To Control the Generation of Fines in Silicomanganese Production

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Abstract— In this paper different causes which enhance the production of fines during Silicomanganese alloy casting breaking, crushing, sizing, handling etc. were studied. The cooling rate and microstructure, alloy composition, handling conditions, and mould coating were found to be real culprit to the production of fines. The prevention methods of these are also discussed.

Key words: CI Pan Casting - Cast Iron Pan Casting, PCM - Pig Casting Machine

I. Introduction

All the data and the observations in this paper have been taken on site from Sarda Metals and Alloys Ltd. Kantakapalli, Andhra Pradesh (India). During casting and other post taphole processes of ferroalloys, an considerable amount of fine is produced, which depends upon different variables, and these variables have been discussed in this paper. The size of PCM mould was 5 litres, and weight of the mould was 155Kg, No. of moulds were 293, conveyor speed was 300 RPM. In CI Pan Casting 7 Pans were attached in line on a bed made of Refractory bricks. These were attached with two pouring basin on both side. The mould size was 2260×2260×260(mm). These were coated with lime for every casting so that the metal cakes did not stick to the CI pan. The average lime thickness was 1-3 mm. A total of 16 tonnes of metal is casted per tapping.

II. Experimentation & Observations

There are different factors on which the production of fines depends. The effects of these variables and their causes are described in the case study. Some of the variables are:

1) Composition of Silicomanganese Alloy.
2) Cooling Rate and Microstructure.
   - Temperature has been measured by a radiation pyrometer on site with respect to time for both PCM machine casted alloy and CI Pan casting alloy.
   - Two casting samples have been picked up, each for PCM casted and CI pan casted alloy, for microstructural analysis.
   - Samples have been polished and microstructural analysis has been done on both the samples.
3) Mould Coatings and Gas Defects.
   - The lime coating in order to prevent the sticking of casting with the moulds is done with lime 28%, molasses 2-3 %, and water 70% on both CI pan moulds and the PCM moulds, which was creating various gas defects in the casting.
4) Unsolidified cavity and cast handling.
   - During the handling of casting and molten metal, each activity had been recorded, and found that during casting from PCM moulds, the casting had been handled improperly and unsolidified metal had been splashed out of the casting.

III. Results & Discussions

A. Composition of Alloys

There are some Micro Cracks induced by thermomechanical stresses resulting from the difference in the coefficient of thermal expansion between silicon and intermetallic. In casting, the part having larger coefficient of thermal expansion would be under tensile stress and the part having lower coefficient of thermal expansion would be under compressive stresses. This difference in stress states instantaneously produces cracks in the alloy and hence increases the friability of the Silicomanganese.

Linear Coefficient of Thermal Expansion of the Elements which are Present in the Silicomanganese Alloys (αT) at 25°C

Sr. No.	Elements	Linear coefficient of thermal expansion (αT) at 25°C
1	Silicon	2.6 µm/mK
2	Manganese	21.7 µm/mK
3	Carbon	4-8 µm/mK
4	Iron	11.8 µm/mK

Table 1: Linear Coefficient of Thermal Expansion of Different Materials

B. Cooling Rate & Microstructure

Large cooling rate gives smaller and equiaxed grains and slow cooling rate gives larger grains. The cracks produced in the alloys largely depend upon the shape and size of the grains as, the round equiaxed grains would be expected to result in lower local stress than grains with sharp edges. The plot between time and temperature is plotted for the CI pan casting machine and PCM casting machine is as shown by taking onsite measurements:

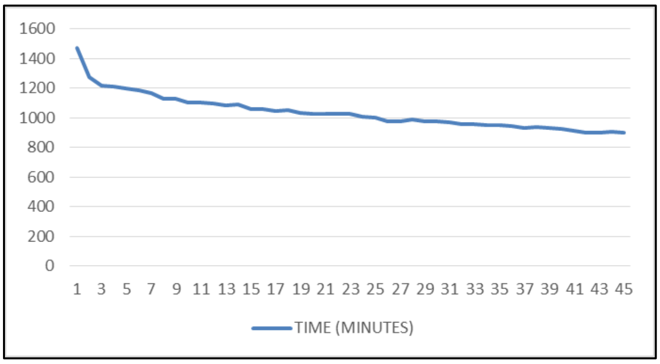


Fig. 1: Temperature vs Time Graph for CI pan Casting

Cooling rate for CI pan casting is approximately 773°C/hour i.e. by taking first pouring temperature and last pouring temperature vs initial pouring time and last solidification time upto which the casting was there on the casting bed.

