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Railway Foundation Properties of Some South African Quarry Stones

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ABSTRACT

Railway ballasts are broken pieces of hard rock within the grain size range of 25mm - 60mm, over which the railway tracks are laid. Quarries in dolerite, greywake, shale, pebbles and granitic rock formations are some of the major sources of large stones that may be selected as railway ballast based on a range of properties. Flakiness index, Roundness, sphericity and shape factor, and Los Angeles Abrasion indices of samples of the five rock types were determined. A strong correlation between the average particle size and flakiness index was observed. Rounded ballasts were found not to be affected by abrasion, while angular ballasts tended to break during abrasion. The granite, shale and dolerite that were tested, performed well during abrasion, are classified as angular (good for rail foundation) by caliper and chart method or rounded to well rounded (bad ballast property) by digital shape analysis and therefore may not be recommended as good ballasts material. The short life span or fast abrasion of some ballast material may be due to selection of sorting and selection by conventional sorting methods i.e. charts and manual linear measurements.

KEYWORDS: Ballasts, Sphericity, Roundness, Flakiness Index.

INTRODUCTION

Good quality ballast are clean and graded crushed stone aggregates with hard, dense, angular particle structure providing sharp corners and cubical fragments with a minimum of flat and elongated pieces (Selig and Waters, 1994). The sleepers lie on top of the ballast, most commonly used type of sleepers is reinforced concrete and is not structurally connected to the ballast, are smooth at the top, but have a very rough surface at the bottom where they come in contact with the ballast (Ebersöhn, 1999). The rough surface makes it possible for the ballast and sleepers to interact together in restraining the external forces. Ballasts are broken pieces of hard rock having a range of 25mm - 60mm size, over which the railway tracks are laid. (Ebersöhn,1999).

Raymond (1985) states that a large variety of rock types can be used as ballast and quarried stone ballast should be obtained from competent strata of reasonable thickness. It is noted (Raymond 1985) that while fine hard mineral grained igneous and sedimentary rock aggregates make the best ballast, the less satisfactory performing rocks are the sedimentary rock types such as limestone, dolomite, sandstone and siltstone. Sedimentary rocks are however the most commonly used rocks because of their wider availability, and their cheaper production cost (Raymond, 1985). The variability of the properties has remain a great concern to railway engineers because of the cost component of the large number of different tests that are required for the screening of rock materials for rail foundations (Baecher and Christian 2003, Currie 1989).

Presently, ballast material is selected in terms of their availability, economic considerations, physical and dynamic mechanical properties. The important physical and mechanical properties of ballasts such as size, shape, surface texture, hardness and durability are best defined by ballast material indices such as mean particle size, roundness, flakiness index, shape factor, sphericity and Los Angeles Abrasion index.

And since good quality ballast should have angular particles, high toughness and hardness, high resistance to weathering, minimum ballast fouling from aggregate breakdown rough surface and minimum hairline cracks (Indraratna et al, 2006). The tests provide information regarding the quality of the ballast in terms of shape and abrasion i.e. the Los Angeles Abrasion test (LAA test) is vital (Fernlund (2005). However for rocks of similar field rating, the impact from the LAA steel ball charge will increase slightly as the hardness of the mineral grains increases. This will result in a higher LAA breakdown (Raymond, 1985) as composition and texture also play a role in influencing the way in which rocks are fragmented due to impact (Fernlund, 2005).

Bowman *et al.* (2001) noted that sphericity and roundness differ as they are two measurements of very different morphological properties because sphericity is sensitive to elongation and roundness is related to angularity and texture. They noted that angular particles have been found to be more liable to creep. Chen, Chang and Lin (2005) investigated the elongation ratio, flatness ratio, shape factor, and sphericity of large aggregates using an image analyzer. They observed that the higher the shape factor the more cubical the aggregate, and also that the cubical shaped particles possess a higher sphericity value than do non cubical particles (Chen, Chang and Lin, 2005).

Angularity and roundness are two particle geometrical properties that mean completely opposite things. Lanaro and Tolppanen (2002) defined angularity as means of measuring if the particle is more like a cube, brick, or pyramid, or if it has prevailing acute or obtuse angles between the faces. Consequently, angularity is a measure of the sharpness of the edges and corners of a particle (Mora and Kwan, 2000). Roundness is a property of form and is best displayed by a sphere. It does not measure sphericity, while sphericity is a measure of total form. Al-Rousan, Masad, Tutumluer and Pan (2007) emphasized the importance of measuring the roundness of the corners, especially when considering the abrasive and perforation properties of the particles as well as the importance of measuring the roundness of the outline, or the overall roundness of the particle which is usually measured in terms of convexity, which is vital when considering the ability of the particle to interlock (Mora and Kwan, 2000).

Roundness and angularity are scaled by Mora and Kwan (2000) as following which describe their degrees: Angular (little evidence of wear), Sub-angular (some wear but faces untouched). A perfect rounded particle would have a roundness of 1, well rounded = 0.6 – 1.0, rounded 0.4 – 0.6, subrounded = 0.25 – 0.40, sub angular = 0.15 – 0.25, angular 0.00 – 0.15.

Krumbein (1941) used a tumbling barrel as an abrasion equipment to abrade a load of twenty-seven limestone rocks particles of sizes ranging from 45 to 55mm where measurements of size, sphericity and roundness were made. A graph of size, sphericity and roundness was constructed (see Figure A1 in Appendix A) and it can be depicted from it that the size is continuously reducing until ultimately the particles will be worn away. It can also be deducted that roundness and sphericity increase continuously during the experiment but they approach limiting values. However, Fernlund (2005) performed an LAA test on a sample of crushed granitic gneiss. The LAA value was determined to be 12, and it was found from this study that all particles were reduced similarly with respect to their longest axes . In addition, the number of particles increased after the test and it was accepted that it was because of the extremely long that probably broke down due to the impact of the steel balls (Fernlund, 2005). Another LAA test was performed by Raymond (1985) using different size particles. Different LAA values were found for track particles and freshly crushed particles. It was therefore recommended that ballasts be compared on a standard size of freshly crushed particles regardless of the maximum particle of the ballast.

