EFFECT OF CORE DIAMETER ON THE BOND IMPACT CRUSHING WORK INDEX TEST

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ABSTRACT

The Bond low energy impact (crushing) work index test is specified to be performed on rock specimens between 50 mm and 75 mm in effective diameter. NQ-diameter drill core, frequently used in mineral exploration programs does not meet that specification, it being 45 mm diameter or less.

This paper reports the effect of performing the impact test on contiguous sections of HQ diameter and NQ diameter core, exploring the hypothesis that the contiguous intervals give equivalent results in spite of the core diameter difference.

KEYWORDS

Comminution testwork, work index, drill core, low energy impact test

INTRODUCTION

The type of comminution tests that can be performed on samples is affected by the specimen size (physical dimensions) of the material available for testing (Doll & Barratt, 2009). One such test, the low-energy impact work index (a.k.a. crushing work index) is conducted only on coarse specimens placed one at a time in the testing apparatus. With respect to the crushing work index test, F.C. Bond (1946) specifies that "In the standard method of testing only broken pieces that pass a 3-in. square opening and are retained on a 2-in. square opening are used. Slabby or acicular pieces are discarded" (p.7).

Drill core with a diameter of approximately 45–47 mm, commonly referred to as "NQ" diameter, is frequently used in mineral exploration drilling programs. This type of core is generally considered too small to be suitable for conducting low-energy impact work index testing because the diameter is less than the 50 mm retained size in Bond's specification.

DJB Consultants, Inc. has been involved in two projects where diamond drilling for metallurgical testing has transitioned from 65 mm (HQ) diameter to 47 mm (NQ) diameter due to drill rig limitations. By collecting samples of HQ and NQ core either side of these transition depths for testing at Phillips Enterprises LLC, the effect of the core diameter has been observed.

The hypothesis being investigated is: "are NQ-diameter core samples demonstrably invalid as low-energy impact test specimens?" The hypothesis is tested by comparing the NQ test results to "nearby" HQ-diameter test results of the same rock type, observing differences in the spectrum of specimen results (maximum, minimum, average, etc.) and asking the question "are these significantly different?"

TEST PROGRAMS INVOLVING NQ-DIAMETER DRILL CORE

The first program involving NQ-diameter drill core was a copper porphyry project in the Western Cordillera of North America. All the drilling was performed in HQ-diameter, except for three very deep holes that transitioned to NQ-diameter when the drill rigs could no longer sustain HQ-diameter drilling. The project used a sampling routine where a single 60 mm long specimen was diamond-saw cut every three metres down a hole. The results of all specimens within a grinding composite were mathematically averaged over the length of drill core represented by the (larger) composites. Figures 1 through 4 display the down-hole measured work index value per specimen for the three drill holes where samples were taken in both HQ and NQ size core. Each point is a single specimen. Two drill holes have a long interval of the same lithology on both sides of the HQ-NQ transition depth (Figures 1 & 4). A third drill hole has a mixture of two rock types, a sedimentary unit (Figure 2) and a granodiorite unit (Figure 3), around the transition depth.

