Int. J. Advanced Design and Manufacturing Technology, 2024, Vol. 17, No. 4, pp. 45-52

DOI: 10.71644/admt.2024.873741 *ISSN: 2252-0406* *https://admt.isfahan.iau.ir*

The Effect of using a Semi-Automatic Foam Cutting Machine on The Characteristics of Foam Patterns in The Lost Foam Casting

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Received: 28 January 2024, Revised: 9 September 2024, Accepted: 2 November 2024

Abstract: In this research, a modern method for making foam patterns, which is one of the most important steps of casting with a lost foam pattern, has been used. A semi-automatic hot wire machine was built to cut and create foam patterns. Two types of foam patterns were prepared by manual method and cutting method with semi-automatic machine. The sizes of the obtained foam patterns were evaluated and the accuracy of each method in the production of foam patterns was compared. According to the density of the foam used in the experiments, the volume of the prepared patterns was obtained by manual and semi-automatic methods. The additional volume in the prepared patterns was calculated by both methods. The amount of economic losses caused by excess volumes was investigated. The results of the research determined that the accuracy of the sizes of the patterns prepared by the semi-automatic method was more than twice the accuracy of the patterns prepared by the manual method. The patterns prepared by the semi-automatic method had an additional volume of 1.9% compared to the volume of the original part. While the mentioned amount for foam patterns cut by the manual method was 9%. Therefore, the economic efficiency of casting parts using foam patterns made by semi-automatic method in terms of melting consumption for aluminum parts was 8% more than production parts using foam patterns made by manual method.

Keywords: Lost Foam Casting, Patterns, Precision, Semi-Automatic Foam Cutting

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Research paper

1 INTRODUCTION

Lost foam casting is a type of evaporative pattern casting process. This method is very similar to precision casting, except that foam is used instead of wax [1]. The main advantage of this method over precision casting (with wax) is the elimination of the melting step and removing the wax from the mold. This is possible by using the low melting temperature and very low density of the foam [2]. This method is used in casting aluminum, magnesium, gray, and ductile iron [3]. The lost foam casting process makes it possible to produce complex parts in a cheaper way [4]. In common methods, cores are needed to create internal cavities, and the use of the lost foam method eliminates this need. In addition, this casting process is capable of producing parts with excellent surface smoothness [5]. This process does not require an exit angle. Therefore, the mold does not have any slit lines and this leads to no pleats. The absence of pleats and the absence of a slope for the exit of the pattern causes the reduction or elimination of polishing operations and final operations (such as heat treatment, machining, etc.). Reducing or eliminating the final casting operations reduces the amount of wastage and material waste during the process. This also leads to a reduction in the total cost [6]. Figure 1 shows an example of a complex piece produced by the lost foam method.

Fig. 1 Complex piece produced by the lost foam method.

In lost foam casting, patterns are made of expanded polystyrene (foam) and placed in sand without glue [7]. The chemical composition of foam and the schematic of foam production steps are shown in “Fig. 2”. One of the most important advantages of using a foam pattern is the elimination of the core in the molding process [8]. The desired pattern is exactly the same as the part in terms of shape and size and is made of foam. The final pattern may consist of one or more pieces that are finally glued together to create a unified pattern. The feeding and runner systems are also made of foam and are attached to the pattern [9].

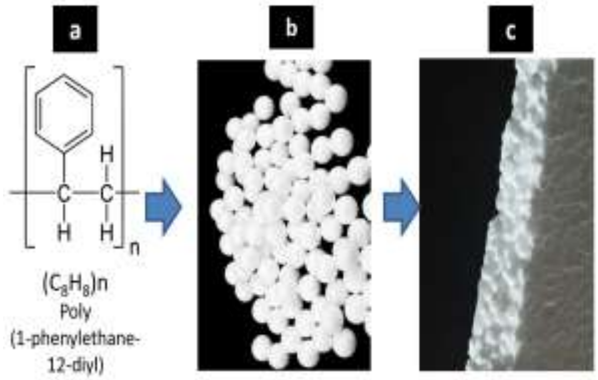

Fig. 2 (a): The chemical composition of foam, (b): Foam balls, and (c): Foam sheet.

