BRIQUETTED CHROME ORE FINES UTILISATION IN FERROCHROME PRODUCTION AT ZIMBABWE ALLOYS

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ABSTRACT

The ever-increasing pressure on the profit margins of ferro-chrome producers and the gradual depletion of deposits of rich hard lumpy chrome ores calls for the ferrochrome industry to maximise the use of fine fractions of concentrates and friable chromite ores. Zimbabwe is endowed with huge deposits of refractory and friable ores that occur on and off the Great Dyke complex. The conventional metallurgical process of smelting of chromite ores in submerged arc furnaces is favoured by the use of refractory hard lumpy ores. The requirement to use all lumpy ore has been circumvented to a large extent at Zimbabwe Alloys. The use of briquetted chrome ore fines in the production of Ferrosilicon Chrome and High Carbon Ferrochrome has yielded positive results over a period in excess of twenty-five years.

Of the three industrially used methods of agglomeration of chromite ores; sintering, pelletisation and briquetting, briquetting is preferred because the other two are associated with higher capital and operational cost.

Zimbabwe Alloys has developed operational and technical expertise on the briquetting and utilisation of chromite ore fines and concentrates. Variations in the quality of available chromite ore fines imply that their amenability to briquetting is a dynamic problem. Appropriate briquetting parameters to guarantee quality briquettes are essential to the successful use of briquetted chromite ore fines.

In developing a technology for briquetting of chromite ores, it is important not only to study the mineralogical and grain-size characteristics of the chromite ore fines but also to make an informed choice of the type and quantity of the binder and the conditions for producing a physically and chemically competent green and cured briquette.

This paper discusses Zimbabwe Alloys' experience on the briquetting process and the advantages derived in the smelting of the briquetted chromite ore fines in comparison to the use of conventional lumpy chromite ore with respect to improvements in chromium recovery and as a consequence related efficiencies and unit cost of production.

1. INTRODUCTION

The conventional metallurgical process of smelting of chromite ores in submerged arc furnaces requires the use of hard lumpy ores. Through the use of the briquetting process for agglomeration of fine fractions of chromite ores, this requirement has been circumvented to a large extent at Zimbabwe Alloys with positive results over the past twenty years. These have been leveraged to become a significant source of sustainable competitive advantage.

The use of briquettes in the production of high carbon ferrochrome alloys has a number of operational, metallurgical and economic advantages. Key among these is the improvement in the metallurgical recoveries and related efficiencies such as energy utilisation efficiencies due to the improved meltability and thermodynamic efficiencies of smelting a small range of size factions.

As a rule and on average the use of fines have massive cost advantages as the fines are a byproduct of screening and would otherwise have had no value apart from handling and processing costs. This use of a cheaper input is a source of cost competitiveness that is a key success factor in the ferro-alloy production industry and this has been borne out by Zimbabwe Alloys' cost structure.

Although Zimbabwe Alloys has accumulated extensive industrial-scale experience with the briquetting of chromite ore fines and concentrates, the problems of establishing appropriate briquetting parameters is far from its definitive solution, especially in view of the continuing variation of the quality of available ore fines and their amenability to briquetting, the reliance on non-renewable fossil fuels in the context of world-wide energy shortage and the environmental impacts of the briquetting operation.

Emissions from the induced draught fan cause air pollution that leads to health risks, reputation damage and complicated legal processes to secure permits and ozone depletion.

In developing a technology for briquetting of chromite ores, it is important not only to study the mineralogical and grain-size characteristics but also to make an informed choice of the type and quantity of the binder and the conditions for pressure of raw briquettes.

Of the three industrially used methods of agglomeration of chromite ores - sintering, pelletisation and briquetting, the latter is preferred because the other two are associated with high capital investment, high cost of grinding and roasting of pellets, low SiO_2 content in the ore because of possible sintering of pellets.

2. BRIQUETTING PROCESS

2.1 Blending

Chrome ore fines are blended in a shed using a set of hoppers fed by an overhead crane. The hoppers discharge onto a common belt over a system of weighing equipment to regulate the proportions of each component of the feed. The multi-component feed is conveyed into a rotary dryer.

