Journal of Advances in Science and Engineering (JASE)

Journal homepage: www.sciengtexopen.org/index.php/jase

Spheroidal graphite iron production of furnace roof hangers

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ARTICLE INFO

Article history:

Received 14 July 2020

Received in revised form 12 September 2020

Accepted 23 September 2020

Available online 24 September 2020

Keywords:

Furnace roof hangers

Graphite

Iron production

Spheroidal graphite iron

ABSTRACT

The wire rod mill of the Ajaokuta Steel Company Limited produces coils, wire rods and re-bars of different sizes. Without the furnace hangers, it will be difficult for the mill to continue to operate. This paper describes the production of furnace roof hangers that are required for re-heating furnace using the spheroidal graphite iron (SGI), highlighting the sand-casting process, charge calculation, and the chemical compositions. The facilities within the foundry shop of the steel company are used to produce furnace roof hangers. The available materials used for the casting of the hangers are the pig iron, scrap ends, foundry returns and magnesium. The process of production was performed through the reheating furnace for the heating of 120 m x 120 m x 120 m billets. One ton induction furnace of low frequency was used as the melting vessel. Also, 6 kg of magnesium was introduced in the ladle before the liquid metal was teemed into it. A Spectro analytical instrument was used to determine the chemical compositions of the materials before and after the casting processes. The analysis of the chemical compositions of produced sample of SGI are presented and discussed.

1. Introduction

The wire rod mill of the Ajaokuta Steel Company Limited, which has the capacity to produce 138, 000 tons needs to continuously fabricate wire rods of sizes from 5.5 mm to 12.5 mm and re-bars of sizes 6.0 mm to 12 mm. Without the availability of the furnace hangers, it will definitely be difficult for the mill to continue to operate. The novelty and the specialty were to use the facilities in the foundry shop of the company to handle such project. The production of these furnace roof hangers was handled by the foundry and pattern making shop of the company to produced damaged ones. The foundry shop has the capacity to produce ferrous and non-ferrous metals. In the premise of these challenges, the foundry shop produced furnace roof hangers using the spheroidal graphite iron (SGI) as the required materials needed for the furnaces. The foundry shop of the company has two electric arc furnaces, one ton induction furnace and other melting devices. It is suffix to state that both furnaces can be used to produce various type of cast

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https://doi.org/10.37121/jase.v4i1.107

2636–607X /**2736–0652**

iron ranging from malleable, grey, white and nodular or ductile cast iron (also known as SGI or SG cast iron).

Spheroidal graphite iron is basically a family of materials with a widespread variety of properties for diverse engineering needs. The importance and usefulness of graphitizing elements in engineering applications have been discussed in literature [1]. The main component is iron, with significant proportions of silicon and carbon [2]. Cast iron, a trendy cast metallic material, is commonly utilized in modern-day production due to its comparative cost advantage, suitable machining property, good castability and wear resistance [3]. The spheroidal iron can be fabricated by adding minor quantities of cerium and magnesium to the base cast iron basically with the same analysis as grey cast iron that fabricates graphite spheroid instead of flake [4]. This was done to change the morphologies of the materials from grey cast iron to spheroidal graphite iron; achieved by modifying the carbon flasks in the grey cast iron to nodules known as SGI. This material was used due to its lightness added as 1-2 % by weight of Ni-Mg alloy. Magnesium content in the alloy is about 10-20 %. Nickel is a graphite. Approximate chemical compositions of SGI are 3.0-3.6 % C, 2.0-2.5 % Si, and 0.6 % Mn, 10.04 max S and balance iron [5].

The effect of calcium and magnesium as spheroidizers on the graphite microstructure in cast iron was investigated in [6]. Samples of cast iron were heated in an induction furnace with a known composition charge as well as with specified ratios of calcium and magnesium as spheriodizers to the molten metal in the mold during casting process. The study found that the introduction of 100 % calcium produced graphite flakes in the microstructure while the usage of a mixture of 20 % Calcium and 80 % magnesium gave rise to a chunky, stubby graphite microstructure but the inclusion of equal proportion (50 % calcium and 50 % magnesium), 60 % calcium and 40 % magnesium as well 80 % calcium and 20 % magnesium resulted in the microstructure with a flaky graphite microstructure. The authors in [7] showed that the solidification of spheroidal graphite iron is controlled by the growth of large austenite dendrites, which form a grain pattern like that commonly found in most metallic alloys.

