ЛИТЕЙНОЕ ПРОИЗВОДСТВО

https://doi.org/10.21122/1683-6065-2023-1-51-57
УДК 621.74

Поступила 10.01.2023
Received 10.01.2023

PERFORMANCE EVALUATION OF METAL MOULD FOR CASTING ALUMINIUM ALLOY (AA6063) OF SCIENTIFIC PRODUCTS IN NATIONAL AGENCY FOR SCIENCE AND ENGINEERING INFRASTRUCTURE

Sh. ABDULLAHI MOHAMMED, T. ABUBAKAR MUHAMMAD, Engineering Materials and Equipment Development Institute, Katsina, Katsina State-Nigeria. E-mail: abdulshab61@gmail.com
S. IBEH CHUKWUEMEKA, Scientific Equipment Development Institute, Minna, Niger State-Nigeria
C. ANYANWU SAMUEL, B-Fame Technology and Integrated Services-Nigeria, Minna, Niger State-Nigeria

The study investigated the major Causes of inconsistency in the cast results of the aluminium cast products from the metal moulds supplied by the then Hungarian Technical Partners to Scientific Equipment Development Institute, Minna. The metal moulds for different scientific products for Schools Scientific Laboratories were to achieve mass production of these products. The aluminium alloy A6063 ingot used were likewise imported. However, another consignment of the ingot used is produced in Nigeria by Nigerian Aluminium Extrusion Company, Lagos. Result of the products defects including shrinkage, blow holes, etc. remained the same, hence the need for this investigation work to ascertain the causes traceable to either moulds or the class or group of alloys.

The outcome as shown could be that pouring speed or melting temperature etcetera are responsible for the inconsistency in obtaining acceptable cast products at different operations and with these moulds. A particular product mould gives inconsistent cast products and varying defects. This is applicable to all the available moulds supplied to the Institute at the same time.

Keywords. *Metal mould, aluminium ingot, casting defects, casting parameters.*

ОЦЕНКА ЭКСПЛУАТАЦИОННЫХ ХАРАКТЕРИСТИК МЕТАЛЛИЧЕСКОЙ ФОРМЫ ДЛЯ ЛИТЬЯ СПЕЦИАЛЬНЫХ ИЗДЕЛИЙ ИЗ АЛЮМИНИЕВОГО СПЛАВА (АА6063) В НАЦИОНАЛЬНОМ АГЕНТСТВЕ ПО НАУКЕ И ИНЖЕНЕРНОЙ ИНФРАСТРУКТУРЕ

Ш. АБДУЛЛАХИ МОХАММЕД, Т. АБУБАКАР МУХАММАД, Институт разработки инженерных материалов и оборудования, Кацина, штат Кацина, Нигерия. E-mail: abdulshab61@gmail.com
С. ИБЕН ЧУКВУИМЕКА, Институт разработки научного оборудования, Минна, штат Нигер, Нигерия
С. АНЬЯНВУ САМУЭЛЬ, B-Fame Technology and Integrated Services-Nigeria, Минна, штат Нигер, Нигерия

В ходе исследования были изучены основные причины несоответствия качества литья алюминиевых изделий в металлические формы, поставляемые венгерскими техническими партнерами в Институт разработки научного оборудования в Минне. Металлические формы были предназначены для массового изготовления различных специальных литых изделий для школьных лабораторий. Первая партия исходной чушки из алюминиевого сплава А6063 также была импортирована. Вторая партия используемой чушки была произведена в Нигерии компанией Nigerian Aluminium Extrusion Company, расположенной в Лагосе. Однако дефекты изделий, включая усадку, газовые раковины и др., остались прежними, соответственно была поставлена задача выявить причины образования дефектов, в первую очередь исследовались сами металлические формы, а также режимы процесса.

Результаты исследований показали, что наибольшее значение имеют температура и скорость заливки расплава в формы. Важнейшую роль играет также конструкция металлической формы и ее качество. Эти выводы применимы ко всем формам и изделиям, получаемым в Институте.

Ключевые слова. *Металлическая форма, алюминиевый слиток, дефекты отливок, параметры литья.*

Introduction

The properties of commercial aluminium alloy depend on the amount of magnesium, copper, silicon, chromium and other alloying elements present in them. The properties are also influenced by the manufacturing techniques and heat treatment procedures employed [1–3]. Aluminum alloy 6063, as well as other similar alloys, which include silicon and magnesium as the main alloying elements, has properties such as high strength, excellent corrosion resistance, heat treatment and weldability, as indicated in Askland and Phule [4].

