4 DISCUSSION

The standard reduction disintegration test results indicates that at least 80 percent of the Northern Cape lump ore remains larger than 8mm and that it should not present any problems in a shaft furnace. It must be recognized that the conditions in the standard test represents only a small fraction of the conditions in the complete shaft furnace operation. This study has indicated that burden size, gas composition, reduction temperature reduction time and microstructure do have an effect on the performance of Northern Cape ore in a shaft furnace and will be discussed in detail.

4.1 EFFECT OF BURDEN SIZE

The percentage unchanged material (material remaining in the same size before and after the reduction disintegration test) increased from 47 percent (-25+20mm) to 72 percent (-10+8mm) with a decrease in burden particle size. However, the standard reduction disintegration test results indicated that, irrespective of the burden size, at least 80 percent of the Northern Cape lump ore remains bigger than 8mm and should not present any problems in a shaft furnace. These findings correlates with those of Loo and Bristow[xii] that also found particles of very similar size to the original material, suggesting that some particles are very tough and do not degrade at all. They found that, although cracks formed in lump ores, the crack propagation process appears to be more random than for sinters, where there are clearly paths of least resistance for the cracks to run.

4.2 EFFECT OF GAS COMPOSITION

The results obtained with the H_2 in the reduction gas also indicate that factors other than percentage reduction influence the degree of reduction disintegration. As Loo and Bristow indicated, H_2 has an effect on the percentage reduction. This study however indicates that lower percentages (less that 5 percent) of H_2 do not have an effect on the degree of reduction disintegration (**Figure 113**). With 10 percent H_2 however the degree of reduction doubled while the percentage fine material increased only from 9 to 13 percent. This compares well with the findings of El-Geassy[xix] (**Figure 18**) that indicated that when H2 is introduced into the reduction gas the compacts swelled at the initial stages of reduction but ended up with overall contraction for the completely reduced compacts.

Contrary to the testwork conducted by Gudenau et al[xxii] no difference was observed in the appearances of the cracks when hydrogen was used as reduction gas compared to carbon monoxide. This might be because of the high temperature (850°C) considered by Gudenau et al.

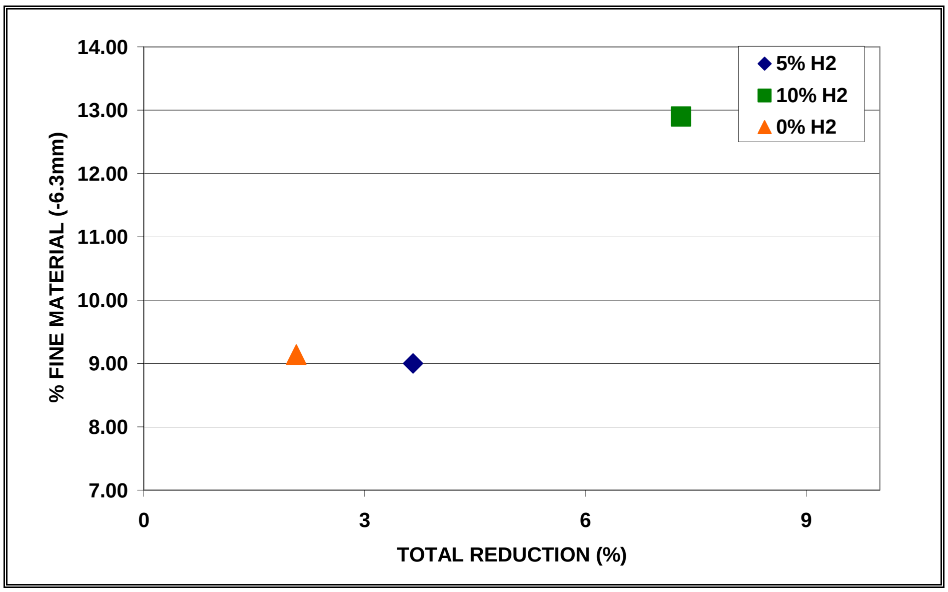


Figure 113: Effect of gas composition on the percentage fine material (-6.3mm) vs the total percentage reduction.

4.3 EFFECT OF REDUCTION TEMPERATURE AND REDUCTION TIME

Figure 114 indicate that reduction disintegration is most severe between 550°C and 750°C for Northern Cape STD. At temperatures above 800°C, more than 80 percent of the particles remain the same size. Similar results were obtained in test 21 of the high temperature microscope, where little cracking was observed at 700°C. This correlates with the work done by Husslage et al[xvii] that indicated that this behaviour could be related to a change in the morphology and the fracture toughness of the magnetite at higher temperatures. Increasing the reduction times, **Figure 41** showed a general upward trend in the percentage of fines generated with an increase in the reduction time. Although there is a decline in the fines generated at higher temperatures, **Figure 114** indicates a general increase in the percentage reduction with an increase in the reduction temperature. **Figure 115** indicates that at 600ºC an increase in the reduction time leads to an increase in the percentage reduction. At 500ºC and 700ºC, the effect is clear.

