Storage, Handling and Shipping of HBI

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Summary This paper summarises work carried out to characterise the behaviour of fines based HBI during bulk material handling and storage. Fines based HBI was found to be stronger than pellet based HBI of similar density in tumble tests carried out to simulate bulk material handling operations. Drop tests showed that loading HBI will have a similar effect on a ship's double bottom as iron ore lump at equivalent loading rates. Corrosion measurements on an experimental HBI stockpile confirmed that corrosion losses in a stockpile are concentrated in a protective outer layer. Separate experiments highlighted the relationship between particle size, density, and corrosion rate.

1 INTRODUCTION

BHP Direct Reduced Iron is building a nominal 2 Million tonne per annum Hot Briquetted Iron (HBI) plant in Port Hedland, Western Australia, due to start up in early 1999. HBI is produced by the hot moulding of direct reduced iron to yield a dense product suitable for open storage, handling and charging to a steelmaking furnace. Although most HBI in the world is currently produced using pellet based direct reduction processes, BHP's Port Hedland HBI facility will use FINMET fines based technology. The major advantage of fines based HBI technology is the ability to directly utilise iron ore fines without the need for pelletising.

HBI is primarily used in electric arc furnace (EAF) steelmaking, although it is also used in basic oxygen steelmaking (BOS) and even in blast furnaces. HBI contains a high proportion of iron in the reduced state (both metallic iron and iron carbide), and has very low levels of residual elements (eg copper, nickel, chrome, tin). These low residual levels are especially critical for the production of flat products from the EAF. BHP's Port Hedland HBI facility is strategically placed to produce merchant HBI for markets in Asia, which is one the fastest growing sectors of the EAF industry [1]. The safe handling, stockpiling, ship loading and discharge of HBI from Port Hedland into Asia are therefore critical links in the Marketing chain, and are the focus of this work.

The FINMET process is an improved version of the FIOR process aimed at higher capacity and lower gas consumption. As part of the FINMET process development, a test batch of 40,000 t of beneficiated Mt Newman fine ore was processed by FIOR de Venezuela, in their existing HBI plant. This material has been used in a variety of EAF and BOS trials. A small portion was also set aside for these studies, and is referred to in this paper as BHP HBI.

2 BULK TRANSPORT AND HANDLING

HBI is a dense metallic product which can be handled in a similar manner to ore or scrap, using standard bulk materials handling equipment, eg, grabs, front end loaders, magnets and conveyor systems. The briquettes are pillow shaped, approximately 90 x 60 x 30 mm in size, and weigh 0.6 kg on average. The briquette density is above 5 t/m^3, with a bulk density of approximately 2.8 t/m^3 and an angle of repose of between 35 and 38°.

Bulk handling of any material will result in size degradation. The chips and fines generated during handling are undesirable as they lead to dust and yield losses when charging to the EAF.

Sampling of shipments of HBI to BHP Steel showed that fines based HBI degraded less during transport than other HBI types. To further investigate this trend, BHP Research developed a strength test to simulate the size degradation that HBI may undergo during typical bulk handling and shipping. The tumble test, similar to the current standard test for iron ore, confirmed the superior strength and abrasion resistance of the fines based product. Results of the tumble test for a high density fines based HBI, a pellet based HBI of similar density, and for a low density fines based product are shown in Figure 1. This test is currently under development as an ISO standard for HBI.