Aluminium alloy 6063 is formed into semi-finished or finished products, using various available fabrication techniques with casting accounting for the greatest percentage of such products. The properties of casting are influenced by moulding process employed and the properties of moulding materials used. Over the years various manufacturing processes such as casting, rolling and extrusion have been developed with the aim of improving the mechanical and micro structural properties of several aluminium alloys [5, 6]. According to [7], the type of mould used in metal casting depends heavily on the type of casting to be produced, the alloy involved and the complexity of the shape to be cast. Heat transfer between the solidifying casting and the mould is critical for high quality casting. In addition, heat transfer between the casting and the mould is primarily controlled by conditions at the mould metal interface. The quality of castings in a metal mould are influenced significantly by its properties, permeability, mould hardness and others which depends on input parameters like sand grain size and shape, pouring temperature, pouring speed, pressure or time etcetera [7, 8]. The distinct properties of 6063 aluminium alloys was known to be affected by some casting parameters such as fluidity, pouring height, metal composition, pouring speed, mould temperature, pouring temperature, casting size and moisture content among others. Some authors [2, 6] stated that enhanced mechanical properties of 6063 aluminium alloys using vertical continuous method was found to be effective as to minimize the overall cost of production. Improper casting procedures may give rise to defects such as pinhole, porosity, shrinkages, cavity and etcetera, which are largely responsible for poor mechanical properties of aluminium alloy products [9].

In this study, however, the effect of the mould on product casting defects of AI (AA6063) and possible remedies are evaluated and presented.

In recent time, Al-Si alloys are the most usual materials used in the casting process. This is due to the many benefits in the alloys such as wear and corrosion resistance, hot tearing resistance, good weldability, high strength to weight ratios and excellent castabilities hence, the alloys are suitable for the manufacture of critical castings for various purposes.

Generally, in alloy selection and classification these are based on whether they are prepared with new material which are called "Primary" alloys and those prepared with recycled alloy materials are called "Secondary" alloys.

Objective of the study

The main objective of this study is to carry out an investigation into causes of inconsistency that exists in the final products cast using some metal moulds meant to cast scientific items for use in the schools' science laboratories. Main issues:

1. What are the major reasons responsible for the inconsistency when aluminium alloy is cast in metal mould?
2. What are the strategies or steps to be used to find out these reasons and obtain consistent results?

Methodology

This research being experimental work took place in Scientific Equipment Development Institute (SEDI), Minna, Nigeria in the Foundry Workshop, using gas fired furnace where the crucible is loaded with ten (10) number aluminium ingots as shown in fig. 1.

The ingots were fired and melted at the temperature between 660 °C and 700 °C, the molten aluminium alloy was poured using ladle into five different metal moulds of various scientific products namely:

Fig. 1. Showing Aluminium Ingot

- Bunsen Burner base
- Double pully wheels
- U-shape clamp
- Connecting Branch for Bunsen Burner
- Bracket for pulley wheel pin.

The sequence of operation carried out in this study is illustrated in the Flow-Chart line diagram as shown in fig. 2. The chart commenced with preparation of all the necessary raw materials, equipment, tools, and machines, for this work.

Then, charging the furnace, firing/melting, casting/pouring molten metal, solidifying and cooling, removal, felting, machining and final inspection for defects or consistency in the result.