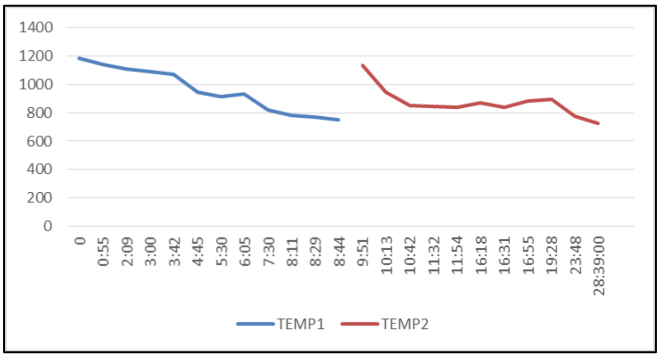
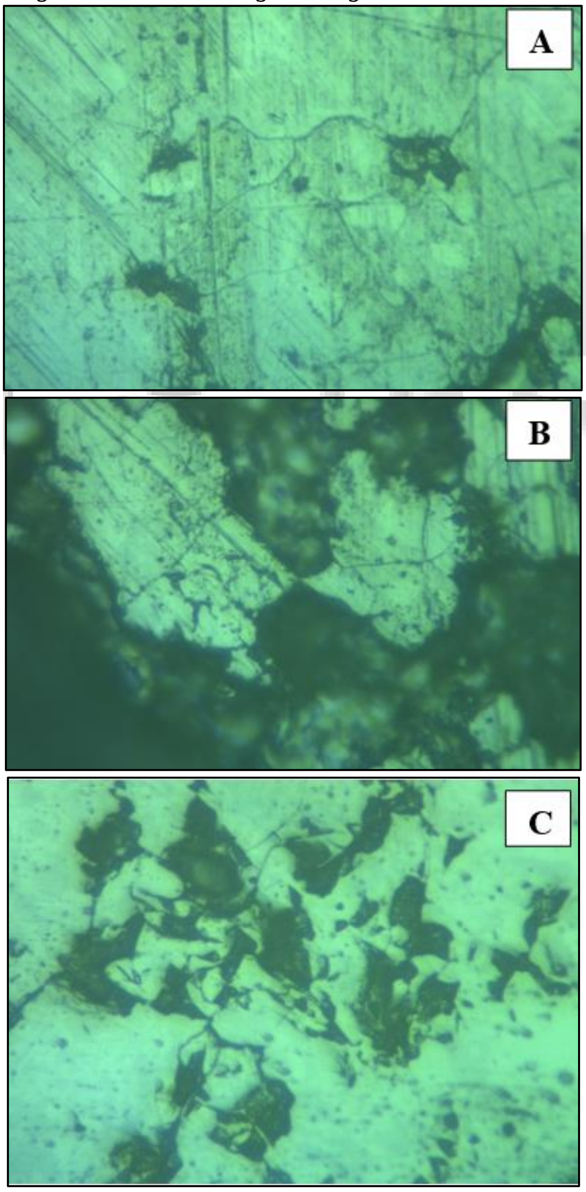
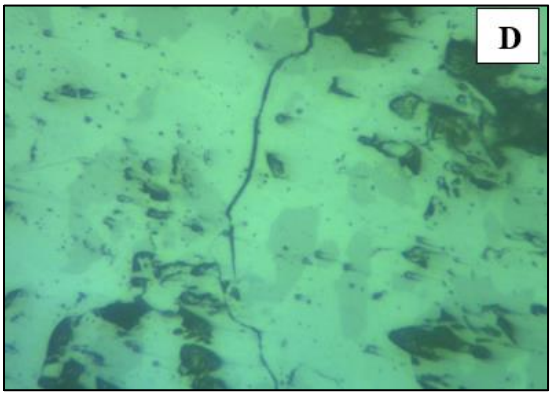


Fig. 2. Temperature Vs Time Graph for PCM Casting

Cooling rate for PCM casting is approximately 2900°C/hour by taking the first temperature at start of the pouring and final temperature at the dumping point from the PCM casting for a single casting. Similarly the same procedure is followed for the second casting also and the times are noted accordingly.

