Report

Report No. F132/00

Testing of Nodubloc® Magnesium Briquettes in Ductile Iron

ASi International, Cleveland, OH

by

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Elkem Research

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External Report

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Summary/conclusion

The present report is undertaken with the objective of testing and evaluating the magnesium-containing briquette Nodubloc in the production of ductile iron. Nodubloc is produced by ASi International, and is a high magnesium-containing briquette specifically designed to substitute for MgFeSi in ladle treatments of ductile iron.

The objective of the present work is to investigate into substitution of MgFeSi by increasing fractions of Nodubloc in a conventional tundish ladle operation. Effects of Nodubloc substitution on slag and fume formation, magnesium recovery, sulphur removal, and final microstructure evolution are evaluated in this investigation.

The following conclusions can be given from the present investigation:

- The present investigation has shown that up to 30% Mg-substitution by Nodubloc replacing MgFeSi is possible. Good and comparable magnesium recovery and microstructure have been obtained from substituting a 1.5 wt% addition rate of MgFeSi with 1.0 wt% MgFeSi and 0.1 wt% Nodubloc.
- Cost savings up to about $1 per 1,000 lbs. treated iron is possible when substituting 30% of the MgFeSi-addition with Nodubloc. When extra silicon adjustments are required, this saving will be restricted to approximately 30 cents.
- Nodubloc is a potentially attractive product for silicon control in ductile iron production, since the nodulizer briquette will only introduce trace contributions of silicon to the final castings.
- Specific MgFeSi and Nodubloc compositions may be designed for optimum cooperation in a package solution. A commercial package may be developed that ensure some kind of protective situation where sales of both products are supporting each other. Also, a designed inoculant solution for the concept should be included to complete the product package.

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1. Introduction

The present report is undertaken with the objective of testing and evaluating the magnesium-containing briquette Nodubloc in the production of ductile iron. Nodubloc is produced by ASi International, and is a high magnesium-containing briquette specifically designed to substitute for MgFeSi in ladle treatments of ductile iron.

The objective of the present work is to investigate into substitution of MgFeSi by increasing fractions of Nodubloc in a conventional tundish ladle operation. Effects of Nodubloc substitution on slag and fume formation, magnesium recovery, sulphur removal, and final microstructure evolution are evaluated in this investigation.

2. Experimental Work

Two heats of ductile iron base have been prepared. Charge composition is as follows:

220 kg pig iron (Sorel grade)

330 kg ductile iron returns

550 kg steel scrap

25 kg recarburizer (Desulco grade)

Heat No.1 has also been added 8 kg FeSi 75% for silicon adjustment. Heat No.2 has been added 3 kg FeSi 75%, and also 0.8 kg ferrosulphur to raise the base sulphur to an elevated level of about 0.03%S.

Both heats are split into 3 subsequent ductile iron treatments, each of 300 kg weight. The treatments are carried out in a conventional straight tundish ladle with removable lid and a sandwich divider wall in the bottom. The treatment sequence has been conducted as follows.

Table 1. Magnesium treatment sequence for Nodubloc testing.

Treatment:	**A**	**B**	**C**
Heat No.1	MgFeSi + 15% Nodubloc	MgFeSi + 30% Nodubloc	MgFeSi + 50% Nodubloc
Heat No.2	MgFeSi + 30% Nodubloc	MgFeSi only	MgFeSi + 50% Nodubloc

The two Mg-treatment agents used in the present work have the following composition.

Table 2. Composition of Mg-treatment agents.

Agent	%Si	%Mg	%Ca	%RE	%Fe
MgFeSi	46.0	5.9	1.0	1.0	Bal.
Nodubloc	13.0	21.0	6.0	-	Bal.

For heat No.1, the equivalent total Mg-addition as pure MgFeSi is aimed at 0.09%. When using only MgFeSi, this means a typical addition rate of 1.5 wt% or 4.5 kg alloy to 300 kg liquid iron. For the treatments A, B and C, this equivalent addition rate has been substituted by replacing a fraction of 15, 30, and 50% of the total Mg-addition by using Nodubloc. Base iron sulphur is aimed at about 0.01%.

For heat No.2, the equivalent Mg-addition as MgFeSi has been set to 0.15%. This is done to compensate for the elevated sulphur level of 0.03%. The intention with this heat is to evaluate whether Nodubloc is capable of reducing base sulphur more effectively than a conventional MgFeSi alloy. Additions of Nodubloc are done at 30 and 50% substitution of the total Mg-addition.

Hence, the following additions of the two respective agents have been made to the individual treatments.

Table 3. Additions of magnesium treatment agents.

Treatment:	A	B	C
Heat No.1	3.80 kg MgFeSi	3.20 kg MgFeSi	2.20 kg MgFeSi
	0.20 kg Nodubloc	0.40 kg Nodubloc	0.65 kg Nodubloc
Heat No.2	1.75 kg MgFeSi	2.50 kg MgFeSi	3.75 kg MgFeSi
	0.67 kg Nodubloc		1.08 kg Nodubloc

For all treatments, Nodubloc has been charged first into the ladle, followed by MgFeSi and 2.0 kg FeSi 75% used as sandwich cover material.

