Study on the Effect of Weight Percentage Variation and Size Variation of Magnesium Ferrosilicon Added, Gating System Design and Reaction Chamber Design on Inmold Process

A. Miss May Thu Zar Myint and B. Dr. Kay Thi Lwin

***Abstract*—** This research focuses on the effect of weight percentage variation and size variation of MgFeSi added, gating system design and reaction chamber design on inmold process. By using inmold process, well-known problem of fading is avoided because the liquid iron reacts with magnesium in the mold and not, as usual, in the ladle. During the pouring operation, liquid metal passes through the chamber containing the magnesium, where the reaction of the metal with magnesium proceeds in the absence of atmospheric oxygen [1].In this paper, the results of microstructural characteristic of ductile iron on this parameters are mentioned. The mechanisms of the inmold process are also described [2]. The data obtained from this research will assist in producing the vehicle parts and other machinery parts for different industrial zones and government industries and in transferring the technology to all industrial zones in Myanmar. Therefore, the inmold technology offers many advantages over traditional treatment methods both from a technical and environmental, as well as an economical point of view. The main objective of this research is to produce ductile iron castings in all industrial sectors in Myanmar more easily with lower costs. It will also assist the sharing of knowledge and experience related to the ductile iron production.

***Keywords* —** ductile iron, inmold process, magnesium treatment, microstructural characteristics.

I.INTRODUCTION

Research of producing ductile iron by using inmold process is the first experience in Myanmar. There are many magnesium treatment methods to produce ductile iron. The alternative sandwich method has been used since long time back. But the ladle treatment method is wasteful of expensive additive materials and has inherent processing problems. As a consequence, the inmold inoculation has become prevalent[3].

A. Miss May Thu Zar Myint, Principal Scientist, Materials Science and Materials Engineering Research Department. Myanmar. e-mail:maythuzar@gmail.com

B. Dr. Kay Thi Lwin, Pro-Rector, Technological University, Thanlyin, Myanmar. e-mail:dr.ktlwin@gmail.com.

The molds used in this method have at least one chamber for retaining nodularizing additive. It is based on positioning a reaction chamber in each mold. The magnesium alloy is placed in the chamber, which is connected to the gating system. The mold is poured with untreated base iron. When the iron flows over the alloy in the reaction chamber, it picks up magnesium. The treatment is thus inside the mold, so called inmold [2]

Nowadays, in Myanmar, industrial and agricultural fields become larger and larger, and the use of ductile iron instead of forged steels become more and more. The significant advantages of the inmold process are excellent recovery of magnesium and lack of air pollution. A disadvantage of inmold inoculation is that the treatment chamber occupies mold space which could otherwise be used for good castings. Extra metal must be poured to assure uniform nodularizing treatment, but metal that solidifies in the treatment chamber is scrap. A further disadvantage to the system is that the chamber is not visible once the cope mold is set on the drag. Once the cope is set, it is impossible to visually determine whether additive has been introduced to a particular mold before or after the iron is poured. False inoculation of the mold will produce a gray rather than a nodular iron casting. Therefore, it needs to ascertain the microstructure of each casting [3].

In this paper, the addition of weight percentages of magnesium-ferrosilicon alloy added were conducted with the amount of MgFeSi 0.5%,0.75%,1.0%, 1.25% and 1.5% respectively. The sizes of magnesium-ferrosilicon alloy added were varied 3mm, 4mm, 6mm, 10mm and 15mm respectively. The reaction chamber designs used were cylinder and rectangular shapes. The gating system designs used were the choke and runner across the reaction chamber, which is not only on a straight line but also not on a straight line. The results of chemical composition of ductile iron are also mentioned.

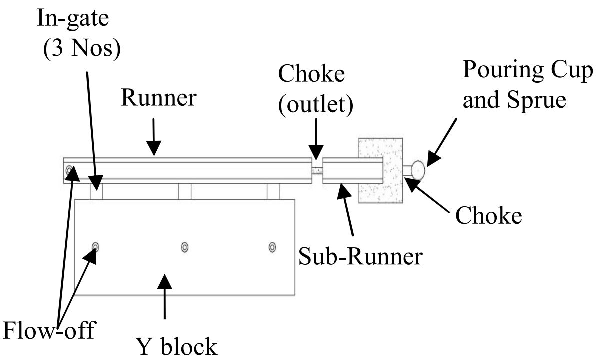
II. EXPERIMENTAL PROCEDURE

A. Gating Design Consideration

Gating system includes runner, sub-runner, ingates, sprue, sprue base, pouring basin, choke and reaction chamber. Runner was kept on upper half of the mold so that the dross cannot enter into the casting. Sprue was meant for gases and direct evaluation from the cavity of the mold during the pouring and feeding of the casting. It decreases the dynamic pressure exerted by the metal over the mold and also indicate the end of pouring. Choke is the smallest area in the feeding channels. It controls the flow rate into the mold cavity and consequently controls the pouring time. Therefore, the reaction of MgFeSi with molten metal can complete by keeping the choke in the gating system. Choke is also used not to enter the dross in the mold cavity [4].

