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Evaluation of Compressive Strength of Briquettes Made of Manganese Ore Fines and Cement

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A B S T R A C T

The manganese ore is the main raw material to the ferroalloy production. During its beneficiation, fines are produced and were placed in tailing dams. An alternative to the material that is dumped in tailing dams is to agglomerate it in form of briquettes. When charged inside the submerged arc furnaces, the briquettes must have enough strength in order to maintain its size and shape. Unless the agglomerates would behave as the unwanted fines undermining its performance. Thus, the work has as subject the study of the parameters that influence the compressive strength on briquettes made of manganese tailing dam material and cement. The work is based on the hypothesis that there is a set of parameters for such materials which maximize the compressive strength. This work has as objective assess the impact of curing time, rate water/cement and top size of the raw materials in the compressive strength of briquettes made of manganese ore fines and cement. To fulfil the objective, briquettes with a mass percentage of cement of 10 % were produced. To find the influence between the rate water/cement agglomerates with rates of 0,5, 1 and 1,25 were produced. To assess the impact of curing time, specimens were produced and cured for 1, 7, 14, 21 and 28 days. To measure the effect of different raw materials top size, briquettes which the top size was 0,250, 1,00 and 2,00 mm were produced. The results showed that the best set of parameters to increase the compressive strength to the an optimal is rate water/cement of 1, curing time of 21 days and raw materials top size of 1,00 mm.

Keywords: manganese ferroalloy; briquettes; compressive strength.

1. Introduction

Manganese is one of the most important elements added during steel production. This material is charged in the steelmaking process as ferroalloy (Olsen,Tangstad&Lindstad, 2007). The main raw material to ferroalloy production is manganese ore. In the manganese ore production, the ore is mined and processed, mainly throughout comminution and sizing operations (Tangstad, Leroy &Ringdalen, 2010). In the manganese ore processing, the most common route comprises the steps of crushing and sieving. During manganese ore process up to 50 % of the material mined is discarded due to its low particle size after the sizing steps (Olsen, Tangstad&Lindstad, 2007). This material is commonly deposited in tailing dams (de Jesus, 2020).

The manganese ferroalloys are mainly produced in Submerged Arc Furnaces (SAF). The SAFs are usually equipped with three Søderberg electrodes. Each electrode has a different electric phase, and during the ferroalloy production process, the electric energy is transformed in heat. The metal and slag are taped in the same taphole (in small furnaces) or in separated tapholes (in larger furnaces). The Figure 1 presents a schematic diagram of a SAF.

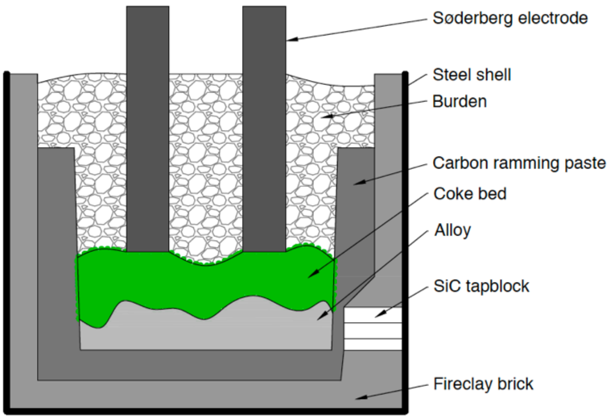

Fig. 1 – Schematic diagram of a submerged arc furnace (de Jesus, 2020).

The raw materials are charged inside the SAF at room temperature. During the manganese reduction process, the reactor may can be divided in two zones, the prereduction zone (upper part of the furnace, with lower temperatures), and the coke bed zone, lower part of the furnace, with higher temperatures (Tangstad, Leroy &Ringdalen, 2010). In the prereduction zone the higher manganese oxides are reduced to MnO by the ascending (CO-rich) gases produced in the coke bed zone. In the coke bed zone, due to the higher temperatures the ore melts, remaining only the carbonous materials in solid state. The MnO-rich slag is reduced by solid carbon, producing CO, which promotes the prereduction reactions. The manganese ferroalloy and slag are deposited in the bottom of the furnace where they are tapped. The Figure 2 show a schematic diagram of the prereduction and coke bed zones, the electrode, and the main reactions inside the SAF.