In this paper, the SGI is utilized in the production of furnace roof hangers. The hangers are required for the re-heating furnace at the wire rod mill of the steel company. Actually, the first condition for production of SGI is to have very low sulfur and phosphorus content. SGI iron is melted in high frequency induction furnace. The melting sequence for the production involves different steps. Metal melting is achieved in one-ton induction furnace. The charge was normally a mix of pig iron, steel scrap and ductile iron scrap to give the desired chemical compositions. Desulphurization of the iron is necessary since the spheroidal agent, magnesium readily formed from stable sulfides and therefore would not be available to perform the spheroid single process until sufficient of these elements have been added to combine with all the sulfur present.

2. Materials and Methods

The wire rod mill (Fig. 1) considered in this study is one of the four mills in the company, which produces wire, coils and re-bars. Fig. 2 shows sample rods produced from the mill with sizes between 5.5 mm and 12.5 mm that is also capable to produce re-bars of sizes between 6.0 mm and 12 mm. However, due to damages experienced sometime at the mill, it therefore became very penitent to produce and replace damaged one.

Fig. 1 Snapshot of the wire rod mill with production capacity to be 138,000 TPA.

Fig. 2 Snapshot of sample rods produced from the wire rod mill.

Table 1 Chemical compositions of available charge materials in the foundry shop.

Foundry Materials	% C	% Si	% Mn	% P	% Cr	% Mo	% S
Grey cast iron	3.20	2.50	0.55	0.10	0.02	0.01	0.10
Pig iron	4.30	2.18	0.46	0.04	0.02	0.55	0.12
Steel scrap	0.36	0.16	0.75	0.03	0.10	0.11	0.41

In order to produce these hangers, engineering design, materials selection, charge calculations, sand preparation and mixture processes and molding techniques, melting and casting procedures are used. To produce a spheroidal graphite iron, some percentages of magnesium or cerium are added into liquid metal in the majority of cases, which is always about 0.3 - 0.06 % into the ladle as modifier.

Magnesium added as Ni-Mg alloy due to problems of evaporation and burning when adding magnesium metal. An alternative was to trap Mg (40 %) – impregnated coke in the bottom of the receiving ladle. Other methods of grading spheroidal agents to the melt include plunging a case containing the agents into the liquid iron, direct addition to the treatment ladle with controlled agitation of the melt by means of passing dry air or nitrogen through a porous plug through which liquid iron cannot pass [8]. The melt was given an addition of Ferro-silicon, which, on entering the liquid iron, provides a number of physical centers or nuclei onto which the spheroidal graphite eutectic cells was formed during solidification. It was though those impurities in the Ferro-silicon, which such as aluminum, radium and calcium gave rise to these nuclei iron, graphite-austenite eutectic. Rather than cooling down to the white iron, iron carbide-austenite eutectic. The timing of the addition of the inoculants is important since the effectiveness of the inoculants decrease with increasing time between inoculation and pouring, and addition of the inoculants.

The casting of the furnace hangers was done by following the entire foundry processes to achieve the desire melting mix. The hangers were produced by implementing special alloy addition and suitable cooling rates so as to convert the carbon to spherical forms that can be utilized in areas where carbon in temper form or flake form cannot be utilized. The nodules formed during solidification can be of the following types: martensitic, ferritic or pearlitic/ferritic; with outstanding mechanical properties that can be compared to steels [9].

The constituents of available foundry materials are indicated in Table 1 while the compositions of other materials added are found in Table 2. The composition was determined via analytical tests performed at the foundry shop with the use of SPECTRO analytical instruments. The instrument was used to determine both ferrous and non-ferrous metals. These available charge materials were used in the production of furnace roof hangers in the foundry shop of the Ajaokuta Steel Company Limited.

Several molding processes can be used to produce grey cast iron, but in this study, the green sand molding was used. In the molding process; pattern for the production of furnace roof hangers were produced at the pattern making shop, woods were used as pattern and allowed 1% as shrinkage allowance [10].