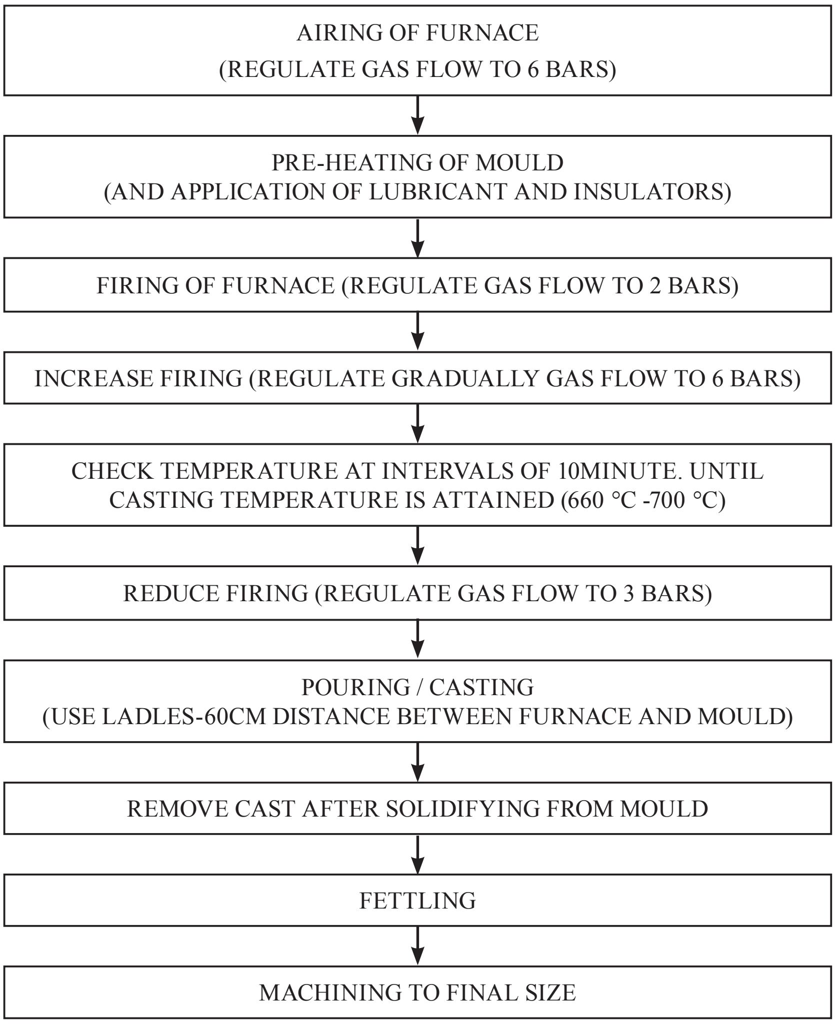

Fig. 2. Flow-chart Showing permanent metal mould casting of aluminium alloy procedure

Material Selection

Metal moulds used for the study were supplied and made from grey cast iron material and with ability of resistance to corrosion and its ability to retain heat. This is shown in fig. 3.

Table 1 shows the recommended materials for the manufacture of permanent molds for various materials, sizes of castings and different number of fillings [10].

Aluminium Alloys

Table 2 shows some typical groups of aluminum alloys that are used for the manufacture of castings in metal molds.

Aluminium alloy 6063 ingot used for this study was obtained from Aluminium Extrusion Company Lagos, and certified by a metallurgical scientist. AA6063 was selected for this study due to its high strength excellence corrosion resistance, heat treatability and weldability. AA6063 chemical composition is shown in table 3.

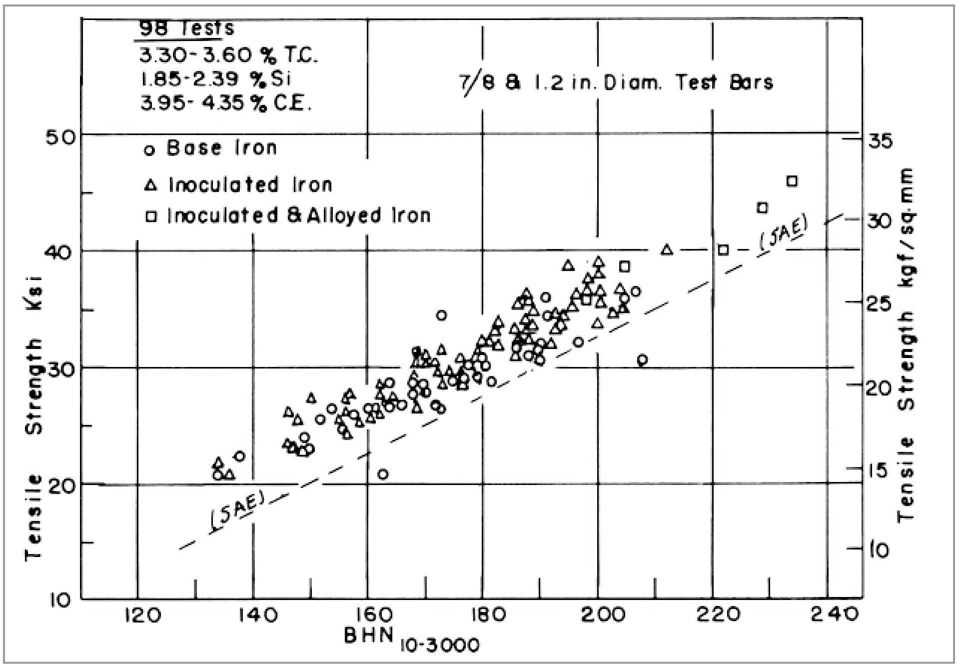

Fig. 3. Showing Grey Cast Iron phase (Brinell hardness-tensile strength relationship for foundry