Inoculation has been done by adding 0.3 wt% of a Ba-containing FeSi inoculant to the metal stream while transferring 25 kg liquid iron into a small pouring ladle.

Sample castings are made from chemically bounded sand moulds containing simple plate castings. Each test has been subject to chemical and metallographic analyses to reveal characteristics of composition and microstructure. Also, after the Mg-treatment reaction is over, the ladle surface has been photographed to show quantity and distribution of treatment slag.

3. Experimental Results

3.1. Chemical composition

The chemical composition of experimental heats is summarized in Table 4.

Table 4. Chemical composition of experimental heats.

	Base 1	1-A	1-B	1-C	Base 2	2-A	2-B	2-C
% C	3.81	3.74	3.74	3.78	3.76	3.64	3.71	3.67
% Si		2.42	2.26	2.23		2.03	2.30	1.86
% Mn		0.44	0.45	0.44		0.30	0.30	0.30
% P		0.018	0.018	0.018		0.017	0.017	0.016
% S	**0.013**	**0.009**	**0.007**	**0.008**	**0.033**	**0.017**	**0.023**	**0.019**
% Mg		**0.044**	**0.038**	**0.031**		**0.055**	**0.056**	**0.039**
% Ce		0.008	0.008	0.006		0.010	0.011	0.008
% La		0.008	0.006	0.006		0.009	0.006	0.008
% Al		0.017	0.018	0.015		0.033	0.030	0.048
% Cr		0.030	0.027	0.025		0.087	0.080	0.087
% V		0.006	0.006	0.007		0.007	0.006	0.007
% Ni		0.05	0.05	0.05		0.10	0.10	0.10
% Cu		0.050	0.049	0.050		0.038	0.037	0.039
% Mo		0.005	0.006	0.006		0.006	0.005	0.006
% Nb		0.005	0.006	0.004		0.004	0.003	0.004
% Ti		0.012	0.012	0.012		0.011	0.011	0.011
% Sn		0.004	0.004	0.004		0.004	0.004	0.004

Hence, all tests represent normal composition for ductile iron. Heat No.1 shows a low base sulphur of 0.013% and a moderate reduction to about 0.008% after treatment. Residual Mg is around 0.04%, which should be sufficient for the low sulphur involved. Otherwise most alloying and trace elements are normal for ductile iron. Silicon shows a falling tendency for increasing substitution of MgFeSi with Nodubloc due to the lower Si-contribution with the briquette.

Heat No.2 also shows a normal development for a higher base sulphur of 0.033%. Final sulphur is around 0.02%, and final Mg around 0.05%, which is required for the higher sulphur involved.

Effects of the various treatment mixtures on Mg-recovery will be discussed in the following section.

3.2. Magnesium recovery

Magnesium recoveries are calculated according to the following formula:

$$Mg_{recovery}(\%) = \frac{Mg_{residual}(\%) + \Delta S}{Mg_{added}(\%)} \times 100\%$$

Where $Mg_{recovery}(\%)$ is the calculated magnesium recovery, $Mg_{residual}(\%)$ is the final analytical magnesium content, ΔS is the difference between base iron sulphur and final sulphur content, and $Mg_{added}(\%)$ is the total magnesium added to the liquid iron in percent. Magnesium added is calculated as follows:

$$Mg_{added}(\%) = \frac{Mg_{MgFeSi}(\%) \cdot wt\%_{MgFeSi} + Mg_{Nodubloc} \cdot wt\%_{Nodubloc}}{100\%}$$

Where $Mg_{MgFeSi}(\%)$ is the analytical Mg-content in the MgFeSi-alloy (here 5.9%), and $wt\%_{MgFeSi}$ is the addition rate of MgFeSi-alloy to the liquid iron. $Mg_{Nodubloc}$ is the Mg-content of Nodubloc (here 21%), and $wt\%_{Nodubloc}$ the respective addition rate of the same. For heat No.1 this Mg_{added} is kept constant at 0.09%, and for heat No.2 it is kept at 0.15%Mg. Hence, calculated Mg-recoveries will be as follows:

Table 5. Calculated magnesium recovery for the individual treatments.

Treatment:	A	B	C
Heat No.1	15% Nodubloc: **53% recovery**	30% Nodubloc: **49% recovery**	50% Nodubloc: **40% recovery**
Heat No.2	30% Nodubloc: **47% recovery**	Only MgFeSi: **44% recovery**	50% Nodubloc: **35% recovery**

Experience from longer series of Mg-treatments using 1.5 wt% MgFeSi of the same composition as used in the present mixture, and for a low 0.01% base sulphur iron, shows Mg-residuals in the range from 0.040 to 0.048% or average of about 0.043% Mg. This means an average Mg-recovery of about 50%. For the elevated sulphur of 0.03%, average Mg-residual is 0.058% and average recovery is 45% when using 2.5 wt% MgFeSi only.

Hence, Nodubloc substitution up to 30% of the total Mg-addition shows no significant change or reduction in Mg-recovery, while the 50% Nodubloc substitution seems to give a reduction in Mg-recovery of about 10%. This is valid for both the low and high sulphur situations.

