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IMPROVING THE SINTER PRODUCTIVITY WITH INCREASED SPECULAR IRON ORE IN SINTER BLEND

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Abstract

Specular iron ores are medium grade iron ores suitable for the use in agglomeration process. However, due to their hard texture, undesirable particle size and shape, poor assimilation performance and low reactivity at high temperature, its uses in agglomeration is very limited and restricted to almost 3-10% at most of the plants. In the present study, the effect of specular iron ore on sintering performance and sinter qualities are examined. It was observed that an increased proportion of specular iron ore in sinter blend showed poor sintering performance in both laboratory scale studies and plant scale trials. In the present work, the effect of blending of specular iron ore with goethite iron ore in sinter mix on sintering performance was examined and an optimum iron ore blend ratio for sustainable performance and quality was proposed. To increase the specular iron ore usage in sintering, goethitic iron ore up to 30% was introduced in sinter blend to overcome the deteriorating nature of specular iron ore. The goethite iron ore contains chemically bonded water which gets removed at higher temperatures (300-500°C) during sintering. The evaporated water gets cooled at lower bed and condenses which retards the air flow during sintering process and thus the combustion zone stays for longer time allowing better melt assimilation and sinter qualities. The poor melt assimilation of specularite is thus countered in presence of goethite iron ore. Having better reactive and hydrophilic nature of goethite iron ore, nullifying or reducing the ill effect of poor reactive and hydrophobic characteristics of specular iron ore during granulation and sintering process. Therefore, the blended specular and goethite iron ore resulted in improved sintering rate and consequently improved sinter productivity. The present work proposed usage of up to 30% of specular iron ore when blended with goethite iron ore in sinter making.

Keywords: *Iron ore sintering; Specularite; Goethite; Melt fluidity; Sinter properties; Sinter productivity*

1. Problem Background

During sinter plant operation, a sudden drop in production was observed, as shown in Figure 1. Under the root cause analysis to find the most probable reason, thorough investigation on man, machine, method, materials and environment was carried out. It was found that almost every other parameter was unchanged except the iron ore (I/O) in blend, I/O-2 (hematite iron ore) was replaced with I/O-1 (specular iron ore/ specularite, details are mentioned subsequently in raw materials heading). The chemical analysis of specular iron ore and hematite iron ore is given in Table 1.

The chemical analysis listed in Table 1 exhibited almost similar iron and gangue content of both I/O-1 and 2. The replacement percentage was one to one replacement so that the final chemical composition of sinter should remain unaltered. The visual appearance of I/O-1 (specular iron ore) looked smooth and flat. Moreover, both types of iron ore samples were examined for its microstructure and mineralogy. Figure 2, 3 and 4 show the mineralogy of hematite, specular and goethite iron ore, respectively. A typical specular structure of I/O-1 having needle shaped smooth grains, goethite iron ore and a massive rough hematite structures were observed in the mineralogy of I/O-2. The mineral component in goethite phase measured using Reitveld analysis through X-ray diffraction method showed the presence of following minerals (Near about fractions; Goethite: 35, Hematite:20, Goethite

Table 1. *Chemical analysis of raw materials*

Blend	Fe	FeO	SiO_2	Al_2O_3	CaO	MgO
Specular Iron Ore (I/O-1)	58.27	--	7.95	3.68	0.05	0.04
Hematite Iron Ore (I/O-2)	57.85	--	7.95	4.45	0.05	0.04

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aluminian: 25, Kaolinite:10. Quartz:3 and remaining other phases).

An elemental analysis of specular iron ore was also performed through energy dispersive spectroscopy (EDS) coupled with electron probe micro analyser (EPMA) as shown in Figure 4 and Table 2.

The EDS analysis revealed high Fe containing

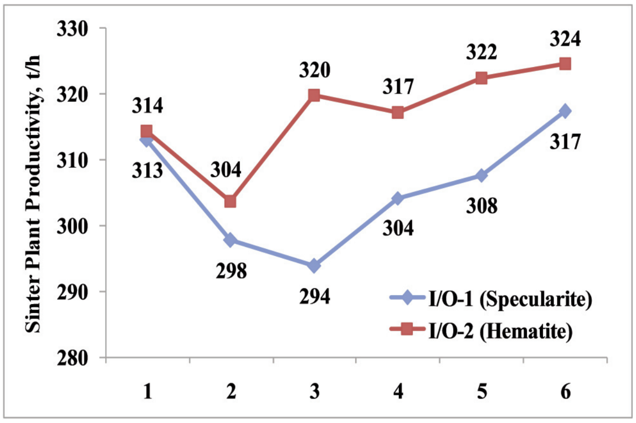

Figure 1. *Effect of iron ore type on sinter plant production (t/h, average of 6 consecutive days)*

