Iraqi Journal of Industrial Research (IJOIR)

Journal homepage: http://ijoir.gov.iq

Production of Ductile Iron Using Inside-Mold Treatment Technique

Harith Hammody Abdullah*, Ali Awad Ibraheem, Ahmed Abdel Ameer Khudhair

State Company for Steel Industries, Ministry of Industry and Minerals – Iraq

Article information

Article history:
Received: May, 21, 2022
Accepted: October, 10, 2022
Available online: October, 20, 2022

Keywords:
Ductile iron,
Sand mould,
Magnesium treatment

Corresponding Author:
Harith Hammody Abdullah
harithaljobory@gmail.com

DOI:
https://doi.org/10.53523/ijoirVol9I2ID176

Abstract

Ductile Cast Iron is a widely used cast iron. Ductile iron applications are used in various sectors of modern mechanical industries. Ductile iron has wide uses in the field of car industry, military industries, agricultural equipment, construction and mines. The production of ductile iron faces many technical difficulties in our local factories due to the difficulty in providing equipment and technologies for its production by common methods. In this study, we resorted to applying one of the modern methods in the production of ductile iron, which is the treatment process for the molten iron in the sand mold. Magnesium alloys were added inside the sand mold within the casting stream and in the casting cavity for casting production. Specific weights were added and experiments were performed to determine the fusible chemical composition appropriate for preparing ductile cast iron. The study proved that adding magnesium alloys inside the sand mold, whether inside the mold cavity or in the casting channel, is both a successful method for producing ductile iron alloys. It is possible to produce different types of ductile iron by controlling the ratio of alloy additions to the molten metal content during casting.

1. Introduction

Ductile Cast Iron, also called spheroidal graphite cast iron. It was discovered in 1943 by Keith Millis. Most types of cast iron are characterized as brittle, while ductile iron has a lot of ductility and flexibility due to the presence of carbon in the form of spherical graphite [1]. The presence of graphite improves plumbing and workability in addition to thermal conductivity. In spherical iron, graphite appears as a spherical shape instead of the flakes that appear in gray cast iron. The spherical shape of the graphite can be obtained by adding proportions of pelleting elements such as magnesium and cerium to the molten iron. Ductile iron has wide uses in the field of car industry, military industries, agricultural equipment, construction and mining [2].

Spherical graphite iron contains a high percentage of carbon and silicon, where the carbon ratio ranges from 3.5 to 3.9%, and the silicon ratio reaches 2.9%, while the magnesium ratio ranges from 0.03 to 0.06%, and that the sulfur content does not exceed 0.015 and phosphorus 0.04%. Ductile iron production has several very complex problems. The main factors affecting the properties of castings are: metal melting process, chemical composition, cooling rate and freezing. The main problem is controlling the shape of the formed graphite and the microstructure of the metal. To overcome this problem, a good knowledge of casting and adding elements must be provided [3].

To obtain the required structure for ductile iron, it is necessary to strictly control the production process, while performing the necessary tests and analyzes. This requires several steps that can be summarized as follows:

Good quality ductile iron is obtained by controlling the shape of the graphite and the microscopic iron core. The optimum form of spherical graphite is obtained by treatment with magnesium to obtain a sediment content of magnesium within certain limits, and then add ferrosilicon to inform and develop the spherical size. Magnesium is an effective and explosive substance that is difficult to control. Many methods were used to obtain ductile iron by successful use of magnesium and with different treatment rates, but all handling methods are subject to many variables that cause obtaining different mechanical properties and these variables need precise control. The second step in the production of ductile iron is the addition of ferrosilicon to help sediment deposition. This step is important to prevent the formation of undesirable carbides that affect the durability and contribute to obtaining graphite in good shape, size and good distribution. It is necessary to examine the microstructure of each production process to ensure the success of the treatment process [4].