The results indicate that it is important to manage the temperature in the blast furnace and the COREX shaft as well as the time spent at temperature to minimize the amount of fines generated.

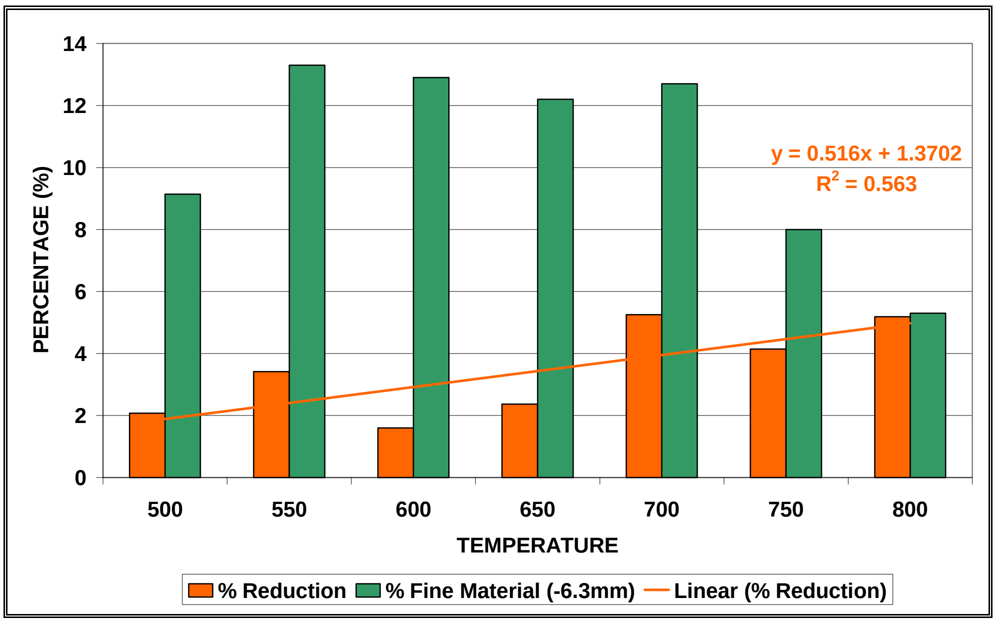


Figure 114: Effect of temperature on the magnitude of breakdown and reduction during reduction disintegration tests.

4.4 EFFECT OF REDUCTION

The degree of reduction was determined for the coarse (+6.3mm) and fine (-6.3mm) fractions, as present after reduction. **Figure 116** is a plot of the coarse and fine fractions vs the fractional reduction of the specific fractions for all the samples tested, that is for a range of temperatures, gas compositions, feed sizes and times. The fines are significantly more highly reduced than the coarse material, as expected from the effect of surface area on reduction rate. What is notable is that there is no strong correlation between the amount of material remaining in the +6.3 mm fraction, and the percentage reduction of this coarse fraction. This lack of a relationship, between disintegration and the degree of reduction of the remaining coarse material, is in contrast with the observation that the degree of fines formation increases with the percentage reduction *of the whole sample*.

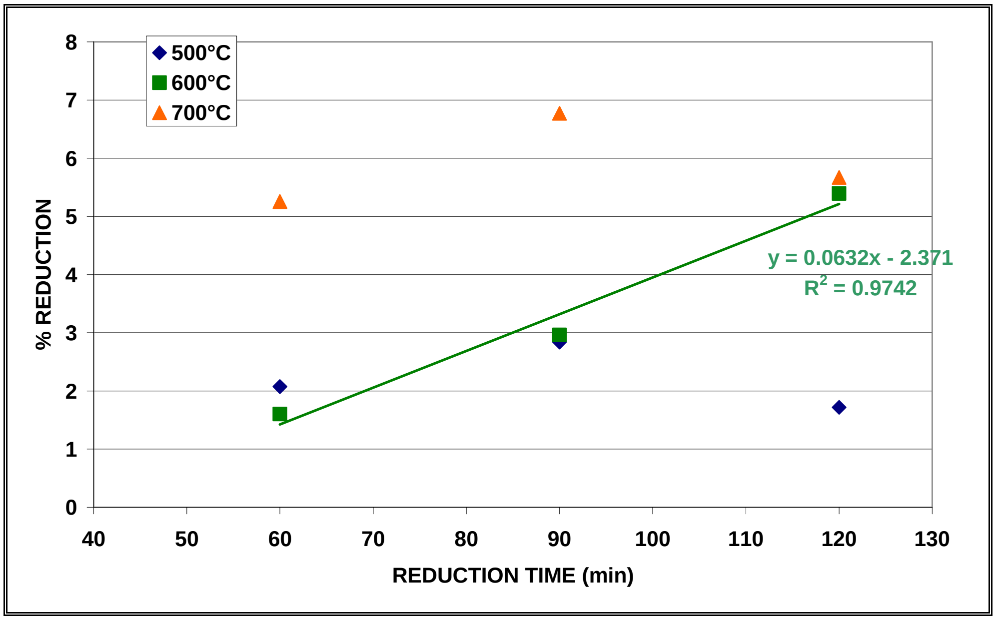


Figure 115: Effect of temperature and reduction time on the total percentage reduction vs the reduction time.

