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Production of cleaner mill scale by dynamic separation of the mill scale from the fast-moving flume water at a hot rolling mill

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ABSTRACT

High oil concentration in mill scale can have detrimental effects on environment, production and equipment when the oily mill scale is recycled in the ironmaking and steelmaking process. Therefore, it is of great importance to develop cost-effective technologies of producing clean mill scale. In this research, an in-process separation technology has been developed to produce the clean mill scale by dynamic separation from the fast-moving flume wastewater. An industrial trial was carried out to capture mill scale particles from the fast-moving flume wastewater with a strong magnet at an ArcelorMittal hot rolling plant. The results show that the dynamically-separated flume mill scale is much cleaner, containing about 6–30 time less oil than the conventional statically-separated pit mill scale. Oil concentrations in the flume mill scale samples are all significantly less than 0.5%, the commonly recognized oil limit in the mill scale for recycling in iron ore sintering. Size-by-size analysis shows that in every size fraction, the oil concentration in the flume mill scale particles is significantly less than that in the pit mill scale particles, and hence the cleaner flume mill scale is not due to coarser particle sizes. The much shorter residence time of the flume mill scale particles in the oily wastewater and the much stronger turbulence of the flume wastewater could be two of the main reasons why the flume mill scale is cleaner than the pit mill scale.

1. Introduction

In steel production, hot rolling is an inevitable step to produce finished steel products. Semi steel products are often first reheated up to about 1523 K in reheat furnaces. The reheated semi steel products are then discharged out of the furnaces, transported on rolling trains, descaled using pressurized water and rolled into finished steel products by various rolls. Simultaneously, a large amount of cooling water is sprayed on the rolling equipment while the hot rolling takes place.

Along with the production of the finished steel products, a great deal of mill scale is generated. The mill scale generation rate is about 2% of the steel production (Gaballah et al., 2013; Paswan et al., 2015; Umadevi et al., 2012). In 2016, the world crude steel production was 1628.5 million tonnes (World Steel Association, 2017). Therefore, it can be estimated that in 2016, the global mill scale generation was around 32.6 million tonnes, representing approximately 23.4 million tonnes of iron loss.

The mill scale is formed on steel surfaces due to oxidation reactions between steel and the oxidizing atmosphere in the reheat furnaces and on the rolling trains and the stands (Basabe and Szpunar, 2004; Vlaicu et al., 2010). The descaling water and the cooling water wash the mill scale away from the steel surfaces, flow with the mill scale into the flumes underneath the rolling lines, run at a high speed in the flumes and eventually are discharged into the deep and wide mill scale pits. The wastewater in the mill scale pits becomes fairly calm. By gravity, the mill scale settles down to the bottom of the pits. The settled mill scale is periodically reclaimed by clamshell excavators or chain conveyers. The unsettled fine mill scale particles are removed at the wastewater treatment plants and become the wastewater treatment plant sludge in the end.

The mill scale is mainly composed of iron oxides. Total iron content in the mill scale could be up to 70–75%. Therefore, the mill scale can be an excellent alternate iron-bearing feedstock for ironmaking and steelmaking. However, the mill scale often contains a high level of oil, which can have detrimental effects on environment, production and equipment when the oily mill scale is recycled in the ironmaking and steelmaking process (Remus et al., 2013; Shatokha et al., 2011). With increasingly strict environmental

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regulations, allowable oil concentration in the mill scale for recycling in the ironmaking and steelmaking process has decreased, from 1% to 0.5%, and even to 0.1% in some plants (Remus et al., 2013). Consequently, it is of great importance to develop cost-effective technologies of producing clean mill scale.

The mill scale is not naturally oily since any oil on the hot steel surfaces will likely volatilize during the hot rolling process. However, the wastewater is generally oily. Bearings are lubricated with grease. Hydraulic machines are operated with oil-containing hydraulic fluids. Both the bearings and the hydraulic machines can leak oil. The leaked oil can find ways into the wastewater. Besides, surfaces of some work rolls are lubricated with oil-containing lubricants to ensure high-quality products and to extend the life of the rolls (Yu and Beard, 2014; Vervaet et al., 2011). This oil can directly fall into the wastewater. Additionally, the oily wastewater is often directly recycled back into the hot rolling mills as part of the descaling water and the cooling water after only preliminary treatment without complete removal of oil. When the oily wastewater carries mill scale, oil droplets in the wastewater tend to stick to and coat the surfaces of the mill scale particles.

How to produce clean mill scale has long been a great challenge since the hot rolling technology emerged. Minimization of oil leakage is often considered in the first place. However, this method is not only very costly, but also often fails due to aged equipment and insufficient maintenance. If the recycled water is oily and if work rolls are lubricated with oil-based lubricants, prevention of oil leakage alone is unable to stop the generation of the oily mill scale.

