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# INFLUENCE OF LD SLAG ON IRON ORE SINTER PROPERTIES AND PRODUCTIVITY

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**ABSTRACT**

Large amounts of slags from steel plants are produced through basic oxygen furnace and LD furnace. The main purpose of LD process is to convert the molten pig iron and steel scraps into high quality steel. In India, the generation of steel melting slag is over 4 to 4.5 Mt per annum. The amount of steel slags from different steel industries are 150–200 kg/t of steel produced. Disposal of large quantities of slag becomes a big environmental concern. JSW Steel Limited is a 7.0 Mtpa integrated steel plant and produces 3200 tons of total steel making slag per day and in that LD slag is 2000 to 2500 t/day. This LD slag consists of 45.75% CaO, 22.0 % Fe and 8.22% MgO. Thus, recycling of LD slag through the sintering process recovers lime, iron and magnesia and thereby saving of flux material and iron ore. Due to high content of CaO one can replace LD slag by limestone in sintering process. Detail investigation was carried out through lab scale studies for estimating the maximum permissible limits of usage of LD slag in sinter making and to know the influence of LD slag addition on sinter productivity and properties. Experiments were conducted using the LD slag in sinter making from 0 to 60kg/t of sinter. FeO content of the sinter decreased, sinter productivity increased with increase in LD slag addition. Decrease in FeO content is due to decrease in sinter bed temperature and increase in productivity is due to decrease in LOI content of the sinter mix and absence of weight loss due to calcination process. The sinter strength and RDI of the sinter deteriorated due to non availability of free CaO in LD slag and this reduces the formation of calcium ferrites phase and more $Fe_2O_3$ remains as free phase due to less reaction with CaO. From the test results it was found that 30 to 35 kg LD slag can be used per ton of sinter to get desired properties of the sinter.

***Keywords:*** *LD slag, Iron ore sinter, Production, Physical and metallurgical properties.*

## INTRODUCTION

Integrated steel plants utilize mostly five materials such as raw materials, air, water, fuel and power to produce steel. In an integrated steel plant, during the production of steel, 2–4 tons of wastes are being generated per ton of steel produced. Accordingly, present day thrust [1–5] is on reduction of the waste generation, recycling and reuse of waste, and minimizing adverse impact of disposal on environment. Slags generated at iron making and steel making units are the largest quantities among all the solid/liquid wastes. Disposal of large quantities of slag becomes a big environmental concern. Slag handling, disposal and its reuse has become a critical environmental issue for steel producers. At present generation of slag has reduced due to improvements in process technologies and its functions. At the same time, the re-use of iron and steelmaking slags has also been expanded, and has led to a significant reduction in the environmental impact of these byproducts.[6–10] However slag generation remains an unavoidable step and focus on its re-cycling remains the greatest concern.

Steel plant slags mainly include, blast furnace slag and steel melting slag (LD process slag). LD slag is a byproduct of steel industry, which comes from pig iron refining using LD converters. The byproducts usually contain considerable quantities of valuable metals and materials. Most of the materials of steel plant wastes are recycled through sinter making in most of the countries. Because of its physical, chemical and mineralogical properties, it can be used as raw material in process like sintering. Recycling of LD slag has the highest cost implication on sintering process. LD slag contains high amount of CaO, iron, and MgO, thus recycling it through sintering process helps in the saving of flux and iron ore. The recycled wastes have some effect on sinter quality, strength and productivity. JSW Steel Limited is a 7.0 Mtpa integrated steel plant and produces 2000 to 2500 tons of LD slag per day. Laboratory pot grate sintering experimentation has been carried out to study the effect of LD slag addition on sinter productivity, and physical and metallurgical properties. The LD slag in the sinter mix was varied from 0 to 60kg/t of sinter.

### LD slag generation at JSW Steel

LD slag is a waste material (by product) generated in process of steel making. Figure 1 shows the Steel making process and LD slag generation at JSW Steel limited. JSW Steel Limited is a 7.0 Mtpa integrated steel plant and produces 3200 tons of steel making slag per day and in that LD slag is 2000 to 2500 t/day. This LD slag consists of 45.75% CaO, 22.0 % Fe and 8.22% MgO.

