Mill Scale:
A Potential Raw Material for Iron and Steel Making

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A substantial quantity of mill scale, containing very high percentage of iron is generated during processing of steel towards production of various long and flat products. In an integrated steel plant, though the major part of mill scale is recycled for in-house consumption, no commercial process for its utilization is so far available for the secondary sector. Thus, it is either dumped or exported at a very low price. The current paper presents some preliminary results of a laboratory scale investigation which involves pelletization of mill scale, using steel plant waste as an additive and subsequent reduction of the air dried pellet by non coking coal fines under conditions, simulating a tunnel kiln. The results of this investigation show that the green pellets could be successfully handled, without generating much of fines and could be converted to highly metalized Directly Reduced Iron (DRI) at a moderate temperature and at a reasonably low heating time.

World crude steel production has unprecedentedly increased by almost 1.6 times when the world entered in the new millennium. Its production has attained 1606 million tons in 2013 with the annual average growth of 6.3% per annum after 2000[1]. India has emerged as the 4th largest producer of steel (81.36 MT) in 2013-14 with 10.8 percent growth rate as compared to 2011-12 (73.42MT). The demand of steel in India is expected to rise by 7% in the coming financial year and expected to reach 200 million tons by 2020 as compared to 83.36 MT in the current year[2]. In steel production, India is also expected to leave behind USA and Japan in couple of years.

The integrated steel industries constitute most of the mild steel production in India. Their main products include flat products such as hot rolled, cold rolled and galvanized steel. They also produce long and special steel in small quantities. On the other hand secondary sector comprises small units which are particularly focused on the production of value added products by melting of scrap or sponge iron or suitable mixture of the two. This sector produces long steel product in form of angles, columns, beams, bars and other re-rollers and accounts for over 50 percent of the total indigenous output[3,4]. Both sectors cater upto 95% non alloys steel production and rest is alloys steel. In 2010-11, out of total non alloys production, long steel product constitutes 50.1% and remaining 49.1.3% was flat products and is expected to be 48.8% and 51.2% respectively in coming 2016-17[5].

Irrespective of the products, during processing of steel to yield long or flat product, mill scale is generated during hot rolling and considered as a waste. The generations of mill scale represent about 2% of steel produced and are available as a secondary material due to its richness in iron (about 72 % Fe)[6]. More than 1.4 million tons of mill scales are generated annually in India and is expected to reach about 3.0 million tons by 2020 as shown in Figure 1[7]. In an integrated steel plant, almost 85% of the mill scale, generated is consumed in-house via sintering. The balance part of the mill scale with particle size less than 0.5 mm is heavily contaminated with oil and is dumped for land filling as waste. This has multi dimensional effect including cost of disposal and environmental pollution.

The scenario is little different for the secondary sector. The credit for producing approximately 90% of the structural steel, consumed in India, is ascribed to the secondary sector. This category of steel undergoes hot rolling during processing and generates a significant quantity of mill scale. The individual production units being small and scattered all over the country, no systematic effort has been made so far for its collection and commercial exploitation. Further, the absence of a sinter making facility in such production units does not offer any scope for in-house recycling of mill scale.

