Experimental Investigation on Factors Affecting the Bulking of Aggregate Quarry Products

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Abstract
Aggregate quarry products have long been essential to the construction sector. These aggregate products are produced by blasting the in-situ rock at quarries and subjecting it to primary and secondary crushing. There is a volume change when converting in-situ rock volume into the product volume because of a phenomenon called bulking, which happens when the rock is broken down into smaller particle sizes. Air spaces develop between the rock particles during blasting and crushing activities increasing the volume of quarry products. This study aims to investigate the effect of moisture content, particle size and rock type on bulking of aggregate quarry products. Quarry products (Dust, Chip, ¾″ metal ,1.5″ metal and ABC [Aggregate-Base-Course]) were collected systematically from six quarries and the bulking factor was tested in different moisture conditions. Furthermore, the mineralogy and specific gravity of collected samples were determined by visual observations and pycnometer method respectively. This study identified that quarry dust and the ABC product exhibit significant deviations in bulking factor with changing moisture content, whereas other products (Chip, ¾″ metal and 1.5″ metal) exhibit no discernible deviations in bulking factor with increasing moisture content and identified that mineralogy almost no effect to the bulking factor since study area contains similar kind of mineralogy.

Keywords: Bulking Factor, Density test, Specific gravity, Moisture content

1. Introduction

The construction sector has always placed a significant emphasis on aggregate materials as a fundamental component. Quarries are the most common source for construction aggregates. These materials from the quarry are utilized for a broad range of purposes, some of which include but are not limited to the construction of buildings and roads, landscaping, the management of erosion, and other endeavours of a similar kind[1].

These aggregate products are produced by blasting the in-situ rock and then subjected to primary and secondary crushing to generate quarry products in a variety of sizes and shapes, such as quarry dust, chip, ¾″ metal, 1 ½″ metal and ABC (Aggregate-Base-Course). When considering a specific volume of the product, it is not possible to assume that 100% of the in-situ rock volume was converted into the volume of the product because of a process known as bulking, which occurs when the rock is broken down into smaller particle sizes.

There is a change in the total volume when in-situ rock is subjected to processes such as blasting and crushing, air voids are generated in between the rock particles due to the way the rock particles are arranged[2].

Bulking factor can be used to estimate the volume of materials generated from excavation. Therefore, this can directly use for Royalty calculation for aggregate quarry products[3]. Currently, royalty levies are calculated only up to the point where the blasted muck pile is, rather than all the way up to the point where the finished products are. Primary objective of this study is to determine the bulking factor of aggregate quarry products. This can also be used indirectly for machine fleet management by estimating wheel loader productivity[4]. Also, Bulking phenomena is important to explain some phenomena in underground mining and in surface excavation. As examples formation of sinkholes and caved zones , explain the volume changes in transportation and storage [5], [6].

It was identified that rock type, particle size and shape distributions and other properties of rubble and the environment could have an impact on the bulking of quarry products[2]. There are not many studies have been done and on the other hand, in the available literature on this topic, it does not appear that not many experimental investigations have been done in this regard. This study focusses on a practical study on how the mineralogy, moisture content and particle size effect on bulking of aggregate quarry products.

2. Methodology

2.1 Study Area

Samples were collected from six different quarries around Sri Lanka. Four quarries from the western province and the rest were in central and the northwestern provinces (Figure 1).

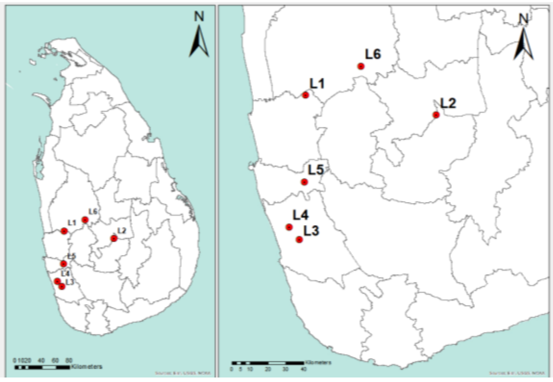

Figure 1: Sample Locations

Details of the quarry locations where the samples were taken are mentioned in the Table 2.