As an alternative to landfilling, the oily mill scale can be reprocessed for removal of oil. “De-oiling” is a general term for this treatment. Clean mill scale can be produced by heating the oily mill scale and letting the oil volatilize at high temperatures, or by dissolving the oil in a solvent (Remus et al., 2013). Liu et al. experimentally studied removal of oil from mill scale by “vacuum distillation + oxidizing roasting” and “vacuum distillation + hydrogen reduction” (2013). Paul Wurth developed the technology of producing clean mill scale by treating the oily mill scale in multiple hearth furnaces (2017). Fluidized beds have been adapted for de-oiling the oily mill scale (Torftech, 2017). Siemens VAI promoted the conventional sintering technology to double-layer sintering for de-oiling the oily mill scale (2017). De-oiling the oily mill scale often faces two challenges: high costs and additional environmental concerns. As a result, steel industry has not shown strong interests in any of the de-oiling technologies (Remus et al., 2013).

In addition to producing clean mill scale for recycling in sintering, many researchers have also made great efforts to directly use oily mill scale. Oily mill scale was briquetted and charged into electric arc furnaces (Saberifara et al., 2014; Yang et al., 2009), basic oxygen furnaces (Kumar et al., 2017), blast furnaces (Mohanty et al., 2016) and rotary hearth furnaces (Michishita and Tanaka, 2010). Hu et al. experimentally studied production of an alloying precursor by carbothermic reduction of a mixture of chromite ore and mill scale (2016). Supino et al. reviewed applications of oily mill scale in production of cement, magnets and other products (2016). However, all these efforts have not played significant roles in recycling of oily mill scale.

In-process separation has been proposed by the authors (Ma, 2012) to produce clean mill scale without requiring intensive maintenance of hot mill equipment or reprocessing oily mill scale. The hypothesis is that the mill scale generated by dynamic separation from the fast-moving flume wastewater should be cleaner than the mill scale generated by the existing common practice, static separation from the wastewater in the mill scale pits. In order to test this hypothesis, an industrial trial of separating the mill scale from the fast-moving flume water was carried out with a strong magnet at an ArcelorMittal hot rolling plant. Details and results of the trial will be discussed in the rest of this paper.

2. Materials and methods

2.1. Regular operation of collecting mill scale

The hot rolling process of forming steel slabs into coils under this study consisted of a series of procedures, including reheating, the first descaling with pressurized water, roughing, cropping, the second descaling, finishing and coiling. The mill scale generated in the process was flushed into the wastewater flumes and was moved into the mill scale pits by the fast-moving flume water. The scale pits had a wide surface area and the water speed became much slower. In the pits, the mill scale particles settled by gravity and were moved from the pits.

There were two main mill scale pits for collection of the mill scale at this plant. The first mill scale pit received wastewater and mill scale from the reheat furnace discharge end, the first descaling stand and the first a few roughing stands. The mill scale from the first mill scale pit was clean with low oil concentration and was recycled back in the sintering process. After oil was skimmed, the wastewater in the first scale pit was directly recycled back into the mill.

The second mill scale pit received wastewater and mill scale from the rest of the roughing stands, the second descaling stands and the finishing mill. The mill scale in the second mill scale pit was continuously removed out of the pit and discharged into trailer boxes by the chain conveyers. The mill scale from the second mill scale pit was oily and could not be recycled in the ironmaking and steelmaking process. The wastewater in the second scale pit was pumped to the wastewater treatment plant for further cleaning.

2.2. Layout of the wastewater flumes and the second mill scale pit

The flumes and the second mill scale pit are schematically shown in Fig. 1. The pit was divided into five cells, only four of which were in service while the research work was carried out. The wastewater from the finishing mill was discharged into cells #2 and #3 and from the roughing mill to cells #4 and #5. There were two finishing mill wastewater streams, finishing 1 and finishing 2. Finishing 1 stream was discharged into cell #2 and finishing 2

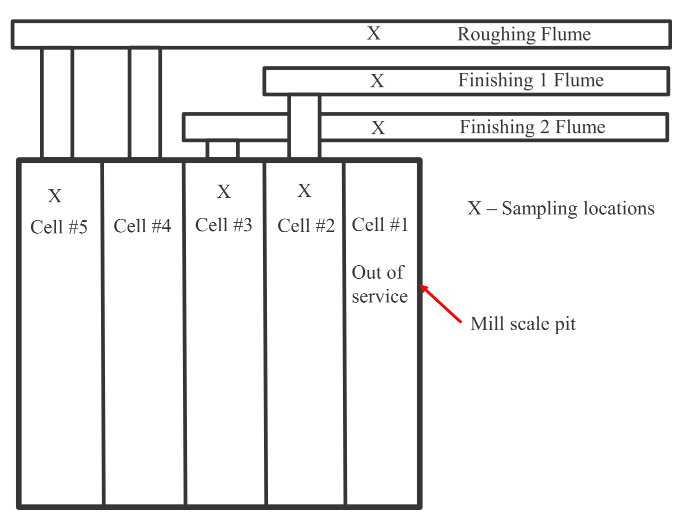

Fig. 1. Layout of the wastewater flumes and the second mill scale pit at an ArcelorMittal hot rolling mill.

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