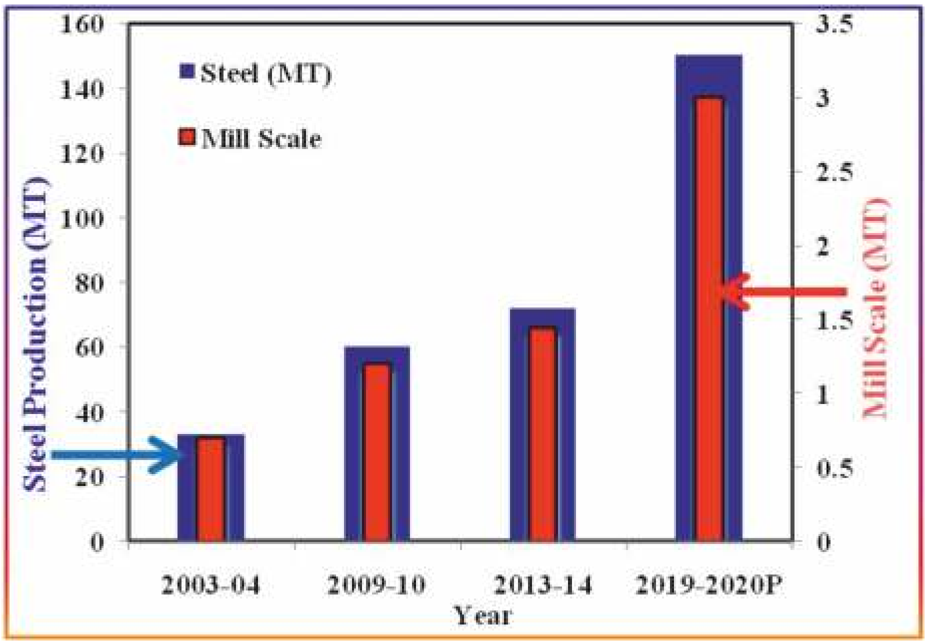

Figure 1: Generation of Mill Scale in India

Mill scale, a high iron containing body was thus treated as a waste for a long time and was dumped. However, in recent past a significant part of mill scale is being exported to China at a very low price. Though a small amount of mill scale is used in ferroalloys, cement and petrochemicals industry[8], there is a potential for production of almost 1.0 Mt of steel, even with the current level of mill scale generation. All the above calls for an initiative to find suitable means for effective utilization of mill scale. The present paper presents some preliminary outcome of an attempt to produce direct reduced iron with high metallic iron content utilizing mill scale as ferrous material and lean grade non coking coal as a reducing agents.

Raw Materials

The mill scale and lean grade coal used in this study were procured from an integrated steel plant. Tables 1 and 2 present the chemical analyses of mill scale and proximate analysis of lean grade non coking coal, respectively.

Table 1: Chemical analysis of mill scale

C	VM	Moist	Ash	SiO_2	Al_2O_3	CaO	MgO
57.96	17.5	2.27	22.29	14.3	5.68	0.43	0.24

Table 2: Proximate analysis of non coking coal

Fe_3O_4	Fe_2O_3	FeO	Fe_T	SiO_2	Mn	Cu
41.5	25.4	3.9	68.5	0.4	4.78	0.72

Sintering being not suitable for such a low volume operation, agglomeration through briquetting or pelletization appears to be the first step in any attempt towards utilization of mill scale. Prima fascia, such a step encounters problems primarily on three inherent characteristics of the ferruginous raw material (i) being flaky and fragile (ii) wide variation in particle size (iii) heavy contamination with oil.

Experimental procedure

The mill scale in as received condition was pelletized into 12-16 mm diameter pellets in a disc pelletizer by using industrial waste as the binding agent and required quantity of water. Pelletization conditions such as time of rotation, amount of moisture, percentage waste as binder etc were varied to adjust the green pellet property. The acid pellets thus produced were air dried for approximately 24 hours and sufficient dry strength could be developed for further processing.

Low grade non coking coal was grinded and screened to -70 +100 mesh size and was charged in a (100 mm ID and 800 mm height) clay crucible in a predesigned fashion along with the mill scale pellets.

The reduction of mill scale pellets were carried out in a laboratory scale, electrically heated muffle furnace, simulating the conditions of a tunnel kiln. Pt – 10%pt-Rh thermocouple was used to measure the temperature of the furnace. A series of reduction experiments were carried out in the temperature range of 1000^{0}C to 1200^{0}C. The reduction time of the samples was varied from 30 minutes to 120 minutes. In order to facilitate collection of sample at 30 minutes interval, four crucibles, containing the samples, were simultaneously inserted in the furnace for experiments at each temperature. This assisted in monitoring the progress of reduction as well as to examine the physical condition of the reduced pellets as function of time. It is worth mentioning that all the samples were inserted in the furnace at room temperature and heated to the experimental temperature. Counting of reduction time started only after attainment of the set temperature. This procedure was followed to simulate the charge preheating in a tunnel kiln. Precautions were exercised to minimize reoxidation of the reduced pellets after taking out from the reaction chamber at hot condition and while cooling. To ensure complete reduction of mill scale pellets, the amount of non coking coal used was 20% over the stoichiometric requirement.

Results and discussion

The reduced mill scale pellets, treated at different temperatures and for varying length of time were used for:

(i) Measurement of swelling / shrinkage

(ii) Weight loss measurement and chemical analyses for calculation of degree of reduction and extent of metallization and

(iii) Phase identification by X-ray

Figure 2 presents the percent reduction against time at the three experimental temperatures. Percent reduction was calculated in usual manner as the removed oxygen to the removable oxygen. Multiple pellets were used to calculate the average percent reduction at all the time and temperatures. It may be noted from the figure that major reduction took place within first 30 minutes for all the three temperatures. While insignificant variation in reduction could be observed with increase in time upto 120 minutes for temperatures 1000°C and 1200°C, a fairly large improvement in fraction reduction was exhibited at 1100°C with time till 90 minutes. It appears from these results that commercial grade sponge iron could be produced at 1100°C with as low as 30 minutes of reduction. However, it needs to be noted here that as the samples were inserted in the furnace at room temperature, the pellets would undergo reduction while heating from 1000°C to the higher temperature and thus the percentage reduction at 30 minutes for the two higher temperatures also included the reduction that took place during this heating time. The conditions prevailing in an actual tunnel kiln being widely different from those in the laboratory set-up, especially in terms of heat transfer, the results of the current study should be looked at with due caution. However, the preliminary results indicate that mill scale pellet could be a potential raw material for production of sponge iron in tunnel kiln.