Before putting the foam into the mold, the foams are coated [10]. The most important purpose of using the coating is to keep the sand and prevent it from collapsing [11]. Applying the coating also keeps the heat in the melt and increases its fluidity. These coatings maintain dimensional accuracy by preventing the shape of the foam pattern from changing during molding and vibration [12]. The chemical composition of the coating includes a powder, a refractory material, an adhesive, and a suspending solvent. Refractory material usually consists of silica, alumina, zinc oxide, chromite, and aluminosilicates such as mullite and pyrophyllite [13]. The resulting coating is in the form of a slurry. This coating is applied to the pattern through dipping, spraying, or painting with a pen. The coating is applied to the pattern in several steps. The drying process is usually done at a temperature of 50 to 60 °C and in a dryer for 24 hours. The thickness of the coating is usually about 0.25 to 0.5 mm [14].

After finishing the process of coating the patterns, the sample is placed inside the copes. The cope is filled with free-flowing dry sand containing carbon and without glue [2]. When pouring sand around the patterns, the whole system vibrates in three directions. This vibration is because the sand completely surrounds the pattern and fills all the holes in the piece [12]. After molding, pouring molten material into the mold causes the foam pattern to evaporate completely. The use of low-density polystyrene grains in the preparation of a foam pattern causes the amount of gas resulting from foam evaporation to decrease [2].

The use of lost foam casting is increasing. Currently, Tractor Sazi Casting Company uses this method to produce intermediate gearbox, tractor gearbox and all kinds of axles. A statistic obtained from the applied growth of this casting method in China is shown in “Fig. 3”.

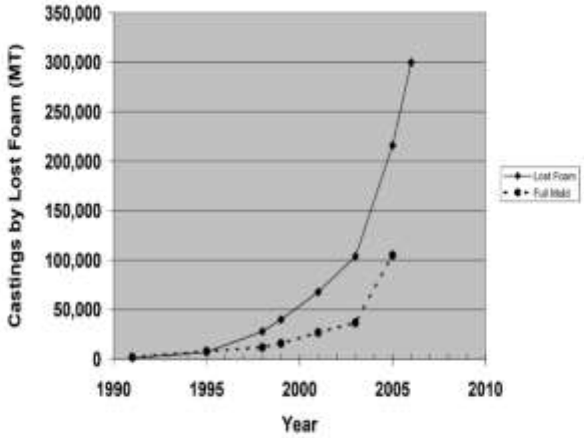

Fig. 3 Comparison of the tonnage of production of parts by conventional casting methods compared to the lost foam method in China [6].

Many different alloys are cast by the lost foam method and this method can have a very favorable effect on the obtained mechanical properties. The casting of Mg-Gd-Y-Zr alloys with this method has caused the maximum ultimate tensile strength to reach 285 MPa [3]. In the research of Xiao et al., it has been shown that the mechanical properties of gray cast iron can be improved using the lost foam method [15]. Jiang et al. have shown in their research that the pressure in the lost foam casting method will have a great impact on the quality of the part coming out of the mold [16]. The effective parameters in the lost foam process are very diverse and a lot of research has been done on this issue [14], [17].

Fig. 4 A hot knife that is used manually in making foam patterns.

One of the most important factors affecting the quality of the final piece is the quality of the foam pattern used in molding. Manual cutting is the first method used in making these foam patterns. However, it is clearly known that this method can have errors. For manual cutting, a variety of tools, including a hot knife, have also been used, as shown in “Fig. 4”. Using a mechanical method and a foam moving machine to cut the foams can increase the accuracy in preparing foam patterns and increase economic efficiency. Little research has been done on the construction of semi-automatic cutting machines and their impact on the last foam casting. For this reason, in this research, the construction and use of a semi-automatic machine for cutting foam patterns were targeted. By making a semi-automatic machine for cutting foams, it was possible to compare foam patterns prepared by the semi-automatic method and manual method. In addition, the effect of using a semi-automatic hot wire machine on the characteristics of foam patterns, including the volume of the prepared pattern, casting, and economic losses, is investigated.