Figure 116 suggests that the observed relationships between the *overall* degree of reduction and fines formation may simply be an artifact: the mechanistic relationship may be that material which form more fines are more highly reduced simply because the fines once formed, have higher reduction rates. In this view, fines formation would be the cause and the degree of reduction would be the effect. The results obtained in the present study did not allow this possibility to be tested further, but it would be an interesting topic for further study.

Although the general thinking is that the disintegration is mainly due to the reduction process, no direct correlation could thus be established between the percentage reduction and the percentage fines generated. Clearly other factors in addition to the reduction process influence the degree of reduction disintegration. That is, the differences in disintegration behaviour of different ore types are not just caused by differences in reduction rate.

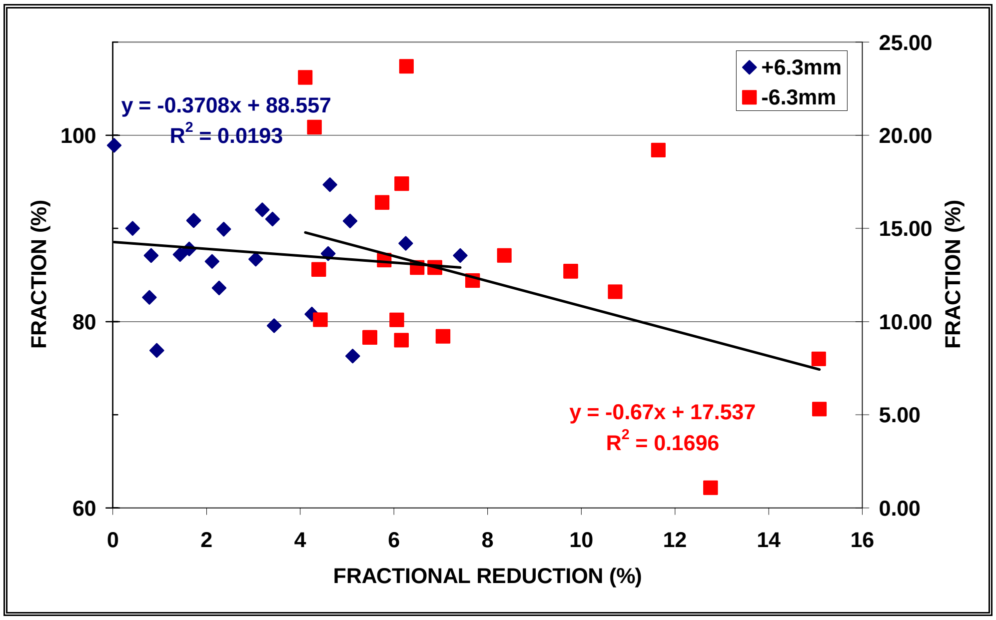


Figure 116: Fractional reduction of the +6.3mm and -6.3mm fractions for all the samples.

4.5 ORE COMPOSITION AND MICROSTRUCTURE

The results indicate that ore composition and microstructure have a definite effect on the degree of reduction disintegration. The fraction of material remaining in the +8mm size range after reduction varied between 70% and 98% for the different ore types (**Figure 117**). **Figure 118** and **Figure 119** however indicate that there is no correlation between the chemical analysis (gangue content) and the percentage fines generated. This conclusion is supported by **Figure 120** which plots the fraction of cracks which are associated with gangue minerals vs the percentage gangue minerals in the samples. Points plotted above the black line would indicate a preference of cracks forming in gangue minerals, while points plotted below the black line would indicate a preference to cracks forming in the iron oxide matrix. From **Figure 120** it is clear that the cracks formed randomly with no preference to gangue minerals or iron oxide. This is in line with the ore structure chart developed by Marten et al[xxv] that indicated that although various micro-structural features impacts in the reduction disintegration of lump ores, gangue minerals is not considered to be an important one.