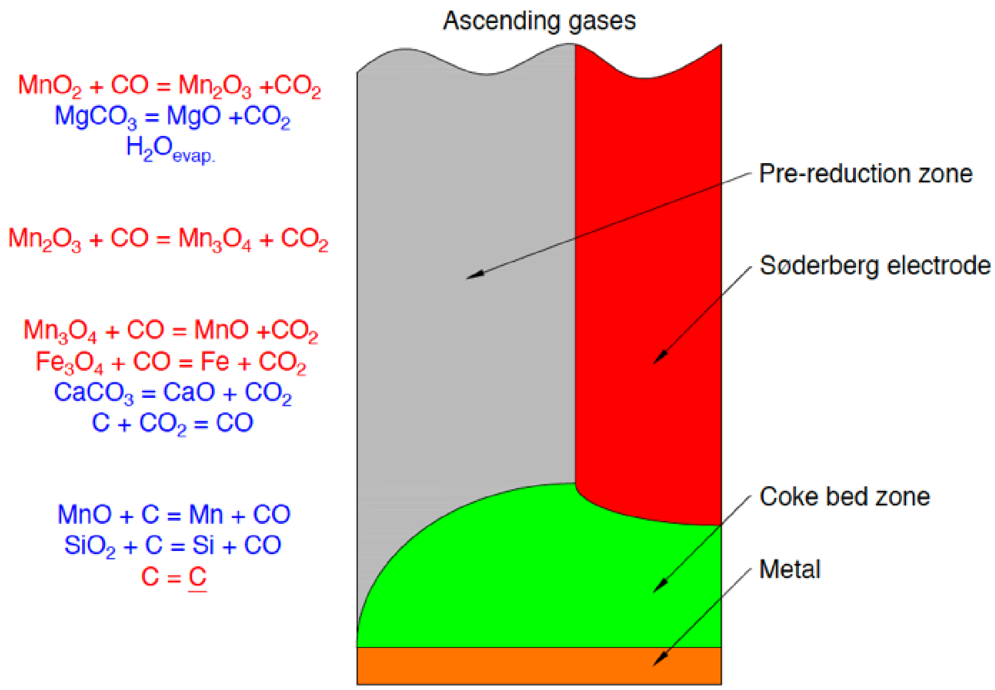

Fig. 2 – Main reactions in the SAF (Olsen, Tangstad&Lindstad, 2007).

The lower temperature zone reactions are solid-gas reactions. Thus, the prereduction zone demands raw materials with coarse particle size otherwise the fine-grained material deposits in the interstice of coarser particles which creates preferential paths to the CO gas which undermine the prereduction zone reactions efficiency (de Jesus, 2020). Therefore, to utilize the fine-grained material produced in the mineral processing steps, briquetting stands as a promising technology, since it agglomerates powders to produce material with suitable size and shape. However, the briquettes must preserve its size and shape when submitted to mechanical stresses within the furnace. Hence, it is important to study the compressive strength of briquettes as it is a valuable index to evaluate how the agglomerate performs at the mechanical stresses imposed by the furnace operation.

Thus, this work has the study of compressive strength of briquettes made of manganese ore tailing dam material and cement (as binder) as subject. The influence of variables such as: influence of binder content; water/binder rate; top size of the raw materials; and curing time were investigated. This work is based on the hypothesis that there are a set of variables that maximize the compressive strength suitable to the ferroalloy production process.

The work has the aim to evaluate the compressive strength of briquettes made of manganese ore tailings and its relationship with binder content, water/binder rate, top size of the raw materials and curing time. To fulfill the main aim of the work, the following specific objectives were pointed out:

1. Find the influence of the rate water/cement.
2. Assess the impact of the curing time.
3. Measure the effect of different raw materials top size.

2. Experimental setup

The experimental setup was performed in the Metallurgy Laboratory of the Federal Institute of Mato Grosso do Sul in Corumbá – Brazil. The raw materials were provided by a local industry. The manganese tailing dam material was received as a powdered material and sieved in three different top sizes (2,00, 1,00 and 0,250 mm). The flowsheet depicted in Figure 3 presents the steps of the methodology developed during the work.

