Waste Management 34 (2014) 1800–1805

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

An assessment on the recycling opportunities of wastes emanating from scrap metal processing in Mauritius

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ARTICLE INFO

Article history:
Available online 13 January 2014

Keywords:
Recycling
Scrap metal processing
Landfill
Slag
Electric arc furnace dust
Mill scale
Wastewater sludge
Waste management model

ABSTRACT

This paper presents an assessment on the wastes namely slag, dust, mill scale and sludge resulting from scrap metal processing. The aim of this study is to demonstrate that there are various ways via which scrap metal processing wastes can be reused or recycled in other applications instead of simply diverting them to the landfill. These wastes are briefly described and an overview on the different areas of applications is presented. Based on the results obtained, the waste generation factor developed was 349.3 kg per ton of steel produced and it was reported that slag represents 72% of the total wastes emanating from the iron and steel industry in Mauritius. Finally the suitability of the different treatment and valorisation options in the context of Mauritius is examined.

1. Introduction

Among all the metals being processed in the world, steel plays a critical role in infrastructure and overall economic development (Dash, 2012). It is one of the fastest-growing sectors of manufacturing industries all over the world (Huaiwei and Xin, 2011). In 2011, the world iron ore trade reached 1.12 billion tons with developing countries representing 49.5% (Mojarov and Mermet, 2012). Additionally, global crude steel production output was 1517 million tons in 2011 (ISSB, 2012). According to Larsson et al. (2004), steel production can be divided into two main processes namely the blast/basic oxygen furnace (BOF) which represents about 60–70% of the world steel production and the electric arc furnace (EAF) representing the remaining (Iacobescu et al., 2011; Branca and Colla, 2012; Abu-Eishah et al., 2012; Pellegrino et al., 2013). The main difference between these two types of furnaces, illustrated in Fig. 1, is the different raw materials used; the BOF uses iron ore while the EAF uses scrap metal as the main iron carrier (Larsson et al., 2004; Iacobescu et al., 2011; Chukwudi et al., 2012). In Mauritius, the EAF is used in which high power electric arcs produce the heat necessary to melt the scrap metal (Yildirim and Prezzi, 2011).

To date, there has been no such study carried out on industrial wastes in Mauritius with emphasis on recycling and an industrial ecology approach despite the fact that there are many newspapers' articles on the heavy pollution from industries. Additionally, a hazardous waste inventory was carried out in 2011 but results were only restricted to the amount of waste generated and failed to consider the remedial actions which are the prime aspects to consider with the unique landfill reaching saturation.

1.1. Types of wastes produced

At a scrap steel recycling plant, an average of 200 kg by-products namely slag, dust, mill scale and sludge are produced per ton of steel processed (Branca and Colla, 2012). The different processes involved as well as the stages where the aforementioned wastes are generated are represented in Fig. 2.

The reactions between oxygen, carbon, silicon, manganese, phosphorus and some iron as liquid oxides produce oxidised compounds that react with lime or dolomitic lime to form slag (Mioc et al., 2009; Branca and Colla, 2012; Wang et al., 2012). Additionally, EAF dust is one of the critical and hazardous wastes encountered in the steelmaking industries. It is produced when the volatile components during the steel melting process are fumed off and collected with particulate matter in the off-gas cleaning system (Pickles, 2009; Oustadakis et al., 2010). Further, during the continuous casting, reheating and hot rolling processes, iron oxides are formed on the surface of the metal (Murthy, 2012; Umadevi et al., 2012). This is removed by water sprays and is known as mill scale (Al-Otaibi, 2008). Moreover, wastewater from the steel

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http://dx.doi.org/10.1016/j.wasman.2013.12.014

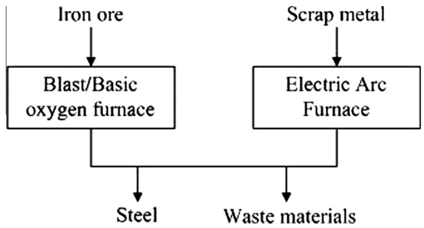

Fig. 1. Types of furnaces in steel production.

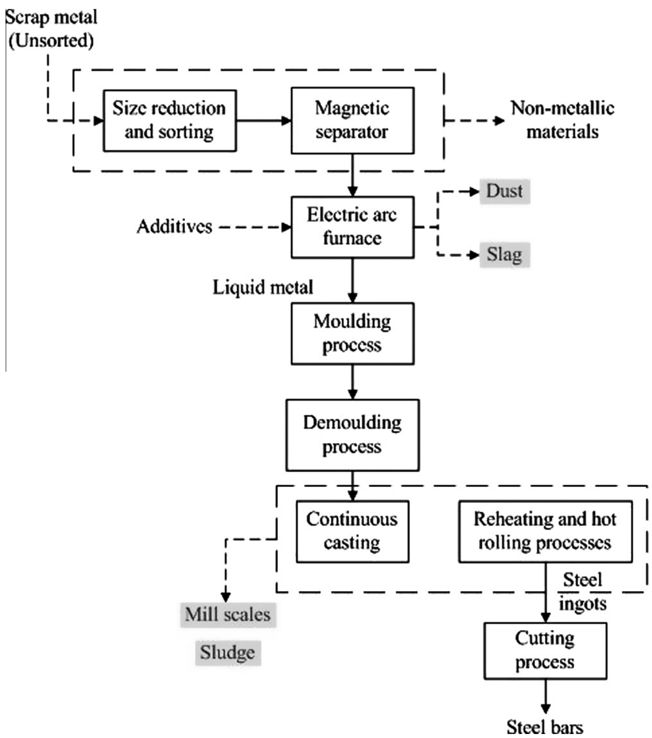

Fig. 2. Scrap metal processing and wastes generated.

industries results from the steel production process, equipment and products cooling, flue gas scrubbing as well as washing facilities. When the suspended particles present in the water settle, sludge is produced at the rate of 20 kg per ton of steel (Ding et al., 2011).

