INVESTIGATION ON THE MECHANICAL PROPERTIES OF BASIC MANGANESE ORES BRIQUETTES USING ALCOTAC CB6 AS BINDER

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Abstract

Manganese ore fines generated during manganese production are either partially recycled as agglomerates using binders, or stored, leading to pollution, and negative environmental impacts due to landfilling. Fines have for long been considered as environmental unfriendly, loss if not recycled and stage threats in the metallurgical industry if not taken care of. Several binders have been tested especially inorganic binders to recondition the fines to be recycled for metal production. However, inorganic binders have been found to be detrimental to the products due to impurities that they carry. The current investigation has focused on testing the impact of organic binders on manages briquettes made from ore fines. Alcotac CB6 was used in this investigation, a specific compression has been adopted to make manganese briquettes. Results have demonstrated that the optimal briquette specifications of the basic manganese ore fines for industrial briquetting tests are 1.2 per cent Alcotac CB6 and 147 kN compressive strength. At these optimal specifications, the briquettes show a dry strength of 2750 kN after 48 hours of cool drying, which is strong enough to handle the mechanical abrasions of transportation in the plant, and the observed degree of disintegration is less than 5 per cent proving to yield stable furnace operations.

Keywords: Metallurgy, manganese ore, briquettes, binders

1. INTRODUCTION

The steelmaking industry requires Manganese (Mn) for strength enhancement, desulphurisation and deoxidation purposes, and most of the Mn used in steel making comes from manganese alloys. Geologically, iron and Manganese have similar mineralogical characteristics, and they always occur in association with each other [1]. Thermodynamically, Fe always gets reduced first leading to all Mn alloys hosting a certain amount of Fe, hence the name ferromanganese alloys. High carbon ferromanganese and silicomanganese alloys are among the most produced alloys for their manganese content. Moreover, in specialized applications, these manganese alloys are refined to either medium or lower carbon alloys by degrading their carbon content [2]. Throughout the entire manganese alloys production cycle, Mn ore fine (< 3 millimetre) are generated as by-products and collected in filters, screens, and off gas cleaning facilities [3]. The major proportion of fines are generated during size reduction stages of manganese ore dressing, and it was approximated to about 45 per cent of the Run of Mine (ROM) treated [4]. These fines fulfil the chemical composition requirement for smelting and can be used to increase the metal production. However, the presence of fines in the submerged arc furnace (SAF) can have negative repercussions on the furnace operations since smaller particles decrease the permeability of the charge layer, leading to furnace malfunction and high likelihood of furnace explosion [4]. Furthermore, fines can easily blow off due to the high temperature in the furnace, resulting into loss of the valuable Mn units and negative environmental impacts. Hence, the necessity of an additional agglomeration stage such as sintering, pelletizing, and briquetting to produce bigger particles that are adequate for furnace operations [5]. Hot agglomeration techniques such as, sintering and pelletizing require heat to produce interparticle bonding of fines, whereas cold agglomeration such as briquetting requires a binder to bond the fine particles together. Briquetting is the cheapest way of agglomerating fines that metallurgical engineers are currently exploring compared to energy-intensive agglomeration techniques such as, sintering and pelletizing [6]. Briquetting is a pressure agglomeration technique which relies on the compression force and the binder to compact fines into bigger particles of desired shape and strength to handle transportation and furnace operations. Unlike non-pressure agglomeration such as pelletizing, where moisture is needed to for fines to acquire the desired shape, briquetting requires little to no moisture since the pressure and the binder will greatly contribute to the cohesion of fines [7]. The addition of carbon as briquetting constituent makes the briquette self-reducing [8]. Furthermore, the ore fines need to be homogeneously mixed with a binder and pressed with adequate strength in a pressing machine to produce a briquette. It was reported that briquetting processes are very sensitive to the particle size distribution (PSD), and that particles of size between 1 millimetre and 3-millimetre act as a nucleation site, while particles smaller than 0.2 mm act as an adhesive layer in the overall structure of the briquette [9].

2. METHODOLOGY

2.1 Materials and equipment

The Mn fines used in this research for briquetting are sourced from the Nchwaning mine, located in the Northern Cape Province of South Africa. Two streams of the ore were used, namely the Nchwaning 1, and Nchwaning 2, which were separated based on their overall Mn content. The organic binder of this research is Alcotac® CB6, manufactured by Baden Aniline and Soda Factory (BASF), which is a world's leading chemical company in providing innovative metallurgical solutions. Furthermore, Coke fines were also added to one of the briquette mixtures to assess the self-reducibility of the briquette. The coke breeze used in this project was an invaluable by-product from coke processing plants. Hence, the usage of this coke breeze during briquetting contributes to circular economy and mitigates coke resource constraints in the future. The experiments were conducted at the University of Johannesburg, and at Mintek. The equipment used for briquetting is illustrated in **Figure 1**.