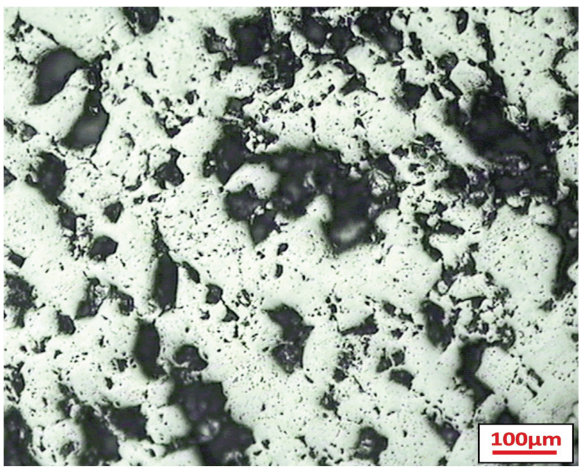

Figure 2. *Mineralogy of hematite I/O (100X)*

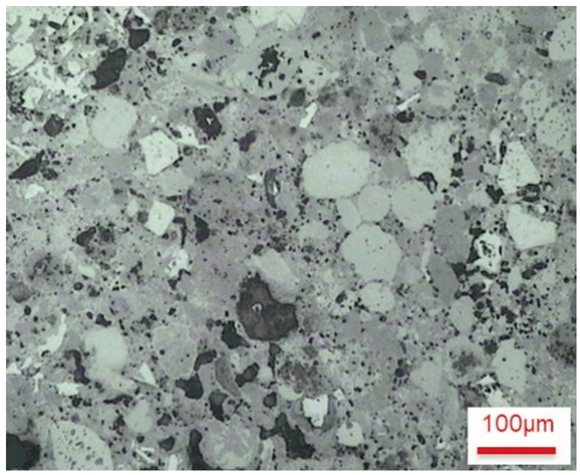

Figure 4. *Mineralogy of Goethite iron ore @ 100X magnification*

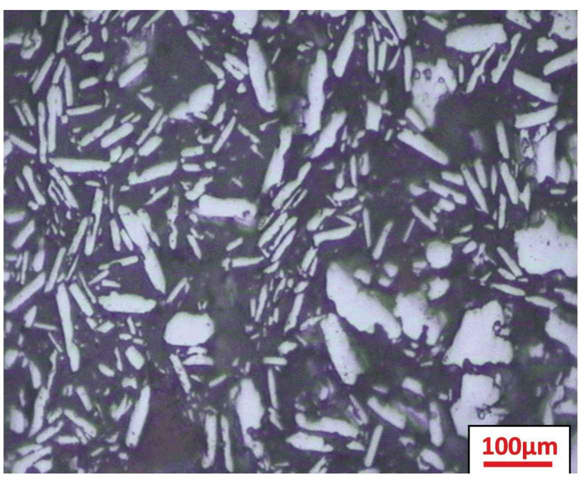

Figure 3. *Mineralogy of Specular iron ore @ 100X magnification*

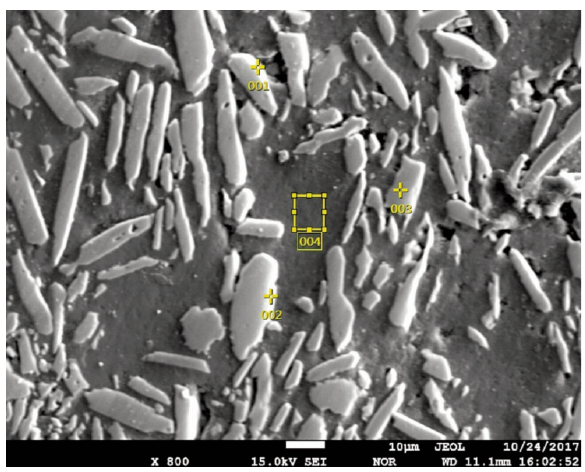

Figure 5. *Mineralogy of Specular iron ore @ EPMA (800X magnification)*

***Table 2.** Elemental analysis of specular iron ore at 4 different places using EDS of EPMA*

Point	Fe	O	Na	Mg	Al	Si	Mn
1	74.9	24.08	0.21	0.05	0.21	0.17	0.19
2	75.1	24.55	nd	0.04	0.07	nd	0.21
3	72.8	26.69	0.07	0.08	0.06	0.01	0.17
4	9.98	56.95	0.14	0.02	32.77	0.06	nd

particles at scanned point 1, 2 and 3 which resembled flat, smooth, blocky, and needles shaped structures. The EDS analysis at scanned point 4, as shown in Figure 5 and Table 2, revealed that the rough greyish surface was a gangue particle mainly aluminium oxide. The present work is directed to understand an effect of increasing fractions of specular iron ore of Indian origin in sinter raw materials blend on sintering process performance and sinter qualities. To nullify the ill effect of specular iron ore during sinter making process, a new raw material blend optimization studies were also performed and reported.

2. Introduction

Iron ore usage has increased in last decades due to rapid development of iron and steel industry, all across the world [1-4]. They are categorized based on their chemical constituents and associated mineralogy. The mineralogical structures found in iron ores are mainly hematite, goethite, limonite, magnetite, specularite, etc. In general, specular hematite iron ore (specularite) contains high iron (Fe) value with very low gangue minerals similar to the high grade of iron ore. They are widely distributed in the world and abundant in some countries such as Canada and Brazil [5]. The physical characteristics of specular iron ore is hard and platy texture, unfavourable particle size, long and flat particle shape and smooth surface [6]. Their assimilation behaviour with other sinter blend ingredients is also poor due to its low reactivity [5, 7-9]. Moreover, owing to smooth surface, hydrophobic nature and flat shape of specularite, its increased fractions in agglomeration affect the granulation, ball formation and thus poor bed permeability that eventually results in decreased productivity of sinter plant. Hence, in spite of its high Fe value, its use in both sinter and pellet making is limited to very low fractions of iron ore in blend.

Several steel plants, such as Baosteel, Wisco, Hansteel and Valin group, have experienced deterioration in bed permeability, productivity and tumbler index of sinter with the increased fractions of specular iron ore in their blend. The solid fuel consumption has also increased with increase in specular iron ore in sinter blend and thus expected to increase the carbon foot print also through higher CO_2 emissions during sinter making. Later, the specular iron ore fractions in sinter blend at plant has been restricted between 3-10 % only except in one plant with 20% of its usage. The maximization of specular iron ore fractions through agglomeration route is still a challenge which were addressed by several researcher's study report and scientific/ technical publications. It has also been reported at many instances that alteration of surface characteristics of specular iron ore may increase its proportion in sinter blend. In this context, several new processes such as fine milling, high pressure roll grinding, composite agglomeration process, binder addition, etc. have been followed during sinter making process [4, 5, 10-13].

To increase the specular iron ore proportion through agglomeration process, increase in lime content in sinter blend [4] and pre-treatment of specular iron ore using mechanical activation [9, 10, 14-15] were also proposed. Pan et al. [9] recommended a pre-briquetting process where the specular iron ore were briquetted in presence of lime and chemical binder prior to mixing with other sinter mix ingredients. They claimed significant improvement in bed permeability, sintering speed, sinter productivity and sinter qualities when compared with the traditional sintering process. However, it required additional capital expenses for setting up a briquetting machine. In the present work, the effect of specular iron ore of Indian origin on sintering process and sinter quality was studied. To increase the fractions of low cost specular iron ore having high Fe value, a different blending options were provided in the present study.