1) Microstructural Analysis & Comparison between PCM Casting and CI Pan Casting Cooling.





Figs. 3: Optical Micrograph of Unetched Samples of Silicomanganese grade 65%Mn 16%Si

(All are at 40X magnification). (A) & (B) are cast at 773ºC/hour in Cast Iron Pan casting machine. (C) and (D) are cast at 2900ºC/hour on PCM machine casting.

The optical micrograph is showing that there are more number of cracks in the material which has been cast at slow cooling rate (773ºC/hour) i.e. in case of CI Pan casting rather than the fast cooling rate which is 2900ºC/hour in case of PCM machine casting. The fine production is slowed down by an increasing cooling rate, providing a smaller silicon grain size, then extending the barrier to the crack spreading.

The large and wide crack in case of PCM casting is probably due to the poor handling of casting during dumping or during alloy breaking process.

2) Proposed Cooling Method for CI Pan Casting and Sand Bed Casting

Friability of the CI pan casting and sand bed casting can also be reduced as explained

This method consists in casting relatively large diameter shallow ingots of ferroalloys such as ferrosilicon, ferromanganese, Silicomanganese, magnesium ferrosilicon, iron-chromium-silicon alloys, and the like.

- When the peripheral edges of the castings are dark in colour, the castings are taken out of the moulds an immediately covered. But inside portion of the casting is still molten.
- The cover may be formed of spaced metal shells with heated and cold insulating material.
- The hot ingots are stacked one upon another within the cover upon a pad of sand, or finely divided ferroalloys.
- The cover may be lined with polished stainless steel or the like, or it may be lined with refractory material for reflecting the heat of the ingots and further retain the heat.
- The ingots are permitted to cool slowly within the cover for a period of thirty to thirty-six hours and should not be above 650°C, when removed from the cover.
- The ingots are then permitted to cool down to room temperature after which they may be crushed by the conventional crusher or manual crushing method into pieces suitable for use as ladle or furnace additions.

As an alternative, instead of covering the stack of hot ingots with an insulated cover, as above described, the stack of hot ingots may be covered with fine granulated or powdered material such as sand, lime, metal fines, fine carbon, graphite or refractory material. Best choice is to use silica sand or ferroalloys fines. All other conditions are set according to previously described method.

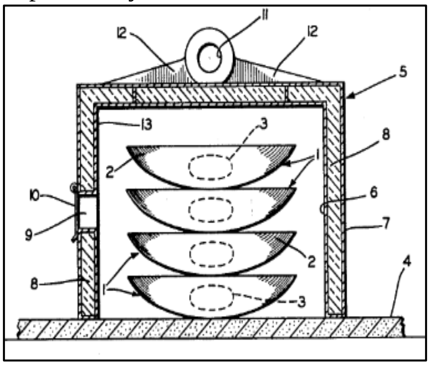


Fig. 4: Design 1 for Ingot Casting

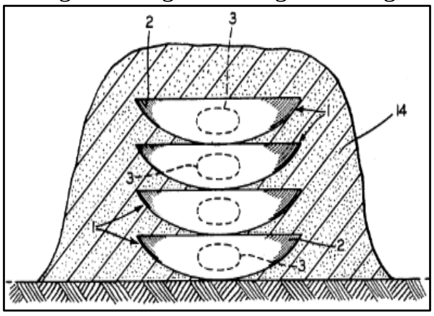


Fig. 5: Design 2 for Ingot Casting

Sr. no.	Description
1	Ferroalloy casing
2	Solidified dark alloy
3	Unsolidified alloy at centre
4	Sand/ferroalloys fine`s pad or bed
5	Metal cover shell
6	Inner cover shell
7	Outer cover shell
8	Heated insulation material
9	Peephole in one side of cover to permit inspection.
10	Hinged door covering the peephole
11	Eye attached to reinforced cover to open/close the cover
12	Reinforced cover
13	Inside polished cover of steels/insulating lining to reflect the heat back to the ingot
14	Sand covering