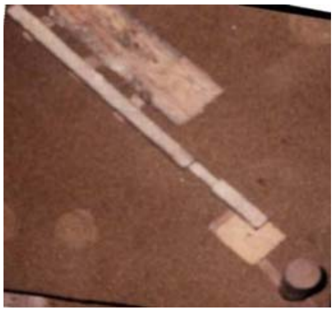
Firstly, the following gating design shown in Figure-1 was carried out. When the choke and runner across the reaction chamber is on a straight line, the reaction between the MgFeSi and the molten metal was not complete. So, the second gating design was carried out again as shown in Figure-2. In which, the choke and runner is not on a straight line, the reaction was completed. And then, the chamber design, the cylindrical shape was changed as shown in Figure-3 to get more homogeneous reaction.

(a)



(b)

Figure 1(a) Photograph and (b) drawing for typical gating system of Y-block test specimen (the choke and runner across the reaction is on a straight line)



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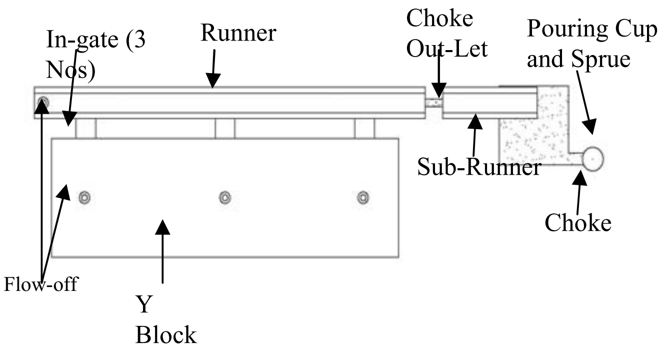


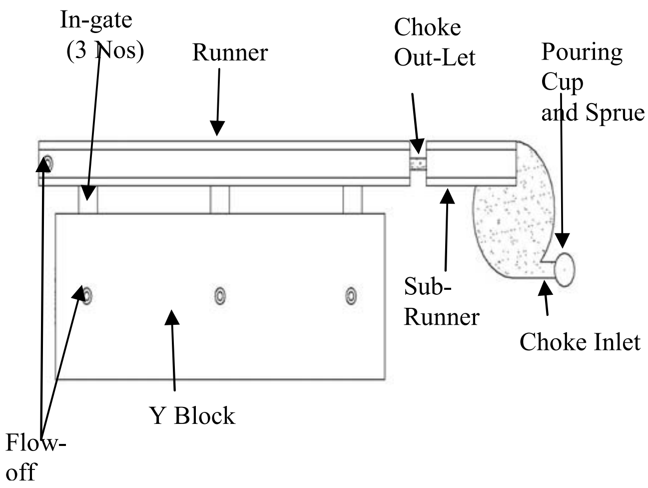
(b)

Figure 2 (a) Photograph and (b) drawing for typical gating system of Y-block test specimen (the choke and runner across the reaction chamber is not on a straight line)

B. Molding

Molds are made by using pep-set process. Firstly, equal portion of pep-set part-R and part-M are added to dried silica sand without clay, 50-60 AFS grain fineness normally. And then the quantity of catalyst part-K is added in accordance with the required curing speed, especially with the usable time. However as the usable time differs considerably according to the sand to be applied. As the quantity of part-K to be added is little, part-K is premixed with part-R normally. And then the quantity of catalyst part-K is added in accordance with the required curing speed, especially with the usable time [5].