The diameter of the pellets was found to decrease on reduction and the extent of shrinkage was found to vary between 16% at 1000°C to 36.5% at 1200°C for 30 minutes of reduction, as an example. Shrinkage was found to increase both with time and temperature.

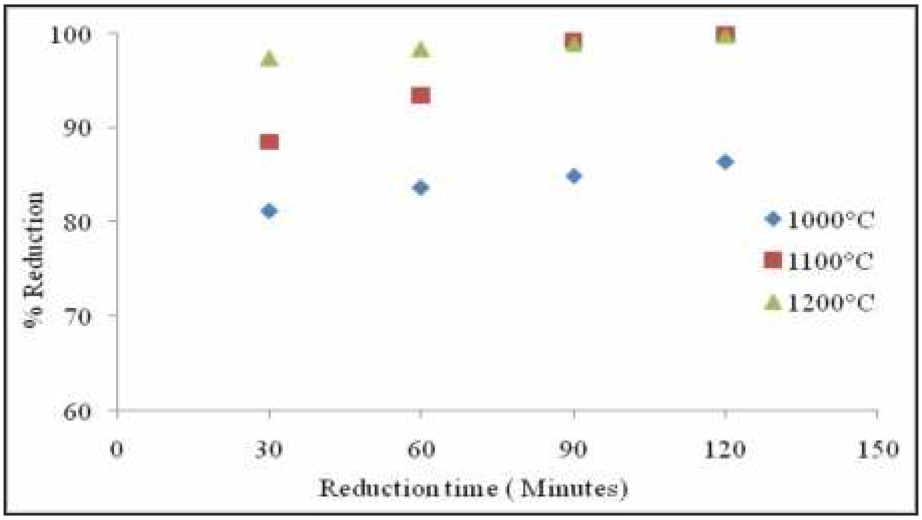

Figure 2: Fraction reduction of mill scale pellet against time for different temperature

The samples were subjected to chemical analysis and XRD (Model: D* Discover, Bruker AXS GmBh, Germany) for calculation of degree of reduction and phase identification. Figure 3 presents a typical XRD plot for a sample treated at 1100°C for 90 minutes. Absence of any peak for iron oxide in the XRD plot indicates practically complete conversion of the oxide to metallic iron. This observation is in accordance with the weight loss data of the sample.

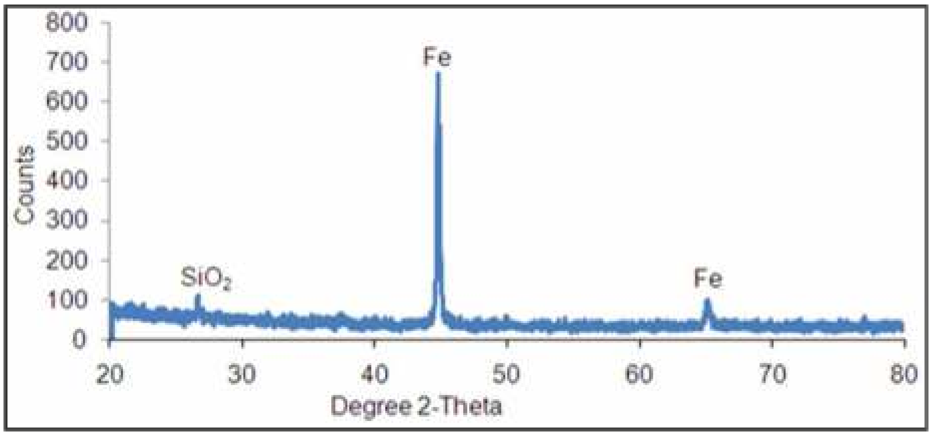

Figure 3: X-Ray diffraction plot for a mill scale pellet, reduced at 1100°C for 90 minutes

Conclusion:

Preliminary investigation has been carried out in a laboratory scale muffle furnace, simulating a tunnel kiln conditions, to produce DRI from air dried mill scale pellets and non coking coal fines. Pellets were found to undergo high degree of reduction at moderate temperature and at a reasonably low time. Overall, reduction of green pellets of mill scale in tunnel kiln appears to provide an attractive way for utilization of this high iron containing waste.

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