern are determined by adding the dimensional sizes, accounting for the material shrinkage of SS316L (2.5~3.5%), wax shrinkage (1%), and machining (5mm). Wax patterns are individually crafted for distinct parts of the impeller, and then assembled into a complete wax pattern that aligns with the impeller's geometry, inclusive of the gating system.

Dipping in Slurry and Stucco: The wax pattern undergoes repetitive immersion in a slurry and stucco mixture until a thick ceramic layer envelops the wax impeller pattern.

Wax Pattern Melting: The wax pattern is melted out from the ceramic mold, leaving behind cavities that replicate the impeller's geometry.

Sintering of Ceramic Mold: The ceramic mold of the impeller is subjected to sintering at 1000°C to form a robust ceramic mold with cavities primed to receive molten metal.

Metal Pouring, Solidification, and Removal: Molten metal is poured into the cavities, allowed to solidify, and subsequently extracted from the ceramic mold.

The resulting cast impeller is now prepared for the machining process.

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