2 MATERIAL AND METHODS

In order to make a semi-automatic hot wire cutting machine, first a steel plate (10 x 15 cm) was prepared. Four steel belts with a length of 32 cm were cut. The steel plate was welded to the four mentioned belts. The above operation results in the construction of movable arms. Two prepared bearings were installed on the transmission shafts. The bearing used is shown in “Fig. 5”. By means of screws, the bearings were connected to the plate and the movable arm. This action causes the longitudinal movement of the mobile arm and creates a rail (wing bush) for the movement of the arms.

Fig. 5 Thermal elements used in the field of the device.

Then a chain with number 25 was installed on the engine sprocket. By connecting the mentioned system to the metal plate, the movement of moving arms is provided by a three-position switch and a driver. The L-shaped arm is connected to the table through a screw, and two movable rails are placed on the horizontal and vertical beams of the L-shaped arm to change the angle of the element. The elements were connected to the current source using a built-in dimmer. The dimmer controls the heat required for cutting. This heat can be adjusted according to the density of the foam and the speed of movement of the longitudinal arm. “Table 1” shows the components of the semi-automatic hot wire cutting machine. The thickness of the wires depends on the application environment and varies from 0.32 to 6 mm. The wire used in these experiments is shown in “Fig. 6”.

Table 1 The components of the semi-automatic hot wire cutting machine

Num.	Component	Num.	Component
1	desk	9	Trans shaft 16 mm
2	Steel (plate - corner - belt)	10	LME bearing
3	Chain number 25	11	22 teeth chain wheel
4	three positioned rail	12	Element tension mechanism
5	Foam retaining clips	13	Dimmer (5000)
6	12 volt DC motor	14	PCDM1 driver
7	12V/10A adapter	15	Thermal element (thick 0.32 mm)
8	Two-stage and three-stage key	16	terminal

Fig. 6 Thermal elements used in the field of the device.

These used elements have the property that they can withstand very large currents. The main material of the elements is nichrome and they have different powers. Most nichrome elements are made with an 80/20 composition (80% nickel, 20% chromium). This material is desirable in the sense that it has high electrical resistance and when it is first heated, it forms a sticky layer of chromium oxide on itself, which prevents internal parts from oxidizing and burning or breaking. It should be mentioned that the thickness of the used wire is directly related to the density of the used foam and the dimensions of the pattern. By increasing the thickness of the wire, the amperage of the device should also be increased.

In the manual cutting method, all cutting operations are done with the help of the operator and through hand movements. For example, for the longitudinal cuts of the foam block, the process is guided with the help of a guide plate. The cutting action is based on the predetermined size and dimensions in the foam. Also, in circular cuts (cylindrical cutting), cutting is done by determining the center and radius of the desired cylinder and by moving the hand around the axis of rotation. In the semi-automatic cutting method, longitudinal cuts are made with the help of mechanisms built into the machine. In the automatic cutting operation, the moving arms that are connected to the rail are connected to the motor by a chain. When the motor is activated and the speed is set by the driver, the arms are guided to the beginning and end of the table. Foam patterns are made by manual and semi-automatic methods. In both methods, the general steps of making a foam pattern are shown in “Fig. 7”.

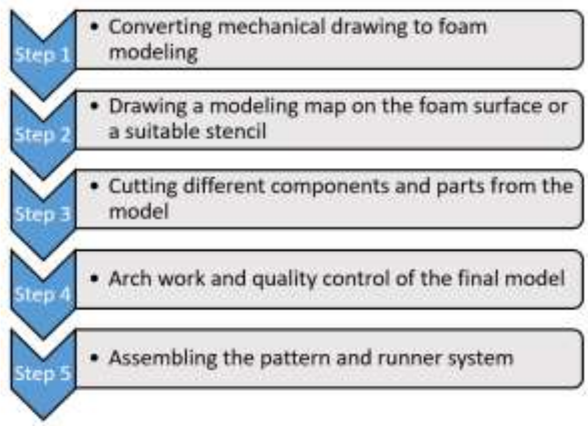

Fig. 7 Flowchart of the general steps of making foam patterns with semi-automatic and manual methods.

