ISSN: 2641-1784

Research Article

Advance in Environmental Waste Management & Recycling

A New Vacuum Pressure Casting Process for Manufacturing Complex and Thin-Walled Components

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Submitted: 29 Apr 2022; **Accepted**: 10 May 2022: **Published**: 24 May 2022

Citation: *Pradheep Anitha Ravichandran, Pratheep Santhanamoorthy, Prem Sekar, Vinoth Kumar, (2022). A New Vacuum Pressure Casting Process for Manufacturing Complex and Thin-Walled Components. Adn Envi Was Mana Rec, 5(2), 119-124.*

Abstract
Manufacturing industries are still in the phase of improving the accuracy in order to improve the quality of a component or product. In this review paper in order to solve this industrial problem we are going to make a study based on vacuum pressure casting for the manufacturing of complex shaped components and also studied the manufacturing of sheet metal using pressure casting method instead of forming method. Vacuum pressure casting will meet the requirement of industries in the case of achieving high accuracy with complex and thin wall body parts. In this method there is no temperature loss during the transfer of the molten metal into the casting machine and because of this the defect like porosity can be solved. In this paper we are investigating the microstructure, porosity, surface roughness and mechanical properties of the component developed using vacuum pressure casting in comparison with gravity casting.

Keywords: Accuracy, Vacuum Pressure Casting, Complex Shaped Component, Thin Wall, Sheet Metal, Porosity, Surface Roughness, Gravity Casting.

Introduction

With the rapid development of manufacturing industries in the foundry sectors, the demand for complex and thin-wall shaped component for the requirement of different mechanisms and processes have been increasing exponentially. In the preparation of sheet metals, as they being manufactured by forming process which can be overcome by using casting processes where the thickness of the sheet metal plays a major role as using general casting process we can prepare sheet metal not less than 4 mm thickness, whereas by using the vacuum pressure casting we can actually achieve minimum thickness of about 0.5 mm which can easily give an alternative approach other than the forming process for manufacturing of sheet metals, complex shaped and other thin-walled components. Unfortunately, it is very difficult to obtain these castings under gravity casting. Meanwhile, the mechanical properties of castings are generally low but this can be solved by utilising vacuum pressure casting [1]. Currently permanent mould casting, sand casting, and die casting are generally utilised in manufacturing. However, permanent mould casting is usually difficult to produce complicated castings because of high solidification velocity of molten metal. In addition sand casting cannot meet the requirements including dimensional accuracy and surface roughness, while die casting method is costly and time-consuming because of the design and recurring modifications of dies, and the die castings cannot undergo heat treatment due to gas trapping.

Vacuum pressure casting that we are using for this study is advantageous, where the loss of temperature during the transfer of molten metal is reduced and results in greater accuracy by reducing porosity to a maximum extent [2, 3]. One of the existing casting process in industries are the conventional investment casting process, which is the oldest metal manufacturing techniques, is a precision casting process and also known as lost-wax casting process as here wax patterns are converted into metal parts through a multi-step process. Though there are many advantages employed in investment casting, it faces some problems. One of the main drawback is that generally the wax has low softening point, so the wax patterns deployed in investment casting are prone to softening and deforming and also for large-scale parts the transportation of wax patterns are inconvenient. In addition investment casting has other disadvantages like high cost, complex manufacturing process and long manufacturing time as investment casting generally involves in the multi-layer shell preparation of about 6-8 mm thick shell, whereas shell is prepared normally based on ferrous metal and components, hence it results in preparation of excessive layer shell in order to perform casting process. It is a great challenge for the productions of the large-scale complex and thin-walled sheet metals investment casting process with gravity casting method [4].

