Effect of Geological Condition on Degree of Fragmentation in a Simpang Pulai Marble Quarry

Nur Lyana K.a, Hareyani Z.a*, Kamar Shah A.a, Mohd. Hazizan M.H.a

aUniversiti Sains Malaysia (Strategic Mineral Niche, School of Materials and Mineral Resources Engineering, Engineering Campus, Nibong Tebal, Penang, Malaysia)

Abstract

This paper aims to study the effect of geological condition on fragmentation produced by blasting in a marble quarry in Simpang Pulai, Perak, Malaysia; as the condition of the in-situ rock mass is one of the major factors influencing fragmentation degree. Parameters taken into account are chosen from the Rock Mass Rating (RMR) system: discontinuity length, strength of intact material, spacing, weathering, separation and infilling. Geological mapping is done at a bench blasting site before blasting operation is carried out to obtain the structural RMR values of the selected site; the value of strength of intact material is obtained through Uniaxial Compression Strength (UCS) test. After blasted, muckpiles photos are taken to evaluate the degree of fragmentation using image processing software, WipFrag. Fragmentation assessment data from a number of different blasts are then compared and are linked to their respective UCS and structural data to evaluate the impact of these properties on resultant fragments size. It is found that strength of rock mass, discontinuities’ direction against the slope face and its structural properties in a blast location do affect the size of fragments produced.

* Corresponding author. Tel.: +60-4-599-6124; fax: +60-4-594-1011.
E-mail address: srhareyani.zabidi@usm.my

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1. Introduction

For centuries, explosive have been used in mining and quarrying industries especially ones that are operated in hard rock area, as a means to break the rock masses and extracting the desired materials as it is the most cost-effective method. When explosive confined within a blasthole is initiated, large amount of gases at very high temperature and pressure is produced in a very short time. This gas act as the energy to break the rock by subjecting the rock surrounding the blasthole to stresses and strains. By utilizing the energy formed when explosives are initiated, rocks are broken and loosened from the wall face and formed a muckpile of rock fragments which are then loaded and hauled for further processing.

Degree of rock fragmentation is an index used to assess the efficiency of rock blasting. Fragmentation, which is the resulting size distribution, is a key issue in this process. By definition, ‘good fragmentation’ is achieved when fragmented rock needs no further treatment i.e. secondary breakage after the primary blast and can be brought straight to the next stage of processing plus with minimum unsalable fraction: the fines. However, it is a subjective matter that depends on characteristic of equipment used to handle the fragments in downstream operations such as loading and hauling equipment, processing plant and the end use of the rock.

Fragments size produced by blasting depends on two parameters: uncontrollable parameters (geology of mine site) and controllable parameters (design of the blast). Main geological features affecting fragmentation are mechanical (rock strength) properties and structural properties with mechanical properties influencing the formation of initial cracks while structural properties influencing the propagation of shock wave and high pressure explosion gas throughout the rock mass. Blast should be designed based on the geological conditions of the mine site since it affects the distribution of explosive energy in rock mass.

Two methods can be used to assess fragments produced:

- Direct method: screen analysis, counting boulders, and measuring the pieces directly.
- Indirect method: image analysis method.

Image analysis was used in this study as it is impractical to sieve fragments from last scale blast operation. Advantages of image analysis over traditional sieving (screening) are:

- Quick; multiple images can be taken quickly, and also analyzed quickly.
- Does not interfere with or disrupting production.
- Inexpensive and fast, many samples can be analyzed; sampling errors are less significant.
- Quantity and variability of fragmented rock from a blast make screening impractical. Image analysis is not limited by the size of volumes of rock.
- Non-destructive; ideal for measurements on weak rock and ore (e.g. coal, gypsum) which tend to break down when screened.

2. Field investigation

The chosen site for this study is a marble quarry situated in the Keramat Pulai industrial area, Simpang Pulai, Perak. Fig. 1(a) shows part of the industrial area where the quarry is located as seen from Google’s satellite image. Keramat Pulai and Simpang Pulai (Kinta Valley) are underlain by marble, schist and granite from west to the east. Schist of Paleozoic (Devonian-Permian) age is the oldest rock which occupies only a narrow zone between the younger Kinta Limestone comprises of recrystallized marble and Slim granite to the east (Fig. 1(b)). The site chosen for this study is part of the area with marble formation, its main product is ground calcium carbonate (GCC).