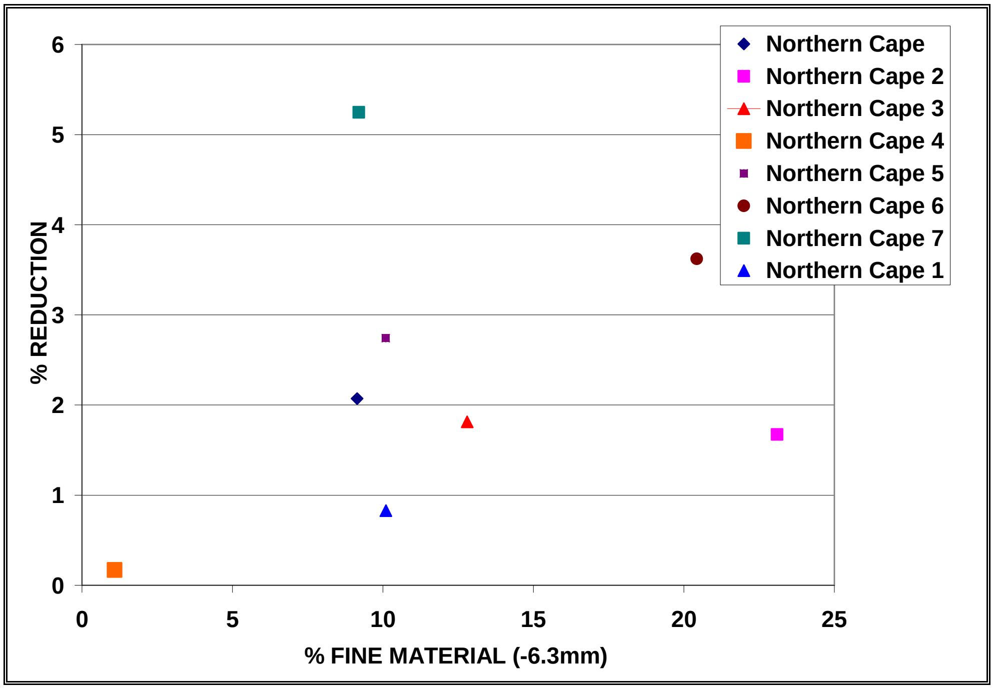


Figure 117: % Fine material (-6.3mm) vs % reduction for the different ore types.

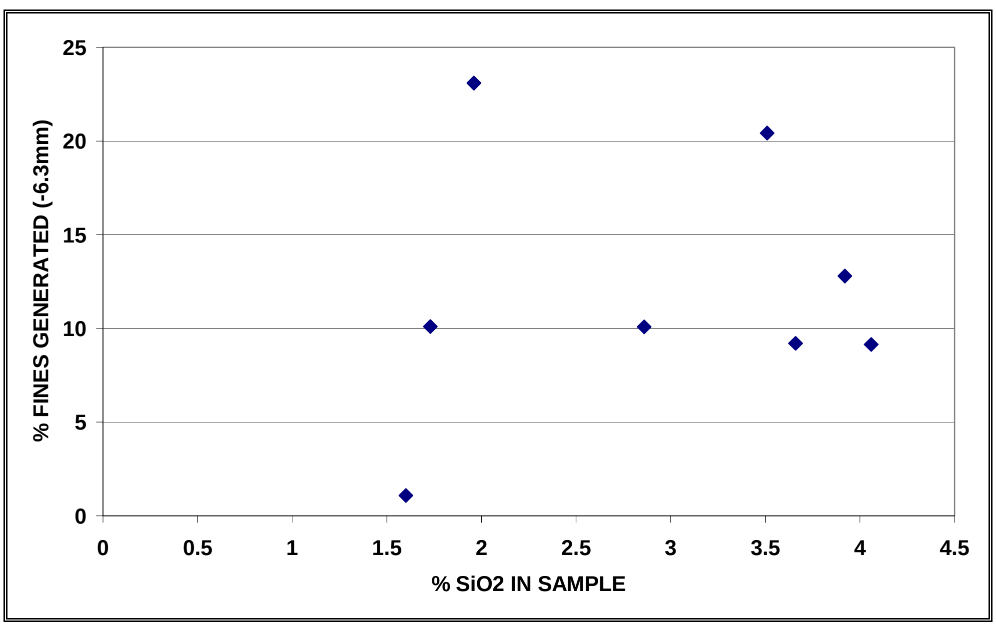


Figure 118: % Fine material (-6.3mm) vs % SiO_2 in samples for the different ore types.