(a)



(b)

Figure 3 (a) Photograph and (b) drawing for typical gating system of Y-block test specimen. (the choke and runner across the reaction chamber is not on a straight line and the reaction chamber is cylinder)

C. *Melting and Casting*

A low frequency induction furnace, coreless crucible type, having 500 kg capacity, was used for melting of ductile iron. The furnace lining consists of rammed silica with addition of 2 to 3 % boric acid. When the charges were thoroughly melted, accurate amount of carbon and silicon were measured by using carbon equivalent meter. Carbon adjustment of the alloys was made in the melting furnace, if necessary. Before tapping, temperature measurement was made by using digital emersion pyrometer.The tapping and pouring of the molten metal are shown in Fig-4(a) and 4(b). The calculated amount of nodulant (MgFeSi) and inoculant (S.G silicon) are placed in the reaction chamber systematically. The molten metal is poured into the pouring cup. It reaches the reaction chamber through the choke. And then, the molten metal reacts with MgFeSi in the chamber. After reaction with MgFeSi, the casting becomes ductile iron [6].

(a) (b)

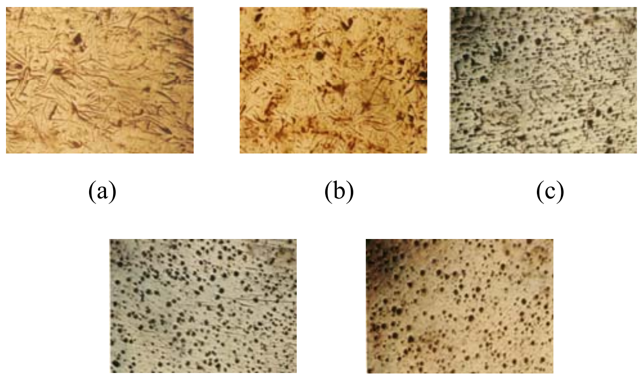
Figure 4 (a) Tapping and (b) Pouring of the molten metal.

III.RESULTS AND DISCUSSIONS

The amount of 1.25 % FeSiMg added gives the highest nodularity. The results of the influence of weight percent FeSiMg added (as cast condition) on nodule counts and nodularity are shown in Table-1,2,3,4 and 5 respectively. Maximum nodule counts were obtained when 1.5 % FeSiMg was added. The resultant microstructures are present in Figures.5,6,7,8 and 9 respectively. Normally, the nodule counts increase the structure and properties become more uniform, segregation is reduced and carbides can be minimized. Higher counts can also generally produce more uniform nodule size. But very high nodule counts are sometimes associated with low hardenability and non-uniform tempering. So, a nodule count of 80 to 150 discrete graphite particles per square millimeter appears to be optimum [6].
If nodule counts are more than 150, ferrite phase around the nodule is more than necessary and the casting becomes soft.

TABLE 1
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 15 MM SIZE OF MAGNESIUM FERROSILICON ALLOY. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.75%	1.0%	1.25%	1.5%
Nodule Count	no	no	44	102	86
Nodularity	Flake	Flake	65 %	95 %	95 %



(a) (b) (c)

(d) (e)

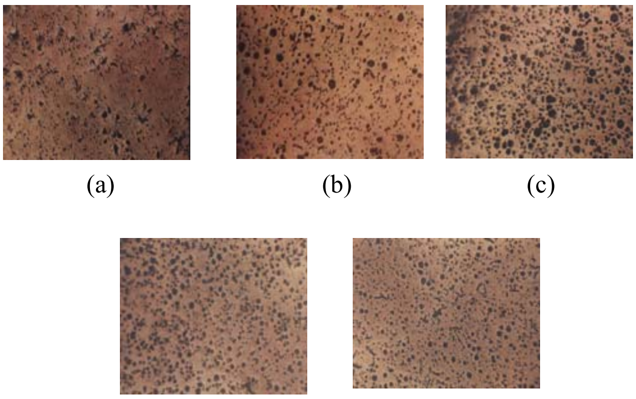
Figure 5 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 15 mm (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 % MgFeSi added

The highest nodularity was obtained when 10 mm size of magnesium ferrosilicon was added. The smaller the size of magnesium ferrosilicon added, the lower the nodule counts and nodularity because the contact surface area of each magnesium ferrosilicon grain is higher and the molten metal does not flow through these grains. So, the reaction of molten metal with magnesium ferrosilicon does not complete and the structure of graphite becomes flakes. When the size of the magnesium ferrosilicon added is larger than 10 mm, its nodule counts and nodularity decrease because the magnesium ferrosilicon grains cannot be soluble completely.