Considering the above problems, the aim of this study is to overcome to improve the manufacturing of complex and thin-walled components and sheet metal by using vacuum pressure casting process [5]. This vacuum pressure casting process combines the lost-wax casting process and low-pressure casting technology. First, the wax pattern based on part shape is prepared as prototype with help of rapid prototyping process by employing 3D printing method, and then the thin shell with fewer layers are manufactured by using shell coating technology of investment casting outside the wax prototype. Then the wax prototype is removed and shell is heat treated. Before the final step, the air inside the cavity is entirely evacuated by using the vacuum technology and finally by the impact of vacuum the molten metal is filled in the cavity and the required component or product with greater accuracy and exact dimension without the need of additional machining can be obtained. The present work reports the progress in wax prototype and thin shell manufacturing, removing wax and heat treatment of shell process, and low-pressure casting process. Thus the successfully manufactured thin-wall and complicated design parts and sheet metal with the help of vacuum pressure casting have been studied. In addition with the study, comparisons in terms of mechanical properties, filling ability, surface roughness and microstructure among the vacuum pressure casting and gravity casting are made to justify the advantages of vacuum pressure casting process for producing complex and thin-walled parts and sheet metal [6].

Process of Manufacturing Components Using Vacuum Pressure Casting

The procedure of vacuum pressure casting mainly consists of seven-steps: preparing wax prototype, fabrication of thin shell, removing wax pattern, heat treating of shell, evacuating of air, injection of molten metal into cavity, shell removal.

This vacuum pressure casting process are characterized as follows:

- The wax pattern prototypes employed by this vacuum pressure casting process possess many advantages, such as cost efficient, readily available in market, easy removal and bonding, easy transportation, less deformation and comfortable for complicated and thin-walled parts. And also the shell used for making the cavity have high dimensional accuracy and surface roughness in the vacuum pressure casting compared to sand casting.
- As the wax prototypes are removed before pouring the molten metal, the porosity and slag inclusion defects which arise due to the decomposition of wax during casting process can be avoided. In addition, the filling capacity of molten metal is usually great and the pouring temperature is lower than that of investment casting.
- The molten metal is trapped inside the cavity with the help of vacuum pressure technology which results in increasing the strength of the material.
- In this vacuum pressure casting process the temperature loss is negligible when compared to traditional casting process, the filling and feeding capacity is much better in vacuum pressure casting because the filling of molten metal and solidification process are completed under vacuum pressure level.

The manufacturing of complex and thin-walled parts are the challenging tasks for industries in order to produce the products in higher accuracy dimension, whereas the vacuum pressure casting helps to overcome this situation, as the key technology used in this process including wax prototype and molten metal filling technique. The other important roles like removing wax, heat treatment and shell removal process will also be studied and discussed in the following sections [7-10].

Experimental

Wax Prototype Preparation

The quality of wax patterns determines the quality of castings since the castings are simply but the replica of the wax patterns. Wax patterns are advantageous as the patterns are needed to be removed before the metal pouring during the casting process as wax patterns are easily removable and it ensures in producing better surface quality and high strength.

The wax patterns are created by using the 3D printing technology as it gives better surface finish, thin wall thickness and complex shapes [11]. The minimum thickness of the component that can be prepared by 3D printing is about 0.7 – 1mm. The wax pattern is created by generating a CAD model using 3D CAD modelling systems, which is transferred into an Additive Manufacturing machine and using the instruction from this machine the pattern is completed with strong structure. Hence, both large and thin-walled patterns can be manufactured using this technology as it is readily operated and less prone to damage. The processing parameters varies with different size and shape of patterns.

Shell - Layer Manufacturing Technology

The shell preparation plays a major role in vacuum pressure casting process, and it must possess high strength and better surface finish. In the shell manufacturing process, silica sol binder is being used which makes sure the better surface quality and high strength is obtained. In this process the three-layer compound this shell is adopted with the help of silica sol binder as surface coating.

The wax pattern is immersed in the silica sol binder for the purpose of preparing the coated pattern. Depending on the size, shape and complexity of parts this operation is repeated for two to three times. For each and every time after the completion of coating it must be dried before coating the next layer in order to avoid desquamation and dehiscence of shell.