Table 2: Drawing Information for Proposed Cooling Method

C. *Coatings & Gas Defects*

Lime water coating (Calcium hydroxide) coating applied on mould surface in order to prevent the sticking of the casting with the mould, but it can cause some problems to the casting as:

1) *Surface Blows & Blow Holes*

Thermal decomposition of Calcium Hydroxide is given as

$$Ca(OH)_2(s) = CaO(s) + H2O(g)$$

This reaction occurs when the molten metal at high temperature falls on the calcium hydroxide coating which is applied on the mould surface. Thus these water vapours gives defects called as blows on bottom surface of the castings, as the vapours are entrapped in the space between upper mould surface and the bottom of the casting surface.

Fig. 6: Surface Blows on the Casting

Molasses added in the lime water coating also burns when the molten metal is poured at high temperature to the mould. This also gives CO_2 and water vapours on burning. The CO_2 thus generated penetrates through the whole thickness of the casting and defects called blow holes are produced in the casting. This burning can be seen from the flashes coming out of the casting surface during pouring of the metal.

$$C_{12}H_{22}O_{11}+12O_2=12CO_2+11H_2O$$

2) *Pin Holes & Other Gas Defects*

Pinholes in casting can progress in several ways:

- The surface reaction of water vapours with other elements in the iron of the mould surface gives atomic hydrogen which diffuses into the molten metal and causes pinholes in the casting.

  M+H2O=MO+2H Where, M=Metal
- The hydrogen from the atmospheric air can also be trapped into the molten metal during turbulence of the molten metal flow and can give rise to pin holes defect.
- The organic adhesive such as molasses used in coating can also produce hydrogen, leading to pin holes in the casting.

3) *Removal of Gas Defects*

Gas defects can be removed by two methods:

- Making hundreds of holes on the back sides of the each permanent mould in order to remove the gases and vapours out from the space in between casting and the mould surface.
- By applying the insulating coating in place of the lime coating. The details are given as follow:

4) *Proposed Refractory Insulating Coating*

- A water mix suspension is made with the refractory particles.
- Particle size of refractory coating material should be less than 10µm.
- A method known as “dry spray” is employed as a carrier gas to move the particulate refractory material onto the active mould surface immediately in advance of the metal being cast. As the mould is already in heated condition, whole of the moisture is evaporated before the casting metal is feed in the mould. Also fewer gas defects and pinhole problems arise on account of lower gas content and water vapours in the coating.
- Bentonite is used as a binder for this coating. But if the particle size is less than 3µm, then binder is not required.

- Uniform distribution and maintenance of "dry spray" is little bit difficult to achieve over the surface when the metal is sprayed.

Sr. No.	Chemical Compound	Weight%
1	SiO_2	35-45%
2	Al_2O_3	8-15%
3	CaO	25-35%
4	MgO	7-13%
5	Fe_2O_3	3-7%
6	TiO	1-2%

Table 3: Chemical Composition of Refractory Coating

D. Unsolidified Cavity & Cast Handling

Solidification phenomenon occurs from all the sides in the casting and solidification front moves towards the inside of the castings. But observation on site shows that the whole of the casting is not solidified completely, as the inside of the casting is still in molten state when it reaches at the dumping point. When the casting falls on the dumping point it breaks into several pieces.

The inside molten material is flown out of the casting, and a large cavity is produced inside, which again gives stress concentration to the cast metal during unloading at dumping point. The flown out metal is still in liquid state and hence solidifies in a thin layers and particles and hence increases the fines generation.