3 RESULTS AND DISCUSSION

3.1. Semi-Automatic Foam Cutting Hot Wire Machine

The trans shaft, bearing, and chain were placed in the longitudinal movement mechanism. As seen in “Fig. 8”, the chain used in the semi-automatic cutting machine has technical number 25 and the length of the chain is 236 cm. The chain is attached to the support plate of the movable arms by three small screws, one side of the chain is mounted on the DC motor sprocket, and the other side is mounted on an idler sprocket. With the activation of the engine and the rotation of the chain wheel, the rotational force of the engine is transferred to the chain and causes the longitudinal movement of the mobile arms.

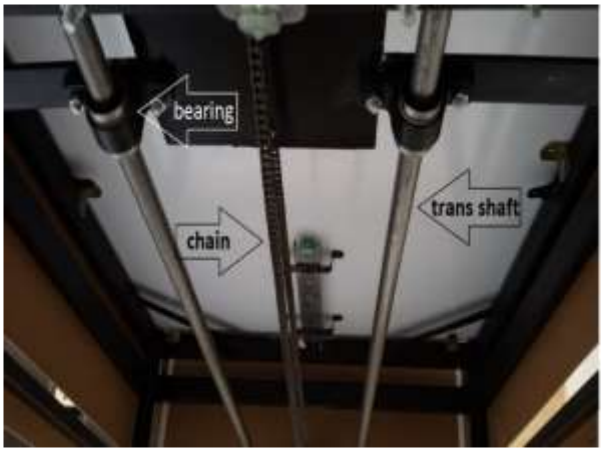

Fig. 8 Final assembly of semi-automatic foam cutting hot wire machine.

As shown in "Fig. 9", a semi-automatic foam cutting hot wire machine was built. Among the characteristics of the manufactured machine, the very low price of the above machine can be mentioned compared to similar machines such as the CNC machine. Despite this low price, the accuracy of this machine is very high compared to manual cutting by the operator. In addition to the mentioned features, this device can cut large objects and has a low maintenance cost, ease of use, and the ability to adjust the temperature of the wire element and semi-automation.

Fig. 9 Final assembly of semi-automatic foam cutting hot wire machine.

In this device, after the main key is pressed, the system allows 220V electricity to enter the terminal in the device. The terminal of the device transfers and changes the input power to the dimmer and adapter. The dimmer gives electric current to the element and as a result, the electric energy is converted into thermal energy. Also, the operator performs the semi-automatic cutting operation by placing the foam between the two moving clamps and activating the motor key. In order to cut cylindrical objects by specifying the center of the foam and placing it in the designed place (flange), the operator performs cylindrical cutting by rotating the foam.

3.2. Preparing Foam Patterns and Comparing the Patterns Obtained by Semi-Automatic and Manual Methods

Two foam patterns were prepared from two different pieces using a semi-automatic machine and a manual method. Figure 10 shows the image of these two examples of foam patterns. The accuracy of the foam patterns prepared using manual hot wire cutting methods and semi-automatic hot wire cutting machine is shown in the graphs drawn in "Fig. 11". Paying attention to the results obtained in these two graphs shows that the error percentage in the size obtained in the foam patterns that were prepared by semi-automatic method is much lower than the sizes obtained in the foam patterns that were prepared by the manual method.

Fig. 10 View of two foam patterns made from two different castings.

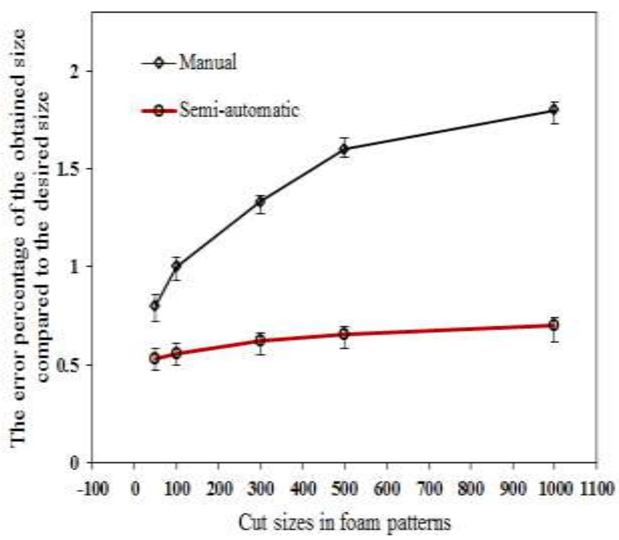

Fig. 11 Graphs of the percentage of mistakes that occurred in the preparation of foam patterns with sizes of 50 to 1000 mm by semi-automatic and manual methods.

