Development of Agglomeration Process to Utilize the Ferromanganese Fines in Steel Making Process

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An agglomeration process is developed to utilize FeMn fines of <3 mm in LD steel making process. Different types of binders (sodium silicate, bentonite, acrylic resin and phenolic resin) were tried and found that phenolic resin is most suitable binder. Mixture of binder and fines was compacted in a cylindrical die and cured at 150°C for 1 h. Briquettes of 30 mm diameter and 20 mm length were prepared and physical properties of the briquettes were tested. Tumbler index and shatter index of the briquettes were ~95 % and >98 %, respectively. Compressive strength was 55 MPa and density was 5 200 kg/m³. Usability of FeMn briquettes along with the FeMn lumps was evaluated in lab as well as in the plant. The results of lab test revealed that FeMn briquettes dissolved faster than lumps. Improvement in Mn recovery was also observed in case of FeMn briquettes. Preliminary cost analysis indicated significant saving in alloying cost in steel making by use of briquettes made of low cost fines.

KEY WORDS: briquetting; steel making; ferroalloy and resin.

1. Introduction

More than 90% of the manganese produced worldwide is used by the steel industry. Mn alloys are added as a deoxidizing agent and as an additive to increase strength, elasticity and abrasion resistance of the steel. In steelmaking, overall consumption is in average 6 to 7 kg of pure manganese per ton of steel. Manganese is mainly added in the form of high carbon ferromanganese. Ferromanganese lumps of 10–80 mm are preferred in the steel making process to optimize the manganese recovery, deoxidation and losses during handling. Ferromanganese is made by carbothermic reduction of manganese ores in the electric arc furnace. Liquid hot metal is casted and crushed into 10–80 mm size. The fines generated during the sizing of metal cake can not be used in the LD steel making process. These fines get oxidized quickly and reduce the overall manganese recovery.^{1,2)} The favorable size of ferromanganese is 3 to 20 mm to improve the dissolution characteristics. But small size means more surface area to transport undesirable gases and moisture. Small alloy size increases dust losses and incurs handling difficulties.^{3–6)}

Agglomeration of ferromanganese fines can be the best method to utilize these fines. Various attempts have been made to agglomerate these fines using conventional binder like molasses, tar, resin, *etc.*^{6–10)} It was found that conventional binders are not suitable because these binders add S and P into the steel which is very much undesired. Whereas, use of hydrocarbon based binders was not technoeconomical. Binder composition and physical strength of the agglomerate are two main constraints to develop a cost effective method. In the current study, a briquetting process

has been developed to utilize these fines in steel making process. The suitability of the produced agglomerate was tested in the laboratory as well as in the plant. The developed method improves utilization of natural resources as well as minimizes the environmental pollution caused by steel industry.

2. Experimental Studies

2.1. Characterization of Samples

Samples of ferromanganese fines were collected from FAP, Joda, India. These were classified in three different size ranges (>10 mm; –10+3 mm; –3 mm). Five (Mn, C, S, P, and Si) important constituents were analyzed using ICP-OES (Spectro Analytical Instruments; Ciro) to find the chemical composition of prepared agglomerate. Particle shape and surface characteristics were also analyzed using scanning electron microscope to study the agglomeration behavior of fines.

2.2. Agglomeration of Fines

Agglomeration of metallic fines is a challenging subject. Selection of binder and strength of agglomerate are two most important process parameters. The binders should not add any unwanted ingredient like sulfur, phosphorus, nitrogen *etc.* in the steel and it should be cost effective. Molasses and other conventional organic binder were rejected because these binders contain sulfur and phosphorus. Sodium silicate and bentonite are the cheapest alternative of these binders and tried as per the conditions given in **Table 1**.

Acrylic resins are thermoplastic resin manufactured by

the polymerization of various monomers such as acrylic acid, methacrylic acid, and esters of these acids. Phenol formaldehyde resin is the earliest commercial synthetic resin. It is formed from an elimination reaction of phenol with formaldehyde. Experimental studies were carried out using the resins to improve the quality of agglomerate. Resins were properly mixed (5, 8 and 10%) in the ferromanganese fines and compacted at 15, 45 and 70 MPa (1, 3 and 5 ton) pressure to prepare suitable agglomerate.

Experimental work plan is given in Table 1 and Fig. 1. A sample of <3 mm fines is collected and binder was mixed properly. Sixty to seventy gram mixture was compacted in cylindrical die of diameter 3 cm at different loads and compact was cured at different temperatures (100°C and 150°C). Briquette density, compressive strength, tumbling index, abrasion index, shatter index and dissolution characteristics were studied.

2.3. Lab Trials in Induction Furnace

Twenty killograms of steel scrap is melted in a 25 kg induction furnace and 5 kg of ferromanganese lumps were added. Experiments were repeated for fines and briquettes to compare the results. Mixing behavior of the materials was observed. Slag and metal samples were collected. Manganese recovery was calculated. Figure 2 shows the lab scale setup to test the dissolution behavior of lumps, fines and briquettes in the liquid steel.