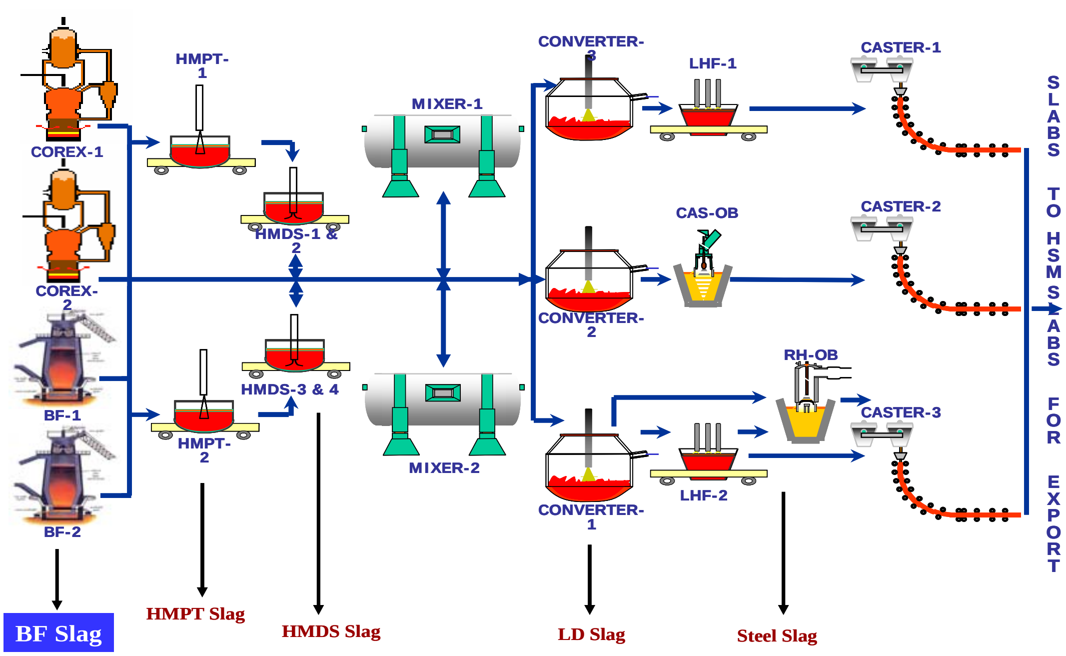


*Fig. 1: Steel making process and LD slag generation at JSW Steel limited.*

Thus, recycling of LD slag through the sintering process recovers lime, iron and magnesia and thereby saving of flux material and iron ore. Due to high content of CaO one can replace LD slag by limestone in sintering process. At present most of the steel plants in the world are reusing LD slag as a flux instead of limestone in sintermaking. At JSW Steel Limited steel making slag is completely dumped or used for ground filling after crushing. Based on the earlier trials at JSW steel making slag is being used up to 40 kg/t in COREX and 50 kg/t in blast furnace. However with the increasing capacities, amount of disposal of huge amount of steel slag is a real challenge. To utilize LD slag in sinter making basic studies are required to know the influence of LD slag addition on sinter chemistry, productivity and sinter properties. The higher phosphorus content in the LD slag is the main restricting factor for utilizing in the sinter making. To optimize the LD slag in sinter making trials have been planned in lab scale and varied the LD slag in the sinter mix from 0 to 60kg/t of sinter. Figure 2 shows the disposal of LD slag at slag yard.