3. Experimental

3.1. Raw materials analysis and characterization

In the present study, four different types of iron ores of which first three (I/O -1 to I/O -3) were from local Indian mines and the last one (I/O -4) was imported iron ore from Australia mines, were used for the laboratory scale pot sinter studies. The first iron ore (I/O -1) was the specular iron ore (also called specularite) having about 58% total Fe and its chemical composition was almost similar to the I/O -2 which was predominantly hematite minerals. The chemical analysis of raw materials was examined using X-ray fluorescence (XRF), which is given in Table 3. All the raw materials were sieved using different sizes of sieves and their typical size analyses are given in Table 4. The sample preparation for XRF analysis was carried out using pick pointing methodology. The raw materials were spread in a rectangular plane after coning and quartering, materials were collected from various places of the plane as a representative sample for analysis. These samples were dried in an oven at 105 °C for 1 hour to remove the trapped moisture and ground to below 100 mesh using ball-mill for examining their chemical constituents.

3.2. Batch scale pot sintering test methodology

Pot sintering experiments were conducted at laboratory scale using a round shaped sinter pot with a diameter of 300 mm with a provision to vary height of the pot from 600 to 850 mm. Removable grate bar was placed at the bottom of the pot for air suction during the sintering experiments. Two sets of experiments were conducted in present study: (1) Effect of specular iron ore in sinter making and (2) Improving the sinter quality and productivity via blending of specular iron ore with goethite base iron ore. The sinter mix proportions used in set-1 and set-2 of the present study are listed in Table 5 & 6, respectively. As the specular iron ore up to 20% in the sinter blend was already used at a few plants and there

Table 3. *Chemical analysis of raw materials used for sintering experiments*

Blend	FeT	FeO	SiO_2	Al_2O_3	CaO	MgO
Specular Iron Ore (I/O)-1	58.27	--	7.95	3.68	0.05	0.04
I/O-2	57.85	--	7.95	4.45	0.05	0.04
I/O-3	62.76	--	3.68	2.91	0.06	0.07
I/O-4 (Goethite I/O)	58.41	--	6.03	2.97	0.05	0.04
Sinter return fines (SRF)	52.88	8.68	6.54	2.98	10.00	2.52
Limestone	0.651	--	0.92	0.20	49.84	4.26
Dolomite	1.127	--	0.20	0.12	31.43	19.78
Calcined Lime	0.182	--	1.10	0.37	93.59	1.86
	Ash	VM	S	FC		
Coke breeze	20.07	3.45	0.59	76.48		

Table 4. *Typical size analysis of iron ore, flux, return fines and solid fuels*

SIEVES	10	8	+6.3	5	+3.15	1	+0.5	100	-100
	mm							#	
Specular I/O-1	11.05	5.95	6.58	2.49	9.09	17.95	5.92	10.16	30.80
I/O-2	---	---	---	---	3.64	15.53	12.78	17.53	50.52
I/O-3	---	---	---	---	2.55	27.53	11.84	16.04	42.04
I/O-4 (Goethite I/O)	7.15	7.82	8.76	3.29	15.42	22.94	6.64	10.16	17.82
SIEVES	5	+3.15	1	-1	-3.15				
	mm								
Limestone	0.35	6.74	56.94	35.97	92.91				
Dolomite	0.42	8.45	54.43	36.70	91.14				
SIEVES	8	5	-5	Cum. +5					
	mm								
Return Fines	0.89	24.16	74.95	44706					
SIEVES	5	+3.15	1	+0.5	-0.5	Cum -3.15			
	mm								
Solid Fuel (Coke Breeze)	1.31	6.04	48.32	21.67	22.67	92.65			

Table 5. *Sinter Mix proportions used for the experimental trials (wt. %)*

Specular iron ore,%	0	10	20	25	30
Experiments	1	2	3	4	5
Total Iron ore (I/O)	47.11	47.10	47.10	47.10	47.10
Specular (I/O)-1	0.00	4.71	9.42	11.78	14.13
I/O-2	14.13	9.42	4.71	2.36	0.47
I/O-3	32.96	32.97	32.97	32.97	32.50
Return fines (R/F)	34.00	34.00	34.00	34.00	34.00
Limestone	6.40	6.40	6.40	6.40	6.40
Dolomite	6.11	6.10	6.10	6.10	6.10
Calcined lime	2.20	2.20	2.20	2.20	2.20
Coal/Coke	4.20	4.20	4.20	4.20	4.20
TOTAL	100	100	100	100	100

was awareness of its performance, the replacement of hematite iron ore with specular iron ore up to 20% was done with an increment of 10%. However, due to unfamiliar behaviour of specular iron ore beyond 20% in sinter blend, its replacement was restricted to only 5%, to understand its behaviour beyond 20% and up to 30 % of iron ore blend.

3.2.1. Experimental Conditions for pot sintering

Approximately 90 kg of sinter mix was blended using balling drum. *Blending condition*: mixing @ 20 rpm for 5 minutes.

The sinter mix in presence of moisture was agglomerated using a drum mixer. A*gglomerating condition:* mixing @ 20 rpm for 8 minutes.

Bed Height: 700 mm (constant), Hearth Layer: 60 mm

The material in pot grate with ignition conditions was sintered under the following conditions:

Ignition conditions:

Suction air flow volume before ignition 2.0 m^3/min

Ignition holding time 2 minutes

Suction pressure during ignition-400 mm H_2O

Suction pressure after ignition -1200 mm H_2O

Once a sinter cake was cooled, the whole mass of sintered ore was crushed using impact crusher and screened using various sized sieves. The chemical analysis of representative sinter samples was examined using X-ray fluorescence (XRF), as mentioned in Table 7. The sample preparation for XRF analysis was carried out using pick pointing methodology after coning and quartering.

The experimental evaluation indices considered for sintering process and sinter qualities were Product Yield (+5mm), Fines generation (-5mm), Cold strength properties such as Tumbler index and Shatter index. Their detailed methodology is mentioned below in 3.2.1.

Table 6. *Sinter Mix proportions used for the experimental trials with a blend of goethite iron ore*

%Specular iron ore in I/O blend (~ 30% Goethite in blend)	0	20	30
Experiment	1	6	7
Total Iron Ore (I/O)	47.11	46.79	46.30
I/O-1 (Specular Iron Ore)	0.00	9.36	13.89
I/O-2	14.13	0.00	0.00
I/O-3	32.96	23.40	18.52
I/O-4 (Goethite I/O)	0.00	14.03	13.89
Return fines	34.00	34.00	34.00
Limestone	6.40	6.40	6.40
Dolomite	6.10	6.10	6.10
Calcined lime	2.20	2.20	2.20
Coal/Coke	4.20	4.20	4.20
TOTAL	100	100	100

The assimilation behavior of specular iron ore was studied based on the melt fluidity which was responsible for the sinter qualities, mentioned below in 3.2.2.