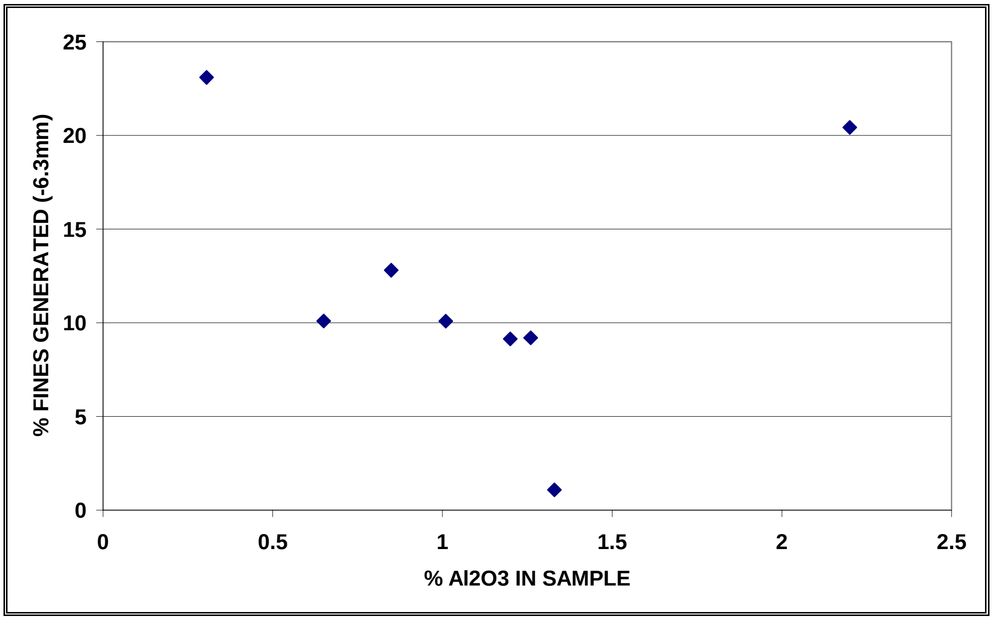


Figure 119: % Fine material (-6.3mm) vs % Al_2O_3 in samples for the different ore types.

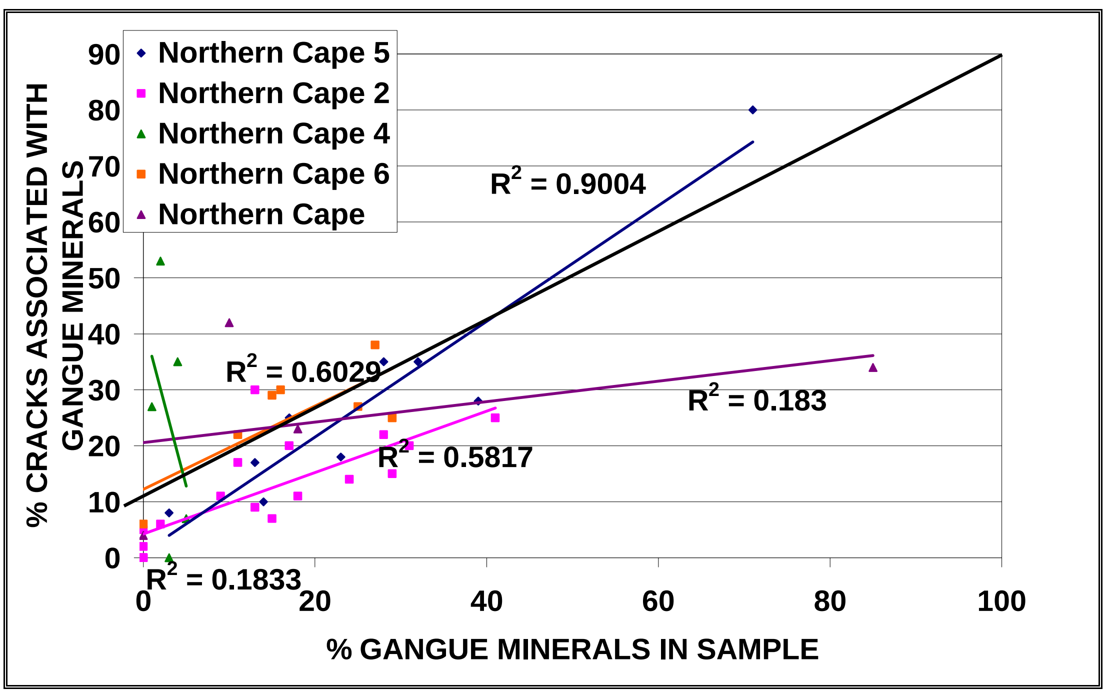
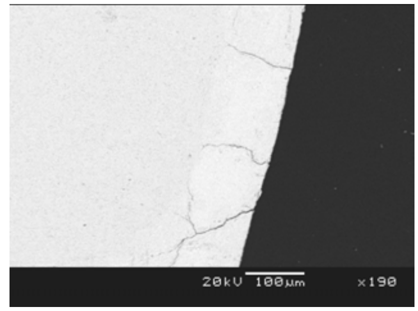


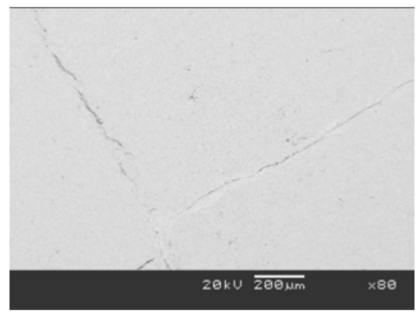
Figure 120: Percentage cracks associated with gangue minerals vs the percentage gangue minerals in the sample.

From the SEM investigation the appearance of cracks was classified in four distinct groups:

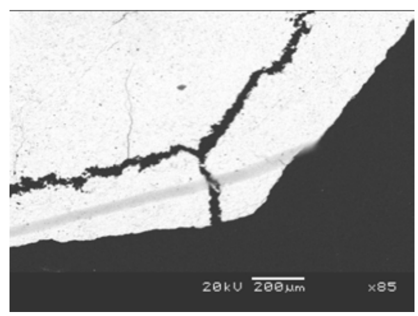
- Radial fractures occurring on the edges of particles penetrating the sample to the depth of reduction. These fractures appear to be directly related to the volume change during reduction.