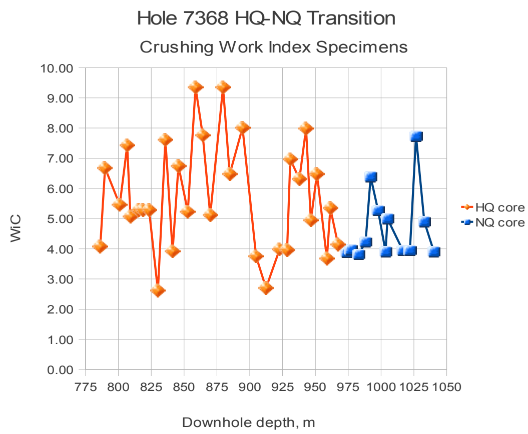

Figure 1: First project, drill hole 7368

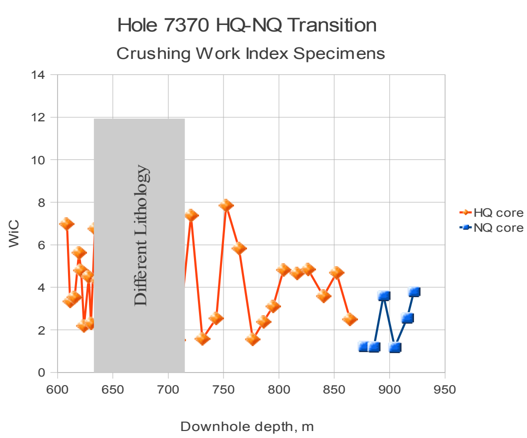

Figure 2: First project, drill hole 7370: sediments

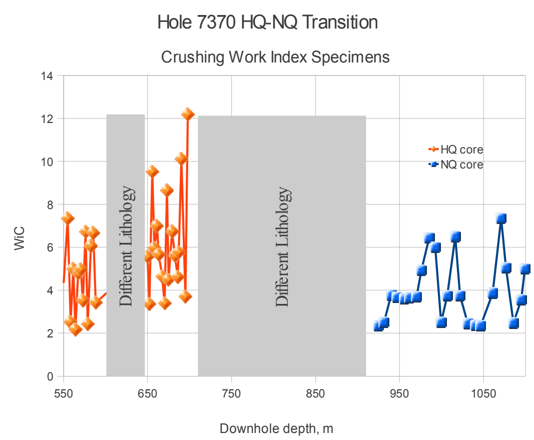

Figure 3: First project, drill hole 7370: granodiorite

Visual interpretation of Figure 1 suggests the work index measurements show a similar degree of variability and (generally) the same average value on both sides of the HQ-NQ transition depth. The lithology is consistent in the range of depths displayed.

Figures 2 and 3 display results for a single drill hole, number 7370, partitioned into the two types of lithology that occur therein. The first comment is there is a small quantity of NQ-diameter sedimentary rock type specimens below the transition depth (Figure 2). Visually, the NQ-diameter appears to give a lower work index maximum, minimum and overall average than the nearby HQ-diameter. The granodiorite contains much more NQ-diameter material, but it is a long distance down the hole from the comparable

HQ-diameter granodiorite material (Figure 3). The interpretation of this hole is that NQ-diameter may give a lower result, but the confidence in this assertion is low due to these complications.

Visual interpretation of Figure 4 suggests the work index measurements show a similar overall average on both sides of the HQ-NQ transition depth, but there is more variability in the NQ-diameter results (greater maximum, smaller minimum). The lithology is consistent in the depths displayed.

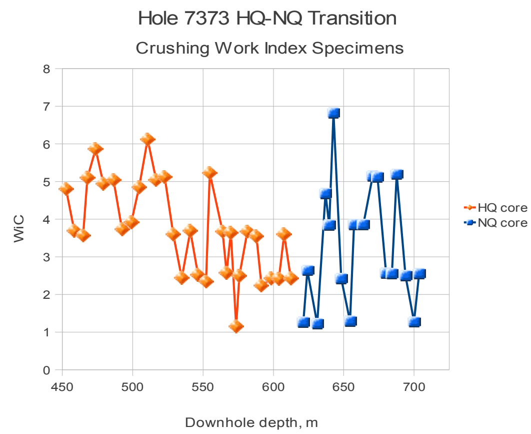

Figure 4: First project, drill hole 7373

Based on these three drill holes, it was decided to use the NQ-diameter results of all three drill holes in the comminution database with no adjustment. For the purposes of the first project, NQ-diameter core was not "judged to be invalid for the purposes of modelling."

The second project involving NQ-diameter core was a South American iron deposit consisting of interleaving iron-rich "manto" zones and iron-poor tuffs. These two zones tended to have abrupt contacts and were easily distinguishable visually. All the drilling was performed in HQ-diameter, except for four deep holes that transitioned to NQ-diameter when the drill rigs could no longer sustain HQ-diameter drilling.