Fig. 7: Unsolidified Cavity in PCM Casting

1) Prevetion of Unsolidified Cavity

Unsolidified cavity can be prevented by:

- By providing an arrangement for smooth flow of the casting, without being falling the casting at some height and breaking.
- Cooling the mould at higher rate during pouring of metal such that no unsolidified cavity is left in the casting.

2) Handling of Casting

The casting at dumping site from PCM machine falls with some height with some velocity and broken down into several pieces having different sizes. Original design of the PCM machine is such that there is the provision of the caste metal to move slowly from the PCM conveyor to the slanted sheet which again feeds the metal to the dumper.

In the original design the problem of cast pieces jamming was there, due to fixed position of the arrangement which is there for avoiding the casting to fall from more height.

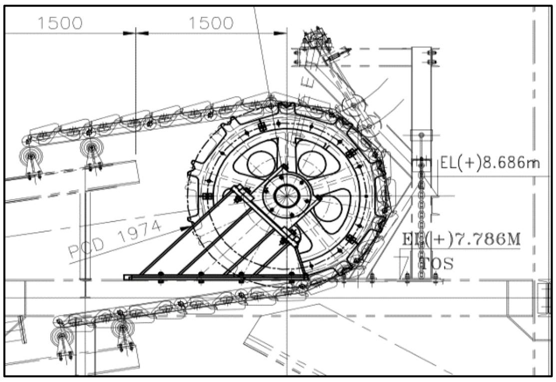


Fig. 8: Original PCM Dumping Area Arrangement

E. Proposed Design of Unloading of Casting

In proposed design, we can make this arrangement a flexible one by providing no. of springs on the back side of this arrangement and also the length of lower limb can be increased and made semicircular. In fact the whole of this arrangement can be made as semicircular i.e. the upper limb and lower limb. The angle of slanted sheet, which dumps the casting into the dumper would also lower down which is currently 30°. In this arrangement the small rollers can also be attached at the different location on the inside of the arrangement downward as well as the horizontal. The distance between the rollers and the cast pieces has to be controlled very finely such that no jamming of casting is there. These rollers can also be attached on inside of the limbs, without the springs being attached to the outside of the limbs.

Another arrangement is as shown in picture having "J" shaped arrangement used for producing casting without breakage.

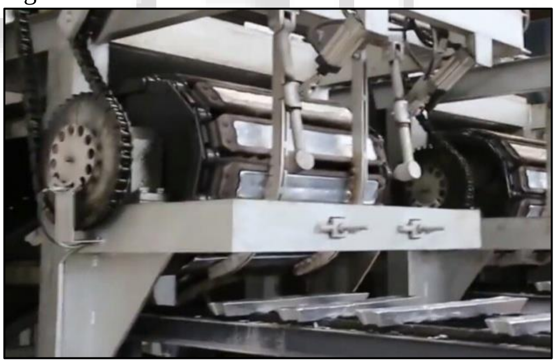


Fig. 9: Proposed Design for Unloading the Casting from Conveyor

All of these arrangements can serve the purpose for preventing the jamming of the castings as well as the casting to reach at the dumper without being broken. Hence the unsolidified cavity, uncontrolled broken pieces of casting and finally the fines generation can be controlled.

IV. Conclusions

- Large variation in coefficient of thermal expansion of different elements give different expansion/contraction gives more number of cracks.
- Cooling rate has significant effect on fine generation as high cooling rate gives lesser crack density than slow cooling in case of CI Pan casting.

- Annealing of CI Pan and Sand Bed casting ingots is required with temperature gradient of 1-0.833°C/hour, the end temperature being 650°C, after that air cooling is required.
- Lime coating applied on the mould surface gives large amount of gas defects, which can be reduced by employing a refractory coating.
- Unsolidified cavity in case of PCM casting can also be prevented by ensuring that, the casting does not break during unloading, which can be done by changing unloading system design. Change in unloading system design also decreases uncontrollable size of the broken pieces during unloading.
- In a nutshell the generation of fines does not depend only upon a single parameter. All the parameters like composition of alloy, phases, cooling rate, coating technique, and operating conditions should be optimised, such that the minimum fine is generated.

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