Selig and Waters (1994) have reported that Dunn and Bora tested a hard crushed limestone aggregate of sizes 4.8 to 38m with flaky particles varying from 0 to 100% using a special triaxial device. Increased shear strength was produced by any amount of flaky particles, but it is suggested that 25 to 75% of flaky particles is better (Selig and Waters, 1994). Indexes are used to measure the flakiness and elongation of aggregate sample, by using the percentages by mass of the aggregate particles classified as flaky and elongated (Kwan, Mora and Chan, 1999). Flakiness is defined by Lanaro and Tolppanen (2002) as the ratio between the length and the thickness of the particle. While Fernlund (2005) defines flakiness index as a measure of how thin particles are compared to their sieve size in general.

Most of the methods discussed above in this paper are called traditional methods of characterizing the physical properties of aggregates. The results of such methods are mostly affected by human errors and time-consuming (Lanaro and Tolppanen, 2002). New user-friendly and quick methods have been developed over the years to characterize both the particle size and particle shape, where this characterization can be done in one-go. The traditional methods had the disadvantage of using one method to classify particle shape, and another to classify particle size.

Attempt to use a 3D-laser scanning technique to study ballast material by developing a geometrical evaluation method of scanned images produced both reliable and repeatable results

(Lanaro and Tolppanen 2002). The method produces images such as those shown in Figure 5, which shows a dimensional view of the particle. Fernlund (2005) developed a method to determine the shape of the particles at the same time that the size distributions are determined for all the axial lengths of all the particles. The method involves the use of two photographed images of the particles in two different positions, standing and lying. This makes it possible to give both the largest and smallest projected areas of the particles, therefore, all three axes of each particle can be easily measured (Fernlund, 2005).

The selection of naturally occurring stones and artificial aggregates for railway ballast in South Africa is guided by the specifications which have been developed over the years by the Transnet Freight Rail mainly at the Spoornet Track Testing Centre. The Specification for the supply of stones (S406, 2004) require that some of the properties of the stones meet the following minimum requirements: Soundness < 5%: Flakiness Index < 30%; Los Angeles Abrasion Index < 22%

The objectives of the study are to determine the different shape and size properties of ballasts that are used to characterize the ballast properties and to examine the inter correlations among these shape properties.

MATERIALS AND METHODS

The practical part of the project involved the evaluation of five different samples from different geological origins (see Figure 6).

1. Dolerite: Ngagane Newcastle Quarry
2. Pebbles: Kimberley Montewa Construction Quarry
3. Greywake: Durbanville Peninsula Quarry
4. Shale: Worcester Peak Quarry
5. Granite: Lafarge Saldanha Quarry

To shorten the names of the quarries, the names of the places where the quarries were taken will be used (e.g. Saldanha Granite; Worcester Shale; Peninsula Greywake; Newcastle Dolerite; and Kimberley Pebbles). The ballasts used during in this investigation complied with SANS 1083 (latest revision) and the requirements specified therein.

The series of tests conducted to fully characterize the naturally occurring quarry stones are divided into three

- Tests based on Laboratory devices (Particle Size Test, and Los Angeles Abrasion Device)
- Direct particle dimension measurements (Flakiness Index Test, Roundness test, Sphericity and Shape factors)
- Particle Dimension Determination by Charts (Sphericity and Roundness)
- Particle Dimension by 2-Dimension Digital Photography (Roundness).

Figure 1: The different types of ballasts samples for the project: 1. Newcastle Dolerite; 2. Kimberley Pebbles; 3. Peninsula Greywake; 4. Worcester Shale; and 5. Saldanha Granite

Test Methods

The summary of series of tests detailed below were done at the Spoornet Track Testing Centre, Engineering (Infrastructure), Ballast Testing Laboratory, Johannesburg.

The ballast samples were screened with the help of the mechanical sieve shaker using the 75.0mm, 63.0mm, 53.0mm, 37.5mm, 26.5mm, 19.0mm and 13.2mm sieves. The samples retained on different sieve sizes are emptied and weighed into different basins that have marks similar to one of the sieves. (Spoornet, 1998).

The LAA value which is defined as the amount of material passing through the 1.70mm sieve taken from a sample batch consisting of 2.5kg sample of ballast passing the 19.0mm sieve but retained on the 13.2mm sieve is prepared together with another 2.5kg of ballast passing the 13.2mm sieve and retained on the 9.50mm sieve, that is abraded by 11 steel balls that were placed inside the steel drum and rotated at a speed of 30 to 33 rpm for 500 revolutions, expressed as percentage of the original sample mass. This value is determined in accordance with ASTM C 131-89 grading B, and (Spoornet, 1998) as

$$\text{LAA value} = \frac{100 \times (W_0 - W_1)}{W_0}$$

W_0= the total of the two dried samples of 5kg;

W_1 = the mass retained on the 1.70mm sieve

The flakiness index is determined in accordance with Spoornet (1998) and SANS 1083 (2007) as the ratio of the mass passing standardized Flakiness Index slots related to three of the highest required mass amongst the mass retained in the following sieves; 5 kg retained on 63mm, 53.0mm, 37.5m and 26.5mm; 4kg retained on the 19.0mm sieve: 13.2 kg retain on 13.2mm sieve

$$\%\ \text{Flakiness index} = 100 \times \frac{A}{C}$$

A = the approximate mass passing the slot;

B = the mass retained on the slot; and

C = A+B.