3.2.2. Experimental evaluation indices

The Product Yield (+5mm), % and Fines generation (-5mm), % were defined as:

$$\text{Product Yield}_{(+5mm)},\% = \frac{W_{(+5mm)} \cdot 100}{W_{cake}}$$

$$\text{Fines generation, } \% = 100 - \text{Product Yield}_{(+5mm)},$$

% respectively

Sinter Productivity (t/h/m^2), +5mm, (%) for the cylindrical pot sinter was calculated based on the following formula:

$$\text{Productivity}_{(+5mm)}, t/h/m^2 = \frac{W_{(+5mm)} \cdot 10^{-3}}{\frac{\pi}{4} \cdot D^2 \cdot 10^{-6} \cdot \frac{t}{60}}$$

Where,

$W_{(+5mm)}$: is the weight of more than 5 mm particles of sinter product after being crushed and screened;

W_{cake}: is the total weight of the product sinter cake;

D : is the diameter of the cylindrical pot sinter;

t : is the sinter time, i.e. the duration of sintering from the start of ignition to the time it reaches to maximum wind box temperature.

Cold strength properties of sinter determined its resistance to impact, tumble and abrasion during handling and transportation from sinter plant to blast furnace. It was determined by the Tumbler and/or

Shatter index as per ISO 3271:1995 and IS 1963-1981, respectively.

Tumbler index was a measure of the resistance of sinters to size degradation by impact and abrasion, when subjected to a tumble test in a rotating drum as per the guidelines mentioned in ISO 3271:1995. This tumbler test was carried out by subjecting 15 kg of 10-40 mm sinter materials to 200 revolutions tumbling at 25 revolutions per minute in a steel drum having 1-meter diameter and 0.5-meter length fitted with two equally spaced lifters of 50mm*50mm*50mm dimensions. The tumbler index was given by the percentage weight of +6.3 mm sinter surviving the test.

Shatter Index represents the resistance to degradation of sinter during its transfer from sinter plant to blast furnace and it depends upon the number of transfer point from one conveyor to another till it reaches to blast furnace, and therefore vary from plant to plant. The tests were performed as per the guidelines mentioned in IS 1963-1981. Under the test, 20 kg of sinter samples between 10-40 mm size range were dropped from a height of 2 meters on a steel plate (dimension: width: 1200 mm, length: 1500 mm and thickness: 10 mm or more; surrounded by an enclosure of 300 mm in height). This method was repeated 3 more times. Finally, the samples were collected and sieved through 10 mm sieves and its percentage weight against the initial materials was reported as Shatter Index.

3.3. Melt fluidity and assimilation behaviour of specular iron ore

Due to the low reactivity and smooth surface of specular iron ore, its assimilation with other sinter blend ingredients has shown extremely poor behaviour [5, 7-9]. The high-temperature melt characteristics of iron ore during sintering process plays a prominent role in determining the sinter quality and sintering performance as it impacts the phases formed as well as permeability of the sinter bed. Depending on the fluidity and volume, melts flow down and reach the intricate boundaries of adjacent particles and coalesce, solidify into porous structures which provides interlocked binding and thus effect sinter qualities. The lesser melt formation can lead to weak slag bond which hampers the sinter properties while too high melt formation can lead to flooding of sinter bed which in turn is detrimental to bed permeability. The melt fluidity of iron ore was influenced by several other factors such as particle size, type and chemical constituent of iron ore, basicity of the blend, residence time, treatment temperature etc. [16-24].

In order to understand the melt behaviour of specular iron ore of Indian origin in presence of other raw materials, assimilation reaction tests were carried out using micro-sinter equipment accompanying with heating microscope and image analysis facility (Hesse Instruments, Germany). Iron ores were grinded to less than 63μm using high energy ball mill. The -63μm sized iron ore was homogeneously mixed with calcined lime in such a way that the basicity (B2=CaO/SiO_2) of blend was maintained to almost 2. A few drops of water were added to the mix to facilitate the binding while moulding. To prepare a cylindrical sample (height: 3mm and diameter: 3mm) as shown in Figure 6, mixed material was placed in a stainless steel mould under a constant pressure of 15 MPa applied by plunger. The cylindrical specimen was placed in the micro sintering furnace. The

Figure 6. *Cylindrical sample*

Table 7. *Chemical analysis of sinter*

Experiment	1	2	3	4	5	6	7
Fe(t),%	53.38	53.34	53.36	53.37	53.35	53.07	52.64
SiO_2,%	5.45	5.45	5.45	5.45	5.41	5.47	5.67
Al_2O_3,%	3.45	3.54	3.50	3.48	3.46	3.65	3.64
CaO,%	12.01	12.02	12.02	12.01	12.02	12.32	12.65
MgO,%	2.21	2.21	2.21	2.21	2.21	2.23	2.24
MnO,%	0.61	0.56	0.59	0.60	0.61	0.49	0.52
CaO/SiO_2	2.21	2.21	2.21	2.21	2.20	2.28	2.23
Al_2O_3/SiO_2	0.63	0.65	0.64	0.64	0.63	0.68	0.64

experimental set up for the melt fluidity test is shown in Figure 7. The heating rate of the furnace was maintained to 20 °C/min from room temperature to 1000 °C followed by 10 °C/min till the flow temperature.

4. Results and discussion

4.1. Effect of specular hematite iron ore in sintering performance and sinter qualities

The sintering process parameters and sinter qualities obtained after the pot sinter trials of specular iron ore and hematite type of iron ore through conventional sintering route are given in Table 8 and their graphical representations are presented in Figure 8. The laboratory scale pot sinter results were in agreement with the plant data. With the increase in specular iron ore up to 10% of the total iron ore, the sinter blend showed drastic reduction in sintering time, which consequently improved sinter productivity. However, the sinter cold strength properties (such as Tumbler Index and Shatter Index) dropped significantly. The increased weight fractions of specular iron ore beyond 10% up to 30% showed a continuous increase in sintering time. Beyond 10% addition of specular iron ore, the cold strength properties such as Tumbler Index and Shatter Index were found to be almost same. The sintering time increased and thus as a consequence the continuous drop in sinter productivity was observed. The fines generation (size fraction below 5mm size) also increased significantly which reduced the required sinter quantity as burden material for blast furnace during plant scale use of specular iron ore.