T a b l e 1. **Recommended materials for permanent mould**

Alloy to be cast	Number of pours	
1000	10,000	100,000
For casting small parts (maximum dimension 25 mm)		
Zinc…………………… .	Gray iron, 1020 steel	Gray iron, 1020 steel
Aluminium magnesium…	Gray iron, 1020 steel	Gray iron with H14
Copper……Gray iron	H11 die steel, Gray iron	
Gray iron…Gray iron (a)	Gray iron (a)	21/2% beryllium copper Quantity not poure (d)
For casting medium-size and large parts (maximum dimension up to 915 mm)		
Zinc……………Gray iron; Hll (b)	Gray iron	Gray iron; H11(b)
Aluminium, magnesium… Gray iron	Alloy iron	Gray iron; H11; H14 (c)
Copper………Alloy cast iron	Alloy cat iron	Alloy cast iron (d)
Gray iron…………Gray iron (a)	Gray iron (a)	

Note: Same composition as being poured (b) H11 is used where polish is required on parts of medium size (c) recommendation are for medium-size parts, for large recommended materials are gray iron with H11 inserts or solid H11 die steel (d) Recommendations are for medium-size parts; large not pours in this quantity (c) Parts are not poured in this quantity.

T a b l e 2. **Showing some typical aluminium alloy groups obtainable**

Double alloys	Al-Si Al-Cu Al-Zn Al-Mg
Triple alloys	Al-Si-Mg Al-Si-Cu
Quadruple alloys	Al-Si-Mg-Cu

T a b l e 3. **Shows Chemical Composition of AA6063 Aluminium Alloy**

Element	Al	Mg	Si	Cu	Mn
(%) comp.	98.64	0.5141	0.5351	0.0013	0.0283
Element	Fe	Zn	Cr	Ti	Ca
(%) comp.	0.2108	0.0035	0.0007	0.0114	0.051

Casting Design Process

A methodical combination of experience and engineering basics are the precepts of prosperous casting. In fig. 4 most important components of the design process are exhibited as shown below.

- Physical design of part to be cast such as size and shape, tolerances with manufacturing and engineering, change of dimension in processes, relationship of this part to others to optimize its design by concurrent engineering.

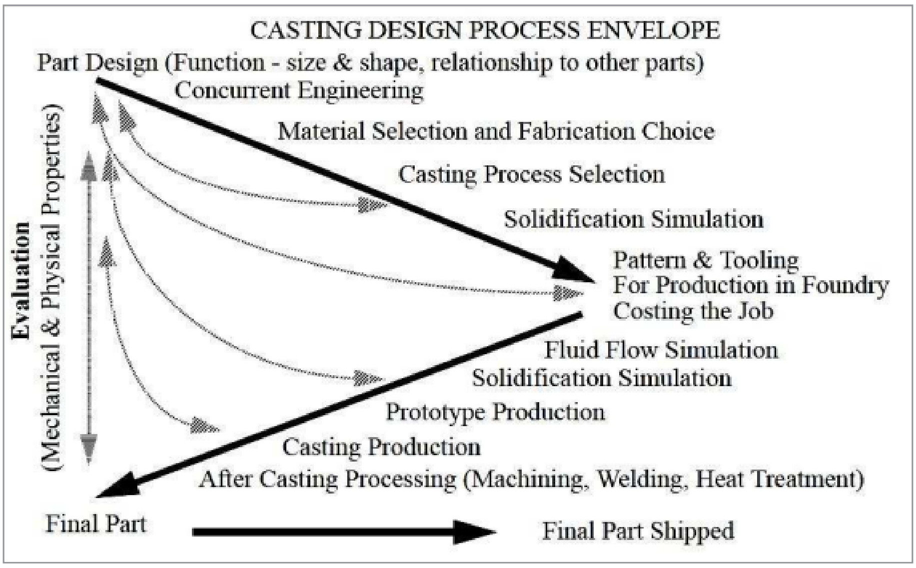

Fig. 4. Showing Casting Design process (MPRA Paper No. 77481, posted 13 Mar 2017 14:26 UTC)

- Select the material of part for casting.
- For moulds and cores gating and riser design by applying pattern production, fluid flow and heat transfer processes
- Select the casting process, limit the casting production because of metal cast, casting size, dimensional requirements for product
- Process of machining, heat treating and welding for after casting
- Evaluate the casting production.