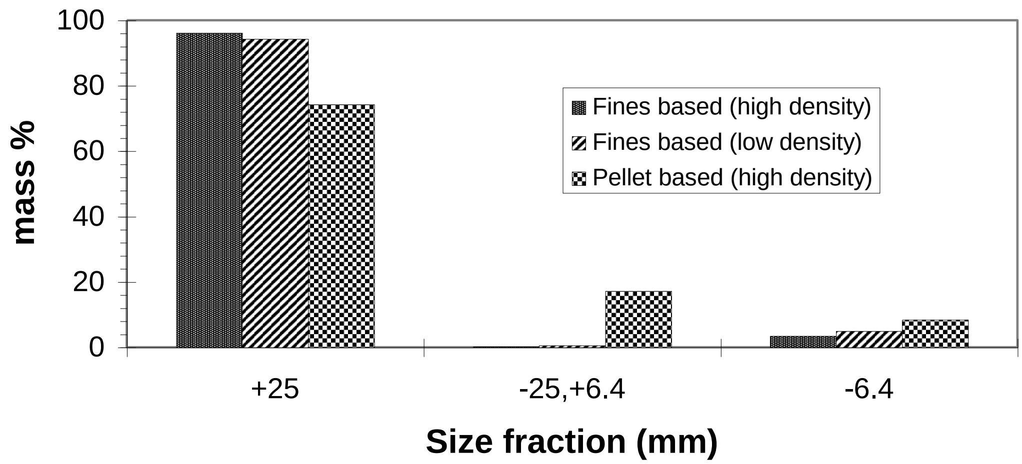

Figure 1. Comparison of size degradation in Tumble test, 500 revolutions.

3 DROP TESTS TO SIMULATE SHIP LOADING AT PORT HEDLAND

It is BHPs intention to load HBI at Port Hedland using the existing Finucane Island shiploader. HBI will typically be carried in handysize ships (45 000t dwt), however the possibility exists of using capesize ships (140 000t dwt) to transport a portion of the HBI produced to the East coast of Australia. This would involve a drop from the ship loading conveyor to the ship's tank top of up to 25 m, in contrast to the drop of 15 m for the handysize or handymax ships that are typically used for transporting HBI.

This work was undertaken to assess whether any damage was likely to occur to ships during loading of HBI, over that associated with loading lump iron ore. Lump ore is routinely loaded at average rates of up to 4-5000 tonne/hour at heights of up to 25 m. Size degradation of the HBI during loading was also assessed[2].

Samples of BHP HBI and lump iron ore were dropped from 15 and 25 metres onto a steel structure designed to provide a realistic simulation of the behaviour of the double bottom of a capesize vessel. The "tank top" test structure is shown schematically in Figure 2. This structure was 3.6 x 4.5 m in size, which is large enough to encompass one span between the ship's longitudinal and transverse girders with an overhang of >500 mm all round, to allow for the fact that the test structure existed in isolation of the surrounding tank top. The underside of the structure was coated with ballast tank paint to marine standards.

The material used to construct the test structure was 250 MPa grade steel which has a minimum yield strength of 250 MPa and a nominal hardness of 120-140 HV. BHP Transport advised that the steel grade used for the tank top plating of their bulk carrier fleet is Lloyd's Grade A, which has a minimum yield strength of 235 MPa and nominal hardness of 140 HV.

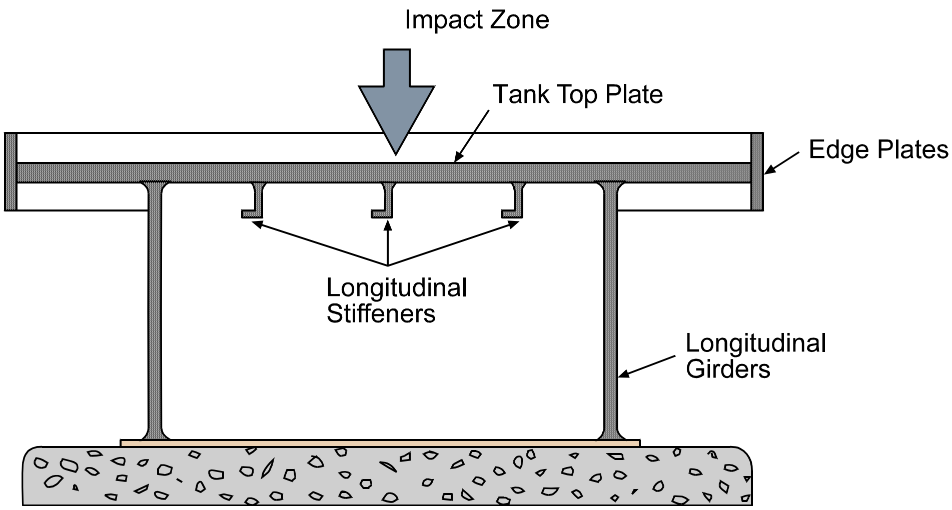

Figure 2. Schematic diagram of the tank top test structure. Sectional view through transverse centre line.