Type of explosive mainly used for production blast in this quarry is ANFO (ammonium nitrate with fuel oil) and NONEL (non-electric shock tube detonator) is used as initiation system. Typical blast parameters for blast operation carried out in the quarry are shown in Table1. The quarry’s primary jaw crusher opening is set at 800 mm. Hence, blasted fragments exceeding 800 mm is considered as oversize.
Table 1. The quarry’s blast Parameters.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of holes (mm)</td>
<td>89.00</td>
</tr>
<tr>
<td>Average bench height (m)</td>
<td>11.20</td>
</tr>
<tr>
<td>Depth of holes (m)</td>
<td>12.20</td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>4.27</td>
</tr>
<tr>
<td>Burden (m)</td>
<td>3.96</td>
</tr>
<tr>
<td>Stemming (m)</td>
<td>2.40</td>
</tr>
<tr>
<td>Sub-drill (m)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

2.1. Method for fragmentation assessment

This study is divided by two phases: 1) before a blast is carried out and; 2) after a blast is carried out. For the first phase, geological mapping and samples collection for Uniaxial Compression Strength (UCS) test of the site to be blasted is carried out. Parameters accounted for were chosen from Rock Mass Rating (RMR)\(^9\) system: discontinuity length, strength of intact material, spacing, weathering, separation and infilling. For phase 2, right after a blast was carried out, several photos of the blasted fragments are taken to cover the whole area. Scales are used in the image as size reference. After site works were done, rock samples collected were prepared for UCS testing to get the rock strength of the area.

There were a total of 6 set of blast data collected. Blast 3’s rock strength data was obtained from 10 specimen of Point Load Test according to ASTMD5731 standard, and then converted to UCS since sample with adequate size for UCS testing was not available. UCS testing was done for the other 5 blast according to ASTMD7012 standard.\(^{10}\)

2.2. Geological observation

A total of 199 discontinuities were recorded: 65 for blast 1, 25 for blast 2, 18 for blast 3, 26 for blast 4, 36 for blast 5 and 29 for blast 6. The length of each blast’s area mapped varies from 30-60 m. Pre-blast observation data were plotted in Fig. 2 to show discontinuities condition of blasted slope face, data recorded were grouped into several conditions based on RMR. Legends for Fig. 2 are as provided in Table 2. As an example, from Fig. 2, blast number 1’s persistence (labeled 1-Persistence) shows that the 13 discontinuities occurred in blast 1 were 10-20 meter long, 14 were recorded as 3-10 m and 38 as 1-3 m.
Overall, it is observed that 79.4% of discontinuities occurred were between 3-20m of length, stretching from bottom to top of the bench. As for aperture, 66.3% of recorded discontinuities are open fractures with no infilling. The weathering state across the quarry was almost the same, which is slightly weathered, only 5.5% discontinuities were recorded as moderately weathered. 61.8% of the discontinuities’ spacing falls within the 4th parameters: 0.6-2m.

![Discontinuities condition pattern](image)

For UCS, 3 core specimens were made from each rock sample collected but for 5 of the total samples taken, there were less than 3 cores from each due to breakage during coring process. UCS result of the blast area as plotted in Fig. 3 indicate that rock strength for all 6 blast falls within weak to very strong rock ranging from 13.31MPa to 120.87MPa. Only 2 specimens are categorized as weak, 15 falls in the medium strong rock, 19 in strong rock and 5 are categorized as very strong rock. Diversity in UCS for the same sample was noted in some of the samples, this might stem from internal fractures in cores that have lower UCS.
Subsequently, from mapping activity done, main joints orientations were (dip/dip direction) 83°/240° and 87°/046°. From the distribution of the orientation plotted in stereonet (Fig. 4(a)), it can be concluded that discontinuities in the all 6 blast location were mainly steeply dipping joints between 70°-90° which can be obviously seen from general observation of the whole quarry area. Dotted line in Fig. 4(b) shows the examples of vertical joints from a part of the quarry. Aside from the joints set, there was also a set of bedding with dip 30°-50° with thickness more than 2 meter dipping out of the slope face (Fig 4(c)). Also, high number of cracks resulted from previous blast were observed on the slope face on some blast location as shown in Fig. 4(d).

Fig. 4. (a) Discontinuities orientation distribution; (b) Steeply dipping joints in the quarry; (c) Flat dipping rock bed; (d) Cracks resulting from overbreak on slope face.
2.3. Image analysis using WipFrag

Image analysis software used for this study was WipFrag: an image analysis software for sizing materials such as blasted or crushed rocks. WipFrag accepts still images (.jpeg) and is also able to capture images from video. During this study, to capture the image of blasted fragments, two 1 meter wooden plank were used as scales instead of just one, this was done for “tilt correction” by placing both at the top and the bottom of the image, as the line of observation was not perpendicular to the muckpile surface.

WipFrag uses automatic algorithms to identify individual blocks by creating outline “net” using edge detection. The net is normally displayed as an overlay on top of the fragments image so the user can evaluate the accuracy of the net outlining the fragments. To increase fidelity, users are allowed to manually edit the net. Analysis result output is plotted in cumulative size distribution graph and histogram. Several images are taken for one blast operation and the results are then combined to get the overall size distribution of that particular blast.10

Table 3. Oversize percentage.

