Fluctuations in Magnesium Treatment of Ductile Iron Some Reasons • Some Solutions

Excerpts from PowerPoint presentation by Mr. Pierre-Marie Cabanne, Manager, Sorelmetal Technical Service, Rio Tinto Iron & Titanium Inc., Canada, at the 1-day S. G. Iron Conclave conducted jointly by Rio Tinto Iron & Titanium, and Kastwel Foundries, Ahmedabad in ***Mumbai*** *on 16-9-11.*

(A) Introductory Remarks

This Subject is often discussed during our visits to various foundries. Recommendations are easy to give if the foundry has sound process control practice (in terms of weighing practice, metal temperature, sulphur content in molten metal etc.) However, different process parameters need to be analyzed.

Please Remember : FeSiMg is a costly alloy. Any saving in its use and consistency in process saves you money, besides improved consistency in Quality of Ductile Iron (DI) castings!

(B) General Formula

General Formula for Calculating the Weight of FeSiMg Alloy needed for Mg Treatment

$$W_{FeSiMg} = W_{ladle} \times \frac{(Mg_{final} + 0.76\,(S_i - S_f) + 10^{-3}\,t)}{\%\,Mg_{FeSiMg} \times R} \times (T\ °C/1450)^2$$

Where:

W_{FeSiMg} = Weight of FeSiMg *(kg)*

W_{Ladle} = Weight of molten metal in ladle *(kg)*

Mg_{final} = Mg in molten iron after treatment *(%)*

$\%\,Mg_{FeSiMg}$ = Mg content in FeSiMg alloy *(%)*

S_i = initial (before Mg treatment) Sulfur in the iron *(%)*

S_f = final (after Mg treatment) Sulfur in the iron *(%)*

t = time between treatment and beginning of pouring *(minute)*

T = temperature of iron *(°C)*

R = Yield of Mg in Mg treatment *(%)*

(C) Effect of Variation in Each Parameter

1. W_{Ladle} = weight of molten metal in ladle (kg)

Only the cored wire process takes into account the weight of molten DI in the ladle. Other processes are influenced by the fluctuation of weight of molten metal in the ladle.

A fluctuation of **± 5%** is 'normal', and automatically generates variations in the final Mg content of treated iron.

Parameter		Target	Actual	Change (%)
W_{ladle}	***(kg)***	**1000**	**1050**	**5.0**
Mg_{FeSiMg}	(%)	6	6	Nil
R	(%)	60	60	Nil
Mg_{final}	***(%)***	**0.0350**	**0.0329**	**-6**
S_i	(%)	0.01	0.01	Nil
S_f	(%)	0.005	0.005	Nil
t	*(minutes)*	5	5	Nil
T	*(°C)*	1450	1450	Nil
W_{FeSiMg}	*(kg)*	12.17	12.17	Nil

Actions to minimize this variation

- Use of a good balance
- Good hydraulic lay-out on the furnace, low speed of tapping towards the end of pouring
- Good design of the furnace neck and ladle
- Good exhaust system
- Training to Operators

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2. W_{FeSiMg} = Weight of FeSiMg (kg)

- All Mg treatment processes present a possible variation in the weight of FeSiMg
- A fluctuation of **± 1%** is frequent (due to inaccuracy of the balance).

Parameter		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1000	Nil
Mg_{FeSiMg}	*(%)*	6	6	Nil
R	*(%)*	60	60	Nil
Mg_{final}	***(%)***	**0.0350**	**0.0355**	**1.4**
S_i	*(%)*	0.01	0.01	Nil
S_f	*(%)*	0.005	0.005	Nil
t	*(minutes)*	5	5	Nil
T	*(°C)*	1450	1450	Nil
W_{FeSiMg}	***(kg)***	**12.17**	**12.30**	**1.1**

Actions to minimize this variation

- Use of clean balance with calibration
- Frequent audits of the automatic distributor system
- Capability of the balance
- Training to Operators

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3. S_i = initial Sulfur (before Mg treatment)

Depending on the melting process and charge composition S_i may fluctuate between 0.08% and 0.01 %.

Parameter		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1000	Nil
Mg_{FeSiMg}	*(%)*	6	6	Nil
R	*(%)*	60	60	Nil
Mg_{final}	***(%)***	**0.0350**	**0.0312**	**-11**
S_i	***(%)***	**0.01**	**0.015**	**50**
S_f	*(%)*	0.005	0.005	Nil
t	*(minutes)*	5	5	Nil
T	*(°C)*	1450	1450	Nil
W_{FeSiMg}	*(kg)*	12.17	12.17	Nil

Actions to minimize this variation

- Good Raw Materials & Charge Composition
- Good Recarburiser and Ferro-Alloys
- Good Process Control (Spectro, Leco)
- Use of Sorelmetal !

The best advantage of **Sorelmetal** versus other metallic charges is illustrated in the table below.