2.2 Drying

The drying process is a solid-state physical preparatory process for the removal of superficial water from the solid concentrates by thermally induced evaporation. This is achieved by passing a forced draught of hot air from burning fossil fuels through a cylindrical 12m long vessel inclined at 5 degrees to the horizontal and rotating about its longitudinal axis. The solid concentrates are introduced into the dryer at the high end and migrate down the slope. As they migrate, they are turned over continually by the rotation of the dryer. Meantime appropriately sized coal fuel is burnt over slow moving stoker gratings and the hot combustion gases pass through the dryer in a co-current draught.

Chrome ore fines and concentrates are dried to eliminate clogging of the downstream ball mill, reduce the corrosion of the grinding media and increase the amenability to the briquetting process by increasing the specific surface area available for binders to agglomerate the ore particles.

The dryer consists of dryer drum; coal travelling chain grates and a combustion chamber. In addition the circuit incorporates cyclones, bag-house filter complete with an induced and forced draught fan.

Factors affecting dryer efficiency:

- *Moisture content of feed* - the higher the moisture content the more energy it will take to drive out the moisture. The use of excessive amounts of energy compound also the energy losses sustained. The targeted moisture content for the dryer output is critically important as progressively higher energy losses are incurred when disproportionately lower moisture levels are targeted.
- *Suction pressure* - the efficiency of the induced draught fan at the discharge end of the dryer in conjunction with the forced draught fan at the feed end of the dryer has an overall bearing on the efficiency of drying
- *Feed-rate* - the higher the feed-rate the lower the residence time in the feed-bed with consequent reduction in efficiency of drying
- *Coal feed-rate* - the coal fuel feed-rate will determine the nature, timing and extent combustion completeness.

2.3 Material and Energy Losses

The bulk of material losses occurs at:

- Belt transfer points
- Transfer point between conveyor and dryer drum chute
- Dryer discharge end
- Conveyor belts
- I D fan off take stack pipe

2.4 Milling

Milling in a ball mill is done to:

- Increase the homogeneity of the briquetting blend
- Reduce the size of the fines so as to increase the exposed surface area for bonding
- To reduce abrasive forces on the mixer blades and briquetting rolls

Factors affecting optimum discharge grinding efficiency:

- Feed rate
- Mill operating speed
- Ball loading

The grinding of feed to a mesh size lower than 50 microns to the extent in excess of 30% is considered over-grinding as the material gets pulverized to a point of surging at the discharge end of the ball mill.

Over-grinding is undesirable as it leads to:

- Excessive dust generation
- Conveying difficulties and increased material losses
- Low briquette strength
- Higher binder consumption
- Increased energy consumption

Under-grinding causes:

- Increased wear on mixer blades due to the coarse particle sizes

2.5 Mixing

The chrome ore fines concentrates discharge from the ball mill, lime and molasses binders are mixed in a set of three mixers configured in series and equipped with mixer blades to facilitate the mixing process.

2.5.1 Binder Selection and Combinations

In developing a technology for briquetting of chromite ores, it is important not only to study the mineralogical and grain-size characteristics but also to make an informed choice of the type and quantity of the binder and the conditions for pressure of raw briquettes.

A combination of various binders on the basis of cost and effectiveness has been tried over the years. The combination of molasses and lime has proved to be the most effective. The various combinations are shown in Table 1.

Table 1. Briquetting Binders Combinations.

Binder Combinations		Utilisation (t/t)		Unit Cost (Z$)		Cost/t of Briquette (Z$)	Ranking
Lime	Molasses 1	Lime	Molasses1	Lime	Molasses1	383.72	1
		0.035	0.065	450	5,661		
Lime	Molasses 2	Lime	Molasses 2	Lime	Molasses 2	497.25	2
		0.025	0.045	450	10,800		
Lime	DHCT	Lime	DHCT	Lime	DHCT	1,597.95	4
		0.035	0.045	450	35,160		
Lime	Road Tar	Lime	Road Tar	Lime	Road Tar	2,486.25	8
		0.025	0.055	450	45,000		
Bentonite	Molasses1	Bentonite	Molasses1	Bentonite	Molasses1	1,702.20	5
		0.030	0.070	43,531	5,661		
Cement	Molasses1	Cement	Molasses1	Cement	Molasses1	642.95	3
		0.030	0.045	12,940	5,661		
Cement	Road Tar	Cement	Road Tar	Cement	Road Tar	2,188.20	7
		0.030	0.040	12,940	45,000		
Cement	DHCT	Cement	DHCT	Cement	DHCT	1,794.60	6
		0.030	0.040	12,940	35,160		