Figure 5: Second project, drill hole 365

Three-metre long intervals of core were collected from both the HQ-diameter and NQ-diameter sides of the transition depth, so long as the lithology was the same. Figure 5 shows a drill hole where both sides of the transition depth are the tuff lithology. Figure 6 shows a drill hole where the lithology changes shortly below the transition depth; in this hole, only the light-coloured tuff lithology was sampled (note the positions of the paper tags identifying the begin and end depths for sampling).

Figure 6: Second project, drill hole 375

Energy spectrum diagrams are used to test for differences in the HQ and NQ-diameter crushing results. In these charts, the specimens selected for testing out of the three-metre intervals are ordered from lowest result to highest result. If the HQ and NQ-diameter give different work index results, then the two spectrum lines will look different.

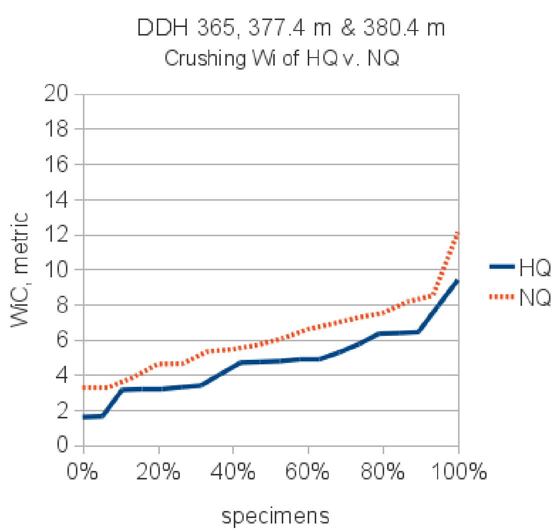

Figure 7: Second project, drill hole 365

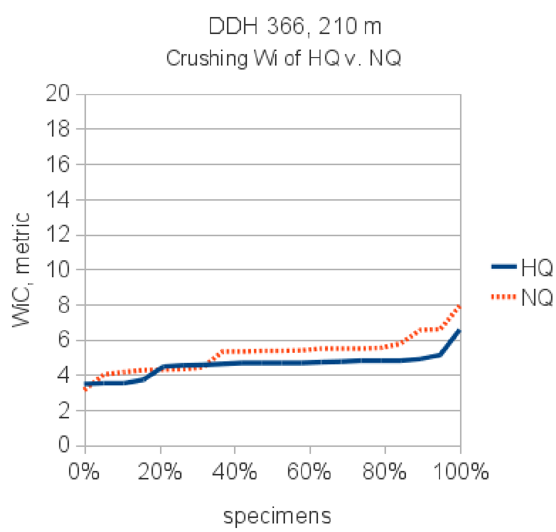

Figure 8: Second project, drill hole 366

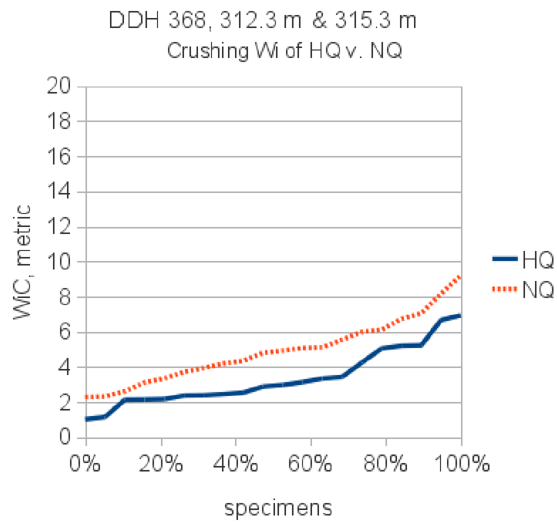

Figure 9: Second project, drill hole 368

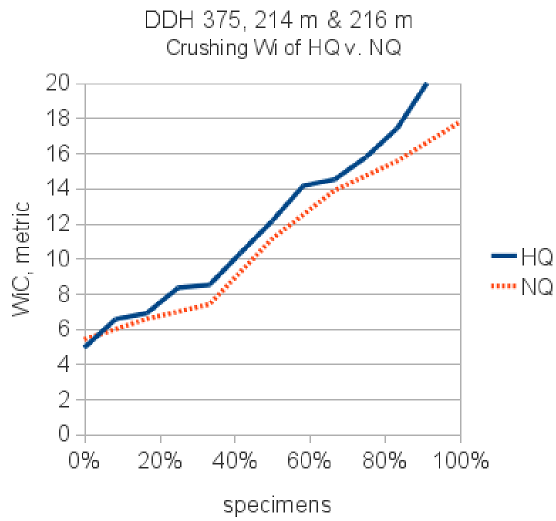

Figure 10: Second project, drill hole 375

Visual interpretation of Figures 7 through 10 is that the shapes of the HQ and NQ-diameter spectrum lines are similar in all cases. The position of the NQ-diameter line is above the HQ-diameter in three of the four cases, by half a unit to two units of work index. The interpretation of these charts is the same as for the first project, NQ-diameter core was “not judged to be invalid for the purposes of modelling.”

DISCUSSION

The measurements that are used in the calculation of the low-energy impact crushing work index are: the Joules of energy imparted by the hammers, the millimetres of width between the hammers at rest of the specimen being impacted, and the density of the specimen, per equation (1). Because HQ and NQ-diameter core tend to break into lengths proportional to their diameters, is there a relationship between the length of a specimen and the resultant work index?

The work index of specimens from the second project are plotted against the width of the specimen (distance between the hammers at impact) in Figures 11 through 14. There appears to be a relationship between a specimen width and the work index determination, although some samples (e.g., Figure 14) have a great deal of noise. A portion of the Wi–width relationship is due to equation (1) that converts J/mm into work index. The hammers are always raised to the same height increments (the Joule increments are the same for all specimens, regardless of size), so any increase in specimen width causes the work index to diminish for the same Joules of energy imparted. This is most evident in the HQ points of Figure 12 where a series of specimens failed at the same energy, but the resultant work index diminishes with increasing width of the specimen.

$$\text{Work Index (metric)} = 53.49 \times \text{Joules/mm} \div \text{density (kg/L)} \qquad (1)$$