*Fig. 2: Disposed LD slag at slag yard.*

## EXPERIMENTAL

Pot grate sintering experiments were carried out in laboratory by using the same raw materials which are used in the sinter plant. The crushed LD slag of –6 mm size was collected from the slag yard of steel making shop. The chemical composition of the raw materials which are used in the pot test is given in Table 1. The coke breeze which is a byproduct of coke oven plant is used as fuel. Size distribution of raw material is shown in Table 2. In total 7 experiments were carried out by varying the LD slag addition from 0 to 60kg/t in sinter base mix. The basicity and MgO was kept constant for all experiments. The target sinter chemistry and the base mix proportion for the pot tests are shown in Table 3 and Table 4 respectively. Small piles were prepared by layering the iron ore fines, coke breeze, limestone, dolomite, burnt lime and return fines and LD slag on weight basis (Table 4). All these constituents were thoroughly mixed. After ensuring proper mixing of these raw materials, the base was transferred to the granulation drum. Granules were prepared in the granulation drum by maintaining a granulation time of 7 minutes. The time required for different actions in the granulation cycle is as follows: Dry mixing – 2 min; water addition: 2 min; granulation – 3 min. The raw mixture having a weight of 70 kg was granulated with 8% moisture. After granulation, the material from the granulation drum was transferred to the sinter pot having an inner diameter of 300 mm and a height of 600 mm and subsequently sintered in the pot under a suction of 1300 mm of WG.

The sintering conditions were kept constant for all the experiments. The pot grate test conditions are given in Table 5 and the experimental setup is shown in Figure 3. Chemical analyses of the raw material as well as sinter products were carried out by using XRF.

Table 1: Chemical analysis of raw material

| Details | Iron ore fines | Limestone | Dolomite | Coke breeze | BF return fines | Lime | LD Slag |
|---|---|---|---|---|---|---|---|
| | Wt,% | | | | | | |
| Fe (T) | 62.59 | 0.48 | 1.22 | 1.26 | 56.11 | 0.15 | 21.51 |
| FeO | | | | | 6.17 | | 27.68 |
| $SiO_2$ | 4.32 | 1.79 | 2.40 | 14.96 | 6.47 | 0.43 | 11.12 |
| $Al_2O_3$ | 2.83 | 0.37 | 0.72 | 7.74 | 3.6 | 0.23 | 4.12 |
| CaO | 0.11 | 52.72 | 31.29 | 0.50 | 7.6 | 92.00 | 45.75 |
| MgO | 0.04 | 1.26 | 18.61 | 0.26 | 2.16 | 0.82 | 8.22 |
| LOI | 2.63 | 42.92 | 44.55 | 7.00 | | 2.00 | |
| C | | | | 74.70 | | | |

Table 2: Size distribution of raw material

| Material | Particle size, mm | | | | |
|---|---|---|---|---|---|
| | +10 | +6.3 | +0.5 | **0.150** | **–0.150** |
| | Wt, % | | | | |
| Iron ore fines | 4.5 | 12.2 | 39.2 | 19.3 | 24.8 |
| Material | Particle size, mm | | | | |
| | 5~3 | 3~1 | 1~0.5 | **0.5~0.25** | **0.25** |
| | Wt, % | | | | |
| Dolomite | 4.0 | 42.0 | 24.0 | 16.0 | 14.0 |
| Limestone | 4.8 | 41.6 | 25 | 15 | 13.6 |
| Coke breeze | 5.1 | 43 | 23 | 16.9 | 12 |
| LD slag | | | | | |

*Fig. 3: Pot grate sinter experimental setup.*

Table 3: Target sinter chemistry

| Composition | Wt, % |
|---|---|
| CaO | <13.0 |
| MgO | 2.20 |
| $B_2$ ($CaO/SiO_2$) | 2.00 |

Table 4: Raw material mix proportion

| Details | LD slag, kg/sinter | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 |
| Iron ore | 55.91 | 55.65 | 55.41 | 55.05 | 54.80 | 54.58 | 54.27 |
| Limestone | 9.31 | 8.97 | 8.66 | 8.43 | 8.14 | 7.84 | 7.57 |
| Dolomite | 7.91 | 7.63 | 7.30 | 7.00 | 6.63 | 6.31 | 5.93 |
| Lime | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Coke breeze | 5.86 | 5.89 | 5.90 | 5.93 | 5.94 | 5.96 | 5.97 |
| BF return fines | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| LD Slag | 0.00 | 0.86 | 1.73 | 2.59 | 3.50 | 4.31 | 5.26 |