The flakiness index of good ballast material is less than 30% (Spoornet 1998).

The roundness of the sample will be done in a table study way where a number of particles will be randomly chosen from a sample and then each sample will be determined for roundness. A ruler, piece of paper, and a pencil will be used. Place the stone particle on the paper and with the pencil; trace the stone on the paper for all the sides of the stone.

Draw a big circle that inscribes the particle on the paper, and draw small circles on all the corners of the particle. Do this for all the sides of the particle drawn on the paper. Calculate the roundness for all the sides by using the formula below, and take the average to get the roundness of the particle.

$$\rho = \frac{\sum_{i=1}^{n} \left({r_i}/{R} \right)}{N}$$

ρ = roundness of the particle;
r = the radius of the small circle;
R = the radius of the large circle; and
N = the number of corners of the particle in the given plane.

The longer, intermediate and shorter dimensions of individual stones in the five groups are measured by vinnear calliper scale rule.

The sphericity and shape factor are then determined according to formulas below.

$$\text{sphericity} = \sqrt[3]{\frac{\text{thickness} \times \text{breadth}}{\text{length}^2}}$$

$$\text{shapefactor} = \frac{\text{thickness}}{\sqrt{\text{breadth} \times \text{length}}}$$

Thickness = the shorter dimension of the particle;

Breadth = the intermediate dimension of the particle; and

Length = the longer dimension of the particle.

The results are expected to be very close to 1.0 for particles that are almost like spheres.

The Roundness and Sphericity of the rock materials were also estimated by visual comparism of individual stones overlaid on standard charts. The roundness chart developed by Krumbien (1941) was used for the visual estimation of roundness as detailed by Masad et al (2007) for characterizing Aggregate Shape, Texture, and Angularity. The Sphericity Chart developed by Rittenhouse (1944) was used for the visual estimation of Sphericity as detailed by Handy and Spanger (2007) for charactering particle size and gradation of large aggregates and boulders.

The image analysis method was done using computer software called Pixcavator. The pixcavator analyzes an image which is imported into the program and gives the identification, type, location, size in pixels, perimeter, roundness, gray, contrast and dimensions of the image in a form of an Excel spreadsheet. The program analyzes the image in two-dimension (2D), and it can analyze an image containing a set of particles or an image having one particle in it.

Two methods were used to determine the roundness of the ballasts. Firstly, an image containing the ten ballasts was analyzed with the pixcavator where the program could determine the roundness for all individual ballasts in the image. Secondly, an image containing only one ballast particle was used and this was done for all five samples of ballasts. Five images were used in the first method, and fifty images were used in the second method.

RESULTS AND DISCUSSIONS

More than 80% of the stones used are contained within the sieve range from 9.5mm to 75mm as seen in Figure 2, with the Saldanha granite containing significantly more stones of the largest diameter. This is reflected also reflected in the average particle sizes of D_{50} of the ballasts shown below in Table 2.

The D_{50} values are as follows:

- Newcastle Dolerite : 35.6mm
- Worcester Shale : 42.1mm
- Peninsula Greywake : 27mm
- Saldanha Granite : 56.5mm
- Kimberley Pebbles : 37mm