Figure (1) illustrates the types and shapes of graphite. Type (I) represents the ideal shape for spherical graphite. Type (II) represents the spherical shape, but is less perfect, but close to the spherical, types (III & IV) represent the spherical shape (vermicular) and these shapes are produced due to insufficient magnesium intake or other elements present in undesirable quantities. type (V) represents an explosive graphite. The spherical shape as in types (I & II) generally represents the necessary form for obtaining ductile iron, and the ratio of this shape should not be less than 80% of the graphite formed in the microscopic structure of the metal. If the ratio is less than 80%, the properties of the metal will not match the properties of the standard ductile iron. For the sake of safety, it is preferable that the percentage of spherical graphite not be less than 90%, and that the appearance of carbides in the metal must either be treated by thermal treatment methods or the product is rejected. Carbides affect metal ductility and operability. The tensile test is an important to measure the quality of the ductile iron produced. The result of the tensile examination is an important measure to determine the extent of control of the metal production process according to international specifications. The second important measure is the measurement of the percentage of magnesium remaining in ductile iron. The acceptable value is 0.03-0.05% or 0.04-0.03% and it is related to the ratio of carbon and silicon [5].

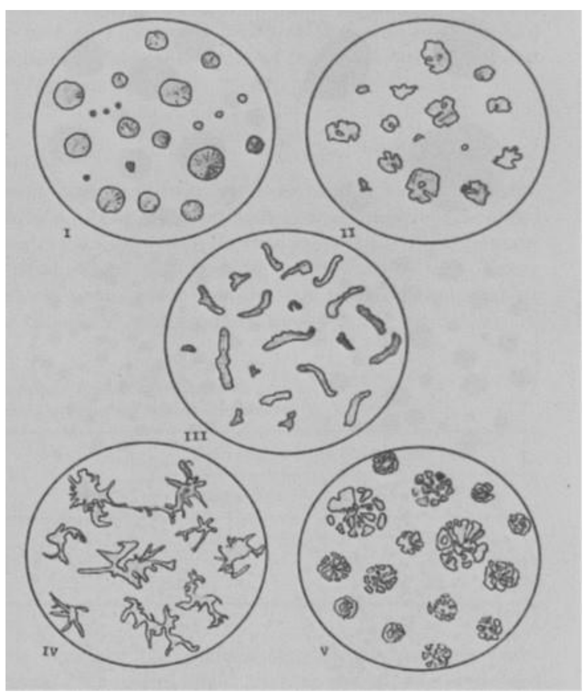

Figure (1). Types of graphite in ductile iron [5].

Magnesium is used as a basic additive to the molten iron to obtain spherical graphite. Magnesium has the advantage of being a very effective element if it interacts with oxygen strongly, generating an explosion when exposed to heat. It is also a light element with a low density that makes it float in the molten iron. Therefore, magnesium is not added directly to the molten. The addition of magnesium requires the presence of technical requirements such as the presence of crucible or special furnace with designs that allow adding magnesium initially and these techniques are often not available locally. See Figures (2 & 3). Magnesium is added in the alloy form, such as ferromagnesium or nickel-magnesium alloys, which are imported materials that are not usually available in the local market due to the lack of demand and limited use [6].