Table 5: Pot grate sinter test conditions

| Parameter | Magnitude |
|---|---|
| Bed height, mm | 600 |
| Hearth layer,mm | 50 |
| Suction, mm of WC | 1300 |
| Ignition Temperature, $^{o}C$ | 1150 |
| Ignition time, sec | 120 sec |
| Moisture content, % | 8 |

## RESULTS AND DISCUSSION

### Influence of LD slag addition on limestone addition and sinter chemistry

Figure 4 shows the influence of LD slag addition on limestone content in the sinter mix. The limestone addition decreased from 108 to 86kg/t with increase in LD slag addition from 0 to 60kg/t of sinter. The CaO present in the experimental limestone and LD slag is about 52.72 and 45.75 % respectively. The high content of CaO in the slag can be used to substitute for a part of limestone as fluxing material and to reduce the steel making cost. Many steel plants of the World utilize LD slag as the replacement of limestone.[11]

Thus, recycling it through the sintering process helps in the saving of flux material and iron ore. Recycling of LD slag has the highest cost implication on sintering process. Figs. 5 and 6 shows the influence of LD slag addition on burn through temperature and FeO content of the sinter. Burnthrough temperature and FeO content of the sinter decreased with increase in LD slag addition. Bed permeability is not influenced by the LD slag addition. Decrease in burnthrough temperature is directly related to sinter bed temperature. The mineralogical composition of LD slag is dicalcium silicate, calcium ferrite and calcio-wustite. These phases demand extra heat for assimilation and this may be attributed to the decrease in sinter bed temperature and FeO content of the sinter. Figure 7 shows the influence of LD slag addition on phosphorus content of the sinter. The sinter phosphorus content increased with increase in LD slag addition. Steel slags contain higher amount of P&S, which seriously affects the direct recycling to iron and steel making process. If phosphorous content increases in the sinter, more than 95 to 98% of the phosphorous enters the hot metal after reduction process. As phosphorous increases in the blast furnace burden, hot metal phosphorous also increases and has a detrimental effect on steel plant operating costs. Although a general trend on recycling of LD slag through sinter has started[12] the higher phosphorus content is the restricting factor for its further recycling.