<table>
<thead>
<tr>
<th>Blast number</th>
<th>+800mm percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38%</td>
</tr>
<tr>
<td>2</td>
<td>35%</td>
</tr>
<tr>
<td>3</td>
<td>45%</td>
</tr>
<tr>
<td>4</td>
<td>51%</td>
</tr>
<tr>
<td>5</td>
<td>28%</td>
</tr>
<tr>
<td>6</td>
<td>24%</td>
</tr>
</tbody>
</table>

Size distribution curve, histogram and other statistical data such as min, max and mean size for all 6 blast obtained from WipFrag analysis are presented in Fig. 5. Taking +800 mm as the criterion to classified the fragments as oversize,
it is observed that the percentage of oversize fragments range from 24% to 51%, with the highest produced by blast no.4. Percentage of oversize for each blast is as per disclosed in Table 2. Largest fragments recorded among 6 blast is 4.5m; also from blast no.4. These large fragments need to be broken with either breaker or secondary blasting before they can be hauled to the processing plant.

3. Geological effect on fragmentation

The percentages of occurrence for each geological condition of all 6 blasts are shown in Fig. 6. Altogether, it suggest that, all blast have high percentage (68.3%) of wide spaced joints more than 0.6m, 79.4% joint stretched between 3 m to 20 m with 34.7% of joints in this range exceeded 10 m. 66.3% joint were open joints with no infilling with 46.7% joints having aperture more than 5 mm. From joints orientation mapping done, main joint sets was found to be at right angle against the slope face dipping at 70-90º. From Fig. 3, 83% of UCS test result falls into medium strong and strong rock, 12% is classified as very strong rock. Based on these data, it is reckoned that thick bed and wide joints spacing forming big blocks in the rock mass plus the presence of joints with aperture along with cracks from overbreak causing explosive’s energy to not be completely confined inside the rock mass but instead travelled through the openings towards the slope face lead to big rock blocks to simply be pushed out of the slope instead of crushed.3,12 Wide spacing of blasthole (the quarry’s spacing is more than 4m) in joints at right angle of the slope face setting could possibly cause the problem to worsen since the energy from explosive might not reach the area between two blast hole due to the joints attenuating the stress wave and halting cracks propagation during blasting.12-13 Bedding plane with dip 30º-50º dipping out of the slope face might have caused the rock mass to slid down during blasting making it easier for the rock blocks to be liberated from the face before they were crushed to smaller fragments.

To get into more details regarding the effect of these conditions, taking conditions percentage comparison between blast 4 (having highest oversize percentage: 51%) and blast 6 (having lowest oversize percentage: 24%) from Fig. 6, we can see that blast 4 has higher percentage of 0.6-2 m spacing: 96.2%, compared to blast 6 that has only 31.0% of the same spacing. As for aperture, 96.2% of discontinuities in blast 4 were open joints of more than 1 mm, while only 55.2% of blast 6’s discontinuities have the same properties. Difference in percentage of discontinuities having persistence 3-10 m was only 10.3% and degree of weathering was the same for both blast so these 2 parameters were not considered as one of the major factor influencing oversize production. Based on the differences, it is presumed that blast 4 had bigger in-situ block size than blast 6. Big block size combined with high numbers of open joints causing the energy from explosive to wedge through the openings resulted in big rock blocks being pushed out from the slope face, not crushed. Hagan opined that rock mass with wide spacing requires more formation of new cracks than closely spaced joints,11 but with the presence of open joints, energy from the explosive was not fully utilized.
Contrary to blast 6, blast 4 has smaller in-situ block size and less number of open joints; higher fraction of explosive energy was utilized to crush the rock to smaller size resulting in lower percentage of oversize. As for UCS, for blast 4, 66.7% of UCS readings were categorized as strong rock and 33.3% as medium strong rock. For blast 6, 57.1% were recorded as strong rock and 42.9% were medium strong rock. There was not much different in both blasts’ UCS but there was 27% difference in amount of oversize produced. This demonstrates that structural properties played a greater role in final fragments size, this is in line with what was found out by Hagan and Chakraborty. According to them, in jointed formation, strength properties of rock material played less role than structural properties in the resultant fragments’ size.3,11

From what was previously discussed, it is concluded that the difference in the two blasts’ geological condition leads to the contrast in percentage of oversize produced hence showing how geological conditions could influence blasting efficiency.

4. Conclusion

Existing discontinuities in a blast site depending on their direction and other properties such as spacing, aperture and the condition of the aperture: either tight, open or filled; plus overbreak’s cracks resulted from previous blast do affect the size of fragments produced. Other geological conditions such as rock strength, and bedding thickness also contributes to the boulder problem. Findings from this study can be used to improve the quarry’s future blast by tailoring blast design parameters to improve fragmentation and the same time avoid the need for secondary breakage.

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References