2.1. Sand Preparation

The following processes were carried out:

(a) Dried ingredients i.e., bentonite, starch and dry silica were mixed in the Muller mixer for 3 - 5 min;
(b) 1 - 2% of water was added into the mixture and was allowed to run for 2 - 3 min;
(c) 1 - 2 % of Core oil was added in the mixture for another 2 - 3 min; and
(d) A baking temperature of 180 – 230 ^{o}C was observed and the baking time was between 2 - 4 h.

2.2. Charge Calculation and Determination of Chemical Composition of Materials

A charge calculation was prepared and used for the production of furnace roof hanger in Table 3. This serves as the model of the charge calculation. Fig. 3 shows the instruments used for the polishing of cast or rolled products before and after the casting operations while Fig. 4 shows the SPECTRO analytical instruments used for the determination of the chemical compositions of ferrous and non-ferrous materials before and after casting operations.

Table 2 Chemical compositions of materials with magnesium used as the inoculant for the formation of nodules.

Materials	Composition (%)
Silicon	43 - 48
Magnesium	6.7 - 25
Calcium	2.75 - 3.25
Aluminum	1 maximum
Mg Fe-Si	0.06

Table 3 Charge calculation for the melting process.

AJAOKUTA STEEL COMPANY LIMITED	
COMPUTER PROGRAMME FOR CHARGE CALCULATION IN FOUNDRY SHOP	
CHARGE CALCULATION:	**FURNACE ROOF HANGER**
HEAT NO.:	**17**
MATERIAL:	**SHEPOIDAL GRAPHITE IRON**
TONNAGE:	**1000 KG**
PRODUCT(s) :	**FURNACE ROOF HANGER**
CUSTOMER:	**WIRE ROD MILL -ASCL**
SPECIFICATION:	**C= 3.20%, Si = 2.5%, Mn= 0.55%, S = 0.10% , P = 0.10%**

MATERIALS	*%C	%SI	%Mn	%P	%S	%Cr	%Ni	%Mo	%Ass	Wt(Kg)
*PiG Iron	4.30	2.18	0.46	0.055	0.117	0.019	0	0	0.7795	779.50
Crop ends	0.36	0.16	0.75	0.032	0.041	0.1	0	0	0.1664	166.43
Fdy Returns	2.7	0.45	0.72	0.02	0.03	0.02	0	0	0.0541	54.07
%loss / Inc	10.00%	15.00%	15.00%	0.00%	0.00%	15.00%	0.00%	0.00%		
Specification	3.20%	2.50%	0.55%	0.00%	0.00%	0.00%	0.00%	0.00%		
Fe-Alloy Grade	0.00%	75.00%	75.00%	0.00%	0.00%	75.00%	95.00%	60.00%		

Capacity of Furance KG =	**1000.00**
Actual % of Pig Iron =	**77.95%**

			Remark	Required	Wt. of Fe-Alloy
C content	3.20%	"SUBT"		0.00	Kg
Si content	1.49%	"ADD"		13.50	Kg
Mn content	0.44%	"ADD"		1.41	Kg
P content	0.05%	"SUBT"		0.00	Kg
S content	0.10%	"SUBT"		0.00	Kg
C r content	0.03%	"SUBT"		0.00	Kg
Ni content	0.00%	"GOOD"		0.00	Kg
Mo content	0.00%	"GOOD"		0.00	Kg

TOTAL MARETIALS TO BE FED INTO THE FURNACE ARE AS FOLLOWS:

Pig Iron	=	779.50	Kg	0.0149	767.88	Kg
Cropends	=	166.43	Kg		163.95	Kg
Fdy Returns	=	54.07	Kg		53.26	Kg
Graphite	=	0.00	Kg		0.00	Kg
Fe-Si(75%)	=	13.50	Kg		13.30	Kg
Fe-Mn(75%)	=	1.41	Kg		1.39	Kg
Fe-Cr(75%)	=	0.00	Kg		0.00	Kg
Fe-Ni(75%)	=	0.00	Kg		0.00	Kg
Fe-Mo(75%)	=	0.00	Kg		0.00	Kg

The total of charge materials to be fed into the Furnace	**1014.91 KG**		**1000 KG**
NOTE: In case you wish to make the charge material to the capacity of the furnace.			**1000 KG**

2.3. Sand Molding

Green sand of high compressive strength with corresponding high green shear strength; permeability sufficient to vent mold gases, sufficient bentonite to absorb expansion and sand grain size, shape and distributions that gave the desired casting finished were used for the molding process.