The compound thin shell prepared will have thickness of about 3 – 4 mm which is far less when compared to investment casting, and this thin shell will have better surface quality, easy process of melting, short preparation time and cost efficient since it requires preparation of fewer-layer shell. The thin shell prepared in this method is generally reinforced.

Removing Wax and Heat Treating Process

In order to remove the wax pattern melting method is employed. In this method temperature is increased periodically and after some time the temperature will be decreased gradually without altering the shell thickness and pattern of the shell.

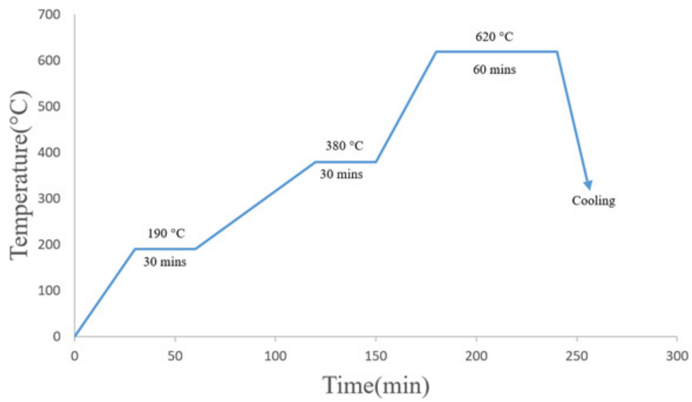

Figure 1: Wax Removal and Heat Treatment Process Curve

This can be achieved by controlling the furnace temperature, as the wax removal and heat treating process used for shell in here is done together, and it is different from investment casting where dewaxing and heat treating of shell are two different processes. Hence, the wax removal and heat treating process are simple. From Figure 1, initially, wax pattern was removed at latent heat temperature for required time in order to remove the wax in the form of liquid state, which is similar to investment casting process and it will reduce the shrinkage of shell due to the phase transformation of solid to liquid state of wax at high temperature. In this stage itself most of the wax gets removed and it is important that the shell should not be destroyed or should not deviate from the required dimension while wax removal process. To remove the residual portion wax the temperature will be raised at a required temperature for a certain time. Then the shell is heat treated at a certain temperature at which the properties of the shell will not get manipulated, by this the shell strength gets better and gains the mechanical property to withstand the heat of molten metal.

Vacuum Pressure Casting

Once the thin shell manufacturing is finished, the next step is to employ the vacuum pressure casting technology. Firstly, the thin shell is placed inside the casting box to avoid the movement of the shell and also to withstand the vibrations. Then using the vacuum technology the air inside the cavity is evacuated. By the vacuum created inside the cavity the molten metal is trapped and the cavity is filled. As a result, the solidification and filling of molten metal is completed under vacuum pressure level.

During this casting process, due to the filling and solidification of the molten metal are finished under vacuum pressure level, the feeding and filling capacity of molten metal is improved significantly. Moreover, the misrun and cold shut defects are avoided, especially for complex and thin-walled products. In addition the shrinkage defects and slag inclusion are also decreased and the casting gets denser. There is no option for oxidation will be incorporated as the molten metal reaching the mold is not exposed to the atmosphere during the casting process.

The vacuum pressure level will be the most important factor for manufacturing components. Usually, due to rapid solidification and difficulty in filling of molten metal, for both complex and thin-walled castings higher vacuum pressure level is required. Hence the thickness and complexity of wax patterns have great impact on casting capability.

With a focus on to prove the advantages of this vacuum pressure casting process for manufacturing the complex and thin-walled parts, comparison are made in terms of mechanical properties, filling ability, porosity, surface roughness and microstructure among this vacuum pressure casting and gravity casting have been studied [12-15].