3.3. Sulphur removal

The capacity of the Mg-treatment agent to reduce sulphur in the base iron has also been evaluated. For a normal base sulphur of about 0.01% and a 1.5 wt% addition of MgFeSi, the typical final sulphur will be about 0.005%. This means that about half the sulphur or 0.005%S typically is removed when using MgFeSi only. Present test series with low sulphur base represented by heat No.1 shows comparable residual sulphur ranging from 0.007-0.009% final with increasing Nodubloc addition up to 50% Mg-substitution. Hence, there are no indications that Nodubloc result in a different final sulphur when used in a low sulphur base iron.

For the elevated base sulphur of 0.033%, increasing Nodubloc substitution shows a slightly different trend. Typically, 2.5 wt% MgFeSi addition to such base sulphur iron gives a final sulphur of about 0.020% or slightly higher. With 30 and 50% Nodubloc substitution this final sulphur is reduced to 0.017 and 0.019%, respectively. This indicates that Nodubloc has a somewhat more powerful capability to desulphurize a high S base iron as compared to only using a low Mg-containing MgFeSi alloy.

3.4. Surface slag formation

Formation of surface slag after the treatment reaction is over has also been evaluated by photographing the metal surface in the ladle. Appendix 1 shows such photos from all six treatment ladles in this experimental series. For the low sulphur base situation, an increase in slag formation has been observed when substituting 50% of the Mg with Nodubloc (Heat #1, treatment C). For the elevated sulphur situation, an increase in slag formation has also been observed for the highest substitution of 50% Nodubloc (Heat #2, treatment C). The lower Nodubloc substitution cases show no significant difference in slag formation versus using MgFeSi only.

The higher slag formation tendency with the 50% Nodubloc substitution should be associated with the lower Mg-recovery for the same treatments.

It was also noted that with increasing Nodubloc substitution, the treatment reaction intensity increased. More flashing and flaring was observed for the highest Nodubloc situations, and some more magnesium fume was also seen escaping the reaction vessel. However, the increased reactivity is not regarded to cause any significant problems in a normal foundry tundish operation. With open sandwich ladles, however, the increased reactivity with Nodubloc may cause a risk for metal splashing out of the ladle. Caution has to be taken with charging of Nodubloc first into the ladle, and the briquettes should then be properly covered by both MgFeSi and a sandwich cover material (e.g. ferrosilicon).

Appendix 2 shows examples of treatment reactions for heat No.2-B and 2-C, without and with 50% Nodubloc substitution, respectively. A photo of manual ladle inoculation into the 25 kg crucible and pouring of test moulds are also included in Appendix 2.

3.5. Microstructure characteristics

Microstructure characteristics for 25 mm square test bars have also been measured in this investigation. Appendix 3 shows the complete collection of Microstructure Reports for all six treatments conducted.

The Microstructure Reports shows that all tests resulted in normal high nodule counts between 164 and 237 N/mm^2, and good nodularity between 83 and 89%. The pearlite content is about 60-70% for all samples. The increasing Nodubloc substitution in Heat No.1 definitely shows no negative interference with nodule count or nodularity. The highest substitution of 50% Nodubloc also shows highest nodule count and best nodularity in this series. It is expected that the lower residual Mg in treatment No. 1-C with 50% Nodubloc substitution is the direct reason for the higher nodule count in this case. Sample No. 1-A with the highest MgFeSi addition also shows a weak tendency to excess RE occurring as isolated exploded nodules.

For the higher sulphur situation in Heat No.2, the nodule count and nodularity is generally somewhat lower than heat No.1. However, no significant difference has been revealed between the pure MgFeSi, 30% and 50% Nodubloc substitution cases.

Hence, it can be concluded from metallographic examinations that Nodubloc substitution in the present case up to 50% of the added magnesium has no proven detrimental impact on the graphite structure represented by nodularity and nodule count. This conclusion is however specific to the present experimental conditions and may not be directly valid under different process conditions of base metal composition, temperatures, ladle design, agent additions, etc.

4. Comments & Discussion

Some cost savings for treatment of ductile iron may be expected from using the Nodubloc briquettes. The example below is meant to illustrate a situation where the initial condition of 1.5wt% MgFeSi is substituted by 30% Nodubloc replacement.

MgFeSi $0.50 per lb.

Nodubloc $1.60 per lb.

Example, costs per 1,000 lbs iron treated

1.5 wt% MgFeSi :

15 lbs MgFeSi x $0.50 = $7.50

1.0 wt% MgFeSi + 0.1 wt% Nodubloc :

10 lbs MgFeSi x $0.50 = $5.00

1 lb. Nodubloc x $1.60 = $1.60

Total treatment cost: = $6.60

When Si-adjustments are required, an additional 0.2% Si has to be added.

