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Assessment of rock fragmentation and strength properties using Rosin-Rammlers and Extended Swebrec Distribution functions parameters

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ABSTRACT

This work assessed the curve fitting ability of Rosin-Rammler and Swebrec functions and the comparison of their fitting parameters with rock strength properties. The work aimed to show if there exists a relationship between the function's distribution parameters and rock strength properties. The rock strengths properties were determined in accordance with International Society of Rock Mechanics standards. The two functions were used to reproduce sieving curves of different rocks fragmented on a laboratory scale using electric detonators. The Swebrec function reproduces the sieving curves better than Rosin-Rammler. The Rosin-Rammler curve fitting performs creditably with well-fragmented rocks of poor grading or uniformly sorted fragments. The Rosin-Rammler curve fitted better to Class II rocks than the Class I rocks. The Rosin-Rammler parameters are shown to be interdependent while only factor 'a' and exponent 'c' parameters of the Swebrec function are mutually dependent. The undulating exponent 'b' of Swebrec is related to the uniformity index, 'n' and characteristic size, 'Xc' of Rosin-Rammler. By comparison, the parameters of the two functions show correlations with rock strength properties (BTS, UCS, E, and v). The uniformity index, 'n' is related to rock properties included in this study while the Swebrec 'c' parameters did not show any relationship with rock properties. The 'Xc' parameter of Rosin-Rammler is related to UCS, E and v. The 'a' and 'b' parameters of the Swebrec function are related to BTS, UCS, and v and BTS UCS and E respectively. In all cases, the correlation coefficients are greater than 0.6 and can be fitted by the power form function.

Keywords: *Curve fitting, Fragmentation, Rock strength, Rosin-Rammler, Swebrec function*

1. Introduction and Literature Review

Rock breakage is achieved traditionally either by mechanical means or using explosives. Under this process, rock is fragmented into various sizes and yielded diverse fragments distributions with different characteristic curves when analysed. Moser et al [1] suggested that particles size distributions of blasted materials are based on the natural breakage characteristics of the rock. Furthermore [1] opined that there exists a comparable and material-specific characteristic of particles size distribution from 0.1 mm to 10 mm for both full-scale and lab-scale blast tests. They observed that characteristics curves of particles' size distribution do not change due to energy input and specific charge upon blasting but can only shift their position on a log-log graph.

Fragments size distribution in mining (e.g. in the aggregate quarry) is typically classified by their sieving curves using image sampling and analysis software [2]. The Kuz-Ram equation (Eqn. 1) in combination with the Rosin-Rammler distribution function is the most widely used prediction model occurring in blasting literature. It has been a generally recognised method for giving a reasonable description of fragmentation of blasted rocks. Kuz-Ram prediction equation for the mean fragment size is given by the relation between the mean fragment size (X_u, cm) and the explosive quantity used per unit volume as a function of rock type categorised as medium hard rocks, hard and fissured rocks, and weak rocks.

$$X_m = A\left(\frac{V_o}{Q_e}\right)^{0.8} Q^{1/6} \quad (1)$$

Where X_m is the mean fragment size (cm), A is the rock factor, (7 for medium hard rocks, 10 for hard highly fissured Rocks, 13 for hard, weakly fissured rocks), V_0 is the rock volume broken per blast hole (m^3), and Q_e is the mass of *TNT* containing the energy equivalent of the explosive charge in each blasthole (kg) and the relative weight.

The Kuz-Ram fragmentation prediction model uses Rosin Rammler or Weibull distribution function to describe the sieving curve of fragmented rocks. The distribution function has two parameters, the characteristic size, Xc, and a uniformity index n. The Rosin-Rammler distribution function is given by Eqn. 2.

$$R_m = 1 - e^{-\left(X/X_c\right)^n} \quad (2)$$

Where R_m is the proportion of material passing the screen, X is the screen size (cm), X_C is the characteristic size (cm), and n is the index of uniformity. The characteristic size X_C is one through which 63.2% of the particles pass. Eqn. 2 can be rearranged to yield the expression for the characteristic size.

$$X_c = \frac{X}{\sqrt[n]{-\ln(1-R_m)}} \quad (3)$$

Since the Kuznetsov formula gives the screen size, X_m for which 50% of the material could pass, therefore substituting the values $X = Xm$ and $R_m = 0.5$ into Eq. 3 gives;

$$X_c = \frac{X_m}{\sqrt[n]{0.693}} \quad (4)$$

The exponent n, the uniformity index in the Rosin-Rammler formula which is a measure of the slope of the distribution curve as indicated in

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Eqn. 2 was further expanded by [3] and provided a technique for its estimation. Cunningham [3] used Blastability Index earlier proposed by Lilly [4] for the estimation. The model has an equation to show that w X_{50} and n depend on the specific charge, rock properties; rock mass jointing, blast pattern, etc.

$$n = \left(2.2 - \frac{14Bd}{d}\right)\left(\frac{1}{md}\right)/2)\ 0.5\left(1 - \frac{w}{Bd}\right)\left(abs\left(\frac{(lb-lc)}{Lch}\right) + 0.1\left(\frac{Lch}{Hb}\right)\right) \quad (5)$$

Where n is the index of uniformity; Bd is a burden in drilling (m), d is blast hole diameter (mm), md is spacing to burden ratio while drilling; W is the standard deviation of accuracy in burden while drilling (m); abs is the absolute value; lb is base charge length (m); lc is column charge length (m); Lch is total charge length (m); Hb is bench height (m).