Glossary:
DHCT - Dehydrated Crude Tar
Molasses 1 - Hippo Valley Estates Molasses
Molasses 2 - Zambia Sugar Association Molasses

The briquettes produced using a combination of road tar with cement were of substantially superior quality in respect of compressive strength, resistance to shattering and wear. The compressive strengths, in particular, were superior to the standard molasses/lime briquettes, being 300 pounds per square inch at the time of production (compared to the standard 200 psi) and improving to 600 psi after 96 hours of curing in contradistinction to 500 psi for the standard briquettes.

However this combination of binders could not be adopted on a sustainable basis because of limited supplies of road tar.

The abrasive strengths were also superior to the standard briquette with less than 0.3% fines generation after 96 hours compared to 18% fines generation for standard briquettes.

The combination of dehydrated crude tar with lime produced briquettes of comparable abrasive and compressive strengths.

The road tar-lime combination produced briquettes of inferior properties in which both the compressive and abrasive strengths were below the standard specification. The briquettes so produced were brittle and prone to shatter with physical handling. However, their properties improved considerably with curing time especially when the lime component was increased to above 6%.

The cement-molasses briquettes were evidently superior to any other combination with the only adverse factor being the cost of cement.

The bentomite-lime combination produced some particularly encouraging results especially their resistance to shatter after being subjected to high temperatures in a muffle furnace.

The binding mechanism involves the adhesion of molasses due to stronger intermolecular forces in the sucrose structure that confers the initial green strength.

The second stage which occurs during curing involves the dissolution of CaO and is characterized by chemical and polymeric metal complexation to form the calcium saccharate bond between lime and molasses.

2.6 Briquetting

2.6.1 Segment Performance

Various combinations of briquetting segments have been tried on the briquetting rolls with varying degrees of success. Roll production averages between 40 and 50 000 tonnes depending on the mineralogy of the briquetted fines as well as well as installation of segments.

2.6.2 Briquette Production: Operational Aspects and Briquette Quality

For Zimbabwe Alloys, preference is given to the following method of briquetting: the initial chrome ore, with variable fractional composition is dried at $800^{o}C$ to a moisture content of at most 2.5% before it is pulverized in a ball mill to 63microns. Lime is then added and mixed with the dried, milled chrome ore after which molasses is added. For thorough intimate mixing the three-component mixture is passed through a set of three mixers in series and then briquetted under pressure by passing the mixture over a set of rolls equipped with segment pockets. The resulting briquette (80-90mm long, 45-50mm wide and 25-30mm thick) is screened; the undersize is recycled in a closed circuit while the oversize is warehoused in a shed.

Factors affecting briquette quality include:

- Molasses and lime binder level
- Molasses sugar content
- Moisture levels
- Rolls speed
- Rolls pressure
- Feed grind and particle size distribution
- Segment condition

2.7 Curing

Curing of briquettes occurs in a shed over a 96-hour period during which lime sets in to confer long-term strength on the briquette.

The briquette stockpiles ought not to exceed 2-3m in height as this may allow for high heat retention with the consequent loss of molasses' binding ability. The compressive strength of the briquette is tested at the point of manufacture and thereafter at 24 hourly intervals for four days, the last test being combined with an abrasive and drop strength test. The briquettes take between 30 - 36 hours to attain complete strength that exceeds the levels necessary for transportation and feeding into a submerged electric arc furnace. After curing the briquettes retain their strength, even when exposed to a humid atmosphere.