Fig. 3 Spectro analytical instrument used to polish cast or rolled material prior to the determination of the chemical compositions.

Fig. 4 Spectro analytical instrument used for the determination of the chemical compositions of ferrous and non-ferrous metals.

Bentonite was added to the sand as binder with water. The sand was hand rammed with pneumatic rammers. Six mold boxes containing three furnace roof hangers each were prepared prior to pouring for cast compositions. (Each mold box contains three numbers- castings in a single box). The mold and core produced were painted (coated) with water mixed zircon immediately in green state. Every part of the mold including runner and in gates were painted, and second coating of zircon paint was done immediately the drying process was competed with spirit mixed. The influence of the molding sand on the quality of the casting skin formation can either be classified as molding sand with binders i.e., furfuryl alcohol and urea-formaldehyde resin (containing sulfur) or the molding sand, which are not bound with binders i.e., phenol-urethane resin (not containing sulfur). However, the sulfur-containing molding sand is more significant, because of its adverse effect on the formation of spheroidal graphite [11].

2.4. Materials Melting Processes

A 0.6 kg of magnesium was added into the ladle before the molten metal was poured into the ladle. The introduction of magnesium converts the structure of the grey cast iron from graphite to nodules. The function of the magnesium is to deoxidize and desulfurized the grey present in the molten metal. The sulfur and oxygen were absorbed on the graphite/melt interface during solidification, as graphite flask such as those found in grey cast iron will be formed. In order to produce the graphite nodules of ductile 1 - 2 % by weight of Ni-Mg alloy was added.

Magnesium causes the graphite to precipitate as spheroid nodules during solidification of the cast iron. Magnesium intensifies the super cooling of cast iron, resulting to chilling. The formation of white cast iron was eluded, injection of magnesium additions makes graphite nodular in shape and ferrosilicon promotes graphitization during solidification. As compared to flaky graphite in grey cast iron, spheroidal graphite does not weaken the matrix significantly; hence, the mechanical properties are of better quality compared to the grey iron [12].

In agreement with standard solidification theories, the austenite usually nucleates on the mold wall with resultant columnar growth, and with a slight reduction in the temperature, the austenite can nucleate on heterogeneities in the liquid metal resulting in epitaxial growth. As reported in [11], the graphite nuclei in compacted graphite cast iron contained CaS and MgS similar to nuclei found in spheroidal graphite iron. Also, graphite nodules in spheroidal graphite iron are nucleated, which afterward freely grow in the liquid.

3. Results and Discussion

Fig. 5 shows the de-slagging process during the melting of grey cast iron after the melt has achieved complete meltdown. This process is always performed before the addition of Ferro-alloys. The reason for doing this is to ensure that slag is not allowed into the casting, which could result to blow holes after the casting process thereby resulting to cast defects. Fig. 6 shows the point at the which the liquid melt is teemed into the one-ton ladle, the inoculant (magnesium was added into the melt through a closed container dropped into the ladle before teeming the grey cast iron into in order to change the morphologies of the cast materials from grey cast iron to SGI known also as nodular cast iron). The aim of this process is to change the carbon flakes to noodles, as required in the research work.

Fig. 5 De-slagging process at the one-ton induction furnace.

Fig. 6 Teaming of liquid melt into the one-ton ladle.