A series of linear variable displacement transducers (LVDT's) were mounted between the concrete base and the underside of the tank top plate to measure any permanent deformation of the top plate. Strain gauges were also mounted at critical locations underneath the top plate and on the webs of the three stiffeners. The gauges measured the shear strain in the stiffeners which was proportional to the load carried by each stiffener. These gauges were calibrated by placing known loads directly above the stiffener and recording the static response of the system. The data was collected by using an analog to digital converter card on a computer. The data was sampled at 1000 Hz to capture the peak dynamic response during the tests.

To simulate the stream of material from the ship loading conveyor, parcels of iron ore and HBI were dropped as a laminar stream from a steel hopper over a period of approximately two seconds at rates equivalent to approximately 2000 and 4000 tonne/hour. These rates cover the operating range of the proposed HBI loading system at Finucane Island which is specified at an initial loading rate of 2000 tonne/hour for HBI with a possible future maximum rate of 4000 tonne/hour (currently limited by the HBI stockpile reclaim system). An photograph of a test in progress is given in Figure 3.

These drops simulated the initial impact of material on the tank top plate. Subsequently loaded material would be expected to fall onto layers of existing material which would absorb some of the impact energy. Several HBI drops were therefore undertaken to test the reduction in impact forces due to the presence of an initial layer and to assess any reduction in HBI size degradation.

The peak strains recorded in the test structure are summarised in Figure 4. It is apparent that the peak strains measured in this simulation for HBI drops were equivalent to those caused by iron ore. It is therefore expected that repeated loading of HBI would be no different to iron ore loading in terms of stress in the tank top.

For both iron ore and HBI loading at 25 m drop height, the measured and/or predicted peak strains may exceed the yield strength of the plate resulting in some permanent deformation. This would be expected to contribute to "dishing" of the tank top over many years, as currently experienced with iron ore loading. The extent of deformation would be dependent on:

A) the point of impact relative to the underlying structure
B) the actual yield point of the plate (compared with the minimum values quoted)
C) the tank top plate thickness

Figure 3. Photograph showing an overview of a drop test in progress. BHP HBI at an equivalent rate of 4000t/hr, from 25 m, onto an existing HBI layer.

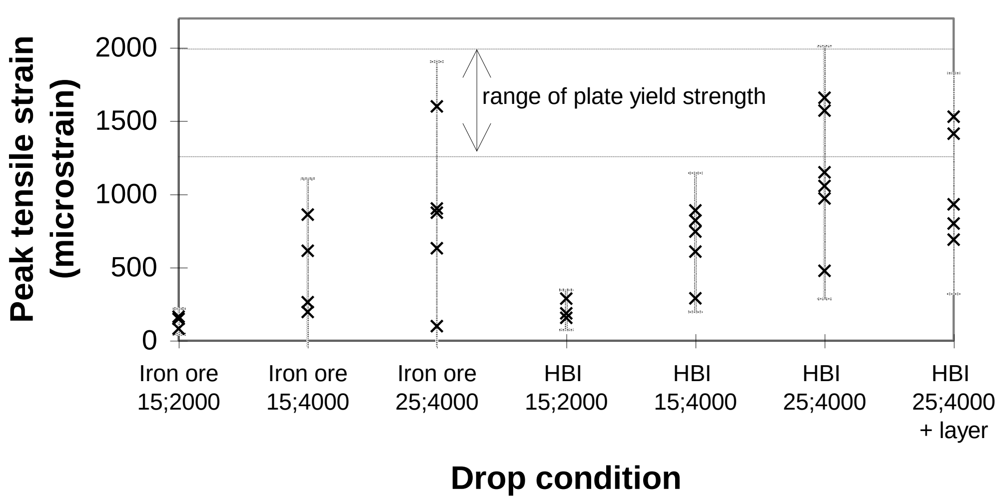

Figure 4. Peak tensile strain measured by the central strain gauge vs. drop condition for all drops. X axis labels are (material)(drop height)(equivalent loading rate). Error bars plotted are ±2 standard deviations.

Initial layers of HBI and iron ore up to 230 mm in depth had no significant effect on strain measured in the plate. As greater depths of material build up on the plate the strain would be expected to decrease, however it was not practical to test this hypothesis during these simulations.

Deflection measurements made using LVDTs, and a manual profile of the plate surface, showed no measurable permanent deflection of the plate after 31 drops, of which 19 were HBI.