Chung and Katsabanis [5] proposed formulas to estimate the two Rosin-Rammler distribution parameters, n and Xc by assuming that rock fragmentation size distribution follows the Rosin-Rammler distribution.

$$X_c = e^{(0.565\ ln\ X_m + 0.435\ ln\ X_{80})} \quad (6)$$

$$n = 0.842/(ln\ X_{80} - ln\ X_m) \quad (7)$$

Where Xm is the sieve size at 50% material passing (cm), X_{80} is the sieve size at 80% material passing (cm), Xc is the sieve size at 63.2% material passing (cm), and n is the uniformity index.

This paper also considered a new distribution function called the Swebrec function. It has been shown to have good results of fragment size analysis of blast discovered during the Less Fines Project [6,7]. It is a three parameters function, with physical meaning, in its basic form [8]. The basic Swebrec function is given by the expression in Eqn. 8.

$$P(x) = 1 / \{1 + (ln\,(x_{max}/x) / (x_{max}/x_{50}\,)\}^{b} \quad (8)$$

Where: $0 < x \leq x_{max}$

The function has 3 parameters, xmax, x_{50}, and the curve undulation exponent b.

An extended version of the Swebrec function extends the function with an extra term containing two parameters, the factor 'a' and the exponent 'c' Eqn. 9:

$$P_2(x) = 1 \Big/ \{1 + a * [\ln(x_{max}/x)/\ln(x_{max}/x_{50})]^b + (1-a) * [(x_{max}/x - 1)/(x_{max}/x_{50} - 1)]^c\} \quad (9)$$

Ouchterlony [9] discussed that the new terms have the effect that $P_2(x)$ behaves like a Gaudin-Schuhmann function $(x/x_{max})^c$ for small values of x. He suggested that its form be chosen to retain the properties $P_2(x_{max})$ =1 and $P_2(x_{50})$ = 0.5. For values of c, c>0, the area integral ∫P′(x) .dx/x converges and the range of fit now includes all points in the set of sieving data. High b-values in combination with high x_{max}-values are likely to arise when the sieving curve appears similar to a Rosin-Rammler curve

Ouchterlony [9] explained further that the b-values tend to be relatively constant for a given material but they are not true material properties as they depend on the explosive type, type of crusher and crusher settings, etc. The three basic parameter values may then be used to improve the initial guesses of the parameters for the five terms extended Swebrec function in a non-linear least-squares fitting. He suggested that the parameter 'a' is normally quite close to the value a=1 and the convergence tends to be sensitive to the initial guess. The exponent 'c' usually lies in the range 0.5<c <3. He further suggested that a manual setting of c<2 to start with, will give a better feeling for the convergence process.

It has been pointed out above that 'c' is related to the mineral variety in the rock and its properties. Also, b-values tend to be relatively constant for a given material but they are not true material properties. Similarly, the Kuz-Ram model that makes use of the Rosin-Rammler function has an equation for how X_{50} and n depend on the specific charge, rock properties; blast pattern, etc. Furthermore, high b-values in combination with high x_{max}-values of Swebrec tend to occur when the sieving curve looks more like a Rosin-Rammler curve. Therefore, there is a tendency that Swebrec and Rosin-Rammler parameters may be connected which this paper tries to examine.

Very few works exist in the literature that makes use of the Swebrec function for fragments size analysis. Despite the conviction by the authors about the robustness of the equation, it has not found meaningful usage. Most works and usage of Sewberc originate from the author (s) of the equation. Similarly, its application is rare among users to describe the fragment size distribution of blasted or crushed rocks. One of the reasons for this could be that the function is complex for users when compared to the Rosin-Rammler equation, conservativeness of user or lack of awareness/information on its application. Some of the works on Swebrec in literature are probably discussed by the following authors.

Hundreds of sieved size distributions from bench blasting in quarries, reef blasting, and model blasting and crushing of many different rock types and concrete/mortar were studied by Ouchterlony [8] and Swebrec function was used to reproduce them. Blair [10] used both a one- and two-component log-normal and sigmoidal function to describe fragment size and compared with the Rosin-Rammler fits by focusing on the fines part down to below 0.1 mm. The findings show that the two-component lognormal function with 5 parameters provided the best fits and the Rosin-Rammler the worst ones. Regrettably, the findings were comparatively sensitive to the initial guesses for the input parameters, so the results were not dependable. Ouchterlony [10] reproduced sieving curves of all kinds of rock and concrete/mortar with the three-parameter Swebrec function and compared them to other comminution concepts such as t_{10} from JKMRC. The paper summarised the research work of Swebrec and SveBeFo (Swedish Rock Engineering Research) of the Less Fines project. Sanchidrian [11] studied the capacity of 17 functions to represent the size distribution of fragmented rock by examining 1234 data sets of screened fragments from blasted and crushed rock of different origins. The work concluded that Rosin-Rammler and Swebrec distributions tie as best bi-component, with a median R^2 of 0.9993.