Figure 1 Piston press briquetting machine

2.2 Experimental Procedure

2 kg of the Nchwaning manganese ore fine sample were collected from two streams 1 kg each, and labelled Nchwaning 1 (N1) and Nchwaning 2 (N2). The two streams were then screened using a sieve shaker and their particle size distributions (PSD) were recorded. The Nchwaning 1 is further splitted into two fractions, the N1 fines (+1 mm) and the N1 ultra-fines (-1 mm) to assess the effect of particle size distribution on the briquetting process. Moreover, 30 g were collected from each of the three streams for XRF analysis as well as chemical titration. The streams will then be mixed with the organic binder and coke according to **Table 1** to produce 10 briquette specifications. The composition of briquettes is summarized in **Table 1**. The green briquettes were dried by leaving them in a room to allow the evaporation of the surface moisture. Furthermore, 12 briquettes from the 28 dried (cured) briquettes were used for mechanical tests while the remaining 10 briquettes were used for pre-reduction tests but not reported in the present work. The product from each test was analyzed accordingly, and the results were presented in the form of tables and figures where applicable. **Figure 2** depicts the experimental procedure. For briquettes produced at 147kN, an extra sample was produced for future investigations not here reported.

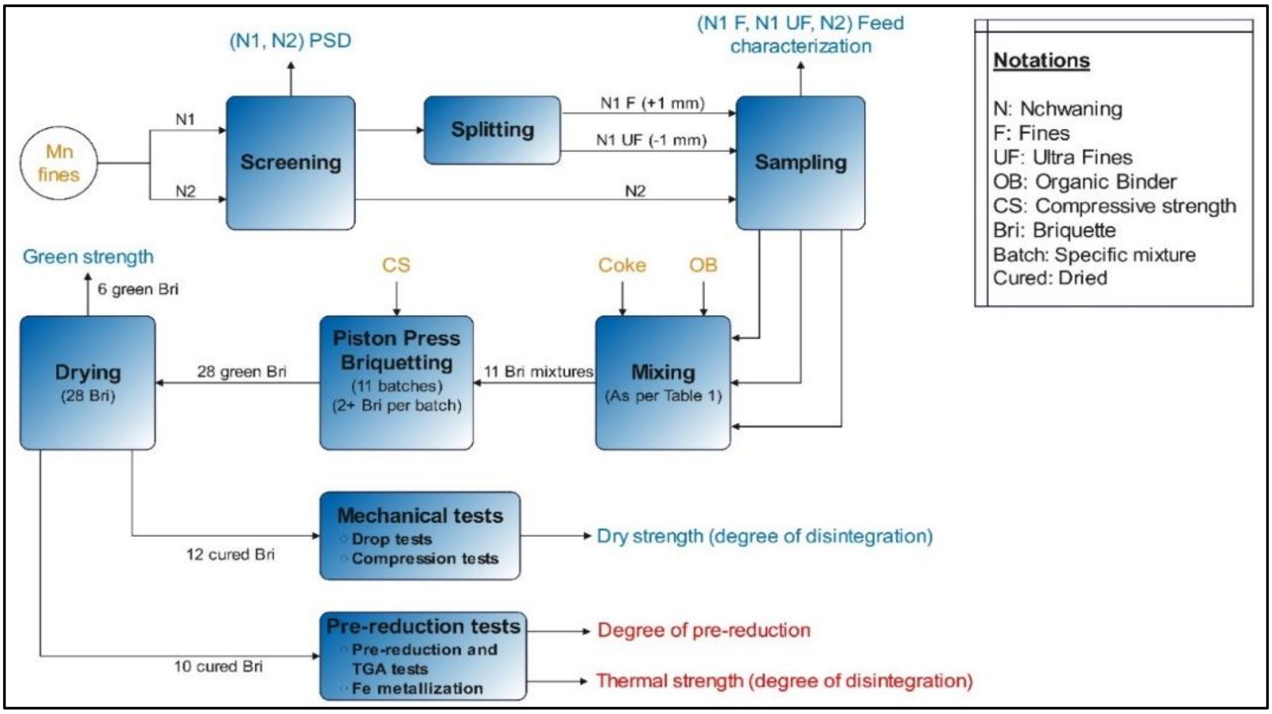

Figure 2 Summarized flow sheet of the experimental procedure

2.2.1 Briquette mixture design

A quantitative methodological approach was adopted; the information was derived through analysis and interpretation of the data obtained after conduction of experiments. The experiments were designed using the Response Surface Methodology-Central Composite Design (RSM-CCD) in the Minitab software. The organic binder content (Alcotac® CB6), and the compressive strength (CS) were the main continuous process parameters, and their levels were extracted from both the literature and the supplier specifications of Alcotac® CB6. After experimental design, the different briquette mixture specifications in **Table 1** were obtained. The coke content was kept constant at 5 per cent for all briquettes.

