Comparison of UCS to Bond Work Indices

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Abstract

Unconfined Compressive Strength (UCS) is a commonly used rockmass strength measurement used by rock mechanics practitioners. This paper examines potential relationships between UCS and Bond Work Index values (crushing, rod mill and ball mill). Data from 11 mines located around the world is analysed for correlations between UCS and various Wi values.

Introduction

Need to accurately predict future mine and mill production rates requires a knowledge of ore grindability well in advance of when ore are actually mined. Traditional measurements of ore grindability are the Bond Work Index (Wi) values (Bond, 1952), divided into a low energy crushing work index (Wi_C) for coarse rocks (75-50 mm), a rod mill work index (Wi_{RM}) for intermediate sized particles (25-3 mm), and a ball mill work index (Wi_{BM}) for small particles (<3 mm) (Ammtec, 2000). Laboratory testwork is required to determine these Work Indices, and each test requires carefully collected samples of rock that is representative of future mill feed. Sample sizes for Wi tests are reasonably small (eg. 10 kg for Wi_{RM} test) and can be obtained from drill core.

Most mines do not have the apparatus on-site to perform Wi tests and must send ore samples to an off-site laboratory. This is one reason why it is uncommon for an operating mine to perform Wi testwork on future pit benches. Rock mechanics testing equipment is more common at minesites; thus, UCS values may be determined easily and at minimal cost. This paper presents the result of an investigation of using the easy to obtain UCS to estimate the more elusive Wi values.

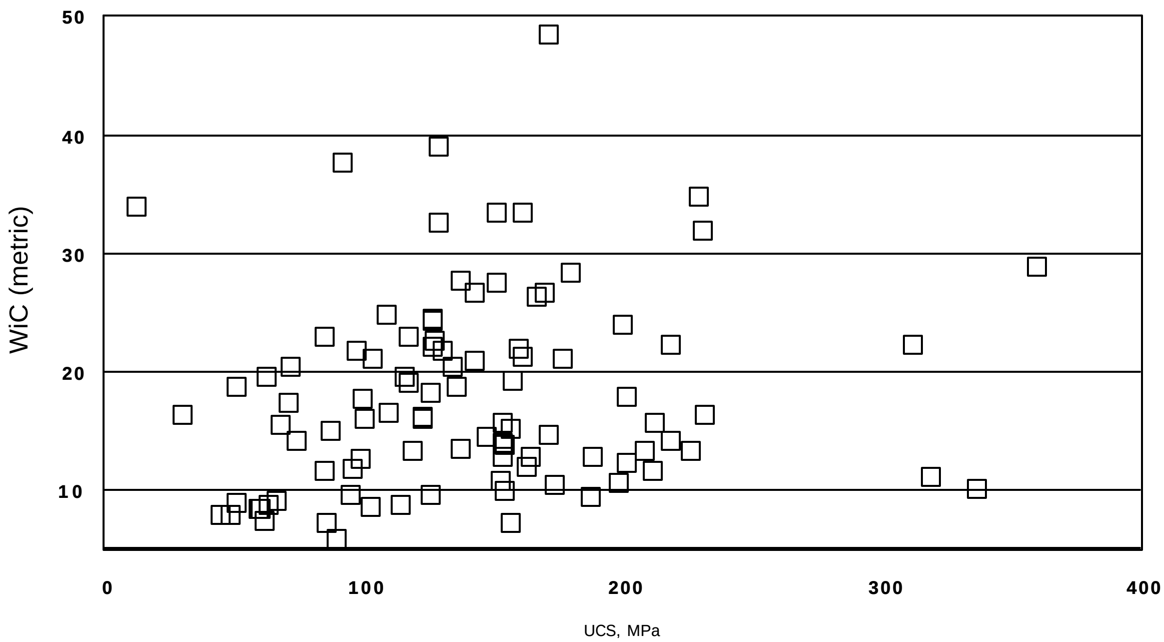
Method

UCS and Wi values were compiled from the archives of Fluor Daniel Wright in Vancouver and plotted in standard computer spreadsheets. Mines selected represented several major mining districts and encompassed a range of ore UCS from less than 50 MPa to over 300 MPa. Graphs were visually interpreted, and only if a visual pattern was revealed were regressions performed on the data set.

Results

Results are presented as a series of graphs. Figure 1 displays the measured crushing Work Index versus UCS for all mines in the data set.