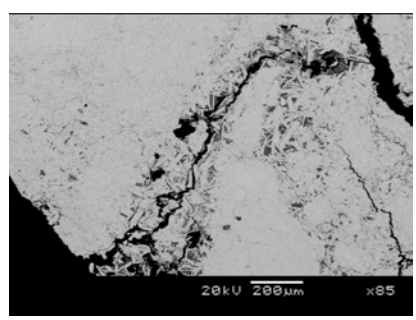
- Internal fractures that occur regularly spaced at right angles to one another – forming a matrix of internal cracks.



- Fractures that occurred perpendicular to the edge of the sample, where the sample has been reduced.



- Fractures associated with gangue minerals or internal structures (internal foliation, open pores or acicular hematite)



Features such as internal foliation fabric and/or bedding planes have a significant influence on the orientation of fractures as the foliation/bedding plane is the primary plane of weakness in the sample. However, cracks occurred randomly in samples where internal foliation fabric was present. Cracks that occurred perpendicular to internal foliation fabric was also observed (**Figure 121**). The results indicated that the presence of gangue minerals alone do not cause fractures to form. However, the gangue minerals do influence the direction and intensity of fractures. It was observed that the presence of gangue minerals only appears to have an impact on the fracture path up until a certain size of fracture is reached. Thereafter with large fractures, the fracture propagates irrespective of the presence or absence of gangue minerals. However, the presence of gangue minerals does not imply crack formation, as was shown previously.

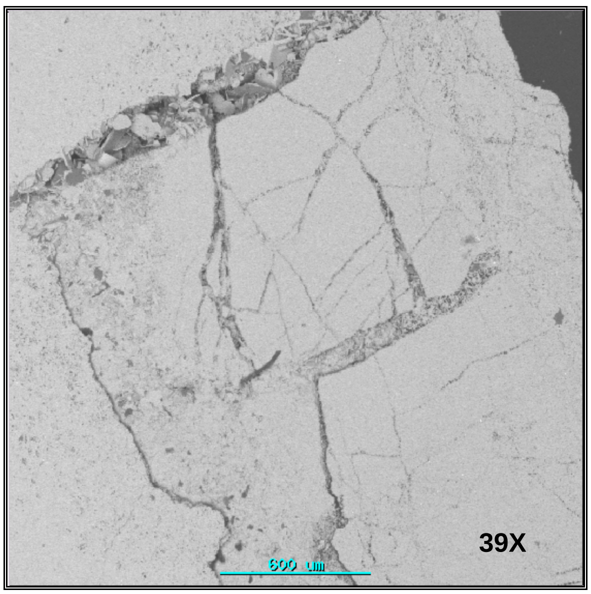


Figure 121: SEM images of the -12+10mm fraction after reduction disintegration test for Northern Cape OT 2

Hardness tests of the different minerals present in the ores would have been valuable to understand this phenomenon better. Although it was never observed (during the SEM analysis or the high temperature microscope work) that the formation of a crack was influenced due to a new mineral coming in the path of the crack as was observed by Loo and Bristow[xv], fractures often dilate as they pass through gangue minerals and a secondary network of smaller fractures is often developed, especially in quartz (**Figure 122**). No occurrences were observed where secondary fractures extended into the surrounding hematite. It appears as though the more brittle gangue mineral would absorb the stresses by breaking up extensively – as indicated in **Figure 122**, and thus "stop" the crack of propagating. This however also occurred without the presence of a large crack as indicated by **Figure 123**, and not at all as indicated by **Figure 124**.

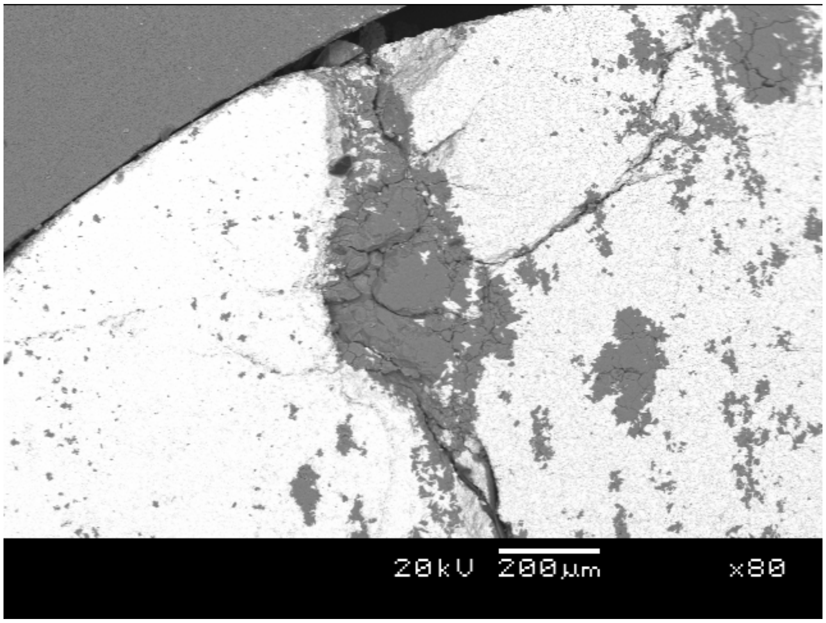


Figure 122: Fracture forming secondary cracks in quartz.