Results and Discussion

Comparison of Mechanical Properties between the Vacuum Pressure Casting and Gravity Casting

Table 1: Comparison of Mechanical Properties between the Vacuum Pressure Casting and Gravity Casting

Process	Porosity(%)	Hardness (HB)	surface roughness (Ra, µm)	Tensile strength
Vacuum pressure casting	0.14	95.2	2.9 – 5.4	285.34
Gravity casting	0.64	87.1	3.0 – 5.5	263.78

Table 1 represents the comparisons of mechanical properties between the vacuum pressure casting and gravity casting. It can be evidently seen that the mechanical properties of the vacuum pressure casting is better when compared to gravity casting. The hardness and tensile strength of castings produced by vacuum pressure casting process are respectively up to 95.2 HB and 285.34 MPa, and are, respectively, 8.5% and 7.6% higher than that of castings manufactured by gravity casting. As an evident of these merits, the feeding and filling capacity of molten metal are enhanced. Moreover, the amount of air trapped in casting is less which results in the improvement of surface roughness because of the molten metal filling under vacuum pressure level [16]. As the molten metal is injected by means of vacuum technology the tensile strength is much better in vacuum pressure casting when compared to gravity casting [17].

Figure 2: Low Magnification Photos of Sample Section Obtained by a. Gravity casting, b. Vacuum pressure casting

Figure 2 displays the low magnification photos of sample sections obtained by vacuum pressure and gravity casting. After examining the sample section obtained by vacuum pressure casting has less pores and its porosity is only 0.14%, which is less than that is obtained by gravity casting which is of 0.64%.

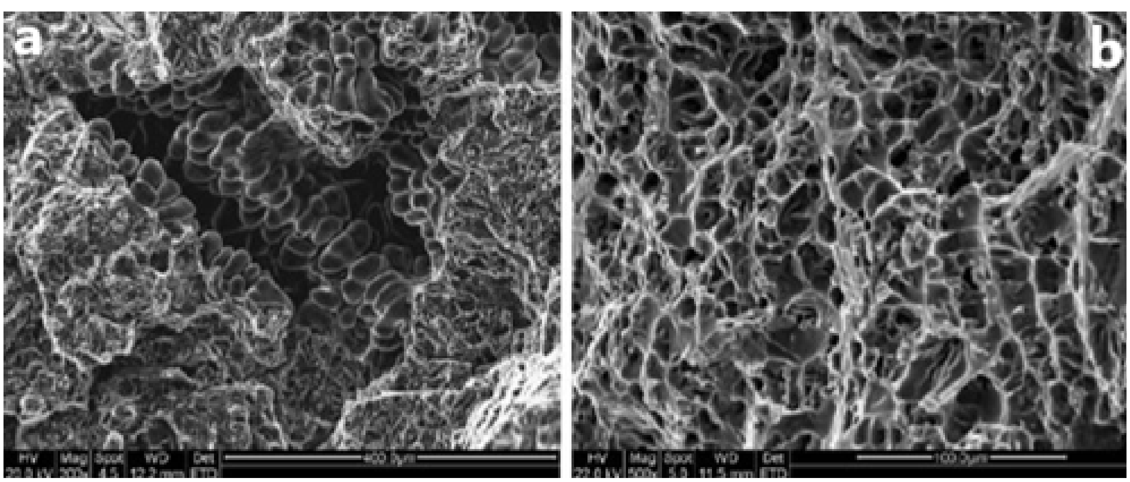

Figure 3: Fracture Morphology of Tensile Samples Obtained by a. Gravity casting, b. Vacuum pressure casting

Figure 3 displays the fracture morphology of tensile samples obtained by vacuum pressure and gravity casting. Due to poor feeding capacity of the molten metal in gravity casting, it will result in shrinkage porosity defect and coarse dendrite which can be observed in the tensile sample of gravity casting and it will lead to poor mechanical properties [18, 19]. The tensile sample of vacuum pressure casting shows higher mechanical properties.