		Sorelmetal RF10	Other Charges
W_{ladle}	*(kg)*	1000	1000
Mg_{FeSiMg}	*(%)*	6	6
R	*(%)*	60	60
Mg_{final}	*(%)*	*0.0350*	*0.0350*
S_i	***(%)***	**0.0073**	**0.0153**
S_f	*(%)*	0.005	0.005
t	*(minutes)*	5	5
T	*(°C)*	1450	1450
W_{FeSiMg}	***(kg)***	**11.60**	**13.29**
Alloy Cost* of Mg treatment		**Rs. 1450**	**Rs. 1660**

* Assuming FeSiMg Alloy Price at Rs. 125/kg

i.e. Use of Sorelmetal saved **Rs. 210** in treatment of 1 tonne.

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4. S_f = final Sulfur after Mg Treatment

- Final sulfur is more a result of the Mg treatment rather than other influencing parameters. However, depending on the quality of the FeSiMg (e.g. presence of Ce & Ca and their level), its content can fluctuate.
- The higher the <u>initial</u> sulfur, the higher the <u>final</u> sulfur, and the higher the risk of getting <u>dross</u> in the casting.
- We recommend final Sulfur < 0.005% for **heavy** castings, or between 0.005% & 0.015% for "usual" castings.

Many foundries have decided to switch from the use of 'normal' PI to our UHPI to minimize the dross defect: heavy castings or big thickness, castings submitted to impact & fatigue,. . .

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5. Mg_{final} = final Mg before pouring

Final Magnesium before pouring depends on :

- casting thickness,
- level of S, Zn and free oxygen in the iron (i.e. quality of charge material, melting process etc.),
- time between pouring of first mould and last one (in that case the time "t" will include this period also).

Final Magnesium before pouring depends on the level of S, Zn and free oxygen in the iron (i.e. quality of charge material, melting process etc.):

$\%Mg^*_{final}$ = MgS + MgO + MgZnO3 + MgX + free Mg

(* Spectro results always show 'total' Mg, i.e. $\%Mg_{final}$.)

- Only the 'free Mg' promotes nodularization, and a very small part of MgS and MgO will create some nuclei !
- Many defects (like poor graphite shape) come from <u>too low</u> 'free Mg'.
- <u>Excessive</u> Magnesium content also promotes defects such as carbides, dross, micro-shrinkage!!

Preventive Action : Thus we ought to look at the PI ratio, like <u>our HPI</u>, to minimize the presence of free O, S and Zn from steel scraps!

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6. $\%Mg_{FeSiMg}$ = % of Mg in FeSiMg Alloy

Often, this ratio is overlooked. But FeSiMg containing 5-7% Mg presents a natural variation close to 0.5 (±0.25)% due to different lots, grain size segregation, grain size, origin etc.

Parameter		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1000	Nil
Mg_{FeSiMg}	***(%)***	**6**	**5.8**	**-3.3**
R	*(%)*	60	60	Nil
Mg_{final}	***(%)***	**0.0350**	**0.0335**	**-4.2**
S_i	*(%)*	0.01	0.01	Nil
S_f	*(%)*	0.005	0.005	Nil
t	*(minutes)*	5	5	Nil
T	*(°C)*	1450	1450	Nil
W_{FeSiMg}	*(kg)*	12.17	12.17	Nil

Actions to minimize this variation

- Selection of a good supplier of FeSiMg alloy
- Frequent audits of the melting platform
- Capability on the product
- Training to operators

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7. 't' = time between end of treatment and beginning of pouring

Only a fluctuation of 2 minutes in the time 't' between end of treatment and pouring decreases the level of Mg by 0.002%. Causes are mainly due to transport and slag removing. Excesses of slag comes from the quality of charge material: sand, rust, sterile, steel coating etc.

Parameters		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1000	Nil
Mg_{FeSiMg}	*(%)*	6	6	Nil
R	*(%)*	60	60	Nil
Mg_{final}	***(%)***	**0.0350**	**0.0330**	**-5.71**
S_i	*(%)*	0.01	0.01	Nil
S_f	*(%)*	0.005	0.005	Nil
t	***(minutes)***	**5**	**7**	**40**
T	*(°C)*	1450	1450	Nil
W_{FeSiMg}	*(kg)*	12.17	12.17	Nil

Actions to minimize this variation

- Good maintenance and transportation machine
- Training to Operators
- Good Raw Materials to minimize dirt & slag

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8. 't' : In case of pouring of large number of castings from the same ladle, time 't' needs to be considered as 'time between Mg treatment and pouring of last mould'.

For a final Mg of 0.035%:

If total pouring period is 15 minutes, FeSiMg needed is 14.94 kg.

If this time becomes only 10 minutes, the need of FeSiMg decreases to 13.56 kg.