2.8 Briquette Conveying and Subsequent Handling

Upon production, green briquettes are conveyed on an evacuation conveyor, dropping a height of one and half meters in the process before being conveyed some twenty-five meters to a shed where they are warehoused for between five to seven days. The stockpiling process involves dropping briquettes a height of between five and twelve meters depending on the stage of stockpile build up. On conveying the briquettes to the furnaces they are subjected to rugged handling using an overhead grab crane over a system of feeders onto a thirty-five meter long conveyor. This conveyor in turn feeds onto a ninety seven meters long conveyor which takes the material to furnace silos situated some height in excess of sixty meters above ground level. The first set of furnace silos feeds onto a second set of secondary silos again subjecting the briquettes to some very rugged handling. In feeding the two sets of silos it must be emphasised that the briquettes have to drop in extreme cases a height in excess of fifteen meters depending on the bin level.

This handling regimes places onerous requirements on the strength of briquettes to be able to withstand these various forces ranging from compressive, abrasive and drop forces during conveying.

2.9 Environmental and Occupational Health Aspects of Briquette Production

The material handling of dried fine concentrates presents considerable challenges as there are massive material losses at transfer points coupled with high levels of respirable dust exposures to employees and lower material recoveries.

No dust dispersion studies have been conducted to determine the dust loading and fallout characteristics and the nature of any adverse impacts on the environment and/or on human health. Ground Level Dispersion studies would enhance and give more credibility to the surveillance programme by mapping the exact dispersion zone of the particulates in the emissions.

The dryer operation relies on non-renewable fossil fuels and characterized by very low energy utilisation efficiencies given huge energy losses in the stack emissions as well as radiation from the dryer.

3. BRIQUETTE UTILISATION AS A SOURCE OF COMPETITIVE ADVANTAGE

The conventional metallurgical process of smelting of chromite ores in submerged arc furnaces requires the use of hard lumpy chrome ores. Through the use of the briquetting process for agglomeration of fine fractions of chromite ores, this requirement has been circumvented to a large extent at Zimbabwe Alloys with positive results over the past twenty years. These have been leveraged to the key success factors in the high carbon ferrochrome production process to become a significant source of sustainable competitive advantage.

The use of briquettes in the production of high carbon ferrochrome alloy has a number of operational, metallurgical and economic advantages.

Improved metallurgical recoveries and related efficiencies through better capacity utilisation. This is shown in Figures 1 to 4, which show the progressive improvement in production output, specific energy consumption, chrome recoveries, and chrome ore specific consumption with increasing briquette proportion. This is attributed, in part to an enhanced thermo-chemistry of a closely sized briquette feed consisting of temporarily bound fines with a higher specific surface area which in turn leads to improved reaction kinetics.

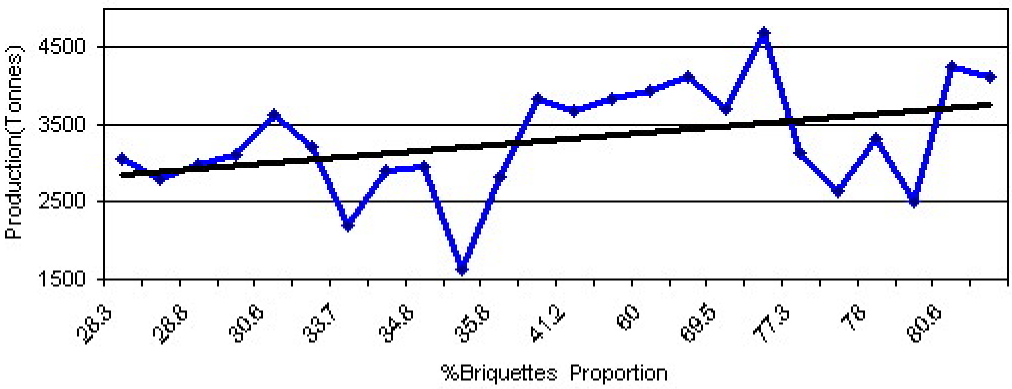

Figure 1. HCFeCr Production.

As shown in Figure 1, there is a definite upward trend in production output with increasing briquette proportion. Although this cannot be entirely attributed to the higher briquette proportion, the use of higher proportions of briquettes is associated with better-sized feed, which leads to improvements in furnace operating conditions.