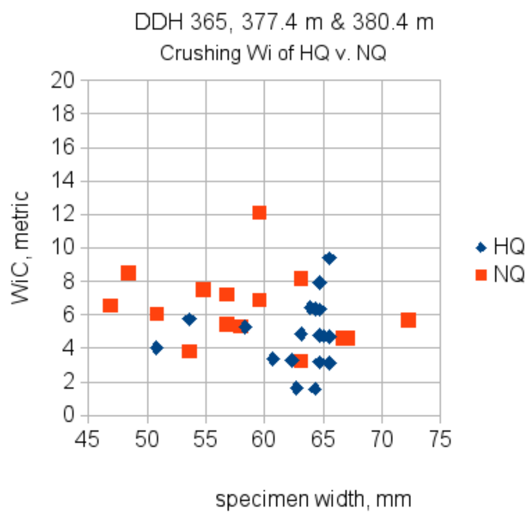

Figure 11: Second project, drill hole 365 effect of specimen width

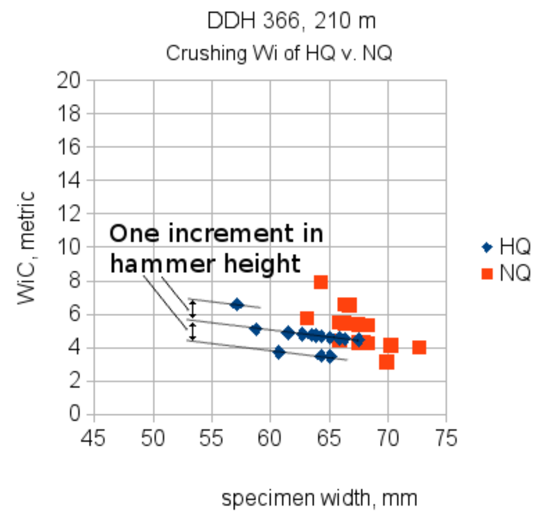

Figure 12: Second project, drill hole 366 effect of specimen width

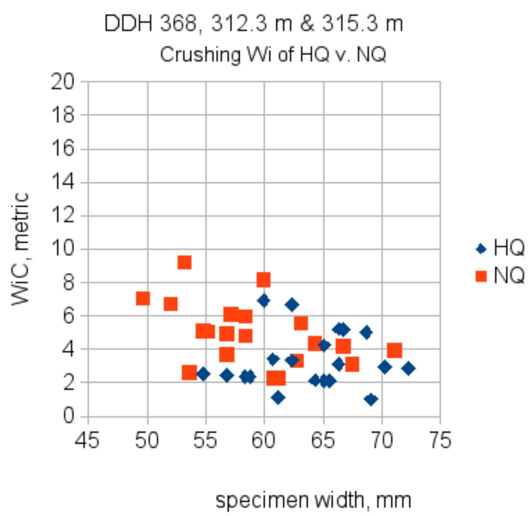

Figure 13: Second project, drill hole 368 effect of specimen width

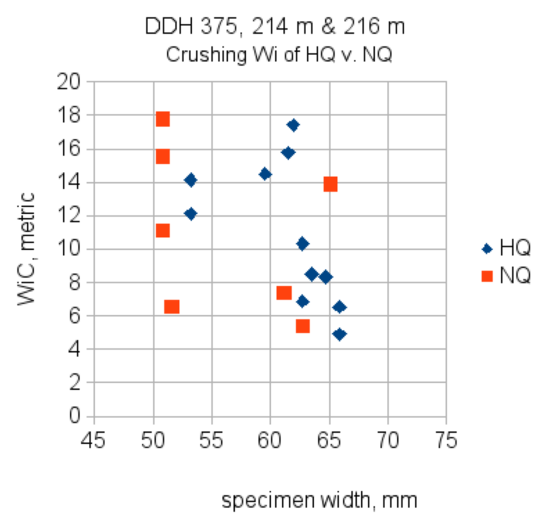

Figure 14: Second project, drill hole 375 effect of specimen width

The observations that the second project NQ diameter core tended to have smaller specimens and smaller specimens tended to have higher (more conservative) work index results gives a measure of confidence that the grinding circuit design for the second project will be slightly conservative when NQ diameter core is used.

Nature of the Low-Energy Impact Work Index Test

Some earlier papers have attempted to draw conclusions about crushing work index testing without addressing the principal variables that can affect the outcome of the test. For completeness, these significant variables are enumerated and the solutions (with rationales) used by the authors are disclosed.

Variable 1: Measured potential energy is not the same as the impact energy absorbed.

A low-energy impact work index testing machine consists of two hammers mounted to pendulums (or bicycle wheels) that swing freely in one plane such that both hammers simultaneously strike opposite sides of a rock specimen at the nadir of a swing. Both hammers are raised a known height and allowed to free-fall onto the specimen. If the specimen does not break, then the hammers are lifted to a greater height a released again. This continues until the specimen is broken, whereupon the amount of energy imparted to the specimen by the hammers is calculated (the potential energy of the two hammers raised to the final height). Implicit in the methodology is the assumption that all of the hammers' potential energy at the start of a swing becomes the kinetic energy striking the specimen, which itself is equal to the amount of impact energy used to break the specimen.