2.2 Sample and Data Collection

Five quarry products (Dust, Chip ,3/4" metal, 1.5" metal and ABC) were expected to be collected from each quarry site. However, available quarry products at selected quarries were collected due to the unavailability of desired quarry products at sampled locations. Samples were collected according to the size of each product and the capacity of the cylindrical mold used to determine the bulking factor. The amounts of samples obtained from each product is shown in Table 1.

Table 1: Details of collected quarry products

Product	Product Size	Capacity of the mold	Collected sample amounts
Dust	<5 mm	3 L	20 kg
Chip	5-10 mm	7 L	30 kg
¾ "Metal	10-22 mm	15 L	50 kg
1.5" Metal	22-37.5 mm	15 L	50 kg
ABC	-	15 L	50 kg

2.3 Sample Preparation

2.3.1 Bulk density test

Coning and quartering method was used to reduce the sample size (required sample amount is directly proportional to the size of mold). In this study BS 812 : Part 2[7] testing procedure was followed. The maximum moisture that can get absorbed by fine aggregate is around 7% [8].

Initially, the natural moister condition was determined. Next, 2%, 4%, 6% water was added to the increase mass moisture content of samples and mixed thoroughly to distribute homogenously.

2.3.2 Moisture content analysis

The actual moisture content absorbed in each sample was determined by measuring the moisture content of representative specimen collected after conducting the bulk density measurement.

2.3.3 Specific Gravity test

Specific gravity testing was done for fine aggregates Following standard ASTMD854 [9]. Quarry dust from each location were taken and sieved through electrical sieve shaker for 5 minutes to get sample which are 600μm passing and 250μm retaining. Then prepared sample was passed through a wash sieve with a mesh size of 75 μm to remove finer particles. Finally, the sample retained on 75mm wash sieve was dried in an oven at 105 °C for 24 hours.

2.3.4 Mineralogy identification

The visual observation method was used to identify the mineralogy. Separated suitable samples (size of around 1.5”) from each location for that.

2.4 Testing Procedure

2.4.1 Specific Gravity Testing Procedure

The mass of empty pycnometers was recorded as W1. Then, the sample was added into the pycnometer and the total mass was recorded as W2. Next, the sample containing pycnometer was filled with water and kept on tray and heated to remove the air bubbles. After cooling they were topped up with water and total mass was recorded as W3. Empty pycnometers were filled again with water and mass of each pycnometer was determined and recorded as W4. Specific gravity (S_g) was calculated using (1).

$$S_g = \frac{W_1 - W_2}{(W_4 - W_1) - (W_3 - W_2)} \quad (1)$$

W1- Weight of Empty Pycnometer (g)
W2- Weight of Pycnometer + sample (g)
W3- Weight of Pycnometer+ sample + water (g)
W4- Weight of Pycnometer with water (g)

2.4.2 Bulk Density testing procedure

Picked the appropriate cylindrical mold that is for the product size of the sample according to Table 1. Mass of the mold (M1) was determined using electronic balance.

First, took the sample at natural moisture condition and sample was carefully poured into the mold from a height of 5 cm above the mold according to the standard procedure. Then the excess amount of sample was cut off using a straightening edge. After that the total mass of sample and mold was recorded as M2. The above procedure was repeated for three times to get average mass for M2. The procedure was repeated for 2%, 4% and 6% moisture condition and the bulking factors were calculated using (2).

$$B = \frac{h \times л \times \left(\frac{d}{2}\right)^2}{\frac{M_2 - M_1}{S_g}} \quad (2)$$

M1- Weight of empty mold (Kg)
M2- Weight of (Mold + Sample) (Kg)
S_g - Specific Gravity of sample
h - Cylinder Height (cm)
d - Cylinder Diameter (cm)
B - Bulking factor

2.4.3 Moisture Content Analysis

Three containers were taken per each sample and the mass of each container recorded as m1. small amounts of sample were added to the containers and total mass was recorded as m2. Then samples were oven dried at 105°C for 24 hours and total mass of dried sample and container was recorded as m3. Moisture contents were calculated using (3).

$$\text{Moisture content} = \frac{[(m2 - m1) - (m3 - m2)]}{(m3 - m2)} \times 100\% \quad (3)$$

m1 – Weight of empty container (g)
m2 – Weight of container and sample before oven dry (g)
m3 – Weight of container and sample after oven dry (g)

2.4.4 Identifying Mineralogy

Mineralogy was determined by visual observation of selected representative samples. minerals presence in the sample were identified using physical properties such as color, streak, luster, habit, hardness, breakage etc. Accordingly, the rock type of each quarry location was identified and listed in Table 2.

