VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DEVELOPMENT OF PATTERN SMELTING METHOD WITH ABS MATERIAL IN INVESTMENT CASTING PROCESS

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ABSTRACT
Investment Casting (IC) is a producing method of high quality casting. It is useful to generate complex geometry in casting product, which cannot be achieved by forging, machining, or machining process with excessive material usage. Currently, IC pattern is made of wax. The wax melts away during the molten metal pouring. In the past, it was stipulated that once a foundry used a wax pattern of particular grades, that it could not be replaced by another grade. This was to avoid the risk of dimensional variety of patterns, coupled with a basic fear of change. The pattern wax compounds have been chosen by foundries with numerous considerations, such as: historical record; the wax the only suitable compound at the time; professional recommendation; and copying from another foundry. Inappropriate wax injector's parameter can create low quality patterns and a ceramic shell. Nowadays, there are wide ranges of material available as an alternative for the IC wax pattern, which in this paper initially highlighted using Acrylonitrile Butadiene Styrene (ABS) as a replacement of conventional pattern material. The pattern with ABS material can be created by Rapid Prototyping Machine (RPM) that is Fused Deposition Modeling (FDM) technology. The experimental outcomes are: there are cracks in the ceramic shell while using the smelting chemical method because ABS material pushed out the shell; perfect ceramic shell with ABS pattern smelting while using burn-out method; and this method can reduce three of seven steps or more efficient about 42.85% of the existing IC process.

Keywords: pattern smelting method, ABS material, investment casting.

INTRODUCTION
Investment casting (IC) or 'the lost wax casting' or 'precision casting' process was developed since 4000 years ago. Investment casting has been used to manufacture weapons, jewelry and art castings during the ancient civilization. The advantages of IC among that are: (1) able to generate complex and intricate geometry of casting product; (2) able to achieve dimensional control within +- 0.075 mm; (3) able to achieve low surface roughness; (4) the pattern wax material can be recycled for the next production; (5) the process is a net shape process, therefore didn't require additional machining process [1].
IC disadvantage is high tooling cost in producing wax patterns. Therefore, the IC is prohibited for low volume production, such as prototyping, customized or specialized component productions. Lead-time range varies between several weeks to months, depending on machine shop scheduling and capabilities. Hence, to that, the toolmaker has to evaluate different mould designs before committing manufacturing, because design errors or iterations are expensive and time-consuming to be amended or accommodated [2, 3]. However, up till now IC is still a preferable process to produce a biomedical application, especially for a prostheses component product [4].

IC is a precision manufacturing technology and easy to be applied, yet in reality the process must undergo many steps to ensure optimum casting results [5]. There are 7 steps in the existing investment casting (see Figure-1): (1) wax patter production; (2) pattern tree production by attaching several pattern to a sprue, coating process of pattern tree with thin layer if refractory material; (4) mould production by covering the coated tree with sufficient refractory material, in order to make it rigid; (5) mould reposition and preheated process, in order to melt down the wax, so automatically it will flow down to the cavity; (6) mould pre-heated process with high temperature, in order to eliminate contaminants and to ease the flow of melted metal to the cavity. Afterward the melted metals undergo solidification process; and (7) separation process between sprue and finished casting product.

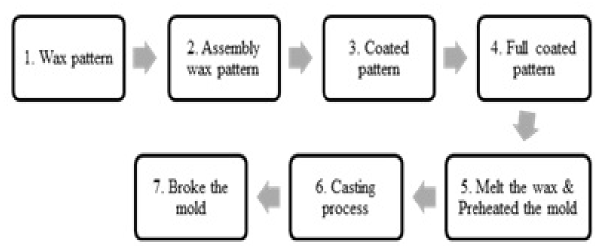


Figure-1. Step in existing investment casting.

Pattern is made of was and mostly reserved for the investment casting process. Pattern is used as the core of a mould to be used for casting [5, 6]. Pattern material is generally made of wax is mostly reserved for the investment casting process [6]. Resin is sometimes used as pattern material, where it applied for sand or permanent pattern process, which belonged to medium to large sizes foundry. Jewelry and accessories are the application of casting investment process [3]. Williams stated in that wax the most commonly used for pattern, because it is easy to be deformed, easy to be hardened, and easy to be melted down at low temperature. The statement also supported by

VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Sopcak [3]. Despite the advantages of wax application as described above, it also has deficiencies or material weaknesses, such as it requires special equipment or machine in manufacturing the pattern. Wax injector is ones of the special equipment to produce a wax pattern basis. Wax injector is a special machine to create a pattern that is quite expensive and need special care in the use and maintenance [3]. The opinion was also expressed by Gebelin *et al* [7] and Sopcak [3], that the machine wax injectors have some consideration prior to its use, including: (1) The flow of wax; (2) Solidification time or cooling the wax; (3) Shrinkage of wax; and (4) Heat the wax into the mould or from the mould to wax.