Table 1 Briquette mixture specifications

Batch	CS (kN)	Fines (%)	Binder (%)	Water (%)	Coke (%)	Total (%)	Samples
C1	74	94.4	0.6	5	5	100	3
C2	147	94.4	0.6	5	5	100	*3+1
C3	74	93.8	1.2	5	5	100	*3
C4	147	93.8	1.2	5	5	100	*3+1
C5	74	93.3	1.7	5	5	100	*3
C6	147	93.3	1.7	5	5	100	*3+1
C7	147	94.1	0.9	5	5	100	*3
C8	147	93.5	1.5	5	5	100	*3+1
C9	74	94.1	0.9	5	5	100	*3
C10	74	93.5	1.5	5	5	100	*3+1
			Total				**35 Bri**

2.2.2 Briquette performance assessments

Two types of tests were conducted to evaluate the performance of each briquette specification, namely mechanical tests, and reduction-disintegration tests. Mechanical tests included physical properties of the briquettes. The mechanical tests included the compression test using the Chatillon DFE 2 force measurement machine, and the drop test according to ISO 7965 standards done by dropping the briquette through a 2 m height onto a steel plate with subsequent screening to quantify the fines (<4 millimetre) regeneration. On the other hand, reduction-disintegration tests were conducted by heating the briquettes from 25 to 600 °C to evaluate the thermal integrity of the briquettes at varying binder contents and compressive strengths.

3. RESULTS AND DISCUSSION

The X-Ray Spectroscopy analysis of the manganese sample recorded in **Table 2**. The elements in Table 2 were the focus in this investigation, therefore no other elements are recorded while the mineralogical analysis using X-Ray Diffraction (XRD) is depicted in **Figure 3**.

Table 2 Ore chemical (elemental) composition (wt%)

Element	Si	Mn	Mg	Fe	Ca	Mn/Fe
composition	1.8	44.0	1.2	13.5	5.1	3.26

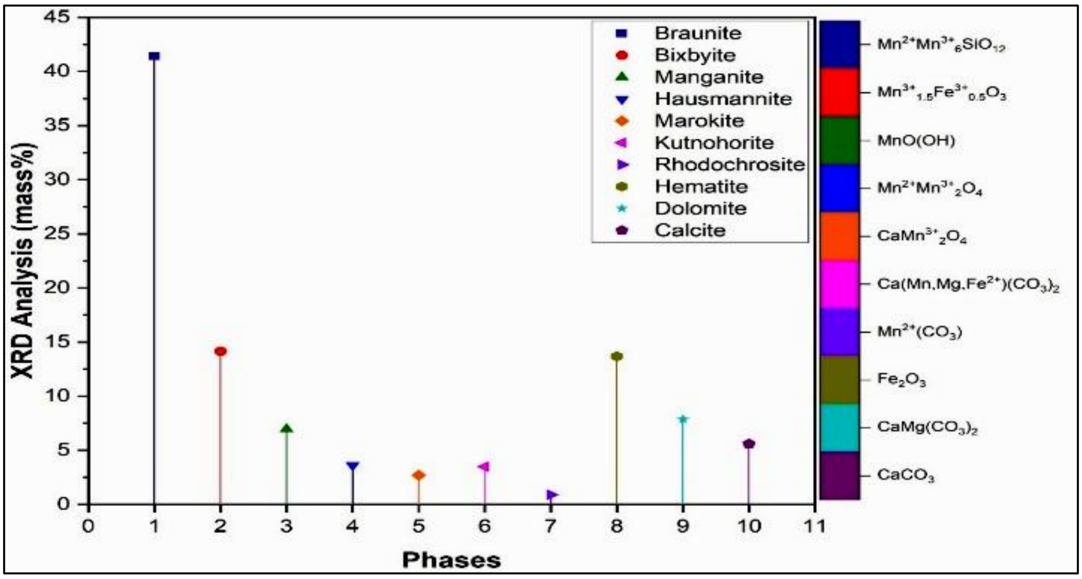

Figure 3 Mineralogy of the manganese ore

Effect of binder content

The binder content was varied from 0.6 per cent to 1.7 per cent to assess its effect on the dry strength of the briquettes and the results are highlighted in **Figure 4**.