Table 2: Identified rock types (Mineralogy) according to the quarry locations

	Name of the Quarry	Rock Type
L1	Access Engineering [Meerigama Quarry site]	Biotite, Garnet, Hornblende gneiss
L2	Access Engineering [Ma-oya Quarry site]	Charnokite
L3	Metal Mix Pvt Ltd [Naboda Quarry site]	Charnokite, Garnet Biotite gneiss
L4	Metal Mix Pvt Ltd [Galpatha Quarry site]	Biotite gneiss
L5	Boulder Mix (Pvt) Ltd [Meepe Quarry site]	Biotite, Garnet Charnokite gneiss
L6	Senarath Engineering [Doratiyawa Quarry site]	Biotite, Garnet, Hornblende gneiss

3. Results and Discussion

3.1 Analysis of Bulking factor with changing the moisture content

3.1.1 Variation of bulking factor with respect to quarry location

Bulking factor was plotted against moisture content for according to the quarry locations (Figure 2).

Figure 2 indicates that all quarry products behave in similar manner regardless of the quarry location. In natural moisture condition, bulking factor shows higher value in chip product than other quarry products. Chip product contains a large percentage of elongated particles, so this behaviour happens due to the particle shape of rock fragments. Rock pieces with narrower thickness-to-width ratios results less packing and create more void spaces resulting high bulking factor, similar behaviour was observed by Ofoegbu et al., 2008 [2].

Figure 2 shows that in all quarry locations ABC product indicates a low bulking factor compared to other products in natural condition as well as with the increasing the moisture value. This happens due to having particles in wide range of sizes. Well graded materials with more variable particle size distributions have less bulking factor than uniformly distributed particle sizes. Because Fine particles tend to diminish empty volume in rock debris results low bulking volume . This is also observed by Ofoegbu et al., 2008[2].

Comparing all the locations in Figure 2 dust products shows the most deviation in bulking factor with increasing moisture content. ABC products also shows considerable deviation while other products have not shown noticeable deviations. So, can observe fine aggregates bulks more comparing to coarse aggregates.