The above considerations will influence the wax behavior and the pattern quality. The wax injector machine can be replaced by making a mould beforehand [8]. There are two material types to make a mould, which are polyurethane and silicone [8]. Yarlagadda and Teo [8] added in his paper, that the parameter factor of the wax injection process the mould caused the decline of dimensional accuracy about 0.2% to 0.4%. Aside those the effect is a low quality pattern and ceramic shell.

Foggia and D'Addona [9] explains that, investment casting process is a complicated process, especially at the time of manufacture pattern. There are 3 (three) process to produce patterns in investment casting, which are: (1) make a mould for wax; (2) perform the injection of wax into the mould wax with a wax injector engine; and (3) carry out the assembly of the wax pattern with gating system parts as well as part of the core if used. This paper initially deals with different material, methods and developments in pattern production. The pattern production is using FDM technologies. FDM technologies are part of the Rapid Prototyping (RP). ABS is a replacement material for conventional wax material, to produce patterns. The application of different techniques is applied to develop material and pattern making. While, various method was apply to produce smelting pattern. This paper represents an experiment about two smelting pattern method to make a ceramic shell. The methods are burn-out and chemical.

EXPERIMENTAL SETUP PATTERN MAKING

Pattern made with FDM technology that uses material ABS type P-430. With FDM technology, pattern-making becomes easier and faster and accurate. The following Figure-2 shows a model pattern for prostheses components used in these experiments:

(a) (b)

Figure-2. The pattern prostheses component model (a) femoral (b) tibia stem.

PREPARATION OF CERAMIC MATERIALS

Mills [10] explained that, the ceramic material for casting mould as a coating pattern is divided into (3) three types, there are: (1). adhesive materials; (2) a filler; and (3) material of cement. Type of material forming the ceramic mould is derived from a mixture of several materials. For liquid-based adhesive material (liquid), this is commonly referred to as slurry and consists of a mix of materials: zircon silicate flour, colloidal silica, deep foamer (DF) and wetting agent (WA). While solid-based coating material (flour or sand), which consists of material: zircon flour and flour mulgrain with large grains of different levels.

The first phase is zircon silicate flour mix material which is solid and a liquid colloidal silica composition with a ratio of 3:1, and then mixed well using a mixer. Furthermore, mixing the deep liquid foamer (DF) and wetting agent (WA) alternately into the mixer containing material previously without dismissing mixed with 1% of the material composition of zircon silicate flour. Stir until the liquid has thickened, then use as adhesives in the pattern. Things to know is easily dried slurry, then kept stirred if you want to use for any other pattern. The processes to make ceramic materials as well as the materials used are presented in Table-1.

Table-1. The process of making ceramic materials.

Process	Activity	
Material prepared		
	Zircon Silicate Flour	*Coloidal Silica*
		
	Deep Foamer (DF)	*Wetting Agent (WA)*
Making of *slurry*		
	Coloidal Silica	+ Zircon Silicate Flour
		
	Mixer Coloidal Silica & + Zircon Silicate Flour	*Mixer* + DF + WA

CERAMIC COATING PROCESS

Investment or ceramic coating on the pattern by means of dipping and then dried [10]. The most important thing in this process is the viscosity and adhesiveness of the slurry, because the pattern material in this experiment

VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

is plastic, the slurry should have a viscosity of the coating material wax. Preceded by making a slurry as an adhesive pattern and coating material consisting of several types of sand.

Each step in the coating process, require ± 4 hours of drying time. In the coating process with material mulgrain flour until the coating material mulgrain sand, conducted two times the coating process with the aim of moulding the resulting thick, so when do the casting process, the mould is not easily cracked or broken. And in the final stages of ceramic mould is coated with a slurry back [10]. The pattern with the ceramic coating process can be seen in Table-2.

THE SMELTING PATTERN

In general the pattern of the mould removal process ceramic by means of melt wax by heating is commonly called the dewaxing process [5]. In this experiment, the pattern removal process is slightly different from the ceramic mould with dewaxing process, because the use of materials of different pattern. There are two experimental about smelting methods, which are:

- Burn-out method, wherein the smelting of a pattern by way of the oven along with the hardening of the ceramic shell or consolidation pattern (see Table-3)
- Chemical method, smelting material pattern by means immersed in a liquid chemical (see Table-4).

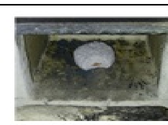
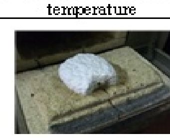
Table-2. The process of coating pattern with ceramic material.