The hammers of the Phillips Enterprises equipment are laterally adjusted prior to each test so that the hammers impact the specimen at the nadir of a swing (refer to Figure 15). The potential energy at the top of the swing should be as close as is feasible to the impact energy absorbed. Some energy is always lost to sound, kinetic energy of broken rock fragments and any bounce-back of the hammers upon impact. These energy loses are believed to be of minor significance.

Figure 15: HQ core positioned between pendulums at rest

Variable 2: Specimens that meet the specification are not representative of the overall sample.

Variable 3: Manual selection of specimens that are not representative of all available specimens within a sample.

The test is conducted on specimens selected by the test operator out of all suitable particles within a sample. This introduces two potential variables, or sources of bias, in conducting the test. One is that the specimens available must be representative the overall sample and the other is that the operator must select specimens that are representative.

With respect to the case studies:

- First project: due to the high RQD core and regular, periodic nature of the sample selection, the overall specimen sets are expected to be representative for the intervals of interest near the HQ/NQ transition depth.

- Second project: For the purposes of this paper, only HQ/NQ samples straddling core dimension changes are considered. Samples are taken of a uniform rock type (manto or tuff) and specimens are judged to be representative if it is the same rock type.

Variable 4: Type of sample and preparation technique, if any.

Test results are influenced by the way samples are prepared prior to testing. Crushed rock conforming to the -75 mm, +50 mm specification is believed to give different results versus drill core that meets the specification. For example, the authors observed an apparent 50% reduction in impact work index on a Canadian gold ore attributed to crushing drill core versus testing whole-diameter drill core.

The same technicians prepared both the HQ and NQ samples using the same techniques in both projects. Samples were not crushed or otherwise physically stressed.

Variable 5: Specimen presentation to the hammers.

The way that specimens are positioned relative to the hammers of the test machine affects the result, particularly when dealing with drill core. F.C. Bond (1946) specifies that the test is to be conducted so the hammers strike a specimen along the smallest of a sample's three principal axes (p.6). The authors think this specification applies to specimens with “natural” edges, such as blasted or crushed rock, but does not apply to drill core because the smallest axis is usually the diameter of the core, an unnatural surface. Further, Phillips Enterprises attempts to orient specimens such that the hammers strike somewhat-planar and parallel surfaces on both sides of the specimen. Whole-diameter drill core only has somewhat-planar surfaces perpendicular to the core axis (see Figure 15). Experiments conducted by the authors suggests impacting drill core through the axis results in a work index value roughly double what is obtained by impacting through the diameter.

In both case studies, whole pieces of core were placed in the test apparatus. In all cases, core was impacted axially.

Variable 6: What does “broken” mean?

The final source of experimental variability may seem trivial: what does “broken” mean? Some specimens are very clear in how they disintegrate (sometimes, explosively) when they are broken. However, other specimens will spall or de-laminate bit-by-bit as the energy level increases, never giving a clear picture of how much energy it will absorb when crushing. Does a specimen splitting in two along a fracture constitute “broken”, or should the test continue until more pieces are generated?

Phillips Enterprises considers a specimen broken when it breaks into three or more "substantial" pieces. Spalling and chipping are not considered "substantial".

CONCLUSIONS

The two case studies failed to validate the hypothesis "NQ-diameter core samples are demonstrably invalid as low-energy impact test specimens". In these two cases, NQ-diameter core was judged to be acceptable feed to the low-energy impact crushing work index test.

This is not to say that all NQ-diameter core is suitable for testing on any project; rather, on these two projects, specimens of NQ-diameter core were tested and compared to HQ-diameter core of the same lithology and the NQ-diameter was not deemed unsuitable for impact testing.

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NOMENCLATURE

DDH = diamond drill hole.

HQ = designation for diamond drill core approximately 65 mm diameter.

NQ = designation for diamond drill core approximately 47 mm diameter.

Sample = a collection of specimens representing an interval of a drill hole.

Specimen = a single piece of rock or core placed in the test apparatus.

Wi_C = work index for crushing, aka low-energy impact work index.

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