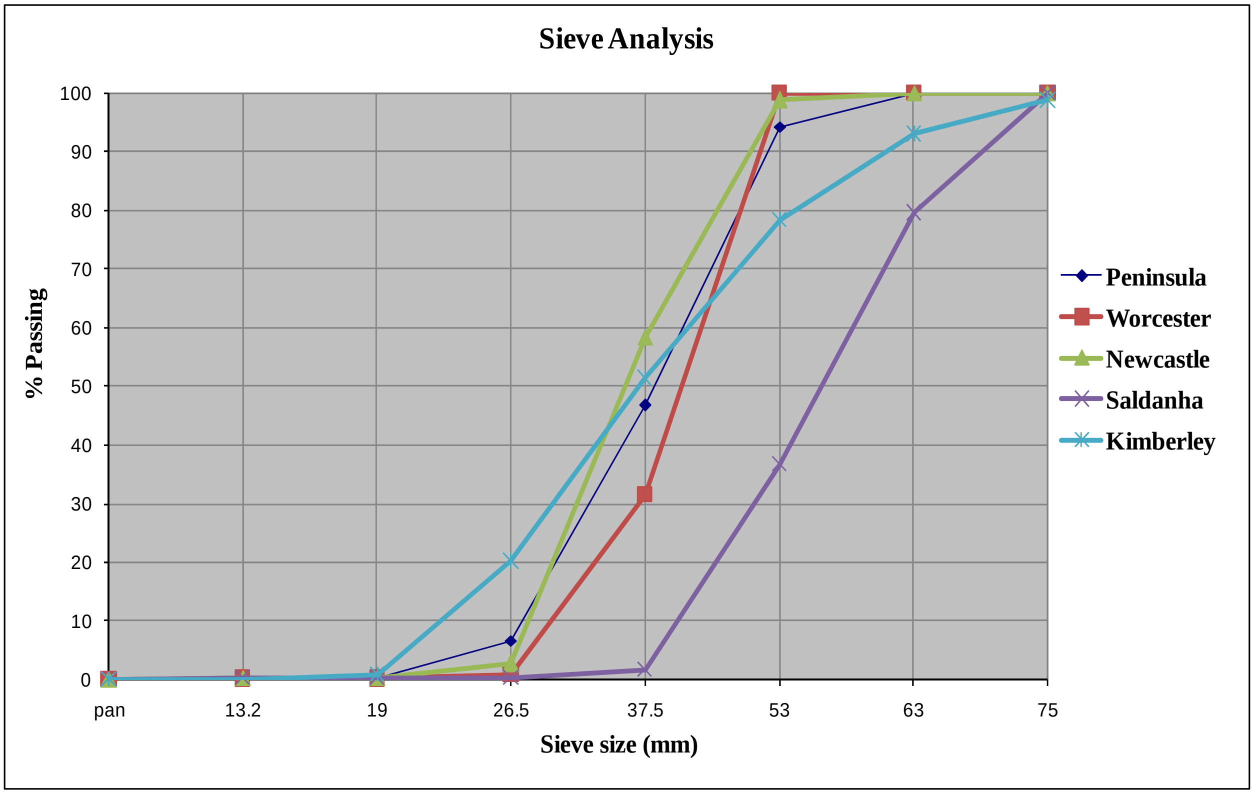

Figure 2: Sieve analysis results

Flakiness Index

The flakiness index test determines the flatness of the ballasts. For stone particles to fail this test they should either be too thin in thickness or very long in length, which means the thickness to length ratio form a basis for this test. Table 6 shows the results for the flakiness index test for epicted from the table that four out of the five samples passed the test. The Peninsula greywake is considered flat, which means they are poor rail ballast material. A relationship between the flakiness and the average size of the ballasts shown in fig indicate a strong correlation between the average particle size and flakiness index. Figure 2 broadly indicate that the larger the ballasts particles the lesser the percentage of flakiness index.

Table 1: Flakiness index test results

Description	Newcastle	Worcester	Peninsula	Saldanha	Kimberley
Total mass not passing (kg) (B)	7.99	8.45	4.9	13.99	8.13
Total mass passing (kg) (A)	3.09	1.58	5.1	1.03	1.93
Total mass of stone in test (kg) (C)	11.08	10.03	10	15.02	10.06
Flakiness index (%)	**28**	**16**	**51**	**7**	**19**
Pass/Fail	**Pass**	**Pass**	**Fail**	**Pass**	**Pass**

$$\%\ \text{Flakiness index} = 100 \times \frac{\text{A}}{\text{C}}$$

If Peninsula greywake were stacked on top of another, a brick-like formation would have been observed. This means that the greywake would have been able to form a stack that leaves no voids in between the stones. This is however not needed for ballasts in the field, because they have very poor drainage. Conversely, the other four samples of ballasts could produce good drainage in the field, but it should be noted that visual examination of the Newcastle dolerite reveals the presence of flat components, since flaky particles are those particles having a thickness that is smaller than 0.6 times the mean sieve size of the size fraction to which they belong, although the material passed the flakiness index test (Kwan *et al.*, 1999). A realistic measure of particle shape is however determined only when a large aggregate sample consisting of many particles is analyzed for flakiness and elongation indexes.

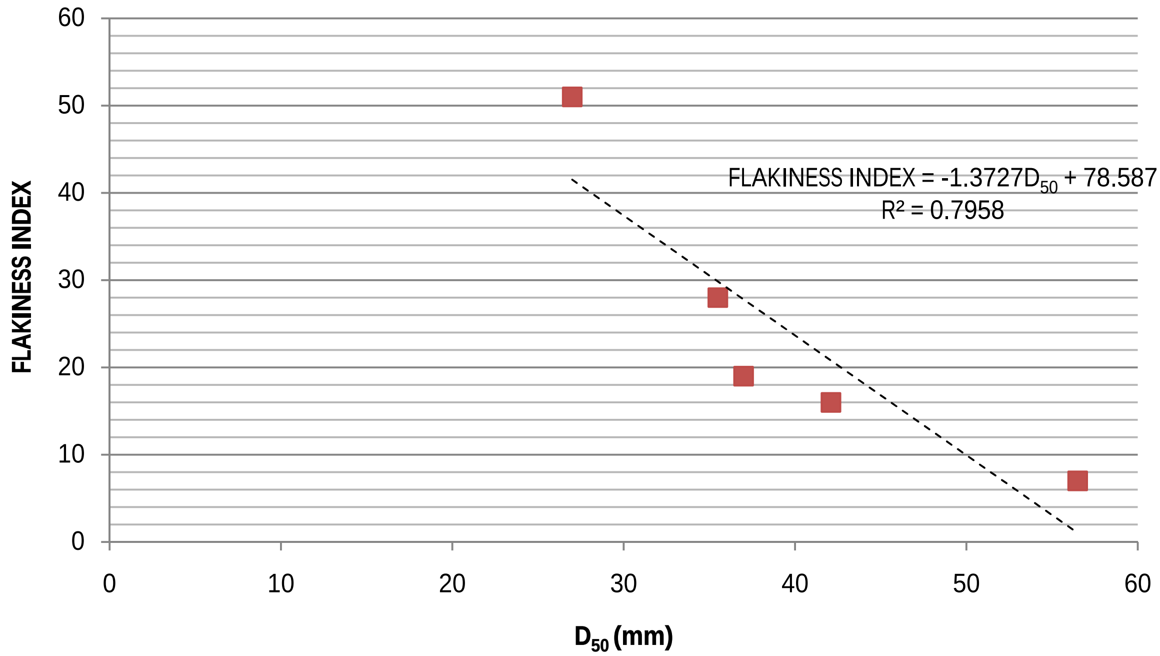

Figure 3: Flakiness index and LAA versus D_{50} values

Roundness, Sphericity and Shape Factors of Quarry Stones

Table 2 shows the results for the calculated values of roundness, sphericity and shape factor based on dimensions that were measured using a calliper scale. The mean values show that the Worcester Shale is angular; Saldanha Granite, Peninsula Greywake and the Newcastle Dolerite are rounded; while the Kimberley Pebbles are well rounded. The average values of sphericity and shape factor range between 0.5 and 0.7, with the Dolerite and Pebbles having the least number of sharp corners or more numbers of smooth corners.