When the choke and runner across the reaction chamber is on a straight line and other parameters are kept constant, the nodularity are toward to worse. And the molten metal during the reaction with magnesium ferrosilicon is non-homogeneous. When the choke and runner across the reaction chamber is not on a straight line and other parameters are the same as above, the nodularity are the best as shown in Figure 10 and Table 6. And the molten metal during the reaction with magnesium ferrosilicon is more homogeneous. When the cylinder chamber was used and the choke and runner across the reaction chamber is not on a straight line, the nodularity is not as good as that of the reactangular as shown in Figure 11 and Table 7.

TABLE 2
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 10 MM SIZE OF MAGNESIUM FERROSILICON ALLOY. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.7%	1.0%	1.25 %	1.5%
Nodule Count	Verm-ular	90	110	130	175
Nodularity	35 %	85 %	90 %	97 %	95 %

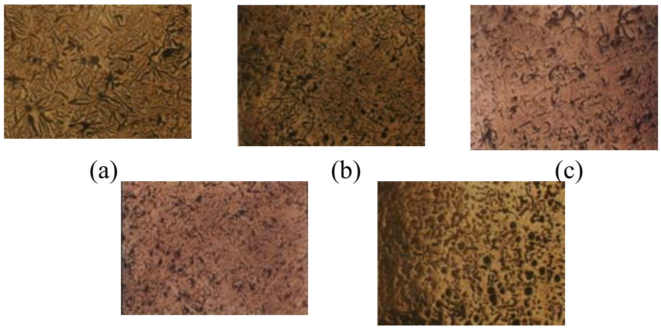


(a) (b) (c) (d) (e)

Figure 6 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 10 mm (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 % MgFeSi added.

TABLE 3
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 6 MM SIZE OF MAGNESIUM FERROSILICON ALLOY. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.75%	1.0%	1.25%	1.5%
Nodule Count	no	no	no	no	no
Nodularity	Flake	Flake	Flake	Flake	Flake

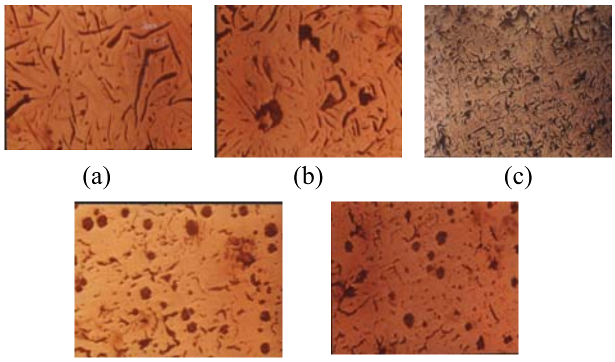


(a) (b) (c) (d) (e)

Figure 7 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 6 mm (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 %MgFeSi add.

TABLE 4
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 4 MM SIZE OF MAGNESIUM FERROSILICON ALLOY. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.75%	1.0%	1.25%	1.5%
Nodule Count	no	no	no	no	no
Nodularity	Flake	Flake	Flake	Flake	Flake

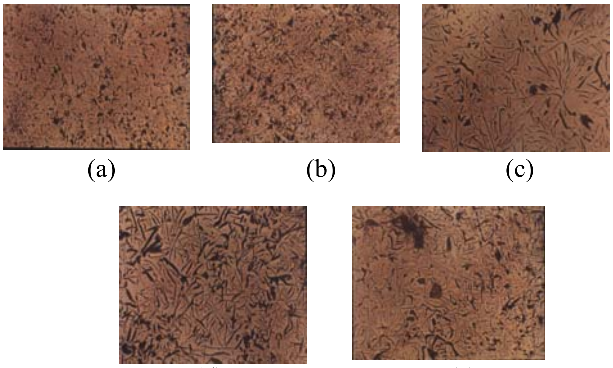


(a) (b) (c) (d) (e)

Figure 8 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 4 mm (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 % MgFeSi added.

TABLE 5
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 3 MM SIZE OF MAGNESIUM FERROSILICON ALLOY. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.7%	1.0%	1.25%	1.5%
Nodule Count	no	no	no	no	no
Nodularity	Flake	Flake	Flake	Flake	Flake



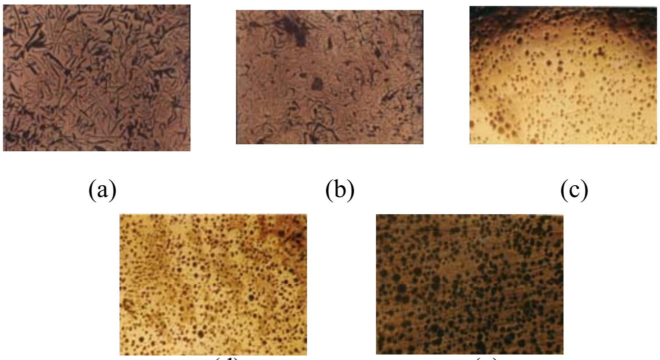
(a) (b) (c)

(d) (e)

Figure 9 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 3 mm (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 % MgFeSi added.