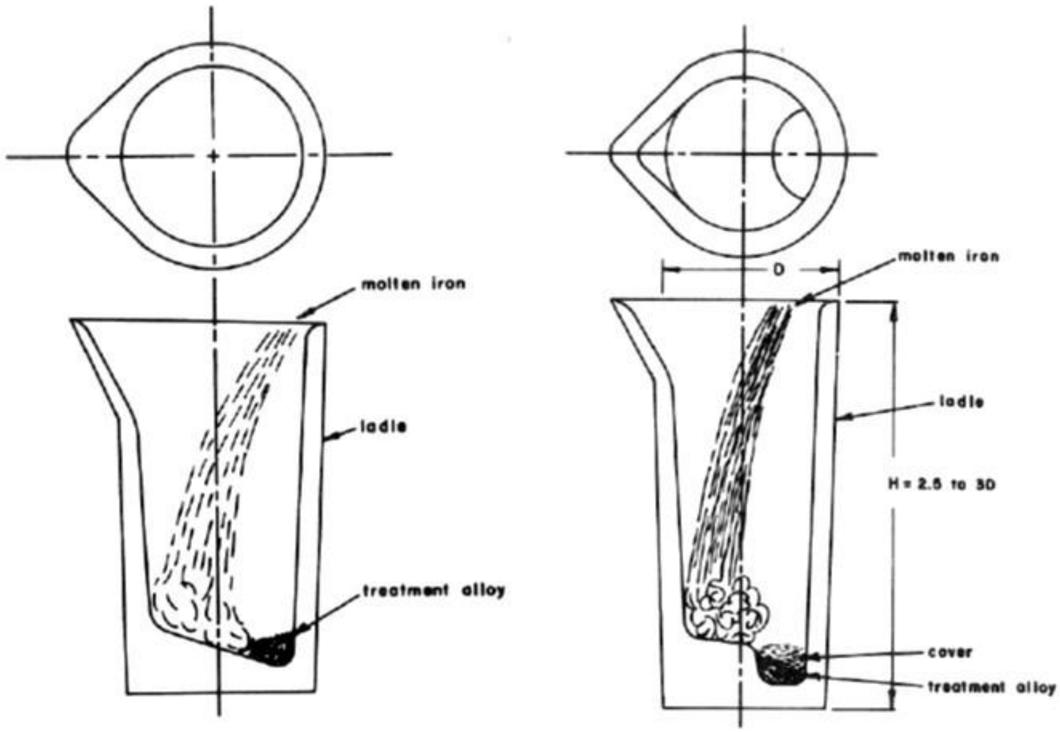

Figure (2). Traditional methods to produce ductile iron using magnesium treatment inside the crucible [5].

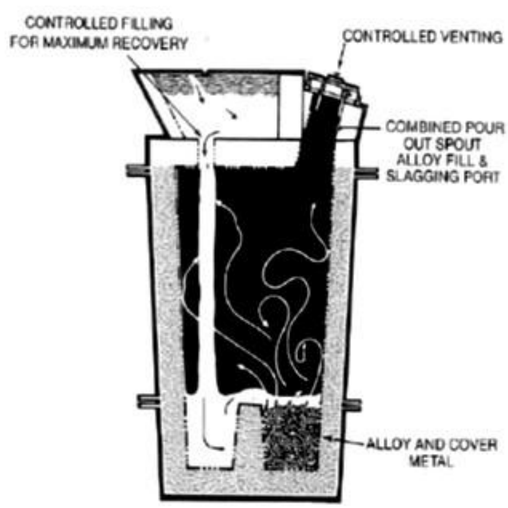

Figure (3). The use of "Tundish" crucible to produce ductile iron [5].

Because of the aforementioned constraints and the difficulty in providing alloying supplies for the treatment of molten iron such as crucibles or special furnaces, consideration has been given to resorting to technically easier methods to save costs and the difficulty of providing these requirements as being start-up and after reviewing global research it was considered using one of the modern methods in the production of ductile iron and is a method Add magnesium and treatment inside the sand mold instead of making it in crucibles or furnaces.

Yap (2009) pointed to using the method of adding magnesium in the mold as a way to perform the processing inside the mold instead of processing in the crucible. He indicated that this was achieved using sand mold [5].

J. O. Olawale, 2016, explained that there are more than seven methods for adding treatment elements into a mold. Some of it is added to the casting sprue , as in Figure (4), and some are added by it to the casting runner , as in Figure (5) [7]. Vadim (2016) also pointed to the method (treatment in the mold) and the need to reduce the sulfur content to the lowest possible level less than 0.015% [6].