The observed phenomena as mentioned earlier can be correlated with the air filtration velocity (AFV) during sintering of iron ore blended with and without specular iron ore. During pot sinter experiments, the AFV measured at an interval of 3 minutes showed an increased speed of air flow when 10% of specular iron ore was blended with other ingredients. Increased AFV could be due to the homogeneous distribution of the mix and to the lesser fines available with specular iron ore, providing better permeability. However, with

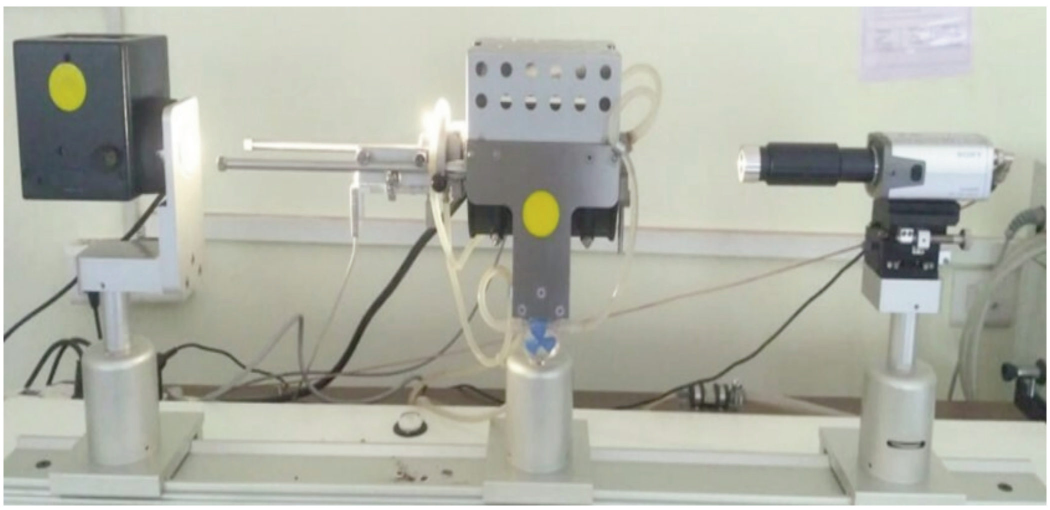

Figure 7. *Experimental setup for melt fluidity*

Table 8. *Sintering performance and sinter qualities with increased fractions of specularite*

Weight fractions of Specular I/O in IOF blend, %	0	10	20	25	30
Experiments	1	2	3	4	5
Shatter Index (%)	71.31	69.57	69.63	69.48	69.12
Tumbler Index (%)	69.27	65.60	64.67	65.73	65.80
Product Yield, +5mm (%)	82.17	82.81	81.47	81.45	80.25
Fines generation, -5mm (%)	17.83	17.19	18.53	18.55	19.75
Sintering Time (min)	20.3	19.3	20.3	21.1	21.4
Sinter Productivity (t/h/m^2), +5mm, (%)	2.12	2.34	2.15	2.07	2.02
Wind Box temp. (ºC)	335	331	329	297	289

increased fractions of specular iron ore in the blend, the poor granulation and ball formation resulted in a drop in APF. It may also be attributed to the fact that the flat and smooth surface of the specular iron ore was stacked and did not allow air passage.

Table 9 and Figure 9 show the average AFV value (m/s) at different experimental conditions confirming to the slow movement of the air. Due to the poor assimilation characteristics of specular iron ore, the melt formation was lower and thus the viscosity of the melt would be lower than with the other hematite iron ore [5, 7-9]. Therefore, the combustion zone and flame front movement moved faster to the lower bed due to increased AFV value as mentioned in Table 9 and Figure 9, resulting in faster sintering which consequently increased sinter productivity with the addition of 10% of specular iron ore to in blend. With increased fractions of specular iron ore in the sinter blend, the wind box temperature reduced significantly which may also be