FIGURE 1: BOND CRUSHING WORK INDEX v. UNCONFINED COMPRESSIVE STRENGTH



The scatter of the points in Figure 1 indicates no correlation between crushing work index and UCS. There is no generalised relationship between the two parameters over the global data set.

FIGURE 2: BOND CRUSHING WORK INDEX v. UNCONFINED COMPRESSIVE STRENGTH (ordered by mine)

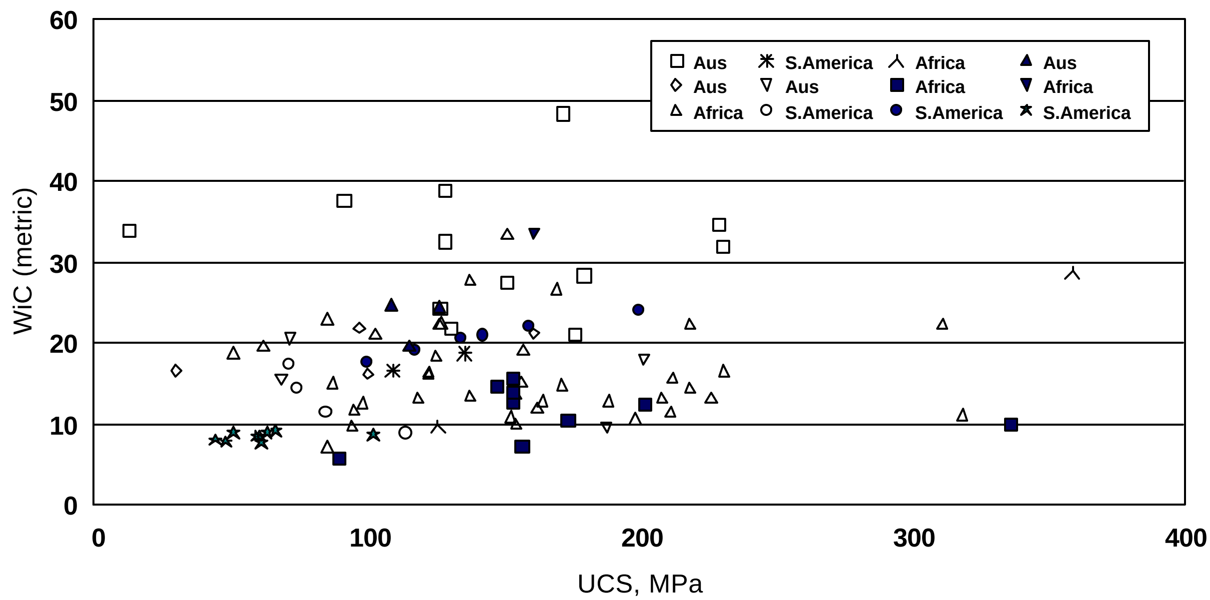
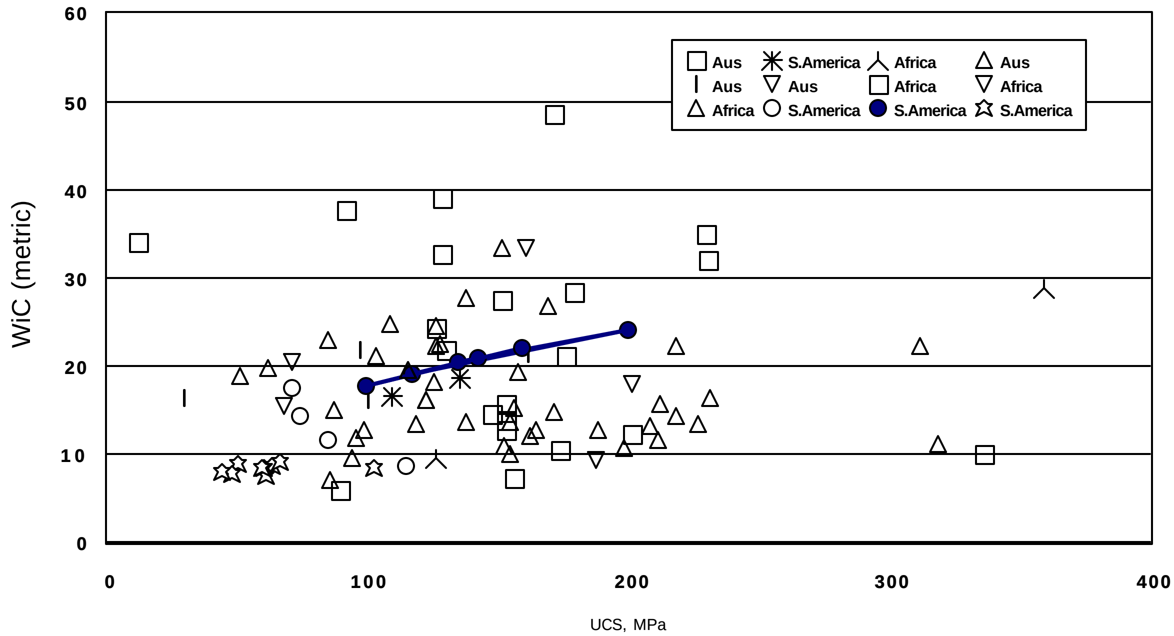