1.2. Areas of applications for these wastes

Various studies have been carried out on the recycling opportunities of wastes emanating from the scrap steel recycling plants.

1.2.1. Slag processing

Out of the wastes produced at the scrap steel recycling plant, slag is the most significant one (Branca and Colla, 2012). Valuable metals can be recovered from slag by applying mineral processing technologies such as crushing, grinding, magnetic separation, eddy current separation, flotation, leaching or roasting and molten salt extraction (Shen and Forssberg, 2003; Das et al., 2007). Additionally, slag can be utilised as an adsorbent for the removal of heavy metals from contaminated wastewater (Lan et al., 2006; Barca et al., 2012; Jha et al., 2008; Xiong et al., 2008; Kumar et al., 2010; Kim et al., 2008; Chen et al., 2011). Besides the aforementioned applications of slag, the latter can be employed as an iron fertiliser in Fe-deficient calcareous soils. It was reported that when using steel slag, yields of experimental crops were higher than those obtained with other liming materials (Motz and Geiseler, 2001; Wang and Cai, 2006; Mioc et al., 2009; Sarkar et al., 2010; Branca and Colla, 2012). Another process in which steel slag can be used is in bioleaching (Cunha et al., 2008; Gahan et al., 2009). Steel slag can also be employed in a novel process for the precipitation of papermaking grade calcium carbonate (Mattila et al., 2012; Teir et al., 2007; Eloneva et al., 2008; Zevenhoven et al., 2009). Another area of application for EAF slag is in concrete and road construction (Motz and Geiseler, 2001; Alizadeh et al., 2003; Mioc et al., 2009; Muhmood et al., 2009; Sarkar et al., 2010; Abu-Eishah et al., 2012; Behiry, 2012; Wang et al., 2012). In this respect, EAF slag was shown to have a lower lime content making it very stable for use in asphalt while also increasing its affinity to bitumen (Sofilic et al., 2010; Branca and Colla, 2012; Pellegrino et al., 2013). EAF slag can also be added as a component in the development of vitreous ceramic tiles (Sarkar et al., 2010; Chukwudi et al., 2012). Additionally, mechanical properties tested indicate that steel slag could be used in floor tiles production (Badiee et al., 2008).

1.2.2. Dust processing

Among the wastes generated at the scrap steel recycling plant, dust should be given prime importance due to its hazardous properties. Hydrometallurgical and pyrometallurgical processes are the main methods used for the treatment of EAF dust (Pickles, 2009). The hydrometallurgical extraction of zinc from EAF dust has been carried out using either sulphuric, nitric and hydrochloric acids (Xia and Pickles, 2000; Cruells et al., 1992; Havlik et al., 2006; Langova et al., 2007; Shawabkeh, 2010). However, among the methods used to treat dust from EAF, pyrometallurgical processes remain the only ones which have reached commercialisation owing to the special characteristics and structures of the wastes (Xia and Pickles, 2000; Oustadakis et al., 2010; Shawabkeh, 2010; Huaiwei and Xin, 2011). Additionally, numerous studies have been conducted on the use of EAF dust in concrete (Maslehuddin et al., 2011). Furthermore, Sikaldis and Mitrakas (2006) investigated the properties of extruded clay-based ceramic building products as well as dolomite-concrete products with up to 20 weight% EAF dust.

1.2.3. Mill scale processing

Besides slag and dust, mill scale is another waste being generated at the scrap steel recycling plant. The components present in it allow its use in many applications. It can be used as fine aggregate in cement (Al-Otaibi, 2008; Akindahunsi and Ojo, 2008). As such, concrete mixtures prepared with mill scale could be used in reinforced concrete structures. Martin et al. (2009) performed a series of tests on the use of mill scale as adsorbent of lead ions from aqueous effluents and concluded that mill scale was an effective adsorbent of lead ions over a wide range of concentrations. Mill scale can also be reduced using carbon-monoxide in order to produce iron powder which could be effectively used by powder metallurgy (Benchiheub et al., 2010; Martin et al., 2009). Apart from these applications, mill scale can also be recycled in sintering process (Al-Otaibi, 2008; El-Hussiny et al., 2011; Umadevi et al., 2012). However, to be appropriate for use in sintering plant, mill scale should have a particle size of 0.5–5.0 mm and an oil content of less than 1.0% (Martin et al., 2009). Additionally, mill scale can be applied for stabilising expansive soil (Murthy, 2012). Mill scale can be recycled into another application namely the processing of mill scale into nano-scale particles (Azad et al., 2008). These particles could be used for hydrogen fuel cell, medical imaging and water remediation technologies. Furthermore, mill scale originating from steelmaking plant can be used to prepare some iron oxide pigments via specific precursors (Legodi and De Waal, 2007). Mill scale can also be employed as an admixture in electromagnetic