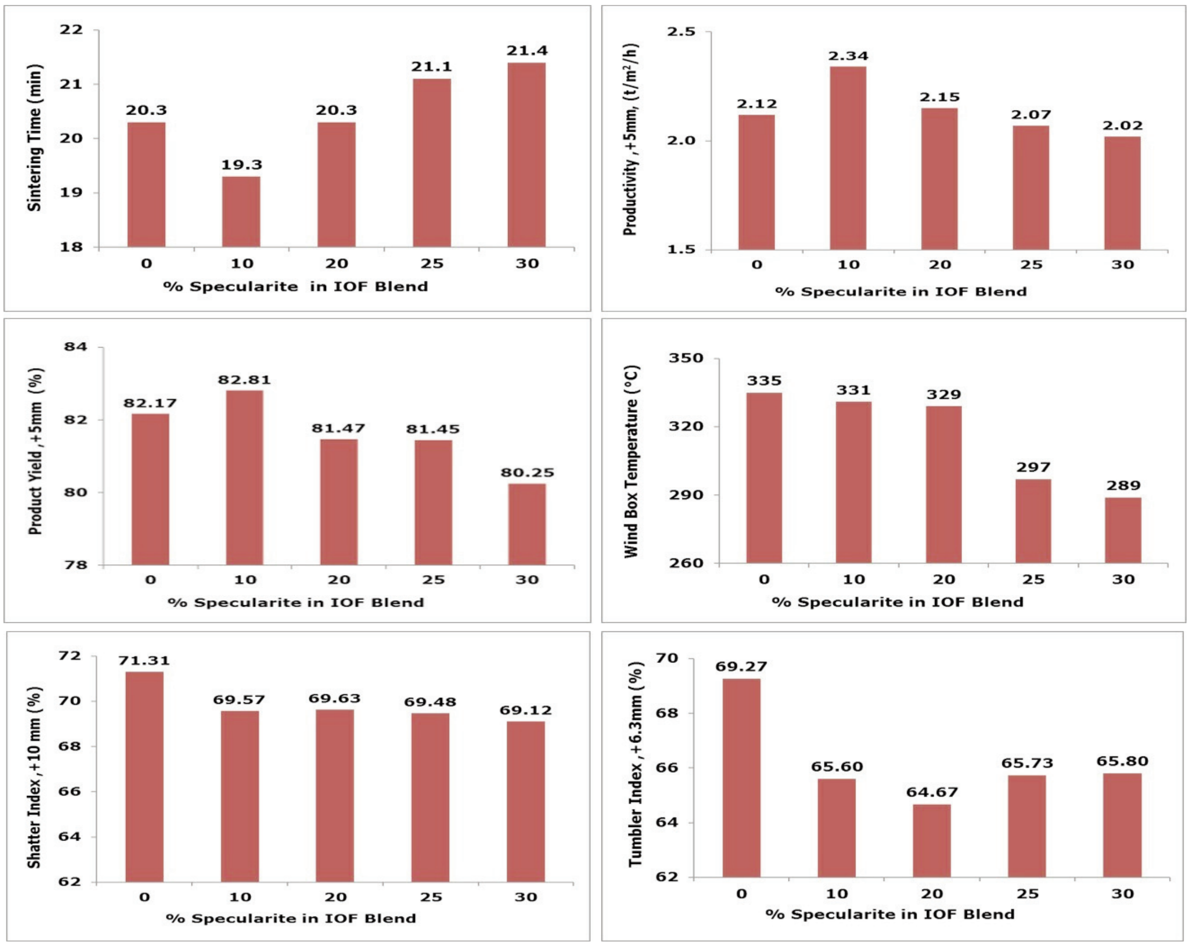

Figure 8. *Graphical representation of sintering behaviour and sinter qualities at different combination of experimental trials*

Table 9. *Air filtration velocity (m/s) at different operating condition*

Time, min	Air Filtration Velocity, m/s						
	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5	Exp-6	Exp-7
6	0.19	0.20	0.20	0.19	0.18	0.20	0.18
9	0.20	0.21	0.20	0.20	0.19	0.21	0.19
12	0.20	0.23	0.21	0.21	0.20	0.22	0.19
15	0.22	0.26	0.24	0.22	0.22	0.26	0.21
18	0.25	0.33	0.30	0.25	0.24	0.31	0.24
21	0.29	0.34	0.34	0.29	0.27	0.35	0.30

related to its poor assimilation behaviour. It can also be attributed to the fact that the amount of heat was getting wasted to the surrounding than being utilized in condensation zone of pot, resulting in reduced wind box temperature.

4.2. Effect of blending of specular iron ore with goethitic type of iron ore on sintering performance and sinter qualities

To maximize the specular iron ore usage with improved sinter quality and productivity, the goethite mineral of iron ore was blended and trials were conducted at laboratory scale pot sinter machine. Effect of goethite mineral on sinter making and sinter qualities have been reported in several published research articles. It has been widely observed that addition of goethite minerals in to blend is detrimental to the productivity due to the excessive melt formation which impede the flame front movement [26]. However, it assimilates faster than dense ore and thus sinter strength enhances [26]. As increased specularite fractions to 10% in blend reduced sintering time significantly and thus enhanced sinter productivity, however the tumbler and shatter index dropped drastically due to poor melt assimilation as shown in Figure 8. Thus, blending of goethite mineral in blend would improve the melt formation due to the combined effect of excessive melt formation of goethite mineral [26] and the poor melt assimilation of specularite [7-9] expecting improvement in sintering performance and sinter quality. In the present work 30% of goethite iron ore was blended with specular iron ore. The hematite iron ore was replaced with specular iron ore to 20 and 30% in blend. The pot sinter test results of such blend is listed in Table 10 and their graphical representation is mentioned in Figure 10. An improved sinter productivity and sinter cold strength property (Shatter index and Tumbler index) was clearly revealed. In comparison to the hematite ore blend (Exp-1), the sinter productivity was maintained till 30% addition of specularite in blend. However, the sinter cold strength reduced slightly which may be in acceptable range.

Loo [26] also proposed to improve the bed permeability and thus the air filtration velocity of goethite iron ore sintering by suitable blend

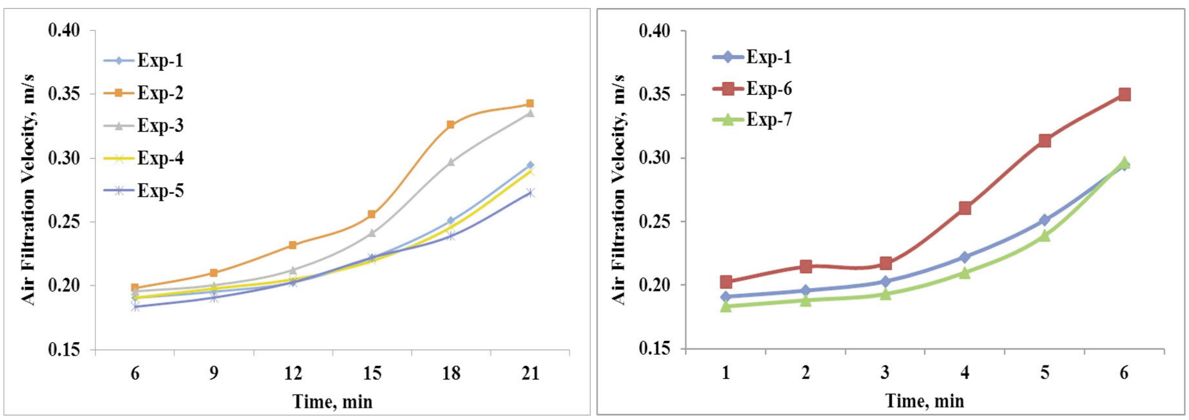

Figure 9. *Average air filtration velocity (m/s) of the sintering process at an interval of 3 minutes*

Table 10. *Sintering performance and sinter qualities with increased fractions of specularite with almost 30% of goethite iron ore in blend*

% Specular iron ore in IOF blend (with ~ 30 wt.% goethite I/O in I/O blend)	0	20	30
Experiments	1	6	7
Shatter Index (%)	71.31	70.49	70.33
Tumbler Index (%)	69.27	67.37	67.30
Product Yield, +5mm (%)	82.17	82.27	81.90
Fines generation, -5mm (%)	17.83	17.73	18.10
Sintering Time (min)	20.3	18	20.3
Productivity ($t/h/m^2$), +5mm, (%)	2.12	2.49	2.17
Wind Box temp. (ºC)	335	368	427

optimization. The wind box temperature also increased with the use of specularite and goethite blend which confirmed better melt assimilation and heat utilization. A significant improvement in air filtration velocity, as shown in Figure 8, also indicated an improved sintering performance and reduced sintering time. Such achievement was attributed to the composite effect of better air flow in presence of specularite and better permeability of goethite iron ore [26]. To understand the melt formation and deformation range of each of these iron ore, the melt behaviour was studied using ash fusion instrument.