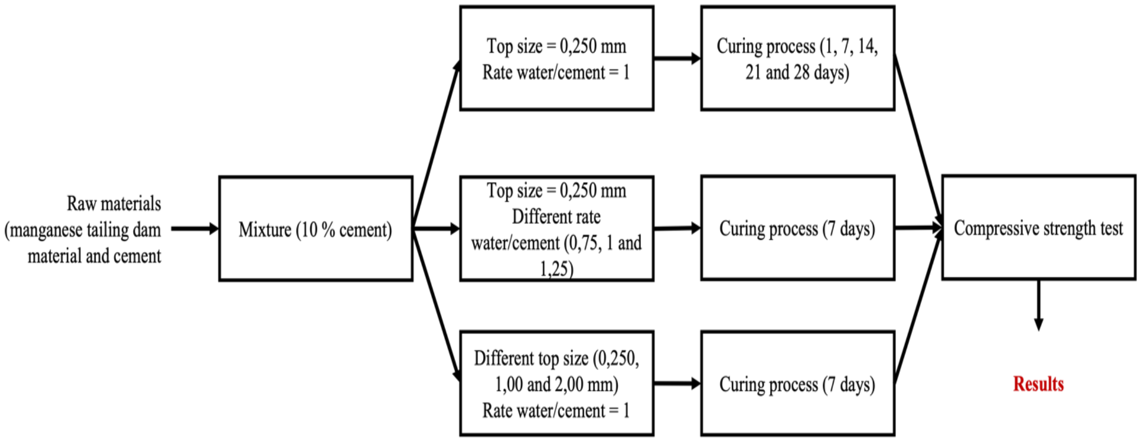

Fig. 3 – Experimental setup flowsheet.

The briquetting mixture used in the work was 90 % of manganese ore tailing dam material and 10 % of cement, as binder.

To find the influence of the rate water/cement, raw materials mixtures with rate of 0,5, 1 and 2 were made. These batch of briquettes was produced with manganese tailing dam material whose the topsize was 0,250 mm, the curing time was set as 7 days. To assess the impact of curing time a batch of agglomerates with 0,250 mm of raw materials top size and water/cement rate equal 1 was produced and stored. After a 1, 7, 14, 21 and 28 days 5 specimens were tested for its compressive strength. To measure the effect of different raw materials top size a batch of briquettes with 0,250, 1,00 and 2,00 mm of top sizer were produced. Those specimens had 1 as rate water/cement and were stored for cure during 7 days.

To produce the briquettes, the raw materials were weighted and placed in a Becker, a propeller mixed the materials for 30 seconds to make a homogeneous mixture. The agglomerates were produced in a cylindrical die and punch which the internal diameter was 10 mm with a pressure of 500 kgf for 30 seconds. To enable the removal of the briquette from the inner cavity of the die, engine lubricant was used in the surface of the die and punch. Thus, the specimens were stored for the determined curing time. After the curing time was elapsed, the specimens were weighted and measured to assess its apparent density then they were tested to measure its compressive strength in a EMIC multipurpose mechanical testing machine equipped with a 20 kN loading cell.

3. Results and discussion

The results obtained throughout the previously described experimental setup were summarized in the Table 1 in which the compressive strength along with the standard deviation are shown.

Table 1 – Summary of the results provided by the methods.

Curing time		
Curing time [weeks]	Compressive strength [MPa]	Constant parameters
0,14	4,7	
1	6,8	Cement content: 10 %
2	9,0	Top size: 0,250 mm
3	12,7	Rate water/cement: 1
4	12,8	
Rate water/cement		
Rate water/cement	Compressive strength [MPa]	Constant parameters
0,5	6,8	Cement content: 10 %
1,00	14,6	Top size: 0,250 mm
1,25	7,9	Curing time: 1 week
Top size		
Top size [mm]	Compressive strength [MPa]	Constant parameters
0,250	7,5	Cement content: 10 %
1,00	9,7	Curing time: 1 week
2,00	2,4	Rate water/cement: 1

Figure 4 presents the results of the influence of the curing time on the compressive strength. It can be seen an increase in the compressive strength during the first three weeks. After four weeks of curing time the compressive strength did not present any improvement. Thus, from three to four weeks of curing time, the briquettes presented a relatively steady compressive strength.