The principal effects of cast iron inoculation with magnesium are that it avoids the formation of hard carbide, which promotes the formation of hard graphite ferrite; decrease the solidification of shrinkage propensity; reduce the segregation tendency of allowing a trace element; lower the hardness; enhance the machinability of castings; improve the ductility and give better homogenous structures and properties in various sections of complex castings. The magnesium used in inoculants was found to the improve most of all these properties largely that other ferrosilicon-based inoculants alloys were achieved. Especially, the improvement in ferrite formation as well as shrinkage minimizing, machinability and microstructure homogeneity have been observed. In the production of grey cast iron some unwanted elements or impurities are removed from the production processes such as sulfur and oxygen. Magnesium reacted with sulfur present in the liquid iron until the residual sulfur was 0.01 %, sulfur was reduced to near (0.01 %,) the magnesium had little effect on the graphite.

Table 4 shows the chemical compositions of the analyzed sample with a SPECTRO analytical instruments in the Quality Control section of the foundry shop of ASCL. The first sample was taken before complete meltdown in the furnace was achieved. The second sample was taken immediately after full meltdown in the melting furnace was achieved after the addition of measured Ferro-alloys in the furnace had melted completely. The third sample was taken from the molten melting after the final de-slagging before the tapping of the liquid was performed. Figs. 7 and 8 show the casting and cast product of the roof hangers respectively.

Fig. 7 Casting of roof hangers.

Fig. 8 The cast product of the furnace roof hanger.

Table 4 Chemical compositions of the analyzed SGI produced sample with a SPECTRO analytical instruments.

Samples	% C	% Si	% Mn	% P	% S	% Mg	% Fe
1st Sample	3.29	2.58	0.61	0.02	0.01	0.06	92.96
2nd Sample	3.30	2.60	0.56	0.10	0.01	0.06	92.93
3rd Sample	3.29	2.59	0.60	0.02	0.02	0.06	92.95
Average	3.29	2.59	0.59	0.05	0.01	0.06	92.95

The development of cast iron, as cast graphite in the form of sphere instead of the usual flakes made it possible to be used as a new engineering material that is becoming increasingly important. This has led to numerous benefits of the SGI including versatility and higher performance at lower cost. The versatility is particularly distinct in the mechanical properties where the spheroidal graphite iron provides the designer with the option of selecting high ductility, with grades guarantying more than 18% elongation or high strength, with tensile strength exceeding 825 Mpa [3].

Conversely, the spheroidal graphite iron is more commercially useful than the steel, cast metal and malleable iron, which decrease in volume during the process of solidification. The formation of graphite during solidification causes an internal expansion of ductile cast iron as it solidifies. Hence, are free of sizeable shrinkage defects either with feeder that are much smaller than those used for malleable iron and steel. The spheroidal graphite iron has a standard mix of properties since its graphite occurs as nodules rather than flakes. These properties made it to have advantages such as good fluidity, low melting point, sand castability, excellent machinability and good wear resistance over grey cast iron. Nevertheless, it also has high strength ductility, toughness and hot workability. The usage of a combined addition of 40 % Ca and 60 % Mg as spheroidal agent and in mold addition technique produces spheroidal graphite cast iron. This coalesced addition lessens the amount of Mg alloy used in the spheroidization process with resultant reduction in the cost of production. The miniature shape of the nodule produced also increased in the nodularity of the cast iron.

4. Conclusion

This paper has described the production of furnace roof hangers that are required for re-heating furnace using the spheroidal graphite iron (SGI), highlighting the sand-casting process, charge calculation, and the chemical compositions. Furthermore, it discussed the sand preparation, charge calculation, and determination of the chemical composition of materials. A charge calculation was used to prepare the required charge materials needed for the melting of the materials. The production of the hangers was successful using magnesium as inoculant. This material will improve the casting performance and properties of the hangers. Magnesium contributes in adjusting to minimalize chill formation as well as to neutralize subversive trace element in the iron. The SGI also contains small and controlled amounts of sulfur and oxygen in a form that make them available for reaction with the introduction of magnesium into liquid iron. The special compositions designed will give highly powerful graphite nucleation conditions in the ductile irons along with very effective chill and shrinkage reduction. The produced hangers will have a combination of properties because the graphite occurs at low melting point, good fluidity sand castability, excellent machinability, and good wear resistance. This material also has high strength ductility, toughness, and hot workability. The experience acquired during this research work has proven that the use of magnesium as inoculants are especially effective in re-installing powerful inoculation conditions in irons of a “dead” nature.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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