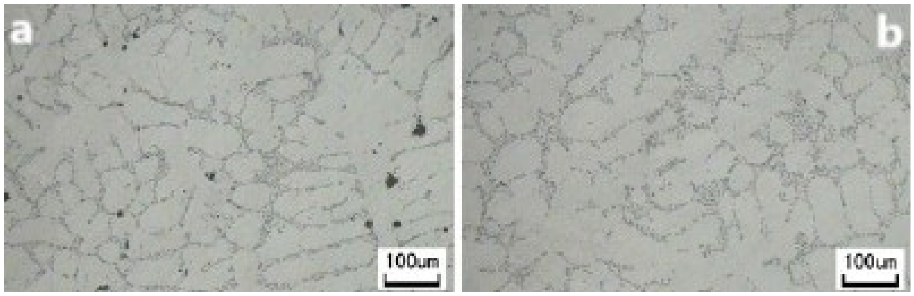

Figure 4: Microstructure of Castings Obtained by a. Gravity casting, b. Vacuum pressure casting

Figure 4 displays the microstructure of castings obtained by vacuum pressure and gravity casting. The microstructure of castings obtained by vacuum pressure casting shows improvement in feeding capacity of molten metal as the coarse dendrites are broken under vacuum pressure level. Thus, the microstructure of castings acquired from vacuum pressure casting has finer grains and is much denser compared to gravity casting. On the contrary, the microstructure of castings obtained by gravity casting have coarse dendrites and shrinkage porosities. Hence, the vacuum pressure casting process have higher advantages in terms of mechanical properties.

Comparison of Filling Ability between Vacuum Pressure Casting and Gravity Casting

Figure 5: Filling Ability of Sheet Metal Obtained by a. Gravity casting, b. Vacuum pressure casting

Figure 5 displays the filling ability of sheet metal obtained by vacuum pressure and gravity casting. When vacuum pressure casting is employed, the sheet metal is completely filled. Whereas, while employing gravity casting it results in misrun and the filling is not done completely. Hence, it is evident that filing ability of vacuum pressure casting is better than gravity casting [20].

Complicated and Thin-Walled Parts Manufacturing

Generally, in the industries manufacturing of thin-walled sheet metal is done with the help of forming methods, because the normalised casting process employed in industries cannot achieve the required minimum thickness. This can be overcome by using vacuum pressure casting process, as by employing this method we can manufacture sheet metal with a minimum thickness of 0.6 – 0.9 mm. In addition, manufacturing of complex parts also made easy with the help of vacuum pressure casting.

Conclusion

- Vacuum pressure casting has various advantages such as higher accuracy, flexible design and cost efficient. Moreover, the formation of product is with exact dimension neglecting the porosity and slag inclusion defects. In addition cold shuts and misruns can be avoided and pouring temperature can be reduced.
- The wax patterns with high strength are fabricated using 3D printing technology, using this technology we can easily fabricate complex parts by adjusting the layers we can also achieve fabricating thin-walled components with exact dimension.
- In industries the fabrication of sheet metal using traditional casting has main disadvantage as its minimum thickness that can be manufactured is about 2.0 – 2.5 mm, whereas in vacuum pressure casting we can achieve thickness of 0.5 – 0.9 mm.
- The moulding parameters would vary according to the shape and size of required component. The thin shell of silica sol is adopted for the casting process, where removal of wax pattern is carried out at the latent temperature and the mechanical properties of shell will not vary which can be seen with careful examination.
- In this vacuum pressure casting process as the process is carried out by evacuating the air, the mechanical properties of fabricated part will be improved compared to gravity casting. As the whole study results that the fabricated parts from vacuum pressure casting have higher internal and surface quality, which reduces the industrial problems. This vacuum pressure casting process can be highly employed in sectors like electronics, machinery, military and other industries.

Declarations

Funding

The authors did not receive support from any organization for the submitted work.

Conflicts of Interest/Competing Interest

The authors have no relevant financial or non-financial interests disclose.

Availability of Data and Material

Data available within the article or its supplementary materials.

Ethics Approval

Not Applicable.

Consent to Participate

Not Applicable.

Consent to Publication

Not Applicable.

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