Figure 2 displays the global data separated by mine.

Most of the mines examined do not have a significant correlation between Wi_C and UCS. Many of the mines examined did not have enough data points to make a significant judgement about relationships.

FIGURE 3: BOND CRUSHING WORK INDEX v. UNCONFINED COMPRESSIVE STRENGTH (highlighting single Chilean mine)



Only one mine from Chile showed any significant positive relation between the two parameters, as shown in Figure 3. Geologists at this mine site report that the ore has a low fracture frequency relative to other orebodies.

FIGURE 4: BOND CRUSHING WORK INDEX v. UNCONFINED COMPRESSIVE STRENGTH (highlighting three rock types)

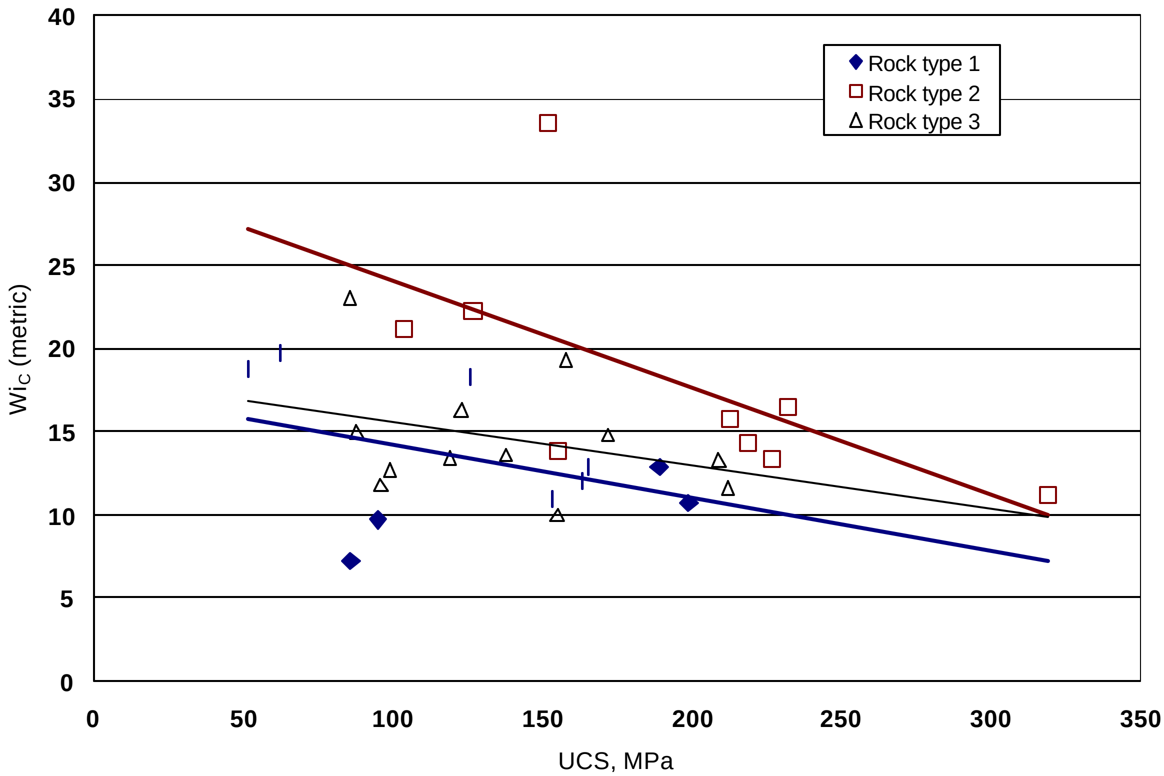
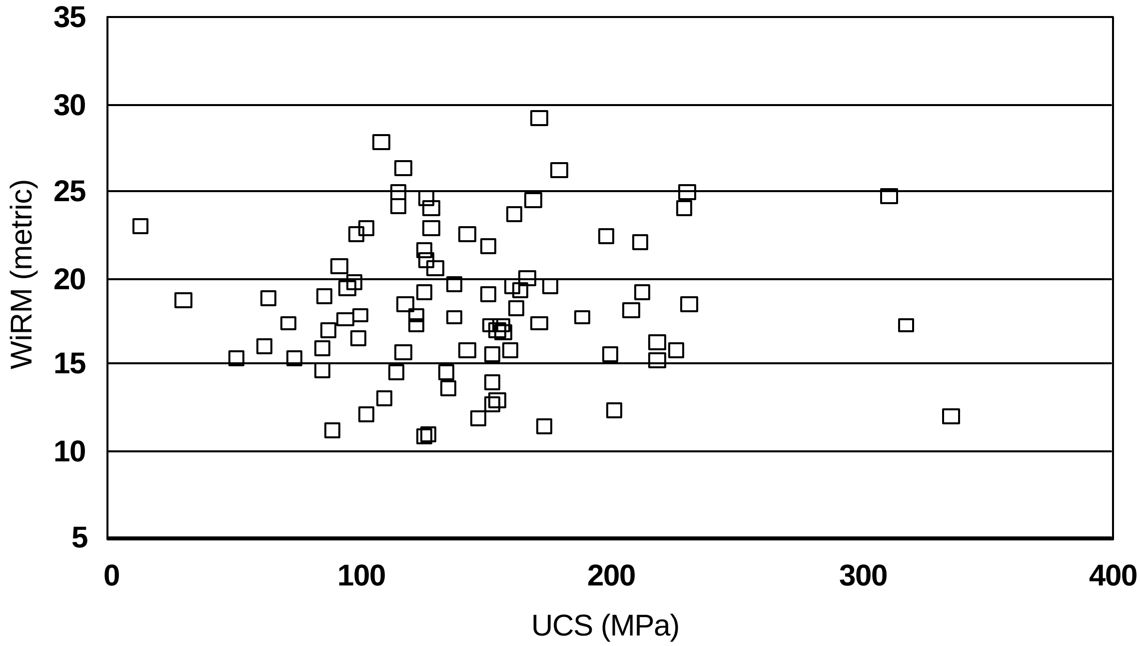