Table 1. Briquetting conditions.

Binder	%	Load (ton)	Curing Condition
Sodium Silicate	5, 7.5 & 10	1 & 5	100 C, 1 hour
Sodium Silicate+ Bentonite	5+2, 7.5+2 & 10+2	1	100 C, 1 hour
Acrylic Resin	5, 8 & 10	1 & 3	100 C, 1 hour
Phenol formaldehyde Resin	5, 8 & 10	1 & 5	100 & 150 C, 1 hour

Fig. 1. Process methodology for binder selection.

Fig. 2. Lab scale trials in induction furnace (a) induction furnace (25 kg), (b) melting of scrap, (c) sample collection before and after the addition.

3. Results and Discussion

3.1. Characterization Studies

3.1.1. Chemical Analysis

Chemical analysis of various size fractions is given in Table 2. It was observed that Si is higher and Mn is lower in finer sizes than the lumps. Whereas, P, S and C do not show any particular trend. Hence, the chemical composition of the fines is suitable for steel making process.

3.1.2. Size and Shape Analysis

Size analysis of ferromanganese fines (0–10 mm) samples were carried out and found that ~70% fines are of 0 to 3 mm size (fines) and 30% are 3 to 10 mm size (chips). The fines of 0 to 3 mm contains 19.88, 42.59 and 37.54% of 1–3 mm, 0.5–1 and <0.5 mm fines, respectively. Particle Size and shape analysis is shown in Figs. 3 and 4. Finer particle sizes are preferred for briquetting but presence of significant amount of very angular particles makes the agglomeration process more challenging. Very angular particles enhance the mechanical interlocking but require high pressure compaction.

Table 2. Size and size wise chemical analysis of ferromanganese fines.

Size Range	%	C	Mn	S	P	Si
>10mm	93	6	>68	0.01	0.193	0.54
-10, +3mm	2	6.75	67.30	0.01	0.175	1.72
<3mm'	5	6.7	66.90	0.01	0.188	1.33

Fig. 3. Particle size analysis.

Fig. 4. Particle shape analysis.

3.1.3. SEM Analysis

SEM samples of the lumps and briquettes were prepared to study the samples and find that fines are not oxidized. Some small slag inclusions were also seen in the briquetted samples. EDS spectra of different phases is shown in **Fig. 5**.

3.2. Agglomeration Studies

Metallic fines show different binding behavior than the conventional ore particles. **Figure 6** shows surface of a manganese ore and ferromanganese metal particle. FeMn particle surface is very smooth and manganese ore particle shows suitable cracks and cleavages. The ore particles usually contain small cracks and cleavages which play important role in binder absorption and binding of the particles. Whereas, smooth surface reduces the wettability metal particles and it adversely affect the strength of liquid bonds.

3.2.1. Conventional Binders

The conventional binder (molasses, cement, lime *etc.*) which are used in agglomeration of ore fines can not keep the metallic particles together because of the difference in the particle characteristics. Hence, glassy or polymer bonds

are required for this kind of materials. Three different combination of sodium silicate was tried and found that the prepared agglomerate does not attain the suitable compressive strength and it varies between 90 and 240 kgf/sample. This can be increased by preparing agglomerate by machine compaction at 5 ton. The strength achieved by machine compaction was 700–1 150 kgf/sample. The small amount (2%) of bentonite was also mixed with sodium silicate and found that it produce better results with 0–0.5 mm size range fines at one ton load compaction. The strength of the briquettes is not suitable for handling and presence of alkalis and silicon are a concern to use this into steel making process.

3.2.2. Resins

Acrylic and phenol based resin were used and found that acrylic resin produce an agglomerate of strength of 650–1 050 kgf/sample and 720 to 1 100 kgf/sample by 1 ton and 5 ton compaction, respectively. This binder produces an agglomerate of brittle nature, which breaks in four or five bigger pieces. Thermosetting resin produces the best agglomerate with minimum compressive strength 1 050 kgf/sample. Agglomerate strength vary between 1 600–2 000 kgf by machine compaction by 1 ton load. This strength increase further by 5 ton loading and it produces an agglomerate with >2 000 kgf strength/sample. This binder produces good strength with manual compaction also and strength varies between 1 050 to 1 440 kgf/sample for 5 and 10% binder content, respectively. A comparative analysis of maximum cold compressive strength achieved using different binders is given in **Fig. 7** and it show that phenolic resin based agglomerate achieve maximum strength. Physical strength of cylindrical agglomerate depends on the length of the agglomerate and as the length increases the strength decreases. This was tested by producing different length agglomerate and finds that best suitable size in 15 to 20 mm. Handling properties of theses briquettes were tested and shown in **Table 3** for the briquettes produced with the most suitable binder combination. Apparent density of briquettes is 5 200 kg/m³ and cold compressive strength is 55 MPa. High compressive strength results into lower fine generation during handling of the briquettes. The briquettes achieve 95% and 98%, tumble and shatter index, respectively. The physical characteristics of briquettes are acceptable to existing LD steel making process.