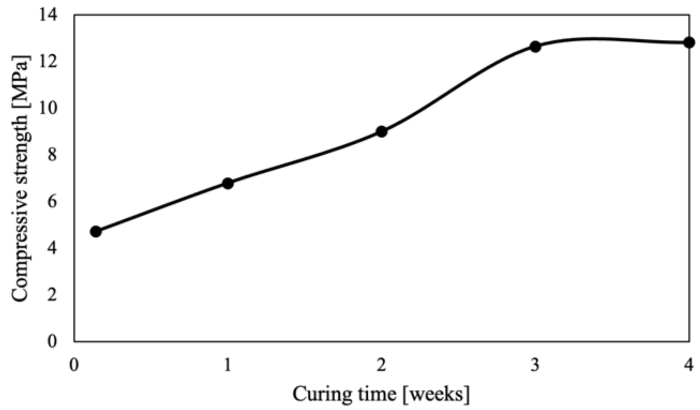

Fig. 4 – Influence of curing time in the compressive strength.

The influence of the rate water/cement in the compressive strength of the agglomerates is depicted in Figure 5. The figure reveals the increase on compressive strength from 0,5 up to 1 however, with the further increase of water content (rate water/cement = 1,25) it is lowered. It is important to point that the results on the higher water content (rate water/cement = 1,25) were inferior then when the rate water/cement was lower (0,5).

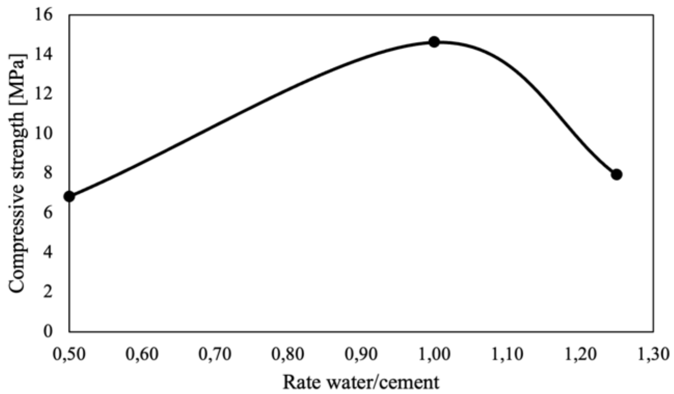

Fig. 5 – Influence of the rate water cement in the compressive strength.

Figure 6 shows the influence of the top size in the compressive strength of the briquettes. There is an increase in the compressive strength when the top size is raised from 0,250 to 1,00 mm. The samples whose top size was 2,00 mm has a sharp decrease in their strength.

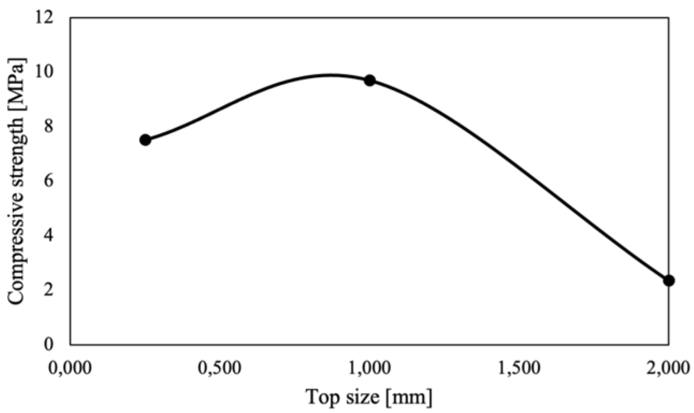

Fig. 6 – Influence of the top size in the compressive strength.

The impact of the bulk density in the compressive strength is shown in the Figure 7. The bulk density of the specimens was assessed by the rate between the mass and the geometric volume, obtained by the measure of the height and diameter. As it can be seen, there is no correlation between those parameters since it is not possible to see any pattern in the values dispersion.