2 lbs Si x $0.30 per lb. = $0.60

Total cost incl. Si: = $7.20

Hence, in this case and with the material prices used, an expected saving of about 30 cents per 1,000 lbs treated iron may be expected from substituting 30% of the Mg-addition by Nodubloc. In cases where the Si-correction can be made up from charging more returns, the savings may be closer to $1 per 1,000 lbs treated iron. For a foundry producing 100,000 tonnes of liquid iron per year, savings will equal approximately $100,000 annually. This will come in addition to potential savings from using a higher share of returns as substitute for steel scrap or pig iron.

One possible advantage with using Nodubloc substitution may be the lower silicon contribution from Mg-treatment. Several foundries will be attracted by the idea of less silicon, since this will allow for more usage of Si-rich charge materials such as returns in the furnace. In some foundries, excess returns is a problem, and the freedom to remelt more may be regarded a great advantage. Also, foundries producing ferritic ductile iron with requirements to impact resistance, will be restricted to a maximum final silicon of about 2.5% to avoid brittleness. In such cases, a lowest possible Si-contribution from alloy additions may be required.

Other foundries using silicon sources in the furnace to compensate for high steel scrap charges may find Nodubloc substitution less attractive, since the lower contribution of Si from the treatment will require more adjustment to the base metal.

Another situation that may facilitate Nodubloc substitution and silicon control is during start-up periods after a line shutdown. For instance foundries that hold treated metal over night or over the Weekend will have a need to boost magnesium first thing in the morning without contributing too much with excess silicon.

Nodubloc with its high magnesium content is also regarded to be a fairly powerful sulphur scavenger in medium S base metal (0.02-0.05% base S). The use of a low Mg-containing MgFeSi alloy is generally not recommended in irons of more than 0.03% base sulphur due to the high alloy addition required. In such cases, Nodubloc substitution may be an attractive alternative to competitive treatment processes such as converter and cored wire. The mixture of MgFeSi and Nodubloc will still keep some of the most interesting advantages of MgFeSi versus pure magnesium when it comes to facilitating good nucleation response of the treated metal.

The present investigation has shown that up to 30% Mg-substitution by Nodubloc is possible. Higher levels may however cause problems related to low Mg-residuals, more slag formation, splashing and fume formation as well as potential structure deviations. Thus, the maximum substitution recommended should be 30% Nodubloc.

Another potential advantage of Nodubloc substitution may be related to heat conservation. Less total addition of nodulizer will cause less temperature losses from heating and melting the materials. In the case of 30% substitution, the reduction will be 0.5 wt% less MgFeSi equivalent added to the metal. This may correspond to a 10-50 degrees temperature saving.

The author of the present investigation expects that Nodubloc substitution will be a useful alternative in cases where the initial MgFeSi addition rate is higher than about 1.3-1.5 wt%. In cases where the treatment efficiency already is very high, and MgFeSi addition is closer to 1.0 wt%, it is expected that a high Nodubloc substitution may be more difficult to implement. A further reduction in MgFeSi addition by 0.5 wt% from

Nodubloc substitution sounds unrealistic as the final MgFeSi contribution will then become very low. The potentials for Nodubloc substitution to irons of a different base metal composition, temperature and addition rate than investigated in the present work, however have to be explored by more systematic testing to determine the total capability limits for this alternative product.

Finally, if Nodubloc and Elkem MgFeSi are going to be marketed together, it is recommended to make a complete product packet from this concept. Specific MgFeSi and Nodubloc compositions should be designed for optimum match, and a commercial solution based on the two products in a fixed package should then be promoted. This will ensure some kind of protective situation where sales of both products are supporting each other. Also, a designed inoculant solution for the concept should be included to complete the package. Building package barriers against competition and ensuring that the concept is only promoted as a total solution, not broken down into single product efforts, will then strengthen the total competitive marketing situation.

5. Conclusions

The following conclusions can be given from the present investigation:

- The present investigation has shown that up to 30% Mg-substitution by Nodubloc replacing MgFeSi is possible. Good and comparable magnesium recovery and microstructure have been obtained from substituting a 1.5 wt% addition rate of MgFeSi with 1.0 wt% MgFeSi and 0.1 wt% Nodubloc.

- Cost savings up to about $1 per 1,000 lbs. treated iron is possible when substituting 30% of the MgFeSi-addition with Nodubloc. When extra silicon adjustments are required, this saving will be restricted to approximately 30 cents.

- Nodubloc is a potentially attractive product for silicon control in ductile iron production, since the nodulizer briquette will only introduce trace contributions of silicon to the final castings.

- Specific MgFeSi and Nodubloc compositions may be designed for optimum cooperation in a package solution. A commercial package may be developed that ensure some kind of protective situation where sales of both products are supporting each other. Also, a designed inoculant solution for the concept should be included to complete the product package.