TABLE 6
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 10 MM SIZE OF MAGNESIUM FERROSILICON ALLOY WHEN THE CHOKE AND RUNNER ACROSS THE REACTION CHAMBER IS NOT ON A STRAIGHT LINE. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.7%	1.0%	1.25%	1.5%
Nodule Count	no	no	118	140	183
Nodularity	Flake	Flake	90%	98%	95%



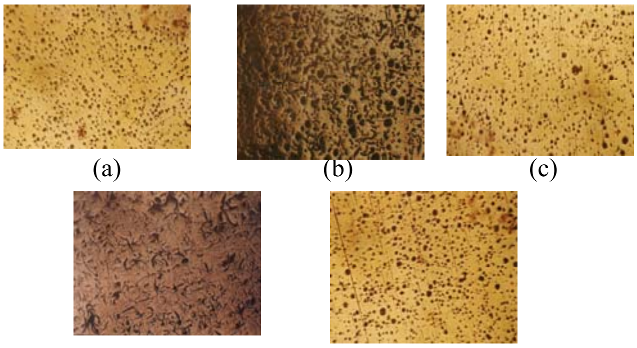
(a) (b) (c)

(d) (e)

Figure 10 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 10 mm and the choke and runner across the reaction chamber is not on a straight line (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 % MgFeSi added.

TABLE 7
NODULE COUNTS AND NODULARITY OBTAINED BY ADDING 10 MM SIZE OF MAGNESIUM FERROSILICON ALLOY WHEN THE CHOKE AND RUNNER ACROSS THE REACTION CHAMBER IS NOT ON A STRAIGHT LINE AND THE REACTION CHAMBER IS CYLINDER. (AS CAST CONDITION)

%MgFeSi added	0.5%	0.7%	1.0%	1.25%	1.5%
Nodule Count	no	36	116	137	132
Nodularity	Flake	50%	90%	95%	95%



(a) (b) (c)

(d) (e)

Figure 11 Microstructures of ductile irons before etching (× 100) by varying weight percentage of magnesium ferrosilicon added when the sizes of magnesium ferrosilicon added are kept constant at 10 mm and the choke and runner across the reaction chamber is not on a straight line and the reaction chamber is cylinder (a) 0.5 % MgFeSi added, (b) 0.75 % MgFeSi added, (c) 1.0 % MgFeSi added, (d) 1.25 % MgFeSi added and (e) 1.5 % MgFeSi added

IV. CONCLUSION

According to the data obtained in this study, the amount of 1.25 % MgFeSi addition gave the maximum metallurgical properties in all sizes of MgFeSi. (15 mm, 10 mm, 6 mm, 4 mm, 3 mm). When the choke and runner across the reaction chamber is on a straight line and 15 mm size MgFeSi added, it can be seen that the optimum nodule counts and nodularity were 102 and 95 %. When the choke and runner across the reaction chamber is on a straight line and 10 mm size of MgFeSi is added, the optimum nodule counts and nodularity were 130 and 97 %. When the choke and runner across the reaction chamber is on a straight line and the size of MgFeSi added is less than 10 mm, it was found no nodules and the graphite shape is flake. When the size of MgFeSi added was kept constant at 10 mm and the choke and runner across the reaction chamber is not on a straight line, the optimum nodule counts and nodularity were 140 and 98 %. When the size of the MgFeSi added was kept constant at 10 mm and the gating design was kept constant, the optimum nodule counts and nodularity were 137 and 95 % by just varying the reaction chamber design as cylinder.

In addition to the results obtained, the optimum metallurgical properties meet when the choke and runner across the reaction chamber is not on a straight line and the shape of the reaction chamber is rectangle. The best size of MgFeSi added was 10 mm.

Less amount of MgFeSi is used in inmold process than other conventional treatment process. Magnesium alloy consumption was reduced from 2 % to 1.25 % compared with sandwich method.

Therefore, the inmold technology offers many advantages over traditional treatment methods (sandwich, tundish, wire, converter) both from a technical and environmental, as well as an economical point of view.

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