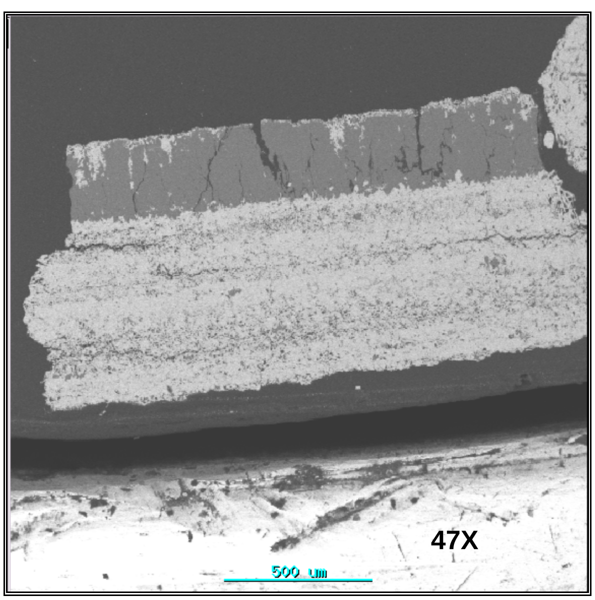


Figure 123: SEM images of the -2+1mm fraction after reduction disintegration test for Northern Cape OT 2

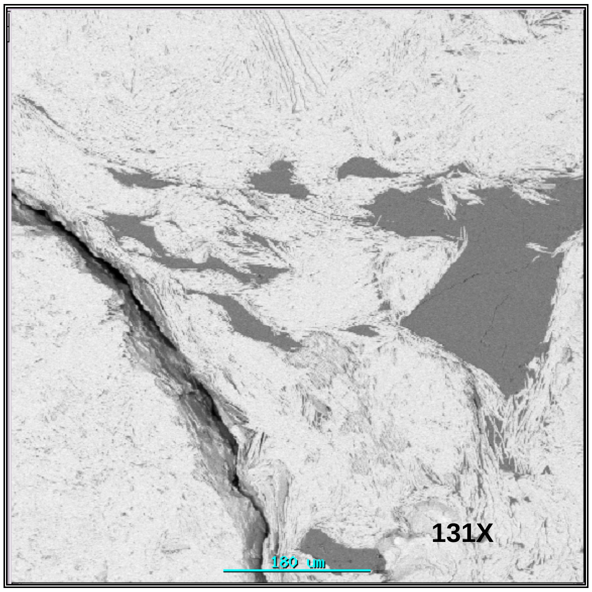


Figure 124: SEM images of the -8+6.3mm fraction after reduction disintegration test for Northern Cape OT 4

Porous samples appear to be less fractured as the open pores impede fracture formation as the pores is able to accommodate the strain of the volume increase during reduction.

Where there are no compositional or textural features in a sample that can have an influence on fracture propagation then fractures will form at regular intervals with similar orientations, often at right angles to one another.

Table 18 which gave a summary of the high temperature microscope work indicated that most of the cracks occurred as smaller internal cracks (that does not lead to breakdown) or border cracks (which relates to small particles breaking off the edges) rather than large cracks that would split the sample. This conclusion is supported by **Figure 125** which plots the percentage fines generated during reduction disintegration vs the inverted average particle size. There is a strong relation between the original particle size and the fraction of fines formed during reduction disintegration for particles smaller than 16mm which confirms that fines are created by spalling from the outside surface. It however appears that the largest particles deviate from proportionality.

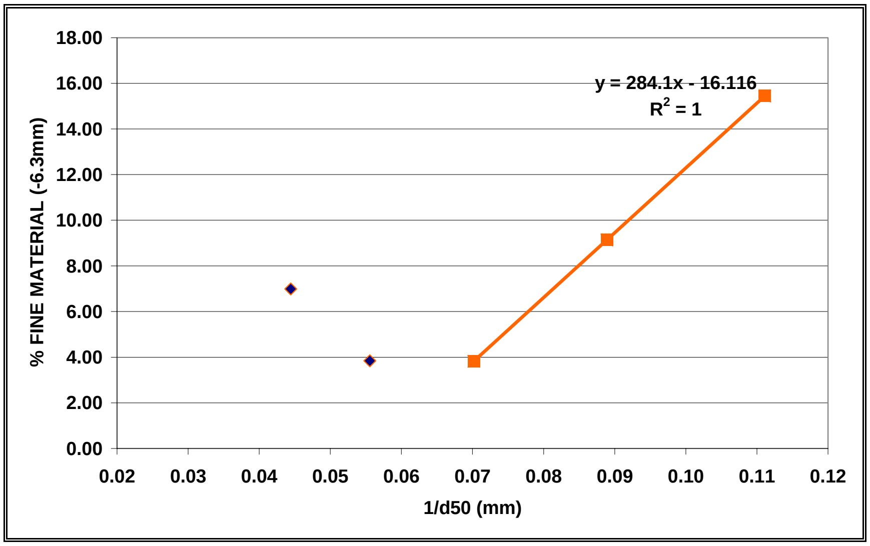


Figure 125: Effect of burden size on the percentage fine material generated during reduction disintegration tests.