In cutting 100 mm using the manual method, an average error of 1% was observed, but in cutting 100 mm using the semi-automatic method, the average error percentage was reduced to 0.56%.
Observing the changes in the error percentage in the trend of the graphs shows that with the increase in the size of the foams and in other words the size required for the foam patterns, the possibility of increasing the error percentage in the manual method increases at a very significant rate. In this way, in cutting a foam pattern with a size of 1000 mm by manual method, the error percentage increases to about 1.8%. While this value for the semi-automatic method is 0.7%.
Therefore, in general, it can be stated that the use of semi-automatic method in the preparation of foam patterns used in casting industries can reduce the error percentage from 1.8 to 0.7% (almost half), and will increase the accuracy of the preparation of foam patterns by more than two times.
In the following, the percentage of additional volume created in the foam patterns prepared by two semi-automatic and manual methods was calculated and the results are shown in "Fig. 12". As can be seen in the diagrams of the mentioned figure, the percentage of additional volume to the volume of the piece in foam patterns by manual method is 9%. This amount of loss is reduced to 1.9% by using the method of semi-automatic hot wire cutting machine. This additional volume reduction in foam patterns can have a significant impact on the cost of parts produced by the method of lost foam casting.

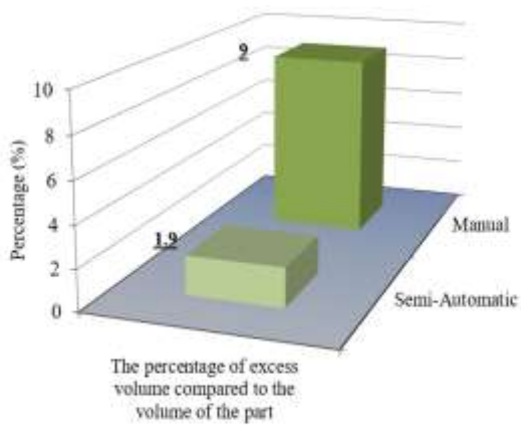

Fig. 12 The percentage of additional volume of foam patterns prepared by semi-automatic and manual methods compared to the volume of the piece.

In the manual method of making foam patterns, patterns are usually cut in larger sizes [18], because the parts should not be smaller than the size required for casting. If they are cast larger, it is possible to machine them to life-size [19-20]. Therefore, in methods of preparing foam patterns that are more accurate in cutting, aluminum consumption and machining costs will be reduced. The comparison of the weight of aluminum used to produce a piece with a volume of 2000 cm^3 in the methods of preparing a semi-automatic and manual foam pattern was done in this research. Figure 13 shows a comparison of the final weight of aluminum used in the two mentioned methods. As can be seen in the figure, the weight of aluminum used in the case of foams cut by manual method is 5.9 kg, but in the case of foams cut by semi-automatic method, this weight is reduced to 5.5 kg. Therefore, by replacing the semi-automatic method instead of the manual method, in the production of casting foams, the amount of aluminum ingots consumed is reduced to 8%. So, using a semi-automatic cutting machine can be a suitable method to achieve casting with higher precision.

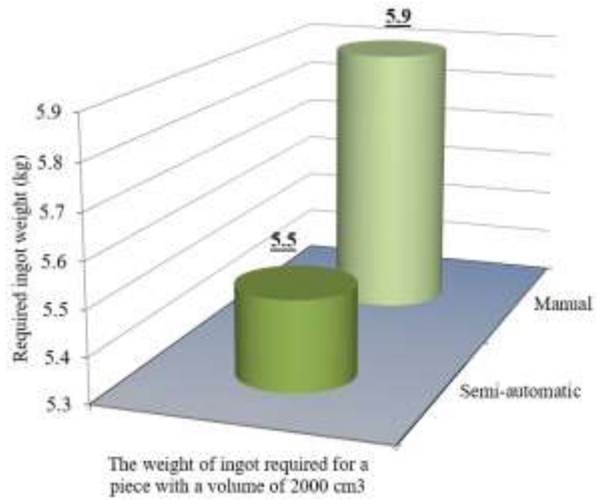

Fig. 13 The weight of aluminum ingot required to produce a piece with a volume of 8000 cm3 in semi-automatic and manual foam preparation methods.