4.3. Melt behaviour of specular, hematite and a blend (specular, hematite and goethite) iron ore

Figure 11 shows the melt behaviour of (a) specular iron ore, (b) hematite iron ore and (c) blend (specular, hematite and goethite) iron ore. It is clear from the figure that the deformation ranges of specularite, hematite and blend iron ores were 1393-1407 ˚C, 1290-1405 ˚C and 1344-1388 ˚C, respectively as mentioned in Table 11.

The deformation start temperature of specularite was higher, i.e. 1393 ˚C, than the other two types of iron ore studied. The deformation temperature of hematite was the lowest, i.e. 1290˚C, whereas the deformation temperature of the blend was in between those two mentioned above, i.e. 1344˚C. However, the hemisphere points for specularite, hematite and blend iron ores were 1407, 1405 and 1388 ˚C, respectively. In a similar fashion the flow points for specularite, hematite and blend iron ores were 1481, 1461 and 1455 ˚C, respectively. The higher the deformation start temperature was, the indication of higher heat requirement for the initiation of melting of specularite iron ore was. Whereas the lowest hemisphere point temperature confirmed that the melting finished faster than other two iron ore.

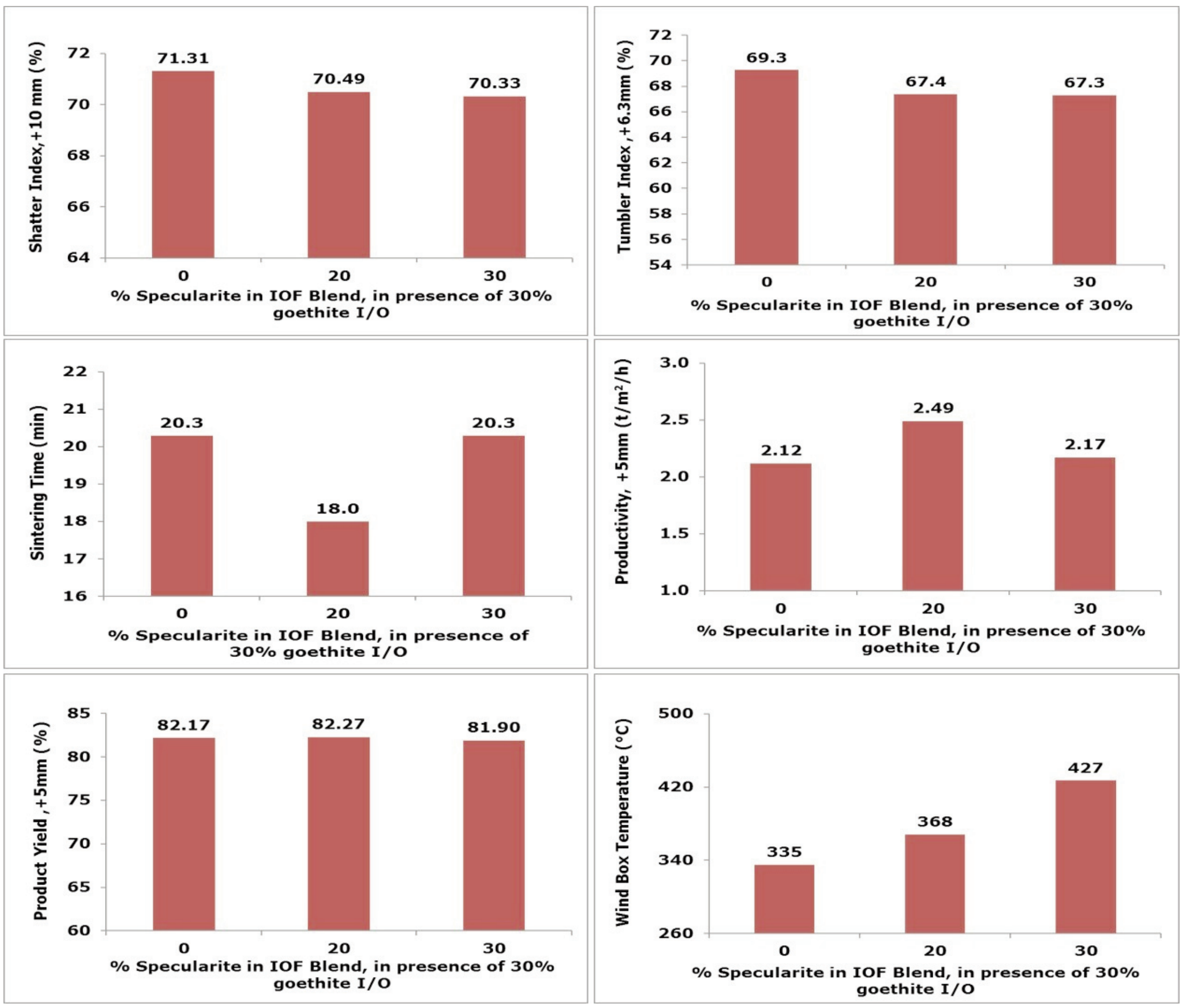

Figure 10. *Graphical representation of sintering behaviour and sinter qualities at different combination of experimental trials*