Kristiansand, March 22, 2000

Elkem ASA, Research

Torbjørn Skaland

Dr. Torbjørn Skaland

Research Manager, Foundry

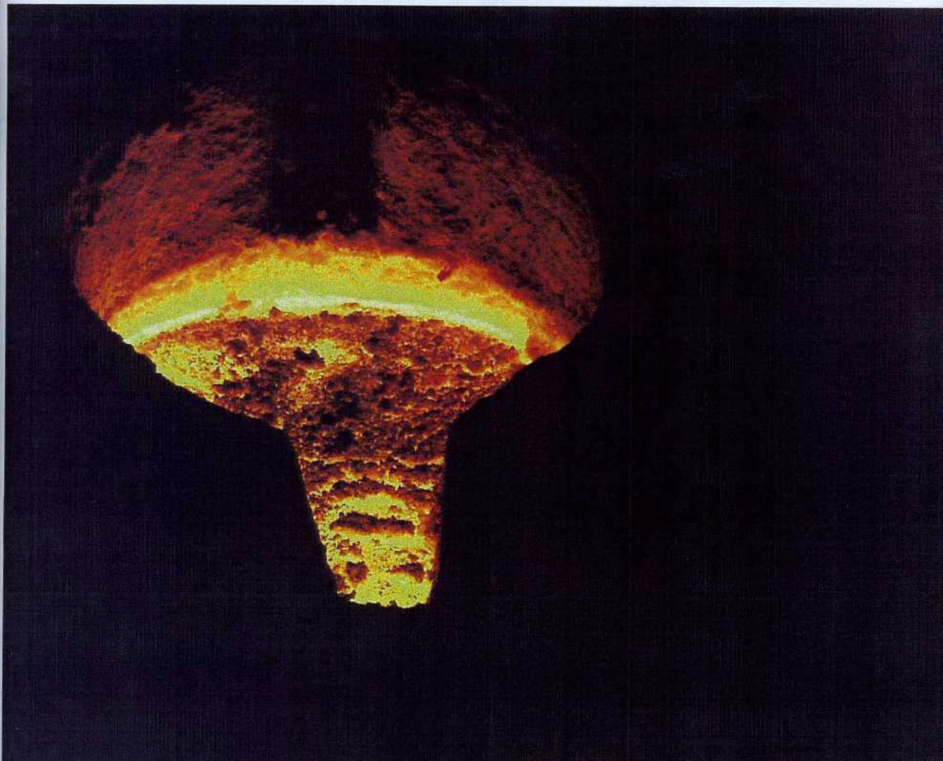
Appendix 1

Heat No.1, Treatment A

MgFeSi + 15% Nodubloc

Heat No.1, Treatment B

MgFeSi + 30% Nodubloc



Heat No.1, Treatment C

MgFeSi + 50% Nodubloc

Heat No.2, Treatment A

MgFeSi + 30% Nodubloc

Heat No.2, Treatment B

MgFeSi only

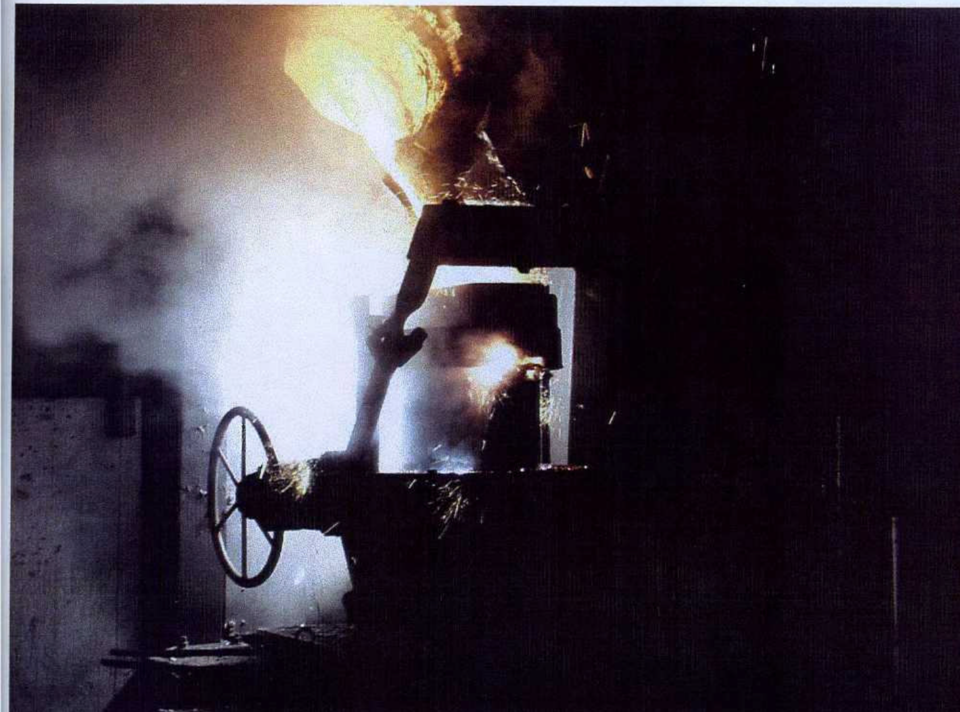
Heat No.2, Treatment C

MgFeSi + 50% Nodubloc

Appendix 2

Heat No.2, Treatment B

MgFeSi only



Heat No.2, Treatment C

MgFeSi + 50% Nodubloc

Ladle Inoculation

Pouring of Test Moulds

Appendix 3

Elkem
Research

Microstructure report

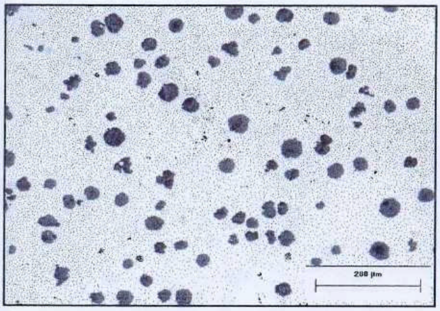
Heat No.1, Treatment A

Sample description: 8a-25mm

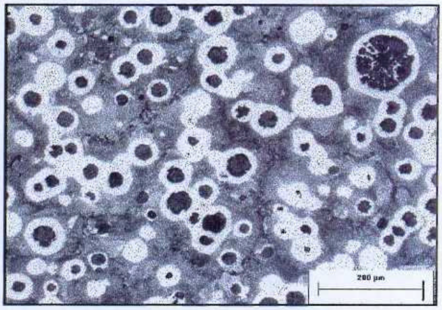
ER Ref.No: 186\99

MgFeSi + 15% Nodubloc

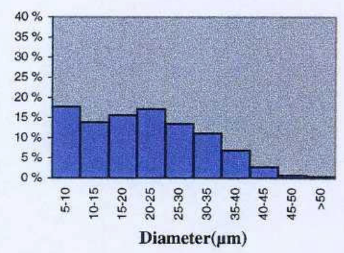
Nodule class	Total area (mm^2)	No. of nod. counted	Nodule count (N/mm^2)	Nodularity (%)	Graphite (%)	Ferrite (%)	Pearlite (%)	$Diam_{ave}$ (µm)	$Shape_{av}$ $\frac{4\pi A}{p^2}$
d_{av} >= 5µm	4.9	926	188	86	9	36	55	21.3	0.8