4 CONCLUSIONS

In this research, a semi-automatic foam cutting hot wire machine was made for the first time and used to prepare foam patterns of lost foam casting. Foam patterns prepared by semi-automatic method and manual method were compared and their important and effective features were studied in the field of casting. The following results are derived from this study.
• The accuracy of the sizes of the patterns prepared by the semi-automatic method was more than twice the accuracy of the patterns prepared by the conventional manual method. In a 100 mm cut by manual method, an average of 1% error occurred, but the same cut by semi-automatic method reduced the error percentage to 0.56%.
• The patterns prepared by the semi-automatic method had an additional volume of 1.9% more than the volume

of the original part. While the mentioned amount for foam patterns cut manually was 9%.

• The economic efficiency of casting parts using foam patterns made by semi-automatic method in terms of melting consumption for aluminum parts was 8% higher than the production parts using foam patterns made by manual method.

REFERENCES

[1] Barone, M. R., Caulk, D. A., A Foam Ablation Model for Lost Foam Casting of Aluminum, International Journal of Heat and Mass Transfer, Vol. 48, No. 19–20, 2005, pp. 4132–4149, doi: 10.1016/j.ijheatmasstransfer.2005.03.031.

[2] Basso, A., Toda-Caraballo, I., San-Martín, D., and Caballero, F. G., Influence of Cast Part Size on Macro- and Microsegregation Patterns in A High Carbon High Silicon Steel, Journal of Materials Research and Technology, Vol. 9, No. 3, 2020, pp. 3013–3025, doi: 10.1016/j.jmrt.2020.01.052.

[3] Brown, J., Foseco Ferrous Foundryman’s Handbook. Elsevier Science, 2000.

[4] Chen, H. Z., Shan, Z. De, and Dong, H. Z., Research of Foam Pattern Processing for Lost Foam Casting, International Conference on Process Equipment, Mechatronics Engineering and Material Science, Vol. 331, 2013, pp. 600–603, doi: 10.4028/www.scientific.net/AMM.331.600.

[5] Guler, K. A., Acar, S., Lost Foam Casting of Metallic Parts and Structures, In F. G. Caballero (Ed.), Encyclopedia of Materials: Metals and Alloys, Elsevier, 2022, pp. 73–86, doi: 10.1016/B978-0-12-819726-4.00008-9.

[6] Guler, K. A., Kisasoz, A., and Karaaslan, A., Effects of Pattern Coating and Vacuum Assistance on Porosity of Aluminium Lost Foam Castings, Russian Journal of Non-Ferrous Metals, Vol. 55, No. 5, 2014. pp. 424–428. doi: 10.3103/S1067821214050113.

[7] Jafari, H., Idris, M. H., and Shayganpour, A., Evaluation of Significant Manufacturing Parameters in Lost Foam Casting of Thin-Wall Al-Si-Cu Alloy Using Full Factorial Design of Experiment, Transactions of Nonferrous Metals Society of China (English Edition), Vol. 23, No. 10, 2013, pp. 2843–2851, doi: 10.1016/S1003-6326(13)62805-8.

[8] Jiang, W., Fan, Z., Liao, D., Liu, D., Zhao, Z., and Dong, X., Investigation of Microstructures and Mechanical Properties of A356 Aluminum Alloy Produced by Expendable Pattern Shell Casting Process with Vacuum and Low Pressure, Materials and Design, Vol. 32, No. 2, 2011, pp. 926–934, doi: 10.1016/j.matdes.2010.08.015.