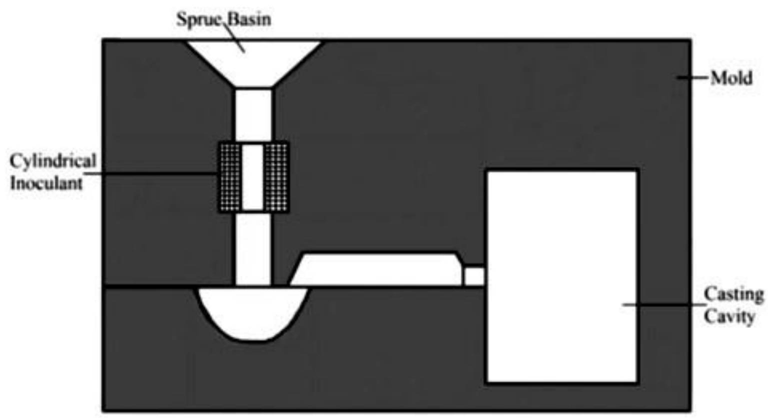

Figure (4). Scheme of the method for producing ductile iron by treatment in sprue.

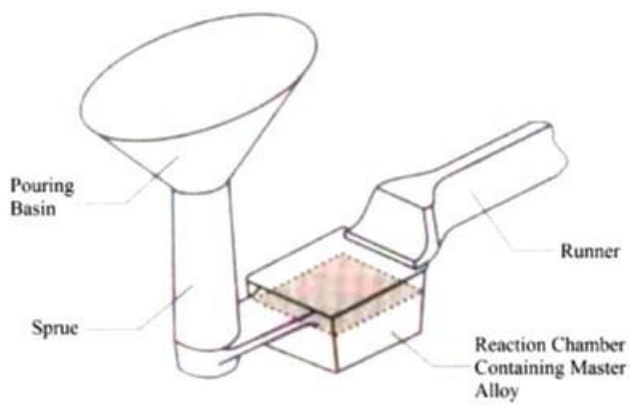

Figure (5). Diagram of the method for producing ductile iron by treatment in the casting runner.

In recent paper we study the cast iron after treating it by magnesium alloys in pouring runners and inside the cavity of mold. This research studies capability of production the ductile iron by treatment inside the sand moulds.

2. Experimental Procedure

The process of producing ductile iron requires careful control of the melting content of sulfur, phosphorous, and manganese elements due to its significant impact on the spherical graphite formation. This is done by carefully selecting the components of the charge that are placed in the melting furnace. The proportions of carbon and silicon must be within certain limits during the melting process. Carbon and silicon are two elements that help in the deposition of graphite and prevent the formation of carbides.

The effect of carbon and silicon on the formation of graphite is evident by the carbon equivalent, which is represented by a simple equation [8]:

$$CE_q = C + \frac{1}{3} Si \qquad (1)$$

A common analysis of the ranges of these elements according to the thickness of the castings appears in the Table (1). In castings with very little thickness, it is preferable to resort to a high level of carbon and silicon, but in high thickness it is preferred a low range for them.

Table (1). A common analysis of the ranges of carbon and silicon in ductile iron.

Element	¼″ thickness	½″-2″	Over 4″
C	3.65-3.80 %	3.55-3.7%	3.40-3.60%
Si	2.50-2.80%	2.40-2.70%	2.30-2.60%
CEq	4.50-4.60%	4.40-4.50%	4.30-4.45%

Initially, a sand mold was prepared for the purpose of the experiment, and the mold was prepared in the ground molding section of the Special Steel Plant at the State Steel Industries Company. The mold was prepared from a mixture of sand with water and the binder using a wooden pattern in the form of rulers with a length of 60 cm and a square section measuring 3 cm and by number 8 to obtain eight cells or cavities in the mold.

Eight cavities were manufactured in the mold to check the effect of different additions on the results of casting. The first cavity was left without any addition to the analysis of its chemical composition and the examination of its microscopic composition, while in the other seven cavities, first a nickel-magnesium alloy was placed in the casting runner second a nickel-magnesium alloy was put in the casting cavity. In the remaining cavities the ferromagnesium alloy was placed in the casting runner and the casting cavity sequentially. This was done to study the effect of nickel magnesium alloy on one side and ferromagnesium alloy on the other side on the formation of ductile iron. These alloys were also placed in the casting runners in a number of cells and in the casting cavity to compare the effect and effectiveness of the additives in those positions of the mold. After preparing the mold and leave it dry, the cavities are coated with a thermal coating to improve the casting surface properties. Thereafter, balanced quantities of nickel / magnesium 80/15 and ferrosilicon magnesium 3% FeSiMg were prepared as a powder. The chemical composition of alloys as in the Tables (2 & 3).