				Ferrite+Pearlite=100:		40	60		

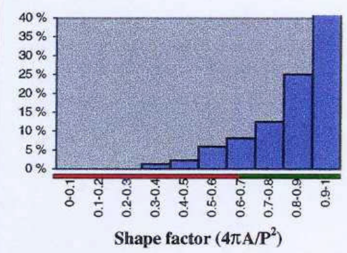


Micrograph showing typical nodule structure in the sample (polished condition)



Micrograph showing typical microstructure in the sample (etched in Nital)





Kristiansand 25.11.99

L. Berhane

Approved:

R. Gundersen

Elkem Research

Microstructure report

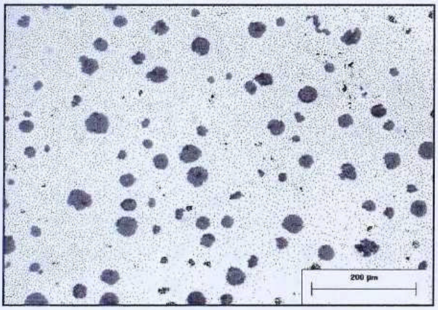
Heat No.1, Treatment B

Sample description: 8b-25mm

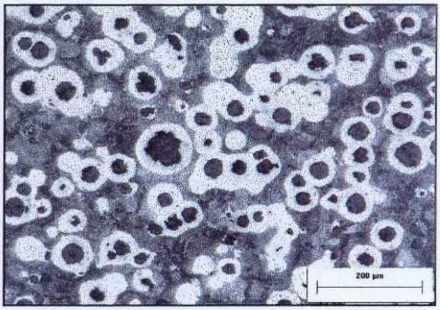
ER Ref.No: 186\99

MgFeSi + 30% Nodubloc

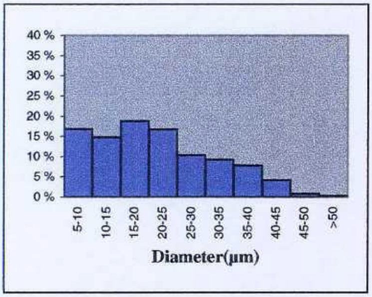
Nodule class	Total area (mm^2)	No. of nod. counted	Nodule count (N/mm^2)	Nodul-arity (%)	Graphite (%)	Ferrite (%)	Pearlite (%)	$Diam_{ave}$ (µm)	$Shape_{av}$ $\frac{4\pi A}{p^2}$
d_{av} >= 5µm	4.9	986	201	89	9	38	53	21.2	0.81
				Ferrite+Pearlite=100:		42	58		

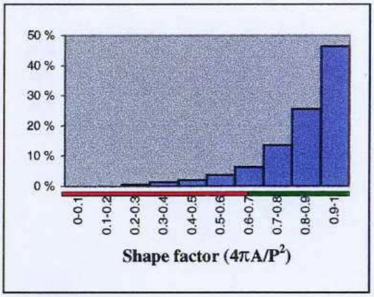


Micrograph showing typical nodule structure in the sample (polished condition)



Micrograph showing typical microstructure in the sample (etched in Nital)





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L. Berhane

Approved:

R. Gundersen

Elkem Research

Microstructure report

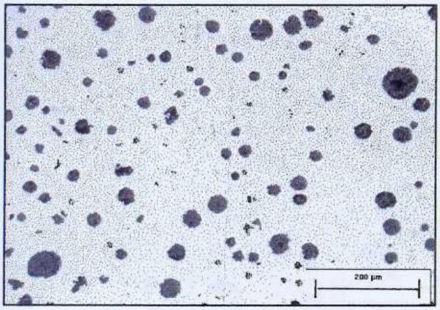
Heat No.1, Treatment C

MgFeSi + 50% Nodubloc

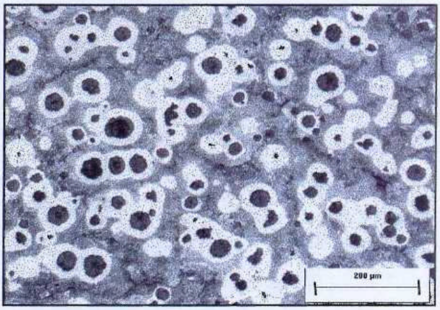
Sample description: 8c-25mm

ER Ref.No: 186\99

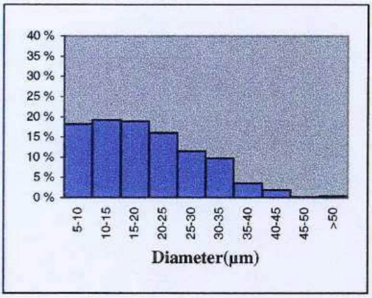
Nodule class	Total area (mm^2)	No. of nod. counted	Nodule count (N/mm^2)	Nodul-arity (%)	Graphite (%)	Ferrite (%)	Pearlite (%)	$Diam_{ave}$ (µm)	$Shape_{av}$ $\frac{4\pi A}{p^2}$
d_{av} >= 5µm	4.9	1167	237	89	9	42	49	19.5	0.81
				Ferrite+Pearlite=100:		46	54		

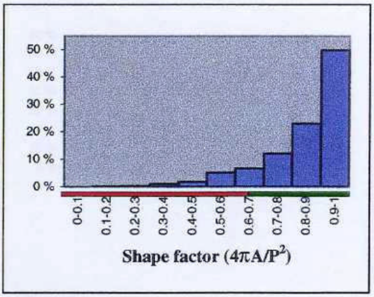


Micrograph showing typical nodule structure in the sample (polished condition)



Micrograph showing typical microstructure in the sample (etched in Nital)





Kristiansand 25.11.99

L. Berhane

Approved:

R. Gundersen

Elkem Research

Microstructure report

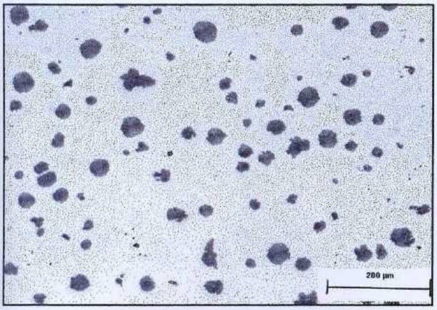
Heat No.2, Treatment A

Sample description: 9a-25mm

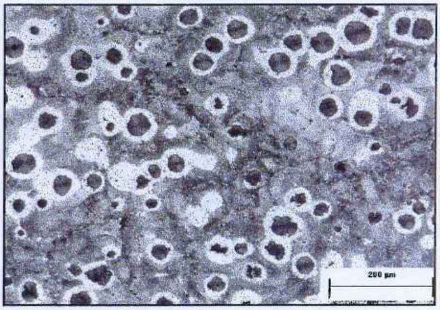
ER Ref.No: 186\99

MgFeSi + 30% Nodubloc

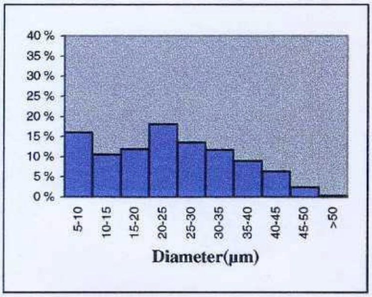
Nodule class	Total area (mm^2)	No. of nod. counted	Nodule count (N/mm^2)	Nodul-arity (%)	Graphite (%)	Ferrite (%)	Pearlite (%)	$Diam_{ave}$ (µm)	$Shape_{av}$ $\frac{4\pi A}{p^2}$
d_{av} >= 5µm	4.9	805	164	83	9	22	69	23.6	0.77
				Ferrite+Pearlite=100:		24	76		

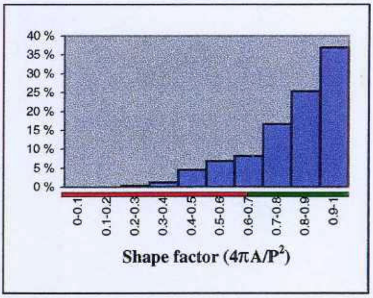


Micrograph showing typical nodule structure in the sample (polished condition)



Micrograph showing typical microstructure in the sample (etched in Nital)





Kristiansand 19.12.99

L. Berhane

Approved:

R. Gundersen

Elkem Research

Microstructure report

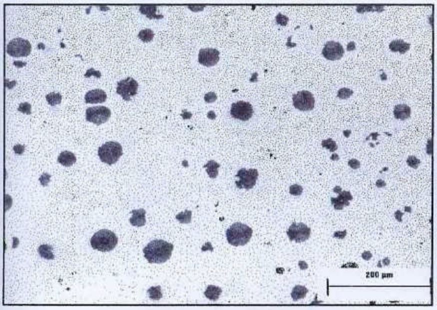
Heat No.2, Treatment B

Sample description: 9b-25mm

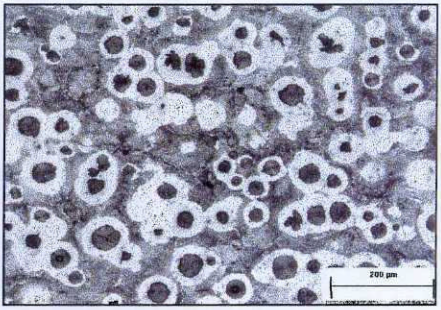
ER Ref.No: 186\99

MgFeSi only

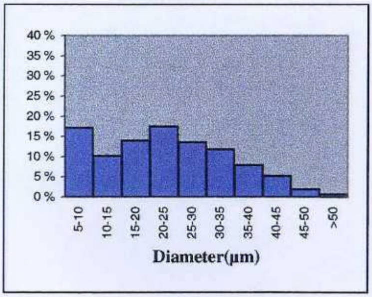
Nodule class	Total area (mm^2)	No. of nod. counted	Nodule count (N/mm^2)	Nodularity (%)	Graphite (%)	Ferrite (%)	Pearlite (%)	$Diam_{ave}$ (µm)	$Shape_{av}$ $\frac{4\pi A}{p^2}$
d_{av} >= 5µm	4.9	874	178	85	9	35	56	22.9	0.79
				Ferrite+Pearlite=100:		38	62		

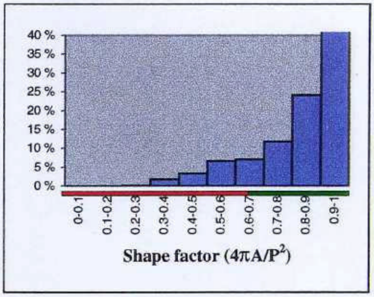


Micrograph showing typical nodule structure in the sample (polished condition)



Micrograph showing typical microstructure in the sample (etched in Nital)





Kristiansand 19.12.99

L. Berhane

Approved:

R. Gundersen

Elkem Research

Microstructure report

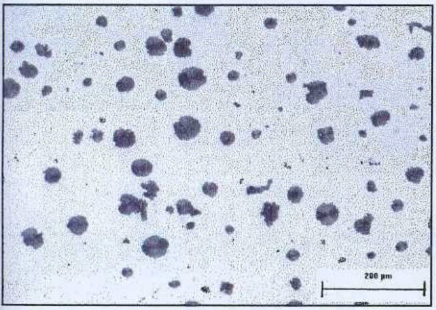
Heat No.2, Treatment C

Sample description: 9c-25mm

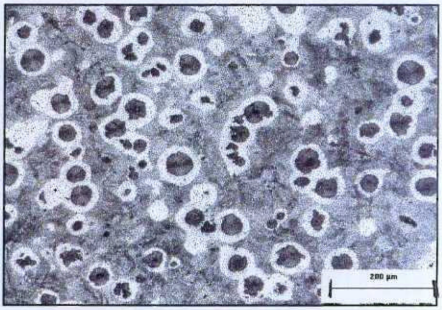
ER Ref.No: 186\99

MgFeSi + 50% Nodubloc

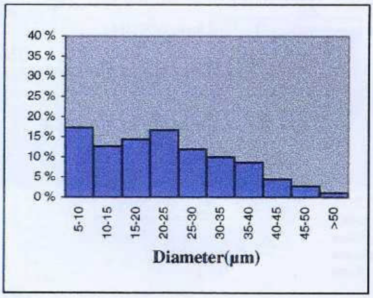
Nodule class	Total area (mm^2)	No. of nod. counted	Nodule count (N/mm^2)	Nodul-arity (%)	Graphite (%)	Ferrite (%)	Pearlite (%)	$Diam_{ave}$ (µm)	$Shape_{av}$ $\frac{4\pi A}{p^2}$
$d_{av} >=$ 5µm	4.9	856	174	84	9	27	64	22.6	0.78
				Ferrite+Pearlite=100:		30	70		

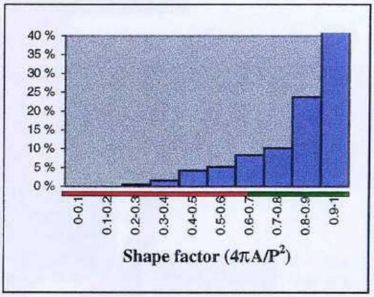


Micrograph showing typical nodule structure in the sample (polished condition)



Micrograph showing typical microstructure in the sample (etched in Nital)





Kristiansand 19.12.99

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Approved:

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