[9] Kannan, P., Biernacki, J. J., and Visco, D. P., A Review of Physical and Kinetic Models of Thermal Degradation of Expanded Polystyrene Foam and Their Application to The Lost Foam Casting Process, Journal of Analytical and Applied Pyrolysis, Vol. 78, No. 1, 2007, pp. 162–171, doi: 10.1016/j.jaap.2006.06.005.

[10] Karimian, M., Ourdjini, A., Hasbullah Idris, M., and Jafari, H., Effect of Pattern Coating Thickness on Characteristics of Lost Foam Al-Si-Cu Alloy Casting, Transactions of Nonferrous Metals Society of China (English Edition), Vol. 22, No. 9, 2012, pp. 2092–2097, doi: 10.1016/S1003-6326(11)61433-7.

[11] LI, J., Chen, R., and Ke, W., Microstructure and Mechanical Properties of Mg-Gd-Y-Zr Alloy Cast by Metal Mould and Lost Foam Casting, Transactions of Nonferrous Metals Society of China, Vol. 21, No. 4, 2011, pp. 761–766, doi; 10.1016/S1003-6326(11)60777-2.

[12] Liu, X. J., Overfelt, R. A., and Bhavnani, S. H., The Effects of Foam Density and Metal Velocity on The Heat and Mass Transfer in The Lost Foam Casting Process, Proceedings of the ASME Summer Heat Transfer Conference, 2003, pp. 317–323, doi: 10.1115/ht2003-47504.

[13] Nicoletto, G., Anzelotti, G., and Konečná, R., X-Ray Computed Tomography Vs, Metallography for Pore Sizing and Fatigue of Cast Al-Alloys, Procedia Engineering, Vol. 2, No. 1, 2010, pp. 547–554. doi: 10.1016/j.proeng.2010.03.059.

[14] Paramasivam, K., Vijay Anand, M., and Sambathkumar, M., Investigation of Optimum Process Parameter of Lost Foam Casting of A356/SiC Metal Matrix Composite, Materials Today: Proceedings, Vol. 47, 2021, pp. 4801–4806, doi: 10.1016/j.matpr.2021.06.035.

[15] Sands, M., Shivkumar, S., Influence of Coating Thickness and Sand Fineness on Mold Filling in The Lost Foam Casting Process, Journal of Materials Science, Vol. 38, No. 4, 2003, pp. 667–673, doi: 10.1023/A:1021859523363.

[16] Shayegh, J., Hossainpour, S., Rezaei, M., and Charchi, A., Developing a New 2D Model for Heat Transfer and Foam Degradation in EPS Lost Foam Casting (LFC) Process, International Communications in Heat and Mass Transfer, Vol. 37, No. 9, 2010, pp. 1396–1402, doi: 10.1016/j.icheatmasstransfer.2010.07.015

[17] Sun, D., An Overview of Lost Foam Casting Technology Development in China. AFS Transactions, American Foundry Society, Vol. 08–035, No. 14, 2008, pp. 1–8.

[18] Wang, L., Limodin, N., El Bartali, A., Witz, J. F., Seghir, R., Buffiere, J. Y., and Charkaluk, E., Influence of Pores on Crack Initiation in Monotonic Tensile and Cyclic Loadings in Lost Foam Casting A319 Alloy by Using 3D In-Situ Analysis, Materials Science and Engineering: A, Vol. 673, 2016, pp. 362–372, doi: 10.1016/j.msea.2016.07.036.

[19] Xiao, B., Fan, Z., Jiang, W., Liu, X., Long, W., and Hu, Q., Microstructure and Mechanical Properties of Ductile Cast Iron in Lost Foam Casting with Vibration, Journal of Iron and Steel Research, International, Vol. 21, No. 11, 2014, pp. 1049–1054, doi: 10.1016/S1006-706X(14)60182-5.

[20] Zhao, Z., Fan, Z. T., Jiang, W. M., and Dong, X. P., Microstructural Evolution of Mg9AlZnY Alloy with Vibration in Lost Foam Casting During Semi-Solid Isothermal Heat Treatment, Transactions of Nonferrous Metals Society of China (English Edition), Vol. 20, No. 3, 2010, pp. 768–773, doi: 10.1016/S1003-6326(10)60579-1.