Table 3 represents the results for roundness and sphericity for the ballasts determined by the chart methods. The average values of roundness are between 0.3 and 0.75 and the average values of sphericity is between 0.5 and 0.8. These values are not significantly different from the values determined from Table 7. However based on table 3, the pebbles is well rounded, penincisular greywake is rounded while the rest are angular. Visually the Worcester shale, Saldanha granite, Peninsula greywake and the Newcastle dolerite have more sharp corners than Kimberley pebbles.

The direct measurement and chart method of visualizing particle roundness and sphericity were based only on the corners of the particles, and not on the whole shape or form of the particle. These two methods are laborious and fairly subjective.

Table 2: Calculated Values of Roundness, Sphericity and Shape Factor of the ballasts

Description	Worcester Quarry			Saldanha Quarry			Peninsula Quarry			Newcastle Quarry			Kimberley Quarry		
Stone number	Roundness	Sphericity	Shape factor	Roundness	Sphericity	Shape factor	Roundness	Sphericity	Shape factor	Roundness	Sphericity	Shape factor	Roundness	Sphericity	Shape factor
1	0.39	0.55	0.53	0.39	0.62	0.60	0.49	0.61	0.35	0.35	0.77	0.68	0.78	0.56	0.43
2	0.44	0.53	0.46	0.65	0.60	0.36	0.57	0.59	0.29	0.37	0.74	0.60	0.57	0.67	0.53
3	0.40	0.54	0.21	0.44	0.79	0.68	0.32	0.53	0.31	0.48	0.51	0.43	0.76	0.69	0.53
4	0.46	0.54	0.59	0.55	0.69	0.57	0.45	0.53	0.22	0.37	0.56	0.33	0.64	0.73	0.57
5	0.42	0.54	0.39	0.37	0.50	0.42	0.39	0.43	0.35	0.36	0.53	0.43	0.71	0.65	0.64
6	0.27	0.53	0.18	0.51	0.78	0.67	0.57	0.58	0.34	0.29	0.72	0.59	0.73	0.77	0.46
7	0.37	0.68	0.59	0.47	0.64	0.47	0.41	0.68	0.41	0.33	0.66	0.60	0.61	0.58	0.45
8	0.35	0.60	0.65	0.34	0.82	0.80	0.37	0.50	0.27	0.69	0.69	0.39	0.46	0.71	0.64
9	0.33	0.49	0.52	0.37	0.64	0.58	0.40	0.64	0.39	0.44	0.71	0.77	0.65	0.87	0.78
10	0.38	0.53	0.58	0.40	0.49	0.43	0.49	0.56	0.37	0.45	0.78	0.74	0.65	0.71	0.50
Mean	**0.38**	**0.55**	**0.47**	**0.45**	**0.66**	**0.56**	**0.45**	**0.57**	**0.33**	**0.41**	**0.67**	**0.56**	**0.65**	**0.69**	**0.55**
Variance	**0.00271**	**0.00233**	**0.02365**	**0.00852**	**0.01178**	**0.01715**	**0.00612**	**0.00458**	**0.00306**	**0.01160**	**0.00887**	**0.02095**	**0.00825**	**0.00697**	**0.01009**
Std deviation	**0.0521**	**0.0483**	**0.1538**	**0.0923**	**0.1085**	**0.1310**	**0.0782**	**0.0677**	**0.0553**	**0.1077**	**0.0942**	**0.1448**	**0.0909**	**0.0835**	**0.1005**
COV	**0.137**	**0.088**	**0.328**	**0.206**	**0.165**	**0.234**	**0.175**	**0.120**	**0.168**	**0.261**	**0.141**	**0.260**	**0.139**	**0.120**	**0.182**
Sum	**3.80**	**5.51**	**4.69**	**4.48**	**6.59**	**5.59**	**4.47**	**5.66**	**3.29**	**4.12**	**6.66**	**5.57**	**6.55**	**6.93**	**5.53**

Table 3: Chart (visual) results for Roundness and Sphericity of the ballasts

Description	Worcester Quarry		Saldanha Quarry		Peninsula Quarry		Newcastle Quarry		Kimberley Quarry	
Stone number	**Roundness**	**Sphericity**	**Roundness**	**Sphericity**	**Roundness**	**Sphericity**	**Roundness**	**Sphericity**	**Roundness**	**Sphericity**
1	0.2-0.3	0.7	0.3-0.4	0.6	0.4-0.5	0.6	0.3-0.4	0.5	0.8-0.9	0.9
2	0.3-0.4	0.6	0.3-0.4	0.3	0.4-0.5	0.7	0.2-0.3	0.6	0.7-0.8	0.8
3	0.2-0.3	0.7	0.4-0.5	0.7	0.4-0.5	0.8	0.3-0.4	0.3	0.8-0.9	0.9
4	0.4-0.5	0.4	0.4-0.5	0.7	0.4-0.5	0.8	0.3-0.4	0.3	0.7-0.8	0.8
5	0.3-0.4	0.8	0.3-0.4	0.2	0.4-0.5	0.6	0.4-0.5	0.5	0.8-0.9	0.5
6	0.2-0.3	0.7	0.2-0.3	0.7	0.4-0.5	0.7	0.3-0.4	0.3	0.6-0.7	0.7
7	0.2-0.3	0.5	0.4-0.5	0.6	0.4-0.5	0.7	0.2-0.3	0.3	0.6-0.7	0.7
8	0.2-0.3	0.6	0.4-0.5	0.7	0.4-0.5	0.8	0.4-0.5	0.5	0.6-0.7	0.8
9	0.3-0.4	0.4	0.2-0.3	0.8	0.4-0.5	0.8	0.3-0.4	0.7	0.6-0.7	0.9
10	0.3-0.4	0.5	0.2-0.3	0.6	0.4-0.5	0.7	0.4-0.5	0.5	0.6-0.7	0.9
Mean	**0.31**	**0.59**	**0.36**	**0.59**	**0.45**	**0.72**	**0.36**	**0.45**	**0.73**	**0.79**
Variance	**0.0044**	**0.0169**	**0.0069**	**0.0329**	**3.0815E-33**	**0.0056**	**0.0049**	**0.0185**	**0.0076**	**0.0149**
Std deviation	**0.0663**	**0.1300**	**0.0831**	**0.1814**	**0.0000**	**0.0748**	**0.0700**	**0.1360**	**0.0872**	**0.1221**
COV	**0.2140**	**0.2203**	**0.2307**	**0.3074**	**0.0000**	**0.1039**	**0.1944**	**0.3023**	**0.1194**	**0.1545**
Sum	**3.1**	**5.9**	**3.6**	**5.9**	**4.5**	**7.2**	**3.6**	**4.5**	**7.3**	**7.9**