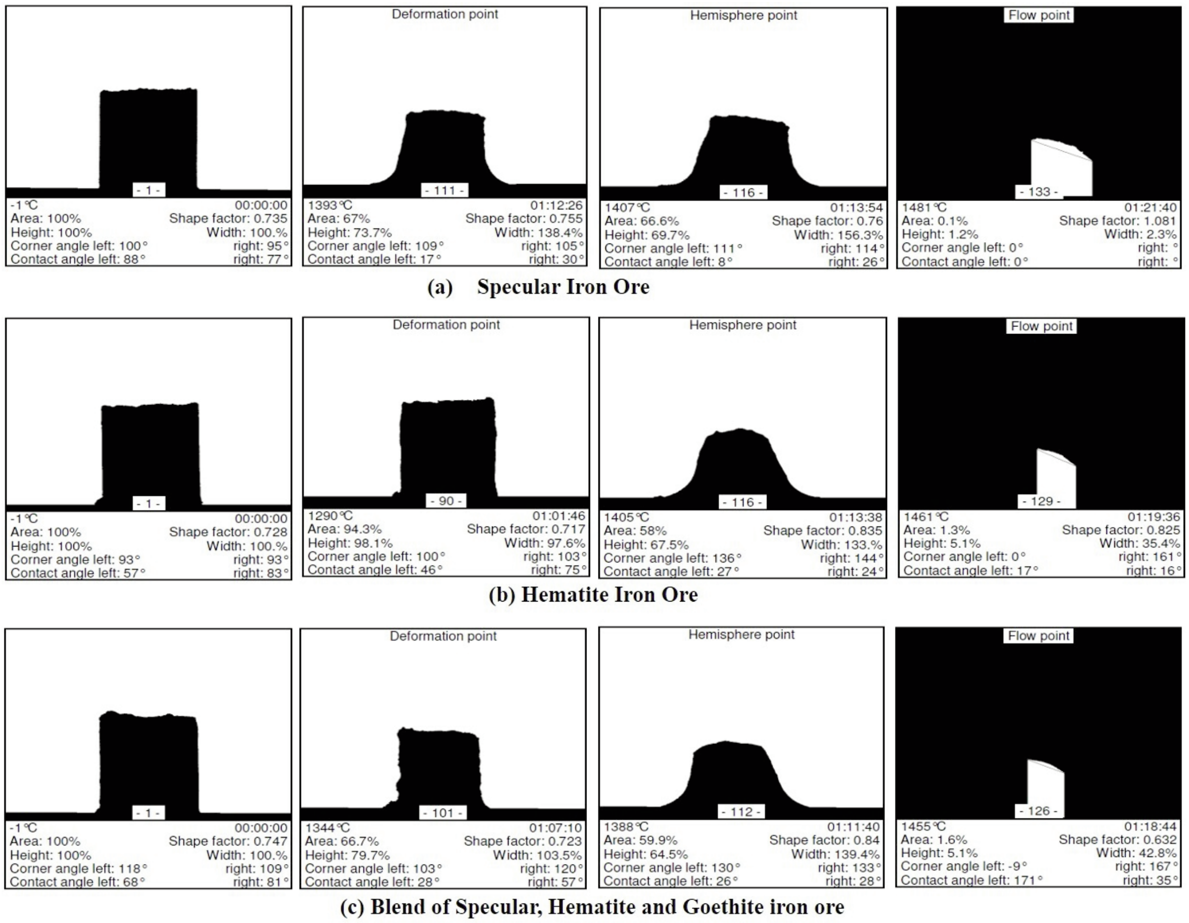

Figure 11. *Assimilation behaviour of (a) Specular I/O, (b) Hematite I/O and (c) blend of (Specularite, Hematite and Goethite I/O)*

Table 11. *Raw material deformation and flow temperature using ash fusion test machine*

Type of iron ore	Deformation Range, ˚C	Hemisphere Point, ˚C	Flow Point, ˚C
Specular	1393-1407	1407	1481
Hematite	1290-1405	1405	1461
Blend (Specular, Hematite, Goethite)	1344-1388	1388	1455

5. Conclusions

The sinter product yield (+5 mm), sintering time and sinter productivity improved with the addition of 10 % of specular iron ore in sinter blend. However, beyond 10% usage they deteriorated to the large extent.

With increased fractions of specular iron ore in blend, a significant reduction in sinter qualities mainly the tumbler and shatter index occurred.

The wind box temperature decreased with increased fractions of specular iron ore in blend, which showed the cooling effect during sintering in presence of specular iron ore.

Addition of 30% of goethite iron ore in blend showed significant improvement in sinter productivity, quality and yield compared to that the blend without goethite iron ore.

In presence of goethite iron ore, the sinter strength of specular iron ore added blend deteriorated slightly, which could be acceptable value depending on the industries norms and acceptance criteria.

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Author's Contribution

Both the primary and secondary author (Mr. S. Kumar and Mr. A. Jaiswal) were involved in planning, execution of laboratory based trials and data analysis of the results obtained, whereas the last/ third author Dr. R. Sah was involved in continuous discussion and review of the work. He has involved as a guide for the whole work.

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POBOLJŠANJE PROCESA SINTEROVANJA POVEĆANJEM KOLIČINE RUDE GVOŽĐA SA METALNIM SJAJEM U SINTERU

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Apstrakt

Ruda gvožđa sa metalnim sjajem (spekularit) je ruda srednjeg kvaliteta pogodna za upotrebu u procesu aglomeracije. Međutim, zbog njene tvrde teksture, nepoželjne veličine i oblika, lošeg učinka asimilacije, kao i niske reaktivnosti na visokoj temperaturi, njena upotreba u aglomeraciji je ograničena na oko 3-10% u većini pogona. U ovom radu su ispitivani uticaj rude gvožđa sa metalnim sjajem na postupak sinterovanja i kvalitet sintera. Primećeno je da povećani udeo ove rude u sinteru ima loš uticaj na učinak sinterovanja i u ispitivanjima izvedenim u laboratorijama i u pogonima. Tokom ovog istraživanja ispitan je i uticaj mešanja ove rude sa getitom na postupak sinterovanja i predložen je i optimalni odnos mešavine ruda za održivi učinak i kvalitet postupka. Da bi se povećala upotreba spekularita u sinterovanju u sinter je dodavan getit do 30% da bi se poboljšale karakteristike spekularita. Getitna ruda gvožđa sadrži hemijski vezanu vodu koja se uklanja na višim temperaturama (300 – 500 °C) tokom sinterovanja. Voda koja isparava se hladi u donjem sloju i kondenzuje, što usporava protok vazduha tokom postupka sinterovanja i na taj način period sagorevanja traje duže i omogućava bolju asimilaciju rastopa i kvalitet sintera. Slaba asimilacija spekularita se rešava prisustvom getita. Bolja reaktivna i hidrofilna priroda getita poništava ili smanjuje loš efekat ovih osobina kod spekularita tokom postupka granulacije i sinterovanja. Zbog toga je mešavina ove dve rude dovela do poboljšanja brzine sinterovanja i samim tim povećala učinak sinterovanja. Kao rešenje problema, predloženo je prisustvo getita do 30% u mešavini za sinterovanje.

Ključne reči: *Sinterovanje rude gvođa; Spekularit; Getit; Fluidnost rastopa; Svojstva sinterovanja; Učinak sinterovanja*