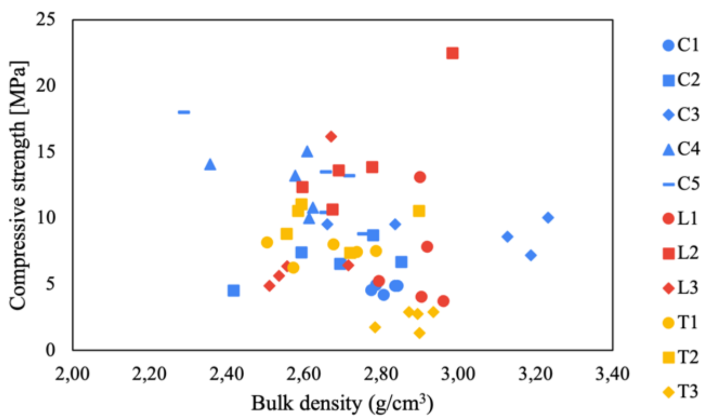

Fig. 7 – Influence of bulk density in the compressive strength, labels were showed in Table 2.

The coefficient of determination of the relation between the bulk density and compressive strength is presented in Table 2. It can be seen by the values that there is a very low correlation between the variables being much closer to 0 than 1 which enhance the information provided by Figure 7.

Table 2 – Results on the coefficient of determination between bulk density and compressive strength.

Curing time		
Time [weeks]	Label	R^2
0,14	C1	0,10
1	C2	0,47
2	C3	0,14
3	C4	0,18
4	C5	0,75
Rate water/cement		
Rate	Label	R^2
0,5	L1	0,00
1	L2	0,85
1,25	L3	0,29
Top size		
Size [mm]	Label	R^2
0,250	T1	0,00
1,00	T2	0,00
2,00	T3	0,17

The relation between the curing time and compressive strength may be explained by the hydration reactions, which consists in reactions of the cement constituents with water. This phenomenon was previously explained by Chatterjee (2018) and pointed by other authors (Ozbayoglu, Hiçyilmaz&Akdemir, 1993; El-Hussiny&Shalabi, 2011) as relevant to the compressive strength of briquettes made of ore fines.

Results which presented the relation of the compressive strength and the rate water/cement pointed to a decrease in the compressive strength when the rate is increased. The increase on the water/cement rate may result in sharp increase in the plastic behavior of the specimens, as mentioned by Chatterjee (2018). Thus, the briquetting mixture presents a behavior similar to concrete in regard of its optimal water/cement rate. Low water/cement rates tend to lower the hydration reactions rate of the cement, high rates may produce a material with plastic characteristics. Therefore, the optimal amount of water and cement in briquettes was similar to the concrete recipe suggested by Chatterjee (2018), which points to a mass percentage of 10 % and a rate water/cement of 1.

Decrease on the compressive strength, presented on Figure 6, may be explained by the use of coarser raw materials (top size = 2,00 mm). El-Hussiny&Shalabi (2011) discussed the effect of size distribution on the compressive strength. Despite most of the studies (Ozbayoglu, Hiçyilmaz&Akdemir, 1993; Yu, Sun, Liu, Kou & Xu, 2014) report a relation that points to coarser sizes distribution results in lowers compressive strength results, El-Hussiny&Shalabi (2011) found that the presence of low amount coarser particles may be beneficial to the strength of briquettes. Thus, the particle size distribution with a top size of 1,00 mm may provide the amount of coarser particles that increase the compressive strength to an optimal result.

It is important to highlight that the best results were obtained with 21 days of curing time, rate water/cement of 1 and 1,00 mm of raw materials top size. Despite the increase of compressive strength obtained on specimens which the curing time was 28 days, the strength increase is negligible when curing time is considered. Furthermore, in terms of economy, it is important to balance the increase of compressive strength and the raise of the curing time. Finally, it is also important to mention that the loss of compressive strength obtained when the top size of the raw materials was increased to 2,00 mm may be compensated (in operational and economical terms) if the amount of recoverable material in the tailing dam is considered.

4. Conclusions

Briquettes made of manganese tailing dam material and cement (as binder) were successfully produced.

Throughout the results it is possible to conclude that the optimal range of curing time is from 21 to 28 days, however it is important to balance the increase of compressive strength for longer times due to economic aspects.

The evaluation of the impact of the rate water cement in the compressive strength led to an optimal result of a rate equal 1.

Regarding the top size influence on the compressive strength, it was found 1,00 mm as the best result.

For the materials and parameters tested, the bulk density had no impact on the results.

Acknowledgements

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