Mean: $\mu_x = \overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$; Variance: $\sigma^2 = \frac{\sum(X-\overline{X})^2}{N}$;

Standard deviation: $\sigma = \sqrt{\sigma^2}$; Coefficient of variation: COV $= \frac{\sigma}{\mu}$

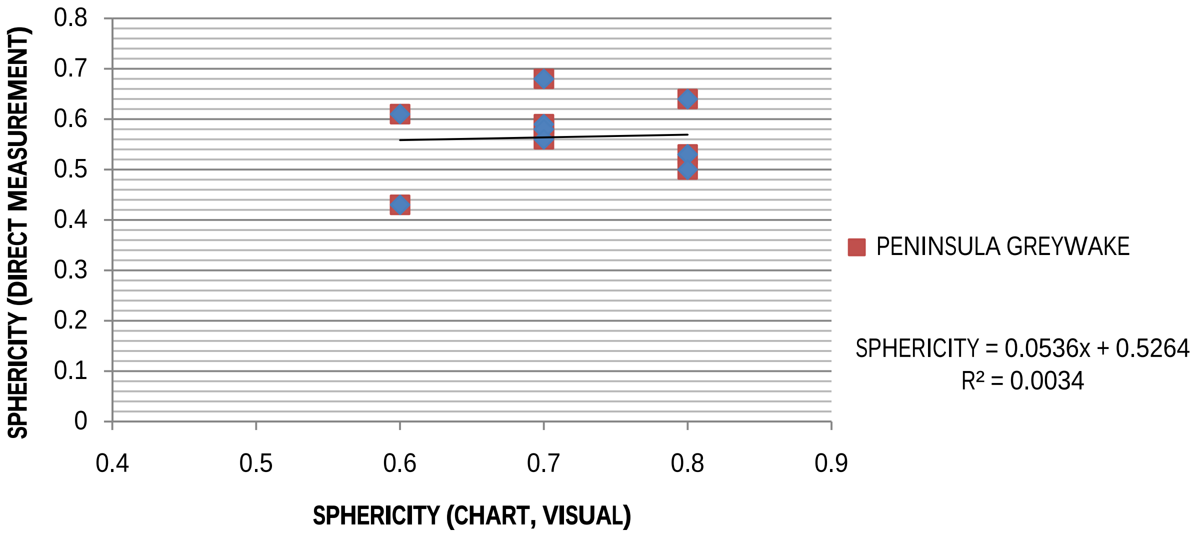

Figure 4: Variance for calculated roundness versus D_{50} values

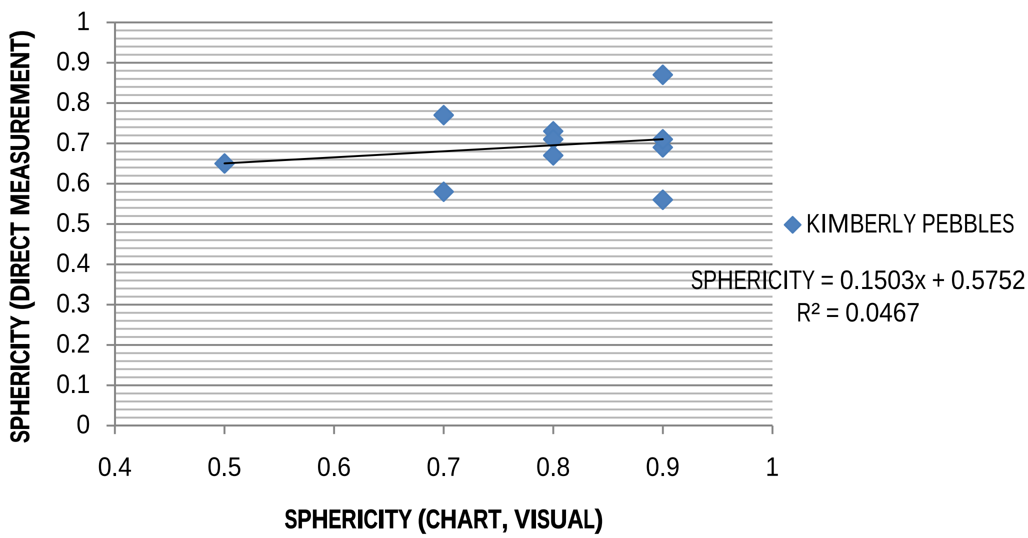

Figure 5: Variance for calculated sphericity versus D_{50} values

Image Analysis Results

The roundness of the stones was analyzed with the aid of a digital image analyzer. The digital images of the stone batches are shown in Figure 6 while the images of individual stones are shown in Figure 7. The roundness of the stones was determined in their repositions or natural sitting positions. The image analysis method is very quick and reproducible.