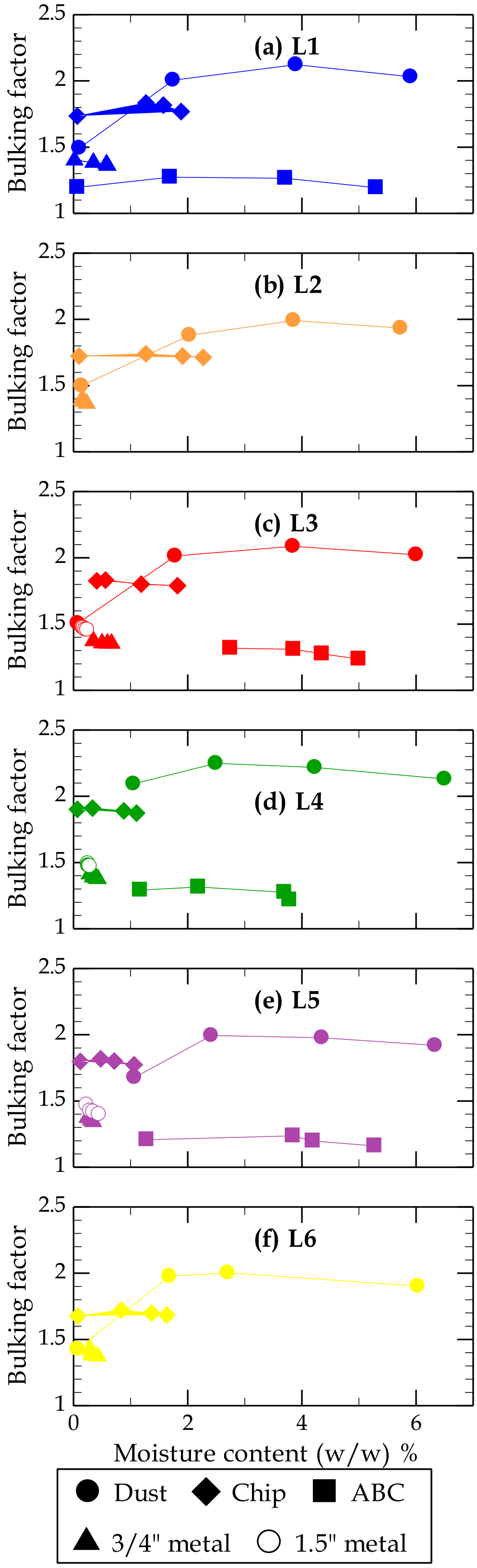

Figure 2: Variation of bulking factor with changing the moisture content with respect to quarry location

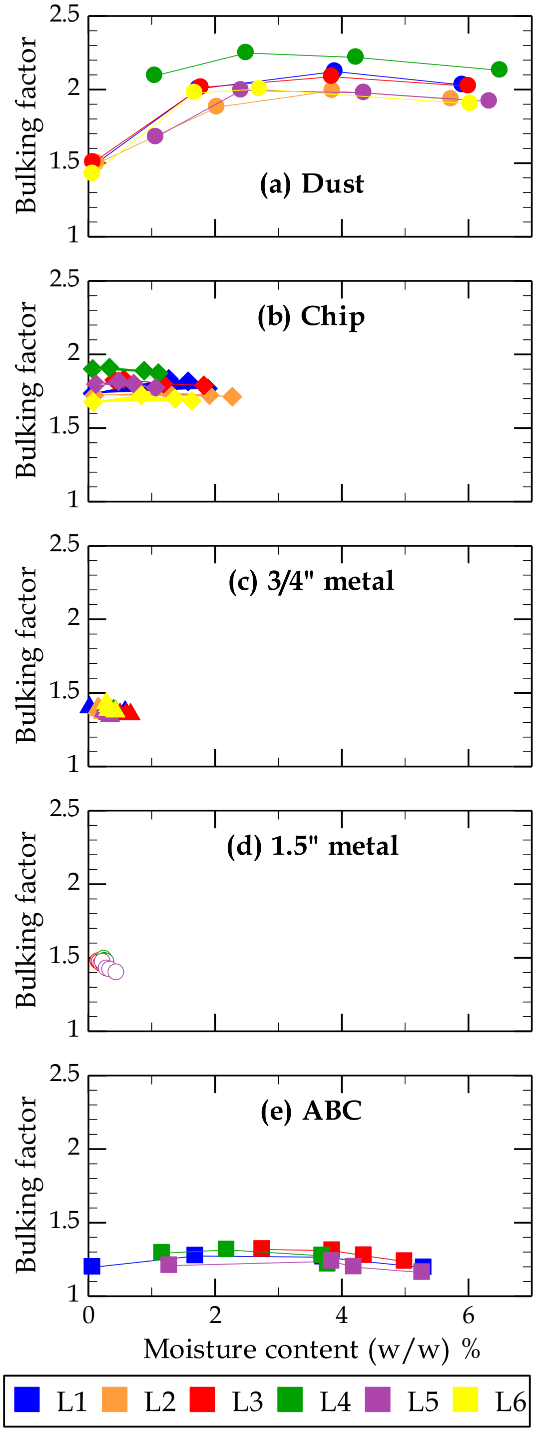

Figure 3: Variation of bulking factor with changing the moisture content with respect to quarry product.

3.1.2 Variation of bulking factor with respect to quarry product

Bulking factor was plotted against moisture content for according to each quarry products (Figure 3).

According to Figure 3, when considering each quarry product, all have shown similar patterns. Bulking factors follow the same trend when moisture is increased. In figure 3 (a and e) L4 an L5 lines have deviated slightly due to having initial moisture.