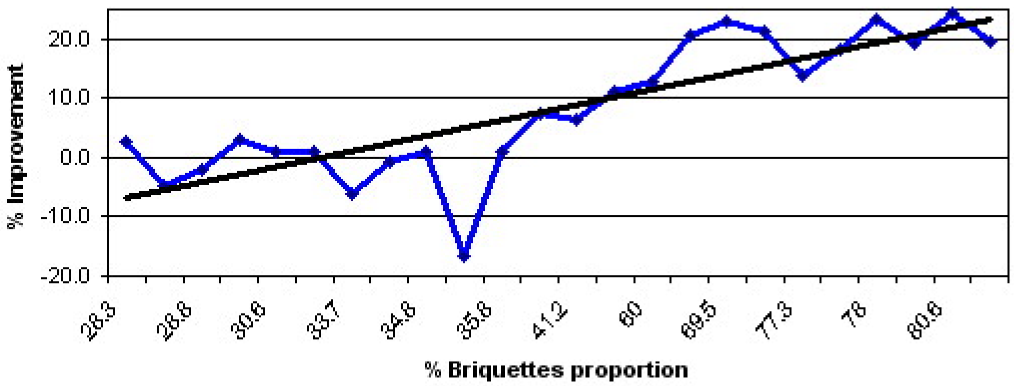

Figure 2. Power Specific Consumption.

The graph in Figure 2 shows a significant improvement in energy utilisation efficiency at higher briquette proportions. This results from the higher production output and improved operating conditions.

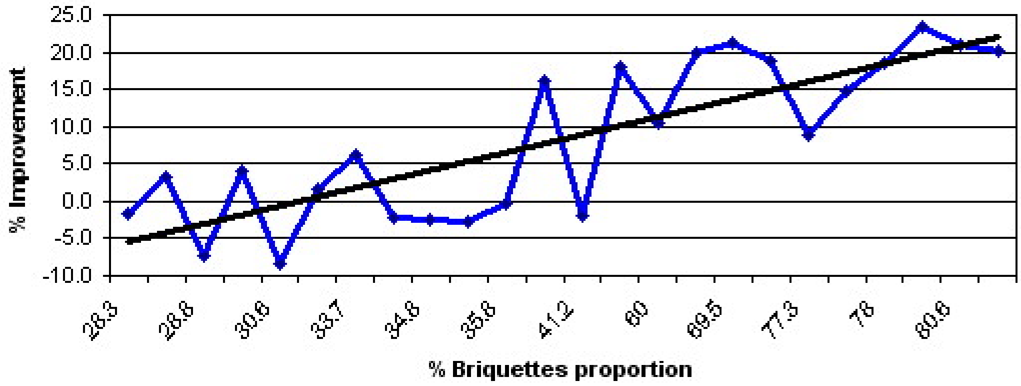

Figure 3. Chromium Recovery.

Chrome recoveries improve with higher briquette usage because of the improvement in feed size distribution that improves the reaction kinetics significantly (Figure 3).

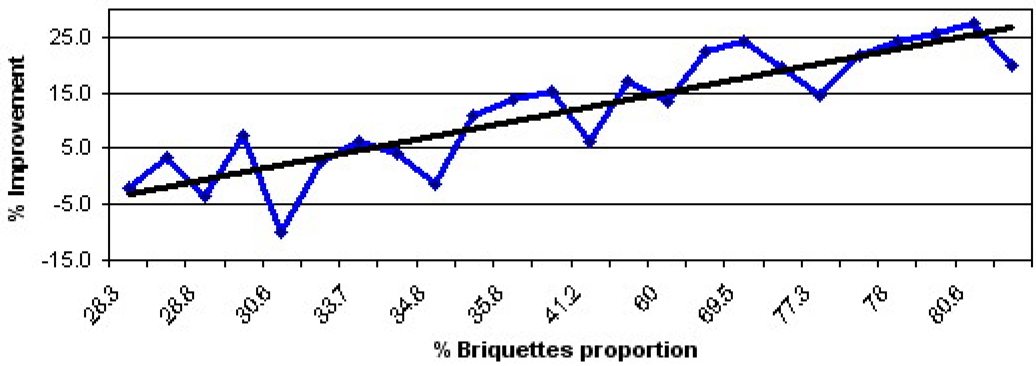

Figure 4. Chrome Ore Specific Consumption.