Figure 6: An image of non-analyzed and analyzed doloritic rock stones (Method 1)

Figure 7: A dolorite ballast image that has been analyzed using the pixcavator (Method 2)

There are differences in the value of roundness shown in table 4 and table 5 despite adjustment for optimal settings. Relative to Method 2, very few seconds were needed to adjust the setting to optimal effect for the analysis of individual stones, i.e. Method 1.

The results of the image analysis of batches of stones are given in table 4 and that of single stones are given in Table 5.

Table 4: Results for roundness determined using method 1

Description	Worcester Shale	Saldanha Granite	Peninsula Greywake	Newcastle Dolorite	Kimberley Pebbles
Stone number	**Roundness**	**Roundness**	**Roundness**	**Roundness**	**Roundness**
1	0.64	0.36	0.71	0.81	0.78
2	0.71	0.75	0.75	0.80	0.77
3	0.77	0.74	0.71	0.62	0.75
4	0.61	0.31	0.77	0.78	0.85
5	0.72	0.38	0.54	0.62	0.75
6	0.71	0.69	0.71	0.79	0.82
7	0.66	0.43	0.80	0.79	0.72
8	0.67	0.74	0.78	0.75	0.53
9	0.60	0.36	0.74	0.84	0.79
10	0.63	0.41	0.74	0.68	0.84
Average	**0.67**	**0.52**	**0.73**	**0.75**	**0.76**

Table 5: Results for roundness determined using method 2

Description	Worcester Shale	Saldanha Granite	Peninsula Greywake	Newcastle Dolorite	Kimberley Pebbles
Stone number	**Roundness**	**Roundness**	**Roundness**	**Roundness**	**Roundness**
1	0.53	0.65	0.75	0.76	0.80
2	0.69	0.73	0.75	0.79	0.71
3	0.73	0.72	0.72	0.62	0.83
4	0.58	0.73	0.76	0.72	0.85
5	0.74	0.59	0.55	0.59	0.81
6	0.65	0.68	0.72	0.78	0.76
7	0.64	0.69	0.76	0.77	0.72
8	0.68	0.76	0.79	0.69	0.77
9	0.57	0.69	0.71	0.76	0.84
10	0.56	0.65	0.73	0.68	0.83
Average	**0.64**	**0.69**	**0.72**	**0.72**	**0.79**