This is also confirmed by the size distribution of the ore after reduction disintegration as illustrated in **Figure 126.** The graph indicates that for larger particles (-25+20mm) less than 50 percent of the particles are unchanged, while 70-80 percent of the particles is unchanged when smaller particles are tested.

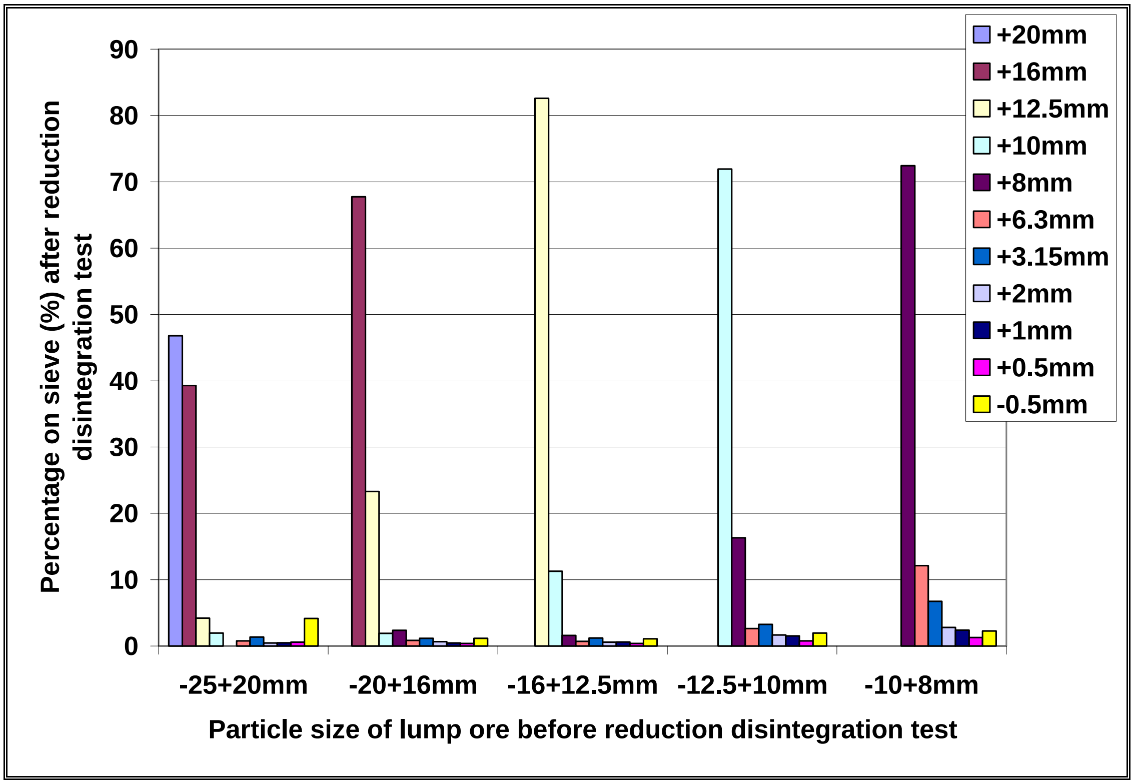


Figure 126: Size distribution of Northern Cape STD ore after reduction disintegration test for different ore sizes as raw material.

This study has indicated that at although Northern Cape lump ore consist of various ore types with varying microstructures, the degree of reduction disintegration depends mostly on the furnace conditions. Indeed, this study has shown that reduction disintegration increases with higher percentages of H_2 and longer periods in the 500ºC-750ºC temperature zone. An inverted relationship between the average particle size and the percentage of fines generated was established for particles smaller than 16mm which confirms that most of the disintegration is due to spalling from the edges rather than particles breaking into smaller clumps. Although the general thinking is that the disintegration is mainly due to the reduction process, no direct correlation could however be established between the percentage reduction and the percentage fines generated. It was also indicated that the presence of gangue minerals alone do not cause fractures to form. However, the presence of gangue minerals does influence the direction and intensity of fractures.

The high temperature microscope testwork revealed that for most of the samples, an incubation period was observed before the first cracks were formed. No crack propagation was observed after the initial cracking of the sample – even in tests extended to more than three hours.

The results indicate that it is important to manage the temperature in the top of the blast furnace and the COREX shaft as well as the time spent at temperatures below 750°C to minimize the amount of fines generated.

5 RECOGNITIONS

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