Table (2). Nickel magnesium composition.

Elem.	Mg	C	Fe	Ni
%	13-16	2 max	5 max	80

Table (3). Ferro-silicon magnesium alloy 3% FeSiMg.

Elem.	Mg	Si	Ce	Ca	Al	App. Fe
%	2.9 – 3.5	46	0 - 20	0.4 – 1.0	1.2 max	49

Alloys powder was distributed to the mold cells according to a specific system where the two powdered cells were placed in the mold cavity separately in a number of cells and placed in the casting runner in the remaining cells and left one of the mold cells without any addition. The cells were numbered for the purpose of distinguishing their content for the purpose of study and then the mold was closed to prepare it for the pouring process. The melting metal was prepared for the experiment according to the standard specifications as in the Table (4).

Table (4). Standard chemical composition of ductile iron.

Element	C	Si	Mn	P	S	Fe
%	3.5-3.9	2.2-2.8	0.1-0.7	<0.1	<0.1	Balance

The sixth furnace was used in the Special Steel Foundry, which is a 1.5-ton electric induction furnace, where the molten cargo was prepared from structural steel scrap, the carbon was slashed, and the pig iron was added. The molten metal was prepared within the standard. Table (5) shows a chemical composition of molten metal. Other elements appeared in the smelting due to the use of steel scrap, but it was considered acceptable for the difficulty of getting rid of them.

Table (5). The chemical composition of melting metal for the production of ductile iron.

Elem.	**C**	**Si**	**S**	**P**	**Mn**	**Ni**	**Cr**	**Cu**	**Fe**
%	3.6	2.4	0.03	0.06	0.7	0.04	0.17	0.03	Balan.

The molten was poured at a temperature of 1550 °C in the prepared mold for the experiment and then allowed to cool until the metal was completely frozen and its temperature reached the room temperature. Then the castings were removed and the process of removing the pouring system such as casting channels, then the castings cleaning with shot blasting.

Samples were taken for the purpose of microscopic examination of the different cells casted for the purpose of microscopic examination and were examined in the University of Technology laboratories. Tensile samples were prepared to test the mechanical properties of the metal and a chemical composition examination was also carried out.

3. Results and Discussion

It was confirmed the success of the production of ductile iron by laboratory methods in the form of three main steps, which were the microscopic installation of samples of the castings that were processed, and then determining the ideal sample in which the spherical structure appeared and then a tensile test for that sample. Samples were taken as cast without heat treatment. In the first sample, which was taken from the cell free from any addition of treatment alloys. The appearance of a gray iron structure is characterized by the appearance of graphite in the form of flakes as in Figure (6).

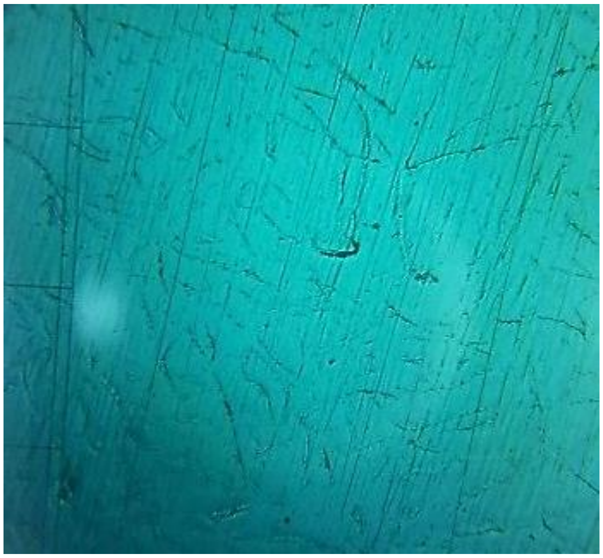

Figure (6). Microstructure for gray iron for sample 1.