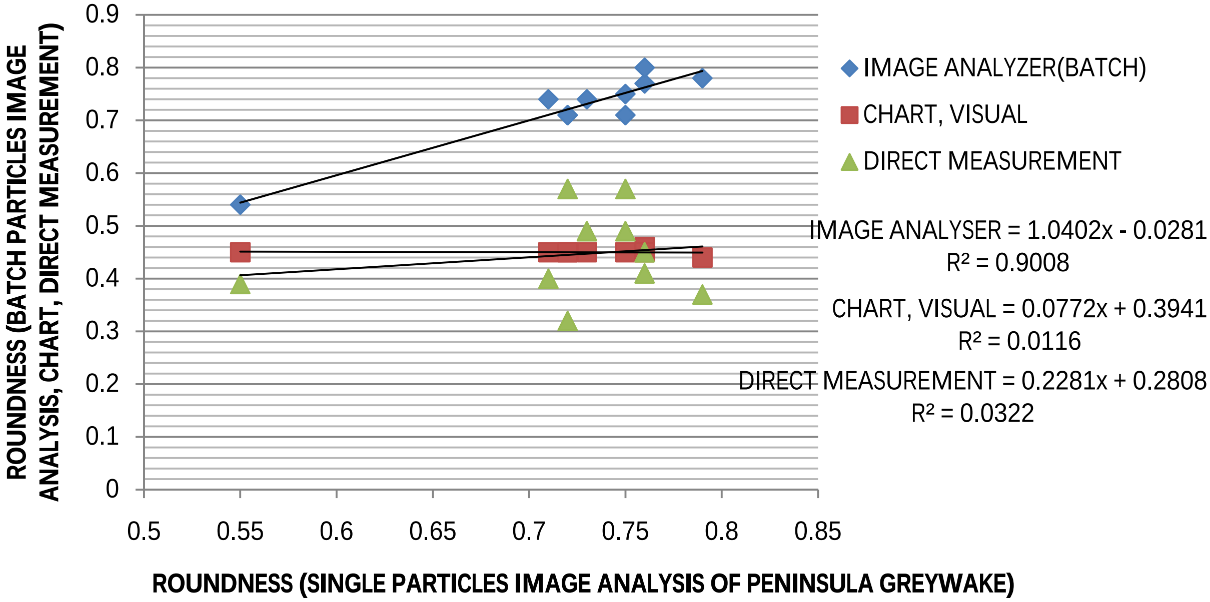

Figure 8: Single versus batch particle analysis of Greywake stones

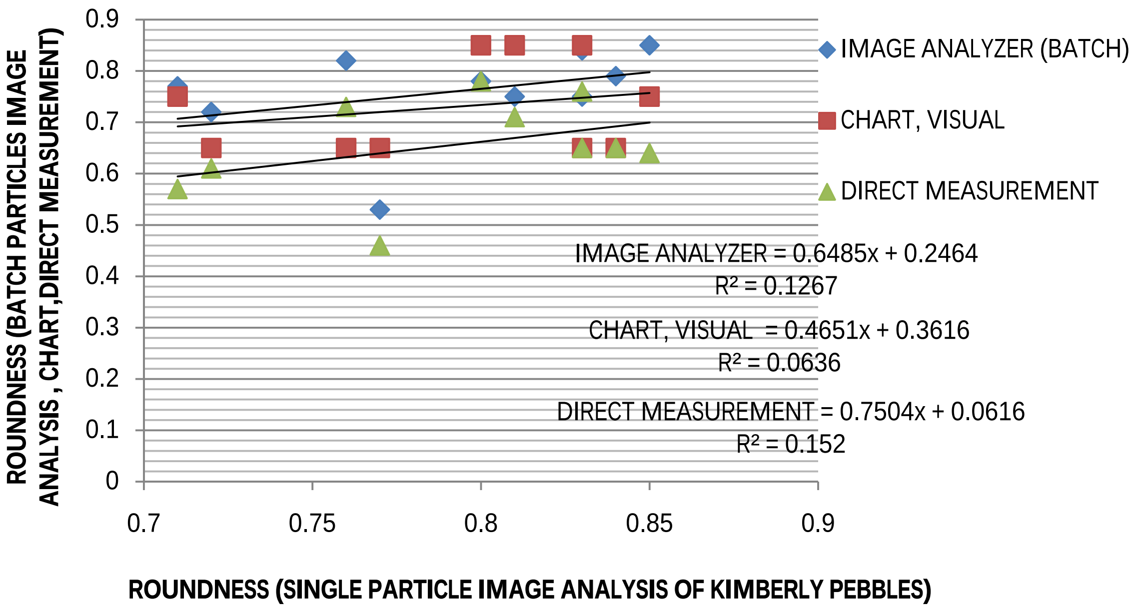

Figure 9: Single versus batch particle analysis of Peeble Stones

The difference in roundness determined by method 4 and 5 as expressed by the coefficient of correlation is marginal for stones with angular stones sharp edges and corners i.e. greywake and significant for stones with near smooth textured and near rounded stones i.e. pebbles. The implication is that the roundness of batches of sharp cornered stones can be quickly and accurately evaluated and sorted because the roundness of the batches is a close approximation of the roundness of individual stones. However the sorting of near rounded stones in batches reflects a very poor approximation of the individual stones.

The correlations shown in Figure 8 and Figure 9, between roundness values determined by method 2 and by chart and direct measurement are very weak for the pebbles and also for the greywake. This is expected because while the roundness determined by the image analysis is based on the total form or shape in comparism to a circle, the component of roundness determined by direct measurement and chart is based on the frequency and number of corners and edges of the stones.

The LAA test was done on the numbered samples that were initially used for the determination of the size and shape properties. The machine and the results are shown in Figure 10 and Table 6 respectively.

Figure 1: LAA machine

Table 6: Los Angeles Abrasion (LAA) test results

Description	Newcastle	Worcester	Peninsula	Saldanha	Kimberley
Total mass retained on 13.2mm (kg)	2.5	2.5	2.5	2.5	2.5
Total mass retained on 9.5mm (kg)	2.5	2.5	2.5	2.5	2.5
Total mass of sample in test (kg) (W_0)	5	5	5	5	5
Material retained on 1.7mm (kg) (W_1)	4.305	4.47	4.52	4.018	5
LAA value (%)	**13.9**	**10.6**	**9.6**	**19.64**	**0**
Pass/Fail	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**

$$\text{LAA value} = \frac{100 \times (W_0 - W_1)}{W_0}$$

It can be seen from Table 6 that none of the samples tested failed the test because none is below above 22%. The Kimberley pebbles were very smooth in texture and had very smooth corners which represented the shape of a circle or sphere. The first four samples in the table were broken during abrasion test because of their dominant sharp corners, as the steel balls in the LAA machine tend to break the corners of the samples. Because the D_{50} is not representative of the shape or geometry of the different stones and also because a limit size range is required for the LAA test, there is no significant correlation between the average sizes of ballasts and their LAA values. The weak correlation is mainly due to smooth pebble with the least abrasion index. Although the Pebbles are the least abraded, they are shown in table 4 and table 5 to be well rounded and thus cannot be used as ballast material. While the Saldanha granite is angular and rough textured, it barely passed the abrasion test 19.64/22.00, the other materials can be classified as angular or rounded based on visual or digital results and passed the abrasion test, thus no single property is a dominant criteria for the selection of quarry stones for railway platforms.

CONCLUSIONS

The D_{50} of the ballasts materials used in this investigation ranged from 27mm to 56.5mm with a nominal particle range of 19mm – 75mm.

To determine the shape properties of the ballasts the flakiness index test, roundness, sphericity and shape factor tests were performed. Four stone types passed the test except for the Peninsula greywake which resulted as being 51% flaky. It is the sample with the smallest average size (D_{50}) and also one with the highest flakiness index and is the Peninsula greywake.

Using a calliper scale, the mean values show that the Worcester Shale is angular; Saldanha Granite, Peninsula Greywake and the Newcastle Dolerite are rounded; while the Kimberley Pebbles are well rounded. However based on visual analysis using the chart method, the pebbles is well rounded, peninsular greywake is rounded while the rest are angular.

Single and batch analysis of stones based on digital image analysis of the roundness yielded slightly different results, with the degree of correlation between the two methods dependent on the density of sharp corners.

While all the samples tested passed the Los Angeles Abrasion (LAA) test, the Kimberley pebbles was not abraded. Angular particles tend to break more than rounded particles and all the particles with sharp corners broke more than the particles with smooth corners. In addition, the performance of the pebbles in abrasion does not necessarily make them good ballasts material. The pebbles have a very smooth texture or surface and are not abraded because of their toughness, however they form poor interlocking. If pebbles were to be used in the field as ballasts material, they would not be able to form a good cohesive or compact foundation; they would also not be able to form near monolithic unit with the sleepers. The Peninsular greywake has good abrasion properties, not well rounded but very flaky.

The granite, shale and dolerite also performed well during abrasion, are classified as angular (good for rail foundation) by caliper and chart method or rounded to well rounded (bad ballast property) by digital shape analysis and therefore may not be recommended to be used as ballasts material. The short life span or fast abrasion of some ballast material may be due to selection of sorting and selection by conventional sorting methods using charts and manual linear measurements.

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