Process	Activity	
Coating Step 1		
	Slurry coating	Zircon Flour coating
Coating Step 2 (repeated step 2 again after drying ± 4 hours)		
	Slurry coating after drying ± 4 hours	Mulgrain Flour coating
Coating Step 3 (repeated step 3 again after drying ± 4 hours)		
	Slurry coating after drying ± 4 hours	Mulgrain Sand 1 coating
Coating Step 4 (repeated step 4 again after drying ± 4 hours)		
	Slurry coating after drying ± 4 hours	Mulgrain Sand 2 coating
Final Step of Coating		
	Final Slurry coating after drying ± 4 hours	Final drying ± 4 hours

RESULT AND DISCUSSION

In the first experiment for the tibia steam model by burn-out method, the oven heated to 100 °C, and then the ceramic shell is inserted into the oven. Holding at a temperature of 100 °C within five minutes, then raise the temperature gradually to 100 ° C intervals. Each interval temperature holding at that temperature is reached within five minutes, so that the temperature inside the mould is stable. Patterns begin to burn at a temperature of 500 °C. However, cracks appear horizontally on the side of the ceramic shell when the temperature reaches 550 °C. Oven process continues until the temperature reaches 700 °C, because of fears of widespread burning of the ceramic shell, the ceramic shell removed from the oven. Due to cracks caused by the burning of ABS material and cracked side was black color and white on the opposite sides.

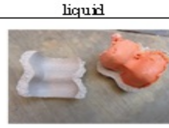
Table-3. The process of smelting pattern with burn-out method.

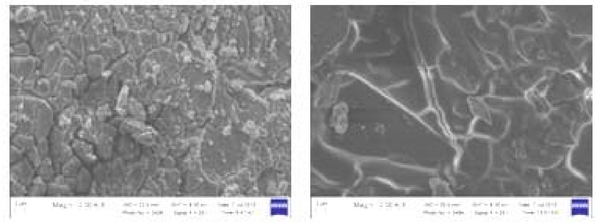
Process	Activity	
Burn-out Method (Experiment 1)		
	Tibia stem model	Patterns begin to burn at a temperature of 500 °C
		
	Cracks appear horizontally on the side of the ceramic shell	Black color in one side
		
	Part of ceramic shell failed result	Under part of ceramic sheel has been formed
		
	Upper part of ceramic sheel has been formed	Residue of pattern
Burn-out Method (Experiment 2)		
	Tibia upper model	The ceramic shell was insert to the oven in room temperature
		
	Patterns begin to burn at a temperature of 500 °C	The result of ceramic shell is good with bright white color

The second experiment (tibia upper model) smelting of fixed patterns of the ceramic shell using burn-out method. However, the ceramic shell is inserted into the oven when the temperature remained at room temperature, then the oven is turned on until the temperature reaches 100 °C and then holding at a temperature of 100 °C within five minutes. Raise the temperature gradually at intervals with each interval 100 °C temperature reached conducted holding at that temperature within five minutes, so that the temperature inside the ceramic shell is stable. Pattern begin to burn at a temperature of 500 °C and cracks do not occur at a temperature of 500 °C, then the process is continued until the oven reaches temperatures 1000 °C. The result is pure white with no residual and charred from the smelting pattern.

The third experiment with a sample of the femoral component test performed using chemical methods, which the pattern will be dissolved with a chemical liquid (technical acetone). In the prepared hole pattern on its side so that the liquid chemical can be entered, then the ceramic shell is immersed in a chemical liquid in 10 to 30 minutes early changes in chemical reactions occur only in the form of a bubble, then and check after 24 hours. After 24 hours of soaking, the position of the pattern still remains, but after the press changes the level of violence (pattern becomes soft), because there is still a significant change, it was decided to carry out soaking up the next 24 hours. The sample was check back after 24 hours the second or after 48 hours. Position pattern still remains and is getting soft, but there cracks in the ceramic shell, it was decided to pick up, because the ceramic shell has been broken and the split in two with a pattern that is still attached and insoluble.

Table-4. The process of smelting pattern with chemical methods.

Process	Activity	
Chemical Method (Experiment 3)		
	Technical aceton liquid	Femoral model
		
	Submerged the model with technical aceton liquid	Cracks occur in the ceramic shell after ± 48 h soaking
		
		
	The ceramic shell split in two with a pattern that is still attached and insoluble	



(a) (b)

Figure-3. Surface of ceramic shell (a) burn-out method (b) chemical method.

The results of SEM photograph shown in Figure-3 that surface of ceramic shell by burn-out method, roughly in comparison to the result using chemical methods. These results will affect the surface of the product, especially for products prostheses. But experiments conducted by chemical methods (technical acetone) were not successful. In the future the experiments will be conducted using other chemical fluids, in order to smelting pattern with ABS material.

CONCLUSIONS

From the experiments, using a chemical method has not been successfully performed as described previously. While the burn-out method successfully done. The surface resulting from the process is smoother than chemical method with the results of burn-out process. Because the chemical process method failed, then selected is using burn-out method. However, to get a smooth surface result from the casting to the burn-out method required an additional process.

IC process to produce the product is becoming simple due to FDM machine application for pattern making. The experiment results show that using ABS as pattern material with burn-out method more effective than wax as pattern material. It is reducing three of seven steps or more efficient about 42.85% of the existing investment casting process.

ACKNOWLEDGEMENTS

Research, design and development activities by the author mention in this paper have been supported by the research grant ‘Hibah Pascasarjana’ from the Directorate of Research and Community Service’s Universitas Indonesia.

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