Figure 3-a indicates that Dust products shows generally high bulking factor with addition of moisture with comparing to other products in Figure 3. A noticeable rise in bulking factor of dust is observed when moisture is added initially, and it has reached to a maximum, then fell with increasing moisture content in all locations. Aggregate's wetness creates a coating surrounding each particle. Each particle is subject to a force called surface tension because of these moisture-filled sheets. This surface tension causes the particles to drift apart from one another. Up to a certain point, bulking rises with an increase in moisture content but, beyond that point, additional increases in moisture content particles tend to compact results drop in volume.

According to Figure 3-a in all locations Dust products absorb moisture around 6-7% (w/w) range by mass and ABC product (Figure 3-e) also absorb considerable amount of moisture around (3-5) % due to containing finer particles. Chip products (Figure 3-b) absorbed moisture around (0-2) % because of they also containing of little amount of finer particles. Hence, 1.5″ and ¾″ metal products (Figure 3 - c and d) have absorbed least amounts of moisture. When there are finer particles water particles can easily create a coating around them, hence absorb more moisture in dust and ABC quarry product samples.

When considering the deviation of bulking factor with moisture content, quarry dust (Figure 3 -a) and ABC product (Figure 3 -e) shows significant variations and similar patterns appears, due to having finer particles present in both products. Chip product (Figure 3-b) shows minor variation with locations due to having different amount of finer particles with chip products.

In ¾ "and 1.5" metal products (Figure 3-c and d), we cannot see a significant behaviour pattern because the data points are clustered together in the same region of the graph. Because of the water absorption of these products are much less than other quarry products. In those products bulking factor slightly decrease because of some amount of the moisture will absorb to the specimens and increase the M2 value (Equation 2) and decrease the bulking factor value.

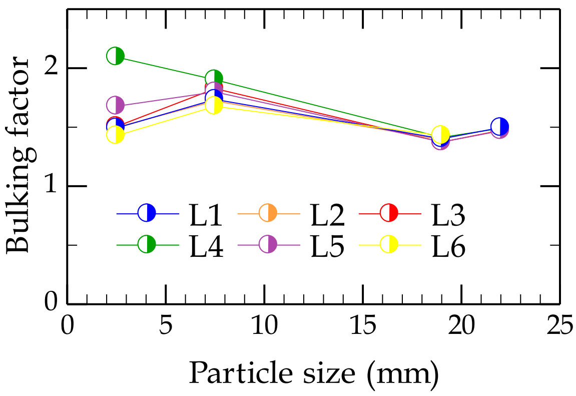

Figure 2: Variation of bulking factor with particle size in natural moisture condition.

3.2 Analysis of Bulking factor with respect to particle size

Bulking factor was plotted against particle size in natural moisture condition for all quarry locations Figure 4.

According to Figure 4 the pattern of each location seems to be similar. For locations 04 and Location 5(L4 and L5 lines), the bulking factor of dust (size of 0-5 mm range) is high because of they had a considerable amount of initial moisture content. Bulking factor gets increased when the particle size is increased up to a certain point, Maximum bulking factor can be seen in the range of (5-10) mm means chip products because of they are having large amount of elongated particles. Therefore, spaces between the particles are high and results high buking factor. In the maximum point bulking factor has changed little between the locations because of the amount ow finer particles mix with the chip products are vary.

After reaching the maximum point Figure 4 shows bulking factor gradually decreases till the particle size is around 19mm (3/4" metal product). Reason for that is particles starts to pack well after reaching to maximum point. Thickness-to-width ratios of the particle is getting low and less elongated particles are present. Then shows an increment of bulking factor when moving towards the 22mm size. This will happen because of the particle size is getting to increase and more homogeneous particles are present and void spaces between the rock specimens are getting increase results high bulk volume.

In Sri Lanka, Currently Royalty levy calculations are made up to the blasted muck pile, rather than all the way up to the final products and use bulking factor as 1.6 without any scientific proof. According to Figure 4 most of the bulking factor values are around 1.6 value, so it can be said that 1.6 bulking factor value is reasonable.