Figure 4 shows improvements in the chrome ore specification as a result of the improved grade of the feed consisting predominantly of briquettes made of concentrates. The upgrading of ore fines to a higher-grade concentrate before briquetting also contributes to the improvement in feed grade.

Briquetted chrome ore fines have a number of advantages over the lumpy chrome ore. On the furnace feeding system the smaller and consistent feed size offered by briquettes enhances the charging of the furnace and effectively eliminates feed chute blockages that are a common feature when lumpy chrome ore is used as a charge. Disruption from lack of feed is, therefore, avoided.

Of greater importance is the particle size of the material that constitutes the briquette. Less power is required for melting the finer chrome ore particles than is needed for larger lumpy chrome ore particles. More electrical energy is, hence, released for smelting resulting in improved energy utilization. Part of the improved power utilization is related to the mode of operation and in particular to electrode management. Experience has shown that an operating regime that favours a deeper reaction zone improves energy utilization. The carbon monoxide released in a deep reaction zone during the reduction process transfers its energy to the charge material, which will be at a relatively lower temperature, thus effectively preheating and sintering the charge on its ascent to the furnace surface.

It is also a requirement for submerged arc furnace operation that the charge be adequately porous to allow gaseous products of the reduction reaction to escape from the furnace charge burden without hindrance. Otherwise, furnace material would erupt causing electrode assembly damage and risking the safety of the workforce. The briquette, because it simulates lumpy charge but has an advantage of a smaller size, allows for a uniform and porous charge so that the ascending gaseous products can escape freely. The combined result of the above is an improvement in chromium recovery and production output, which have a positive impact on related key efficiencies as the briquette proportion is increased.

There are obviously cost benefits derived from the use of chrome ore fines. The fines are, under normal circumstances, a by-product of the mining and handling of the lumpy fraction of the ore. The fines are typically lower grade than the lumpy proportion. This does not present major problems as the fines are upgraded to high-grade concentrates before briquetting. Without briquetting the fines would have been scrapped at no value as a result of which the lumpy chrome ore that reaches the furnace would end up carrying the major, if not all, the cost of the mining and handling. Hence, the fines are relatively cheap. This is critically so for coke fines which have been treated as a waste.

Table 2 compares the furnace performance for two regimes, one with 30% briquettes and the other one with 70% briquettes. It is clearly demonstrated that both production output and key efficiencies are significantly better at a higher briquette proportion than at a lower proportion for essentially the same grade of chrome ore smelted and comparable furnace running time.

Of marked significance is the cost reduction brought about by the use of fines both of chrome ore and of coke as shown in the cost reduction.

Table 2. HCFeCr Performance: 30% Briquettes and 70% Briquettes.

Process Parameter	Unit	70% Briquettes	30% Briquettes	% Improvement
Production	tonnes	44063	34957	26
	tpd	120.7	95.8	26
Cr Recovery	%	88.0	74.4	18.3
Availability	%	89.4	89.5	0.1
Ore Grade	%Cr2O3	39.2	39.3	0.3
Cost reduction				
Ore fines for lumpy ore	Usc/lb	4		
Coke fines for lumpy coke	Usc/lb	0.8		
Specific Consumption				
Ore	t/t alloy	2.4235	2.9439	17.7
Coke	t/t alloy	0.3858	0.4861	20.6
Power	kWh/t alloy	3456	4233	18.4
Paste	t/t alloy	0.0283	0.038	25.5
Tapping bars	t/t alloy	0.002	0.0044	54.5

As the Table 2 shows an improvement in furnace operating conditions leads to many other positive impacts on other furnace operating parameters and related efficiencies.

4. CONCLUSIONS

The use of briquettes in the production of high carbon ferrochrome alloys has a number of operational, metallurgical and economic advantages:

- The use of briquettes has significantly improved metallurgical recoveries and related efficiencies.
- Briquettes make a homogeneous feed size and grade thus improving furnace-operating conditions.
- The briquettes are a source of cheap inputs thus yielding massive cost advantages and improving the
- overall process economic viability.
- The process of making briquettes presents massive environmental challenges which are yet to be
- tackled.