In other cells, there was no significant effect of the addition of a nickel-magnesium alloy on the microstructure of castings, whether the addition was in the casting runner or in the casting cavity the results were the same.

In the cells in which a nickel-magnesium alloy was used, the microscopic structure as in Figure (7) was observed with the appearance of a spherical-like structure (Vermicular), where we notice the presence of nuclei scattered with a small number in the microscopic structure of the metal in addition to the graphite flakes we find distinguished by a large thickness in relation to the usual composition in Gray cast iron [9]. This composition shows that the reaction of the nickel-magnesium alloy was not carried out effectively to obtain the spherical structure, and that the amount of the added alloy, which is 0.5%, was not sufficient to produce the appropriate reaction to convert all the flakes.

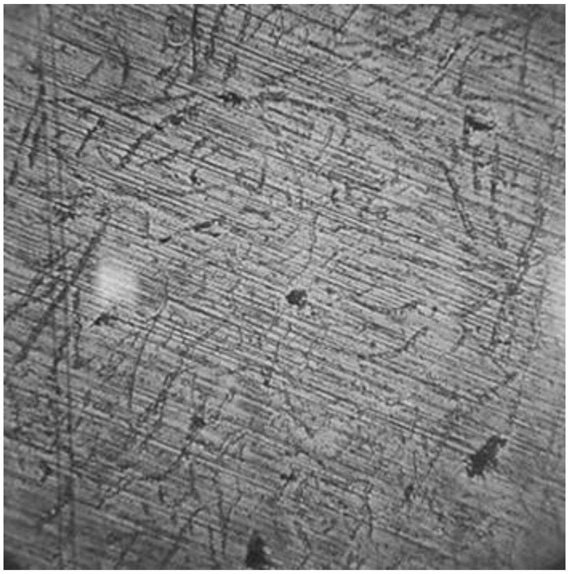

Figure (7). Iron treated by Ni-Mg alloy.

In the cells in which the ferromagnesium was added, where the volume of the addition of ferromagnesium was equivalent to 0.005 of the weight of the castings, its microscopic structure showed spherical graphite as clearly as Figures (8 & 9). Where we observe the emergence of spheroidal graphite impended in the ground of the ferrite. We also note that the size of the spheres is very small due to the lack of adding auxiliary materials for the growth of spheres in order to study the pure effect of ferromagnesium in the production of ductile iron.

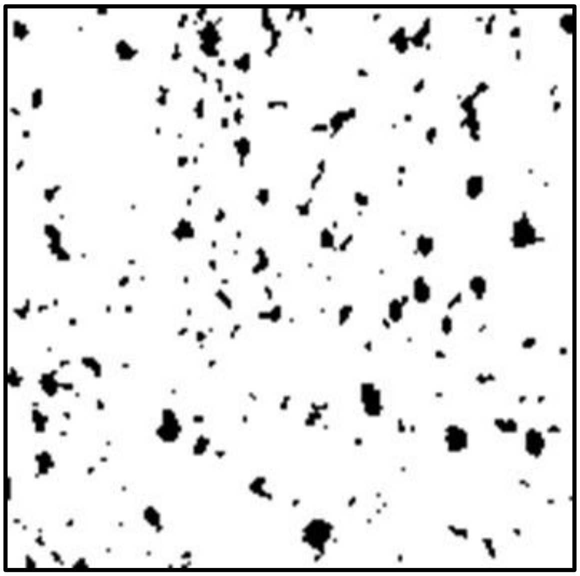

Figure (8). Microstructure of ductile iron sample (200X).