Metal Casting Process

The metal casting process is the simplest and often at least cost. This process only requires a mold cavity of the desired shape and molten metal. Most often pouring molten metal into moulds made of sand have been produced by human beings for thousands of years. The basic components of a mould cavity contains cups, drag, parting line, riser, sprue, pouring basin, (part of the molten metal handling system) is known as a ladle, etc.

In the permanent mould casting, two halves of the mould is made of metal that are usually made of cast iron, steel, or refractory alloys for moulds. the cavity includes the runners and gating system which are machined into the mould halves. For hollow parts, either permanent or sand-bonded cores may be used.

This investigative study adopted the use of permanent metal moulds available in Scientific Equipment Development Institute, (SEDI) Minna, Nigeria for this purpose. The following fig. 5 and 6 show a metal mold with two cavities for making a pulley casting.

AA6063 ingot was charged into 50kg standard crucible after been pre-heated and placed in a lift-out crucible furnace. The molten alloy was poured into the cavities of moulds at the temperature of 700 °C and cast samples were allowed to cool for 4 hours before stripping. Some samples were produced, hand cleaning of the cast samples were carried out to remove protrusions and to obtain clean surfaces accordingly.

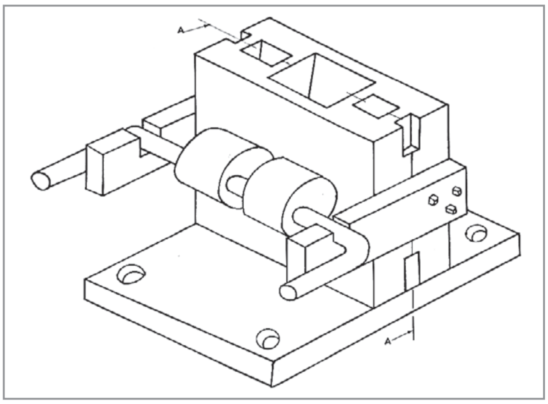

Fig. 5. Assembled Metal Mould for Double Pulley product

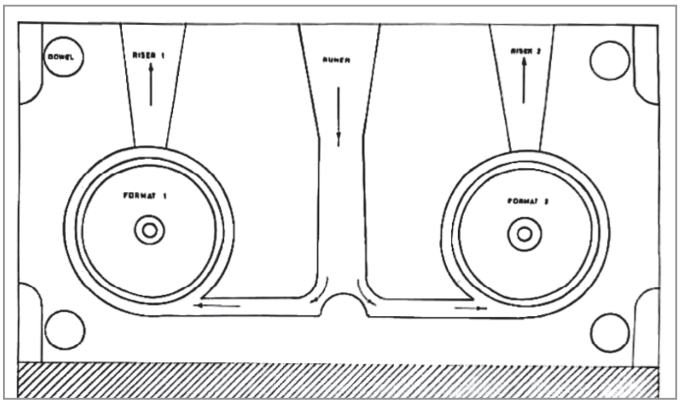

Fig. 6. Sub-Assembly Showing Pulley Cavity (One half)

Figure 7 showing cast samples from different metal moulds used for casting in this study before machining and cleaning.

Fig. 7. Samples of castings obtained during the study, before machining and cleaning

Discussion of Result

Table 4 shows the results of manufacturing castings from AA6063 alloy, the observed defects, the causes of defects and possible means of their elimination.

The surface finishing of the Bunsen Burner base is not satisfactory due to roughness and linear shrinkage observed on the size obtained. These defects could be due to faulty mould cavity, for example dirts, micro structural distortions in the mould etcetera, hence the need for laboratory inspection of the mould.

Table 4. **Analysis of castings from AA6063 alloy**

Name of Products	Scientific Products					Observed Defects	Possible causes of Defects Observed
	sp1	sp2	sp3	sp4	sp5		
Bunsen Burner	✓	–	–	–	–	Rough with Linear Shrinkage	Suspected faulty mould surface, dints, etc.
Pulley Wheels	–	✓	–	–	–	Smooth with cracks	Solidification time and speed of molten metal, etc.
U-Shape clamp	–	–	✓	–	–	Smooth, blow holes	Molten metal not properly degassed, excessive gas entrapment
Connecting Branch for Bunsen Burner	–	–	–	✓	–	Smooth, Linear shrinkage Lamination defects and blow holes	Too many sharp internal comers causing hot-spot isolation, low rpm extremely high rpm during metal solidification and liquid metal not properly degassed
Bracket for pulley wheel pin	–s	–	–	–	✓	Hot Tears/Cracks and flashes	Mould rough handling before complete solidification and high pouring pressure, etc.