Figure 4 displays Wi_C and UCS values separated by the major rock types from a single African mine. The three rock types do show a mild correlation between crushing Work Index and UCS (R^2 values between 0.1 and 0.4).

Unfortunately, the correlation observed does not make sense: the correlation is expected to be positive (increasing towards the right) rather than negative (decreasing towards the right). A rock with a high UCS is more resistive to breakage by compression; but crushing is the mechanism of breaking rocks by compression. It is counterintuitive for a rock with a high UCS to have a low crushing Work Index. Therefore this result is considered unreliable and use of UCS to estimate Wi_C is not recommended for this mine.

FIGURE 5: BOND ROD MILL WORK INDEX v. UNCONFINED COMPRESSIVE STRENGTH



The lack of fit observed relating the crushing Work Index was expected to carry over to the other Bond Work Indices. Figure 5 displays the plot of rod mill Work Index (Wi_{RM}) versus UCS. These parameters also display no recognisable relationship.

FIGURE 6: BOND BALL MILL WORK INDEX v. UNCONFINED COMPRESSIVE STRENGTH

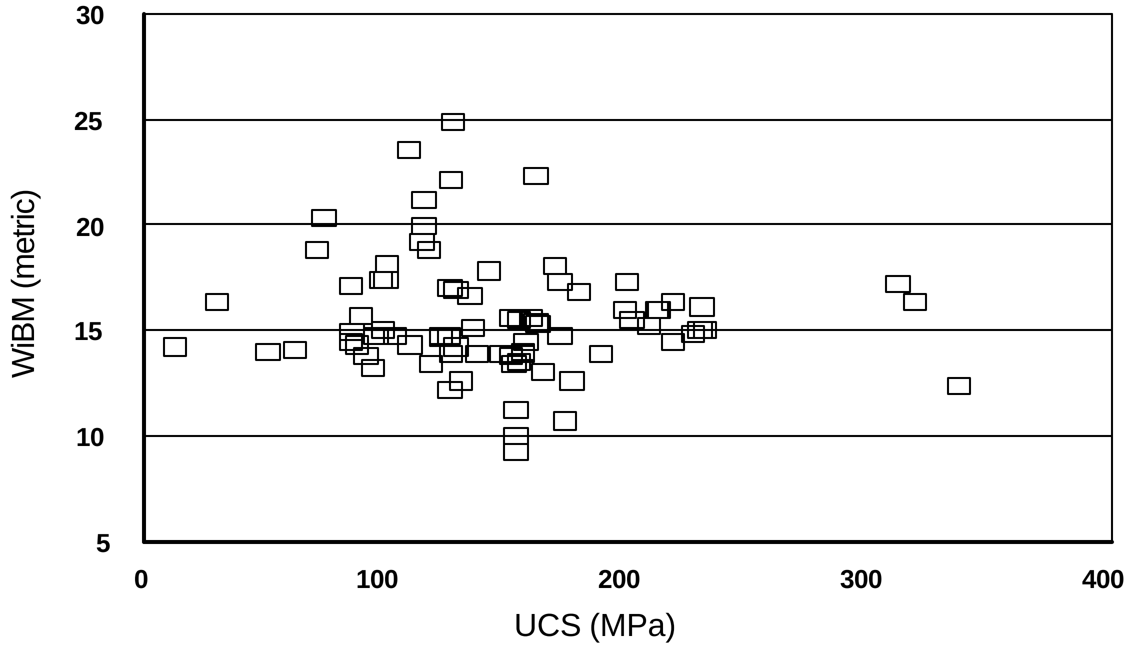
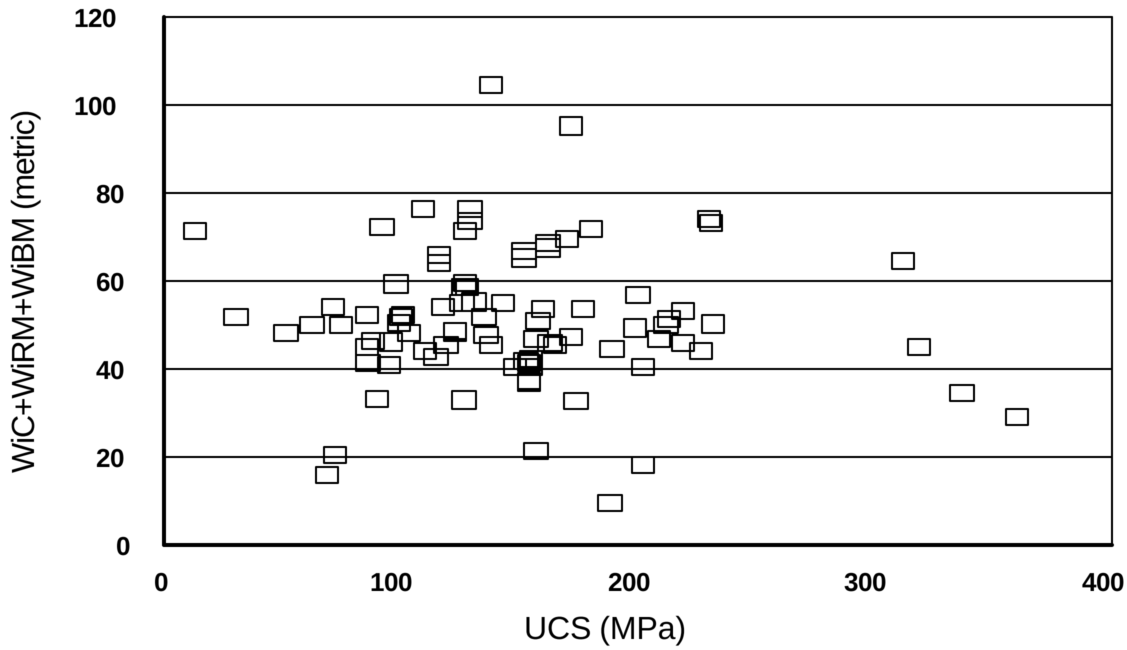


Figure 6 displays the plot of ball mill Work Index (Wi_{BM}) versus UCS. Still no relationship is observed.