The results of HBI sizings following the drop tests are summarised in Table 1. These results suggests that drop height is the major factor influencing the breakage of HBI and that the presence of an impact absorbing layer of HBI up to 230 mm in thickness does not diminish the rate of chips and fines generation. Subsequently loaded material would be expected to degrade less as the cargo built up in the hold and the drop height reduced. Note that the HBI used to perform these tests had been transported and handled previously. “Fresh” HBI may degrade to a slightly greater extent during loading than that measured during these tests. For the HBI drops, the gain or loss of material for each drop was in all cases less than 1% of the mass of material dropped.

Table 1. Summary of the additional HBI size degradation caused by the drop tests. The increases in chips (-25.4 +6.3 mm fraction) and fines (-6.3 mm fraction) are expressed as percentages of the material dropped.

Drop height	Equivalent loading rate (t/hr)	Increase in Chips	Increase in Fines
15 m	2000	2.0	0.9
15 m	4000	1.9	0.9
25 m	4000	3.8	1.7
25 m (150-230 mm initial layer)	4000	3.8	1.7

The International Maritime Organisation code[3] for ocean transport of HBI specifies that the content of -4 mm material in any HBI cargo shall be less than 5%. Given the results above, the contribution to the fines level of a cargo due to loading from a conveyor belt at heights up to 25 metres will be less than the maximum specified.

4 STORAGE

HBI can be stored in open stockpiles in a similar manner to scrap steel or pig iron. Previous work has shown that rainfall only wets the surface layer of an HBI stockpile, protecting material in the core of the stockpile from corrosion (Jensen and Smailer [4], Hassan et al [5], anon [6]).

To test the corrosion behaviour of BHP HBI a 65 t stockpile was built next to an ocean breakwall on the outer harbour, Port Kembla, and the corrosion of surface briquettes measured over time. This was a severe corrosion test, as the HBI pile was small and in a salt spray environment, and the corrosion rates measured were expected to be greater than those likely in practice. The loss of metallisation (defined as the percentage of total iron in the HBI that is present as metallic iron or iron carbide), over time is presented in Figure 5, with data from the literature for comparison. The initial rate of metallisation loss for the BHP HBI was rapid in comparison to the examples plotted in Figure 5. This may be due to the salt spray in the maritime environment. Metallisation loss due to further exposure was comparable to the examples in the literature.

After one year the pile was dissected and corrosion vs depth determined. It was found that the majority of metallisation loss occurred in a surface layer approximately 0.2 m mm thick, and a transition layer approximately 0.5 m thick, with a relatively unaffected core. These results are consistent with measurements made on a 600 tonne stockpile after 6 months[6], suggesting that the layer thickness is independent of stockpile size. The overall metallisation loss for this 65 tonne experimental stockpile was calculated to be 8%. For the larger stockpiles likely in practice, the surface layer would represent a much smaller fraction of the total volume of a stockpile and therefore have less impact on the overall metallisation loss for the stockpile.

In further work on corrosion of HBI, different briquette types were arranged in single layers on trays and exposed to a maritime atmosphere. Exposure time had the largest effect on metallisation loss, however, a correlation between metallisation loss and HBI density was also found, as shown in Figure 6. HBI fines and chips were found to corrode to a greater extent than whole briquettes, as shown in Figure 7.

These results highlight the importance of briquette density, as high density briquettes typically degrade less on handling and are inherently less susceptible to corrosion.

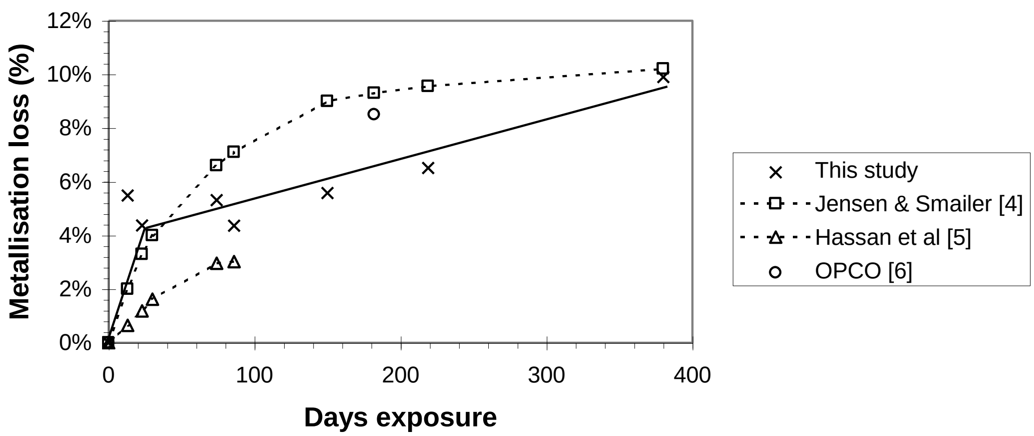

Figure 5. Metallisation loss vs exposure time for 65 t BHP HBI stockpile, maritime conditions.