The double pulley wheels cast has smooth finishing but with cracks on one side of the pulley and therefore, defect maybe as a result of improper solidification time and pouring speed of the molten metal into moulds. While the U-shape clamp exhibited some level of inconsistency in the cast.

The cast products has smooth surface and with blow hole defects. The possible causes could be as a result of improper degassing or excessive gas entrapment, etcetera, therefore, the need to implore appropriate and adequate use of degassing agents and reduction in gas entrapment.

The connecting branch for Bunsen Burner after cast showed some observed defects include linear shrinkage, lamination and blow holes. These might be due to many sharp internal angles (intricate parts) resulting into hot-spot isolation, low rpm and extreme rpm at solidification period, improper degassing of molten metal, etcetera.

The pulley wheel bracket cast product exhibited hot tear, cracks and flashes on the surface which are attributable to possible mishandling before the complete solidification and as well high pouring speed and pressure, etcetera.

Conclusion

The following conclusions can be deducted from the study's findings:

1. The study of metal mould in casting AA6063 was successful.
2. Casting using metal mould exhibited not as high degree of casting defects when compared to sand casting process.
3. A better surface finishing of cast samples were observed and casting intricate parts using metal mould was achieved, though, not very satisfactory.
4. Rapid solidification was achieved using metal mould when compared to sand mould.
5. Various defects observed on the samples of scientific products may be attributed to many reasons or causes, including:

– heat treatment employed – the cast alloys require more holding time at the solutionization temperature;

– grain dexture of the gray cast iron of these metal moulds used is not established, that is, the iron-carbon diagram group was not determined as at the time of casting;

– dirt in the mould due to improper maintenance and or small amounts of interstitial impurities in the mould;

– lack of pressure gauge to control and monitor the pouring pressure speed;

– the classification group of this aluminium alloys are not known, it is assumed to be 4××× Al-Si alloys (AAA-Aluminium Association of America) adopted by International Alloy Development System (IADS), hence, a critical issue unresolved in the study.

Recommendations:

• There is a need for laboratory inspection of moulds available in the Institute.

• There is the need for proper monitoring of solidification time and pouring of the molten metals into moulds.

• The need to implore appropriate and adequate use of degassing agents and regular maintenance of the pipeline gas entrapment.

• Casting of products with intricate parts should be handled with expertise and experience in order to minimize hotspot isolation during casting as well ensuring proper degassing of molten metal before pouring.

REFERENCES

1. **Kutz M.** *Handbook of materials selection.* New York, John Wiley & Sons, 2002, 1486 p.
2. **Al-Marahleh G.** Effect of heat treatment on the distribution and volume fraction of Mg_2Si in structural aluminium alloy 6063. *Metal Science and Heat Treatment,* 2006, no. 48 (5–6), pp. 205–209.
3. **Eady J.A., Smith D.M.** The effect of porosity on the tensile properties of Al-alloy castings. *Mat Forum,* 1986, no.9 (4), pp. 217–223.
4. **Askland D.R., Phule P.P.** *The science and engineering of materials.* Toronto, Thomson, 2006, 863 p.
5. **Alicia E. Ares, Raúl B. Rebak, María V. Biezma, Claudia M. Méndez.** Corrosion of Nonferrous Metals and Their Alloys. *Advances in Materials Science and Engineering,* 2018, May, pp. 1–2.
6. **Tolga D., Costas S.** Recent developments in advanced aircraft aluminium alloys. *Materials & Design,* no. 56, pp. 862–871.
7. **Fischer U.** *Mechanical and metal trades Handbook.* Haan-Gruiten, Europa-Technical Book Series, Verlag Europa-Lehrmittel, 2010, 428 p.
8. **Lerner Y.S., Rao P.N.** *Metal casting. Principles & Techniques.* University of Northern Iowa, *American Foundry Society*, 2013, 259 p.
9. **Vaibhav I., Madhukar S.** Defects, root causes in casting process and their remedies. *International Journal of Engineering Research and Application*, 2017, vol. 7, iss. 3, pp. 47–54.
10. **Charles F.W.** *Gray and Ductile Iron Castings Handbook.* Cleveland, Gray and Ductile Iron Founders' Society, 1971, 679 p.