FIGURE 7: SUM OF BOND WORK INDICES v. UNCONFINED COMPRESSIVE STRENGTH

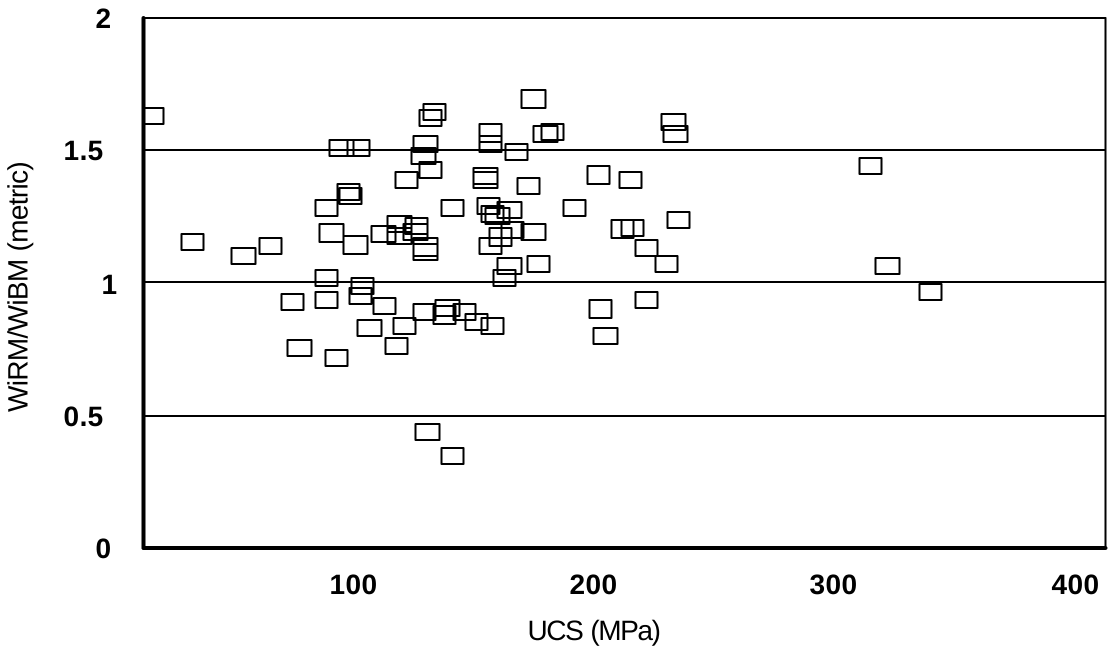


None of the individual Work Index versus UCS graphs displayed a correlation with Unconfined Compressive Strength. Figure 7 shows an attempt to relate the sum of all Bond Work Indices to the UCS. The Y-axis on this graph measures $Wi_C+Wi_{RM}+Wi_{BM}$.

The sum of the Bond Work Indices fails to show a relationship to UCS.

A related graph plotted UCS versus the total comminution energy required to grind a 100 mm rock to 200 microns. The distribution of points was similar to Figure 7; thus, total energy failed to show any relationship to UCS.

FIGURE 8: ROD MILL/BALL MILL WORK INDEX RATIO v. UNCONFINED COMPRESSIVE STRENGTH



Siddall et al (1996) identified the ratio of Bond rod mill Work Index and ball mill Work Index as being indicative of an ore's compentency. Figure 8 plots this ratio versus UCS; no trend is apparent.

Interpretation

Unconfined compressive strength tests apply compression to a rock sample until it fails. The "plane of failure" in a rock typically occurs along a structural weakness rather than breaking along grain boundaries. These joints and shear planes that control the failure of rock in a UCS test play a minimal role in determining the total grinding energy required to fracture rocks inside of tumbling mills. The cohesion between grains provides the overriding power demand inside such mills.

Unconfined compressive strength may only be related to Work Indices in a small subset of rock types that have minimal rock fractures and where the UCS test measures the energy to break grain boundaries rather than the energy to break fractures.

Summary

Attempts to relate Bond Work Index values to Unconfined Compressive Strength from data collected from 11 mines indicates no significant correlation between Wi and UCS. Further examination of values for individual mines and individual rock types generally confirm that there is no reliable correlation.

Forecasting of grinding circuit throughput for future mine production likely cannot use UCS measurements made on-site. Laboratory testing of samples of future ores is necessary to make reasonable predictions of future grinding circuit productivity.

References

Bond, F.C. "Third Theory of Comminution", *Trans. AIME*, Vol. 193, 1952

Ammtec Ltd web site http://www.ammtec.com.au/services/comminution.html.
(Summary of laboratory tests)

B. Siddall, G. Henderson and B. Putland, "Factors Influencing Sizing of SAG Mills from Drillcore Samples", *SAG 96 Proceedings*, PP 463-480

Project archives, Fluor Mining & Minerals, Vancouver