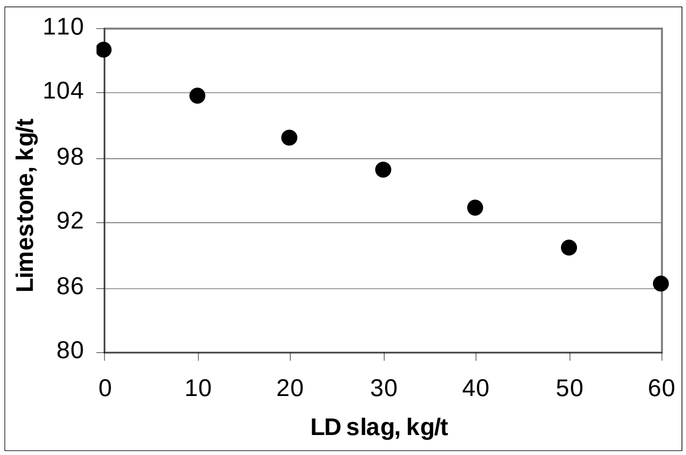


*Fig. 4: Influence of LD slag addition on limestone addition.*

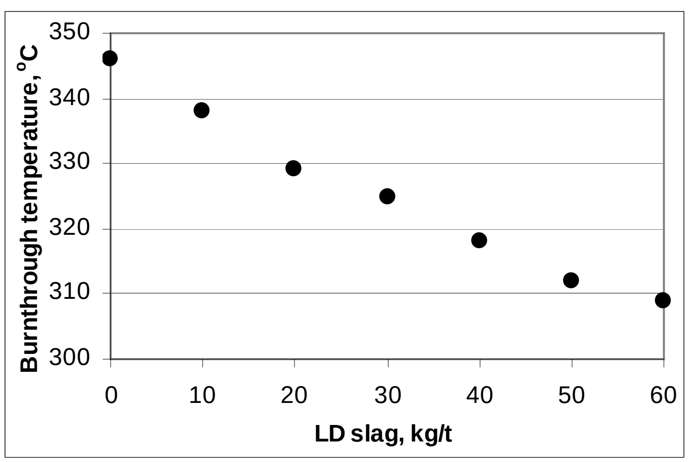


*Fig. 5: Influence of LD slag addition on burnthrough temperature.*

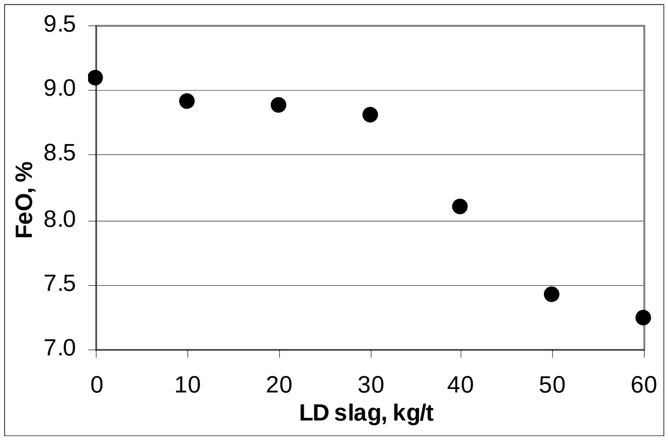


*Fig. 6: Influence of LD slag addition on sinter FeO content.*

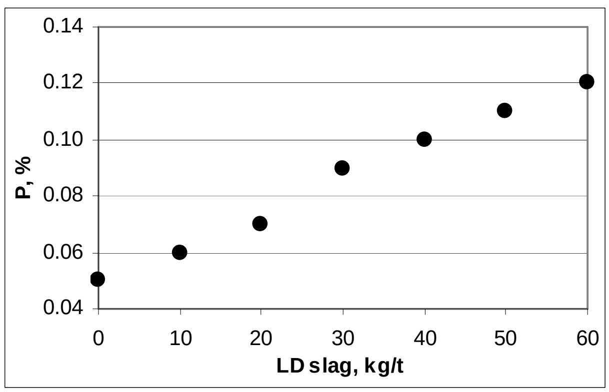


*Fig. 7: Influence of LD slag addition on sinter phosphorus content.*

**Influence of LD slag addition on sinter productivity**

The influence of LD slag addition on sintering time and sinter productivity is shown in Figure 8. The sinter productivity increased and sintering time decreased with increase in LD slag addition. LD slag addition decreases the limestone content in the sinter base mix. Decrease in limestone addition in the base mix decreases the LOI from 10.93 to 8.83% (Figure 9). Thus decrease in loss of ignition increases the sinter productivity. During sintering process limestone undergoes calcination process and loses half of its weight. After calcination only CaO is available for melt formation. With the addition of LD slag weight loss due to calcination is not there and CaO is available in the form of dicalcium silicate, dicalcium ferrite and Calcio- wustite for melt formation. Due to absence of calcination process with the addition of LD slag sintering front may move immediately. This is the reason for improvement in sinter productivity with the addition of LD slag. The movement of flame front along the bed height is one of the key process parameters which affects formation and stabilization of phases in sinter. The rate of travel of flame front has bearings on productivity and quality.[13]