One of the objectives of this graph (Figure 4) was to see if we could extend this graph to estimate the bulking factor quarry products of sizes in between, before or after the tested products. Below factors implies why it was nearly impossible to fulfill the so-called objective. ABC is a mixture of particles of different sizes, this product cannot be added into this graph. Which leaves a maximum of 4 data points for each location. Therefore, number of data points were limited. And each product has a size range Table 1. In here we chosen its median value for ease of graphing. So, it has an effect too. Also, in here consider only the natural moisture condition, this is varied with the locations. So can't apply this for all conditions.

4. Conclusion and recommendation

This study aims to investigate the effect of moisture content, particle size and rock type on bulking of aggregate quarry products. For that samples of five different quarry products from six different quarry sites were investigated. According to the results, it was clearly observed that the moisture content and the particle size effect to the bulking factor. Because the tested sample locations had the same type of mineralogy or rock types, didn't identified much deviation with the mineralogy.

Quarry dust and the ABC product shows high deviation of bulking factor with changing the moisture while other products (Chip, ¾" metal and 1.5" metal) have not shown noticeable deviations in bulking factor with increasing moisture content.

The study has been conducted only in a limited area. This is not enough to represent all mineralogical complexes of Sri Lanka. therefore, it is recommended to extend the study area so that the research can be thoroughly related to Sri Lankan context.

Quarry products contain a distribution of particle sizes. So, the bulking factor for these products varies according to the particle size distribution. Therefore, it is important to have a clear understanding about the particle size distribution of the tested samples. hence, it is recommended to conduct sieve analysis for tested samples, especially for ABC product.

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References

[1] M. Galetakis and A. Soultana, "A review on the utilisation of quarry and ornamental stone industry fine by-products in the construction sector," *Constr. Build. Mater.*, vol. 102, pp. 769–781, 2016, doi: 10.1016/j.conbuildmat.2015.10.204.

[2] G. I. Ofoegbu, R. S. Read, and F. Ferrante, "BULKING FACTOR OF ROCK FOR UNDERGROUND OPENINGS Prepared for Center for Nuclear Waste Regulatory Analyses San Antonio , Texas," no. February, pp. 31–35, 2008.

[3] T. Perera *et al.*, "Analysis of Bulking Factor as a Basis for Royalty Calculation in Aggregate Quarrying in Sri Lanka," in *2020 Moratuwa Engineering Research Conference (MERCon)*, Jul. 2020, pp. 521–525. doi: 10.1109/MERCon50084.2020.9185200

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[4] S. P. Singh and R. Narendrula, "Factors affecting the productivity of loaders in surface mines," *Int. J. Mining, Reclam. Environ.*, vol. 20, no. 1, pp. 20–32, 2006, doi: 10.1080/13895260500261574.

[5] A. B. Goktepe and A. H. Lav, "Method for Optimizing Earthwork Considering Soil Properties in the Geometric Design of Highways," *J. Surv. Eng.*, vol. 130, no. 4, pp. 183–190, 2004, doi: 10.1061/(asce)0733-9453(2004)130:4(183).

[6] V. Palchik, "Bulking factors and extents of caved zones in weathered overburden of shallow abandoned underground workings," *Int. J. Rock Mech. Min. Sci.*, vol. 79, pp. 227–240, 2015, doi: 10.1016/j.ijrmms.2015.07.005.

[7] BS 812-2, "Method of determination of density. British standard," *Br. Stand.*, no. March, pp. 1–22, 1995.

[8] O. K. Kim, C. A. Bell, and R. G. Hicks, "Effect of Moisture on the Performance of Asphalt Mixtures.," *ASTM Spec. Tech. Publ.*, pp. 51–72, 1985, doi: 10.1520/stp35324s.

[9] ASTMD854, "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer 1 ter (Moisture) Content of Soil and Rock by Mass Purposes (Unified Soil Classification System) Engaged in the Testing and / or Inspection of Soil and Rock Construction Mate," *Annu. B. ASTM Stand.*, vol. i, pp. 1–7, 2008.

[10] S. K. Jain, "Investigations on physical properties and bulking of natural sand and artificial sand," vol. 10, no. 4, pp. 471–474, 2021.