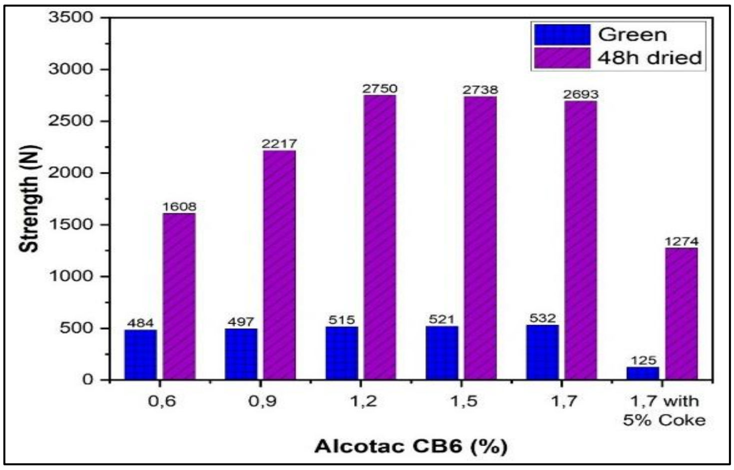

Figure 4 Effect of binder content on the mechanical strength (N)

Effect of compressive strength

The effect of the compressive strength is highlighted in **Figure 5**, the briquettes were subjected to two levels compressive of compressive strengths, namely 74 kN and 147 kN.

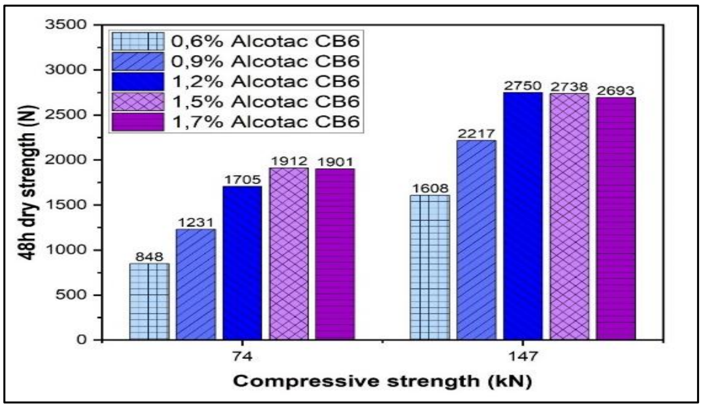

Figure 5 Effect of compressive strength on the dry strength of briquettes (N)

The effect of binder content on the mechanical strength of briquettes is highlighted in **Figure 5**, at a constant compressive strength of 147 kN, the binder content of 0.6 per cent yields a green strength of 484 kN and a 48 hour dry strength of 1608 kN, whereas a binder content of 1.2 per cent produces a green strength of 515 kN with a corresponding 48 hours dry strength of 2750 kN. Generally, increasing the binder content improves the dry strength, but the green strength remains roughly constant regardless of the binder content increment. Furthermore, one can notice further increment of binder content from the 1.2 per cent composition results into a slight decrease of the dry strength. This can be due the binder used was a dry binder, and the effective mixing ratio of water and the binder has been exceeded since the amount of water was kept constant for all the binder dosages. The advantage of dry binders over wet binder is that can homogeneously mix with the fines resulting into an even distribution of the binder in the briquette and consistent mechanical properties throughout the briquette [10]. However, exceeding the ratio of water and the binder can deteriorate the mechanical strength and integrity of the briquette. Moreover, the addition of coke to the briquette mixture completely deteriorates the mechanical strength of the briquettes, this can be exemplified in the 1.7 per cent binder content, whereby the dry strength from 2693 to 1274 kN after coke addition. Also with reference to

Figure 5, it can be seen that at a constant binder content of 1.2 %, the dry strength is 1705 kN at 74 kN compressive strength, and it increases to 2750 kN at 147 kN compressive strength. It can be seen that increasing the compressive strength does significantly improve the mechanical strength. However, increment in compressive strength decreases the porosity of the briquette, which will ultimately affect its CO reactivity. Therefore, the generic trend is that variation in both binder content and compressive strength is directly proportional to the variation in mechanical strength to some extent.

4. CONCLUSION

The optimal compressive strength and binder content for the briquetting process of the Nchwaning manganese fines to facilitate sustainable recycling during smelting were investigated. Results have demonstrated that the optimal briquette specifications of the basic manganese ore fines for industrial briquetting tests are 1.2 per cent Alcotac CB6 and 147 kN compressive strength. At these optimal specifications, the briquettes show a dry strength of 2750 kN after 48 hours of cool drying, which is strong enough to handle the mechanical abrasions of transportation in the plant, and the observed degree of disintegration is less than 5 per cent proving to yield stable furnace operations.

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