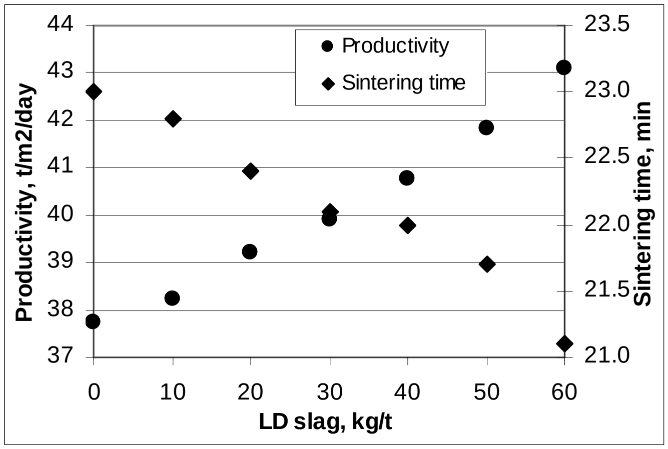


*Fig. 8: Influence of LD slag addition on sintering time and productivity.*

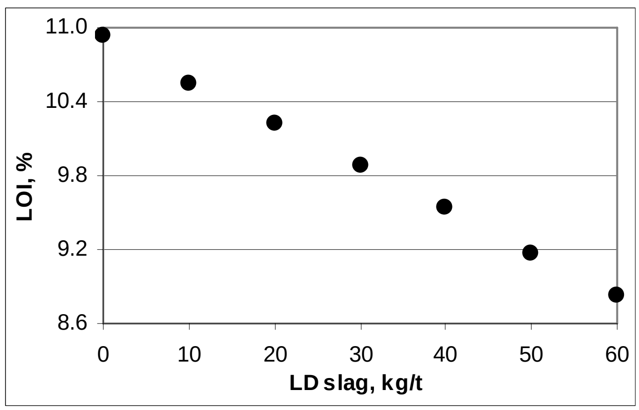


*Fig. 9: Influence of LD slag addition on LOI of sinter green mix.*

**Influence of LD slag addition on sinter strength**

Influence of tumbler and abrasion index of the sinter is shown in Figure 10. Tumbler index decreased and abrasion index increased with increase in addition of LD slag. Strength of sinter mainly depends on the phases present in the sinter and melts available for formation of sinter. Usage of limestone in the sinter base mix provides free CaO after calcination for melt formation and calcium ferrites formation takes place. In case of LD slag CaO is not available in free form and it is combined with $SiO_2$ and FeO as dicalcium silicate, dicalcium ferrite and Calcio- wustite for melt formation. The availability of CaO phase for assimilation and for melt formation decreases with increase in addition of LD slag. Decrease in availability of free CaO for melt formation and assimilation leads to formation of less calcium ferrites and poor bonding. Proper assimilation of fluxes with hematite during sintering process gives good mechanical strength.[14] Calcium ferrite is the major mineral constituent of the sinter structure and it imparts strength to the sintered mass. High content of calcium ferrites favors the tumbler strength of the sinter.[15, 16]

Figure 11 shows the influence of LD slag addition on sinter mean particle size and cum +10 mm percentage. In the present study sinter mean particle size was not influenced by the LD slag addition. The sinter cum +10 mm decreased with increase in LD slag addition. The +10 cum size of the sinter is directly related to the strength of the sinter.