Parameter		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1000	Nil
Mg_{FeSiMg}	*(%)*	6	6	Nil
R	*(%)*	60	60	Nil
Mg_{final}	*(%)*	0.0350	0.0350	Nil
S_i	*(%)*	0.01	0.01	Nil
S_f	*(%)*	0.005	0.005	Nil
t	***(minutes)***	**10**	**15**	**50**
T	*(°C)*	1450	1450	Nil
W_{FeSiMg}	***(kg)***	**13.56**	**14.94**	**10.2**

Actions to minimize this variation

- Good maintenance and transportation machine
- Training to Operators
- Ladle with Cover
- Automatic pouring line

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9. T = treatment temperature (°C)

Treatment temperature is the sum of:
Pouring temperature (function of casting thickness and type of risering) + Loss of temperature during transfer and pouring* + Loss of temperature during Mg treatment**.

(* between 5 to 12 °C per minute)

(** 10 kg of "cold" ferro-alloy in a ladle of 1 tonne at 1500 °C decreases the temperature of treated iron by 15 °C.)

An increase of pouring temperature by 50 °C decreases the final magnesium by 0.003%.

Parameter		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1000	Nil
Mg_{FeSiMg}	*(%)*	6	6	Nil
R	*(%)*	60	60	Nil
Mg_{final}	***(%)***	**0.0350**	**0.0321**	**-8.3**
S_i	*(%)*	0.01	0.01	Nil
S_f	*(%)*	0.005	0.005	Nil
t	(minutes)	5	5	Nil
T	***(°C)***	**1450**	**1500**	**3.4**
W_{FeSiMg}	*(kg)*	12.17	12.17	Nil

Actions to minimize this variation

- Use of insulating refractory + cover for ladle(s)
- Small addition in the ladle
- Quick transfer(s) and short pouring period

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10. R = yield of Mg treatment

From the mathematical formula, we automatically get the yield, and all the past parameters could have an influence!

$$W_{FeSiMg} = W_{ladle} \times \frac{(Mg_{final} + 0.76\ (S_i - S_f) + 10^{-3}\ t)}{\%\ Mg_{FeSiMg} \times R} \times (T\ °C/1450)^2$$

However, yield is a typical parameter like the previous ones, And, it is more a sum of subjective items than purely a mathematical list.

Actions to minimize this variation

- Quality of the spectrometer and spectro samples, how and where the spectro sample is taken, its design, cleanliness of the ladle (body and pocket) and quality of its lining
- Quality and cleanliness of the steel cover
- Output of the furnace during tapping
- Time between input of FeSiMg and beginning of tapping
- Level of oxidation of molten iron and practice of pre-conditioning
- Exhaust system directly attached on the ladle as in case of cored wire process etc. .....

If all the previous parameters are "under control", we recommend to recalculate the yield for each treatment.

- In case of major deviation, the foundrymen will be alerted and will check all items in the precedent list.
- For a similar design of ladle and process (melting treatment,...) the yield can vary from 60 to 40% from one foundry to another!!!
- Our "job" is to give information to our customers or potential customers.

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11. Summary of Calculations

(a) For the same final Mg = 0.035 %, if we consider all the possible fluctuations (on industrial level), **Mg alloy cost** of the treatment will become:

Parameter		Target with RF10 & Well Process	Actual or Others	Change (%)
W_{ladle}	*(kg)*	1000	1050	5
Mg_{FeSiMg}	*(%)*	6	5.7	-5
R	*(%)*	60	57	-5
Mg_{final}	*(%)*	<u>0.0350</u>	<u>0.0350</u>	Nil
S_i	*(%)*	0.0073	0.0153	110
S_f	*(%)*	0.005	0.005	Nil
t	*(minutes)*	5	6	20
T	*(°C)*	1450	1500	3.4
W_{FeSiMg}	***(kg)***	**11.60**	**16.89**	**46**
Cost of FeSiMg Alloy	***(Rs.)***	**1,450**	**2,110**	**46 (i.e. Rs.660)**

(b) But for the <u>same</u> weight of FeSiMg, if we consider all the "negative" fluctuations (on industrial level), the **final Mg** will become:

Parameter		Target	Actual	Change (%)
W_{ladle}	*(kg)*	1000	1050	5
Mg_{FeSiMg}	*(%)*	6	5.7	-5
R	*(%)*	60	57	-5
Mg_{final}	***(%)***	**0.0350**	**0.0197**	**-44**
S_i	*(%)*	0.0073	0.0153	110
S_f	*(%)*	0.005	0.005	Nil
t	*(minutes)*	5	6	20
T	*(°C)*	1450	1500	3.45
W_{FeSiMg}	*(kg)*	<u>11.60</u>	<u>11.60</u>	Nil

(D) Concluding Remarks

- The **final** <u>Magnesium content</u> is one of the most important parameters to obtain spheroidal graphite. Possible causes for its fluctuation are multiple.
- The quality of the process, including charge materials, is the major way to get good castings in DI.
- Rio Tinto Iron & Titanium, our Agents, our Literature, our Technical Services, and our famous Sorelmetal can help foundries to maintain magnesium treatment under control.

Ductile Iron Foundrymen!

This presentation is valuable. You will find its content highly educative. Please read it carefully and study the calculations shown here. It will act as a Road Map to improve Process Control in your foundry, particularly for producing high value and/or heavy ductile iron castings for stringent and/or sub-zero temperature applications. – Editor