Fig. 5. SEM micrograph of Lumps (Pt1, high carbon phase; Pt2, low carbon phase) and briquettes (Pt1, high carbon phase; Pt2, slag particle).

(a) Mn Ore Particle

(b) FeMn Particle

Fig. 6. Surface roughness of Mn ore and FeMn metal particle.

Fig. 7. Maximum cold compressive strength achieved by the briquettes using different binders.

Table 3. Properties of briquettes.

Properties	Briquette
Size & Shape	Diameter : 30mm, L : 20mm
Apparent Density	5200 kg/m ³
Compressive Strength	55Mpa
Tensile Strength (Load Applied in radial direction)	15Mpa
Tumbler Index (Wt 15kg, rpm 200@25)	95% (>6.3mm)
Abrasion Index (Wt: 15kg, rpm 200@25)	3% (<0.5mm)
Shatter Index (Wt : 10 kg, No of Drops : 4, Height : 2m)	98% (<5mm)

Fig. 8. Comparative analysis of Mn recovery from lumps, briquettes and fines.

3.3. Product Validation

Suitability of these briquettes was tested in the lab as well as in the plant. Mixing and other operational performance were observed during the lab scale induction furnace operation. It was observed that fines do not mix properly in the liquid steel and make bubbly structure on the top of the hot metal and also generate significant amount of slag. The slag generation was lowest for lumps and it was highest for fines. Manganese recovery is shown in **Fig. 8**. Mn recovery was lowest for the fines but it was similar for lumps and briquettes. Mn recovery was also observed for different types of briquettes tested for tumbling test. It was found that recovery reduces with the physical strength of briquettes and slag content increases. The best recovery was observed for the briquettes of 30 mm diameter and 20 mm thickness (weight: 65 g) briquettes and same were used for the plant trial.

Plant trials were carried out using 500 kg of FeMn briquettes. The Plant adds 150 to 600 kg of ferromanganese in ladle of heat size 155 tons to produce different grade steels. 200 and 300 kg ferromanganese briquettes were added and operational efficiency was measured by Mn recovery. It was found the Mn recovery was 5 to 10% higher than the lumps. The improved dissolution characteristics can be an important cause of improved Mn recovery.

4. Conclusion

The ferromanganese fines are an inferior grade material which is generated in process of ferromanganese making. These fines can not be used in LD steel making process be-

Fig. 9. Process flow sheet to agglomerate the FeMn fines.

cause of the smaller size hence an agglomeration process is developed for particles size enlargement by agglomeration. These fines can be agglomerated using resin as a binder followed by compaction and curing at 150°C temperature for 1 h. Process flow sheet is shown in **Fig. 9**. The processing cost can be further reduced by optimizing the binder dosages and other processing conditions. The prepared agglomerates were tested in the lab as well as at plant and successful results were achieved. Handling and addition of ferroalloy fines into foundry add significant amount of metallic dust into environment and the proposed process can reduce this environmental pollution. A one million ton annual capacity steel plant can consume 3–5 k ton high carbon ferromanganese depending on the product grade. In the current market scenario the proposed process can save \$ 200–250/ton including the improved process performance and cost difference between lumps and agglomerate, which will result into saving of \$ 5 million/annum.

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REFERENCES

- 1) K. D. Peaslee, D. S. Webber, S. Lekakh and B. Randall: 58th SFSA Technical and Operating Conf., Steel Founders' Society of America, IL, USA, (2005), 4.1.
- 2) P. G. Sismanis and S. A. Argyropoulos: Proc. of the 69th Steelmaking Conf., Vol. 69, Iron & Steel Society, Warrendale, PA, (1986), 315.
- 3) Y. Lee, H. Berg, B. Jensen and J. Sandberg: *Iron Steel Soc.*, **54** (1996), 237.
- 4) M. Tanaka, M. Mazumdar and R. I. L. Guthrie: *Metall. Trans. B*, **24B** (1993), No. 4, 639.
- 5) H. Berg, H. Laux, S. T. Johansen and O. S. Klevan: *Ironmaking Steelmaking*, **26** (1999), No. 2, 127.
- 6) V. Singh, S. M. Rao, B. D. Nanda and D. Srinivas: International Patent Application No. 2009-PCT/IN2009/000532, (2009).
- 7) V. L. Calbert: United States Patent 1946-2405278, (1946).
- 8) R. Saunders, P. Earle and L. Richard: United States Patent 1960-2935397, (1960).
- 9) L. Robert and Ranke: United States Patent 1975-3898076, (1975).
- 10) J. P. Beukes, J. Nell and S. D. McCullough: South Africa Patent: 2001-4091.
- 11) A. Ramu, P. K. Banerjee and B. R. Choudhury: Unpublished Report, R&D Tata Steel, India, R&D-INV-011-96-1-13-97(1997).