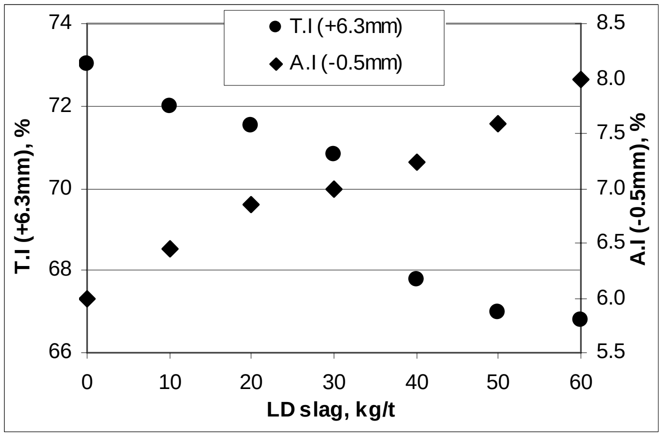


*Fig. 10: Influence of LD slag addition on sinter T.I and A.I.*

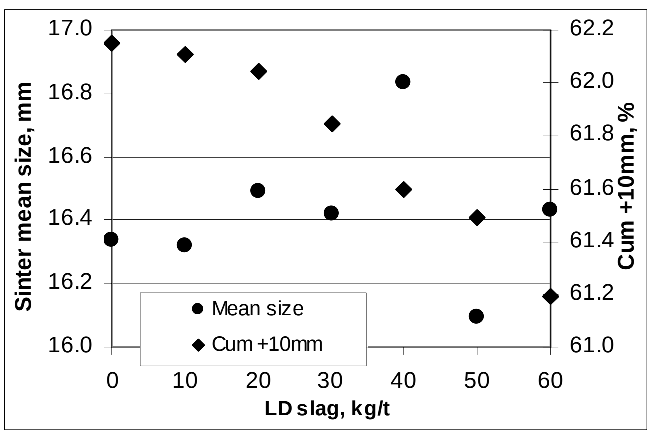


*Fig. 11: Influence of LD slag addition on sinter mean particle size and Cum +10 mm.*

**Influence of LD slag addition on sinter reduction degradation index**

Figure 12 shows the influence of LD slag addition on sinter reductuion degradation index. The RDI (–3.15 mm) and RDI (–0.5 mm) of the sinter increased with increase in LD slag addition. Non availability of free CaO in LD slag reduces the formation of calcium ferrites phase and more $Fe_2O_3$ remains as free phase due to less reaction with CaO. The weakening and degradation of sinter is associated with volume increase due to the phase transformation of hematite to magnetite present in sinter. The usage of LD slag in sintering process results in a higher fraction of free hematite phase, lesser fraction of magnetite and calcium ferrite phases. Higher fraction of hematite phase is the main reason for deterioration of sinter RDI. A study carried out by Pimenta et al has shown that in case of pure hematite to magnetite transformation, the volumetric expansion was 4%. This results in development of mechanical stresses which are relaxed by crack propagation.[17]

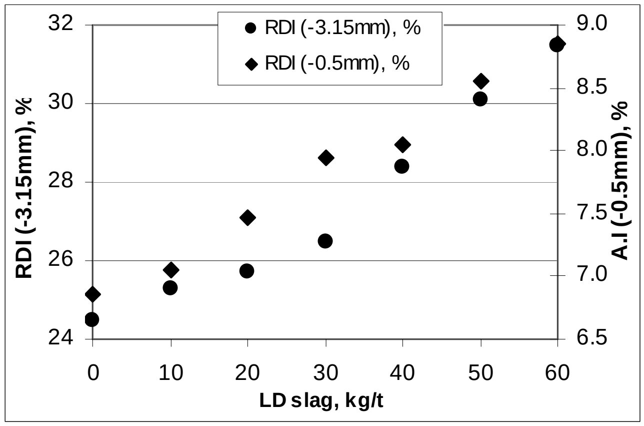


*Fig. 12: Influence of LD slag addition on sinter RDI.*

The desired properties required for sinter product is as follows:

T.I (+6.3 mm), % – ≥ 68 (Lab scale)

RDI (–3.15 mm), % – ≤ 28.0%

From the test results it was found that maximum 2.5 to 3.0% (30 to 35kg/t of sinter) LD slag can be used in the sinter making to achieve desired properties of the sinter.

**CONCLUSIONS**

- The FeO content of the sinter decreased with increase in LD slag addition due to decrease in sinter bed temperature.
- The phosphorous content of the sinter increased with increase in addition of LD slag because LD slag consist of high phosphorous.
- Limestone percentage in the sinter mix decreased with increase in LD slag addition because the high content of CaO in the LD slag replaced part of limestone as fluxing material.
- The sinter productivity increased with increase in addition of LD slag. This is due to decrease in LOI content in the sinter base mix and absence of weight loss due to calcination process.
- Tumbler index decreased and abrasion index increased with increase in addition of LD slag. This is due to less availability of free CaO phase for assimilation and melt formation results in poor bonding.
- The both RDI (–3.15) and RDI (–0.5 mm) increased with increase in addition of LD slag due to non availability of free CaO in LD slag reduces the formation of calcium ferrites phase and more $Fe_2O_3$ remains as free phase due to less reaction with CaO.
- Usage of LD slag upto 30 to 35kg/t of sinter (2.5 to 3.0%) in the sinter base mix gives better physical and metallurgical properties of the sinter within the desired values.

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