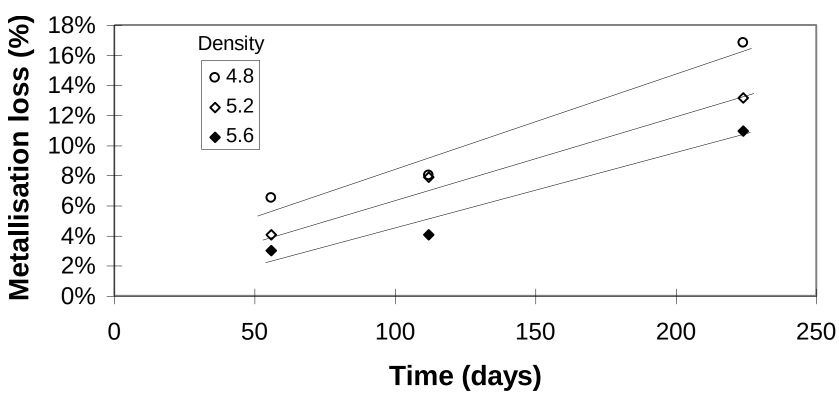

Figure 6. Metallisation loss with respect to density for briquettes in tray test exposed to maritime conditions.

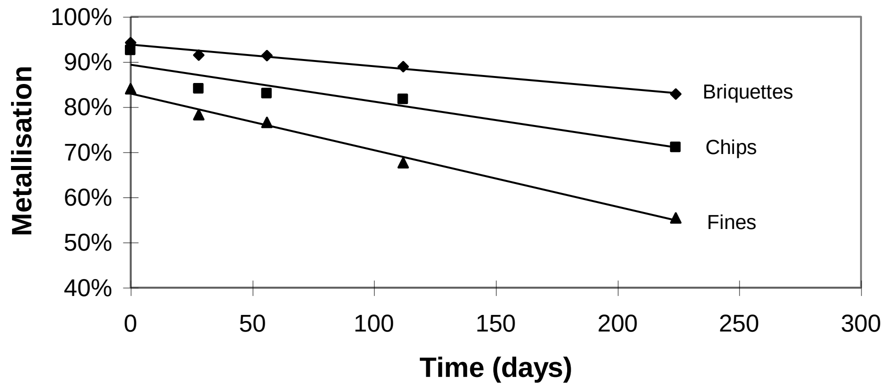

Figure 7. Metallisation vs time for briquettes, chips and fines in tray test, after exposure to maritime conditions.

5 CONCLUSIONS

HBI produced by the FIOR fines based process was found to be stronger than pellet based HBI in tumble tests intended to simulate typical materials handling operations.

Drop tests were carried out to simulate loading of HBI into handymax and capesize ships:

- Stresses measured in the tank top plate were similar for HBI and Iron Ore. The peak stresses exceeded the yield strength of the plate during some 25 m tests, although no permanent deflection of the plate was measured. Some permanent deformation (dishing) of the tank top would therefore be expected to occur after repeated loading, as currently experienced after loading of iron ore. No additional damage is expected.
- Some size degradation of the HBI was observed during the tests. For the 25 m drops the increase in fines content (-6.3 mm size fraction) for the initial portion dropped was less than 2% and for the 15 m drops less than 1%. Subsequently loaded material would be expected to degrade less as the cargo built up in the hold and the drop height reduced.

Corrosion of HBI during storage was found to be predominantly limited to the outside layers of a stockpile. BHP HBI was found to have similar corrosion resistance to other commercial HBI types.

Corrosion rate was found to be a function of briquette density and particle size, ie briquettes, chips and fines. High density briquettes are advantageous as they have a lower inherent corrosion rate and are more resistant to size degradation, and are therefore expected to exhibit lower overall corrosion rates.

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