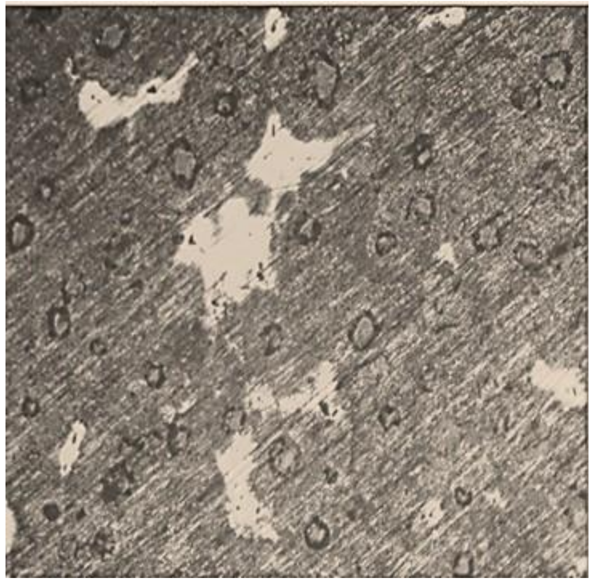

Figure (9). microstructure of ductile iron after etching (400X).

The chemical composition of the ductile iron sample was examined, as was the result of the examination, as in Table (6). We can note that the chemical composition of castings is within the standard ranges of carbon and silicon content, and that the remaining magnesium after treatment was within the specification. After that, the casted iron casting was cut and tensile test samples were prepared in Thu-Alfiqar factory of the State Steel Industries Company. Tensile and hardness tests were performed on the samples and the average test results were as in Table (7). As shown in the table, the results of the tensile examination showed a maximum tensile stress value within the limits of the American Standard ASTM A 536, which showed that the minimum limit of ductile iron in terms of tensile strength should be not less than 414 N/mm^2. It is clear from the chemical, microscopic, and mechanical tests that the addition of ferromagnesium inside the mold achieved the required treatment to convert the calories to the required spherical shape.

Table (6). chemical composition for ductile iron sample.

Elem.	C	Si	S	P	Mn	Ni	Cr	Mg	Fe
%	3.6	2.5	0.03	0.06	0.4	0.07	0.17	.05	Balan.

Table (7). Mechanical properties of ductile iron sample.

Tensile strength N/mm^2	Hardness HB
440	198

4. Conclusions

The addition of magnesium alloys inside the sand mold, both inside the mold cavity or in the casting runners, is both a successful method of producing ductile iron alloys. It is possible to produce different types of ductile iron by controlling the ratio of alloy additions to the molten metal content during pouring. The production of ductile iron by treatment inside the mold requires precise control over the chemical composition of the smelting of iron and the proportions of added magnesium alloys.

References

[1] M. A. Kenawy et al , “Mechanical And Structural Properties Of Ductile Cast Iron”; *Egypt. J. Sol.*, vol. 24, no. 2, pp. 151-159, 2001.
[2] S. K. Sahoo et al, “Mechanical Properties Enhancement of Ductile Iron by Austempering and Copper”, Addition; pp. 30-31, 2013.
[3] Vadim Pikhovich,” Ductile Iron Quality Assurance Guide”, Ductile Iron Society, pp. 3-5, 2016.

[4] J. R. Davis, "ASM Specialty Handbook Cast Irons", pp. 11; ASM International, 1996.
[5] Yap Min Choo," Investigation Of Ductile Iron In Mold Treatment Process Parameter", University Malaysia Pahang, 2009.
[6] S. Bockus, A. and Dobrovolskis , "Effect Of Melting Techniques On Ductile Iron Castings Properties", *Metabk*, vol. 45, no. 1, pp. 13-16, 2006.
[7] J. O. Olawale, S. A. Ibitoye, K. M. Oluwasegun, "Processing Techniques And Productions Of Ductile Iron: A Review", *International Journal Of Scientific & Engineering Research*, vol. 7, mo. 9, 2016.
[8] Johny Wahyuadi Soedarsono et al, "Effects of Carbon Equivalent on the Microstructures of Thin Wall Ductile Iron", *Journal of Materials Science and Engineering*, vol. 5, pp. 266-270, 2011.
[9] Y. Zhang et al, "Effect of the matrix structure on vermicular graphite cast iron properties", *Int. J. Mater. Res. (formerly Z. Metallkd)*, vol. 5, pp. 397, 2020.