2. Experimental Investigation

The strength properties of the rocks were determined in accordance with ISRM standards. The strength properties included the unconfined uniaxial compressive strength, UCS and Brazilian tensile strength, BTS. The elastic modulus, E, post-failure modulus, and Poisson's ratio, v were estimated from the stress-strain curves of the specimens. Five tests were conducted for each rock type and the average result was reported.

Blocks of the rocks measuring 150 mm length, 100 mm height, and 100 mm width are prepared from dimensional stones. The blocks were cut into dimensions using a diamond cutting machine. The faces of the blocks through which it was prepared were not smoothening. A template was prepared with plastic measuring 150 mm length x 100 mm width. On the template, 4 holes were cut on it with a spacing of 44.7 mm between 2 holes on a row and 28 mm across holes forming a rectangular pattern. A drilling machine with an 8 mm drill was used to drill through the blocks with the template taped on the top. The template ensured that the holes on the rocks blocks are of identical geometry.

A 720 mg electric detonator with two lead wires was inserted into each hole of the block of rock prepared for blasting. The power factor is calculated as1.92 kg/m^3. This is high compared with powered factors used in most aggregate production quarries which vary between 0.6-0.85 kg/m^3. Each lead wire was connected to the lead wire by the side's holes serially. The free two lead wires were connected to an instantaneous electric exploder. This arrangement was performed inside a huge cylindrical steel blasting chamber measuring 2 meters in diameter and 4 meters in height at African Explosive Ltd Blasting Services, South Africa. The inside of the chamber was encircled with thick rubber mats to reduce secondary fragmentation as a result of the blasted fragments heating the wall of the chamber. The firing of the rock block was done outside the blasting chamber. After firing all fragments from each rock block were gathered together with a brush and screened. Five tests were conducted for each rock type and the average result was reported. The data were characterized by percentages passing through different screen sizes. A commercial program called TableCurve2D was used to reproduce the curves. The fitting was done with the use of non-linear least-squares fitting based on the Levenburg-Marquardt algorithm.

3. Results and Discussions

The sample consists of high to low strength rocks. The average UCS ranges from 390 MPa to 35 MPa. The average Brazilian and elastic modulus ranges from 22 MPa to 2 MPa and 94 GPa to 10 GPa respectively (Table 1). Table 2-3 shows that the parameters of Rosin-Rammler and Swebrec functions varied widely. Generally, the parameters of the Swebrec function a, b, c for this laboratory blast tests have higher values than the field blast parameters as published in the pieces of literature this may be due to the higher values of the powder factor (of 1.92 kg/m^3 as compared to field blast that ranges from 0.6-0.85 kg/m^3) used in laboratory blast test.

Table 1. Strength and Elastic Properties

Strength parameters/ rocks	Rock Class	BTS (MPa)	*V*	E (GPa)	UCS (MPa)
Gabbro	II	22.029	0.264	94.389	390.463
Norite	II	14.599	0.302	91.035	220.194
Coarse Granite	II	13.971	0.292	70.387	238.56
Fine Granite	II	12.679	0.274	68.957	192.804
Marble	I	5.555	0.329	65.79	76.819
Sandstone	I	2.94	0.49	10.64	40.326
Feldspathic Arenite	I	2.617	0.409	10.742	35.228

Table 2. Rosin-Rammler parameters

Rosin-Rammler Parameters/rocks	Xc	n	R^2	std error
Gabbro	24.9	1.13	0.9825	0.7534
Norite	10.3	0.95	0.9995	0.5463
Coarse Granite	8.4	0.71	0.9998	1.0085
Fine Granite	7.1	0.79	0.9996	0.3475
Marble	17.1	0.86	0.8868	0.1286
Sandstone	1.36	0.37	0.8189	0.6483
Feldspathic Arenite	1.21	0.42	0.8165	0.5643

The complete stress-strain curves for the rocks were determined. The rocks were classified based on the sign of the post-failure modulus of their curves. They are classified as Class I for rocks with characteristic negative post-failure modulus and Class II for positive post-failure modulus (Table 1). Figure 1 shows Class I and Class II characteristic behavior in the post-failure regime. Fig. 2 shows the fragmentation of the samples. The Gabbro, Granites, and Norite (which are Class II rocks) were finely fragmented and uniformly sorted or poorly graded (containing predominantly fines). However, the Sandstone, Feldspathic arenite, and Marble (which are Class I rocks) were poorly fragmented or poorly sorted and well-graded (containing lumps and fines). Akinbinu [12, 13] showed that by breaking rocks under the same loading conditions, the Class II rocks tend to be more fragmented than the Class I rocks of similar strength as a result of the self-sustaining fracturing behavior of the Class II rocks.

The finely fragmented and uniformly sorted or poorly graded samples (i.e. the Class II rocks) were properly described by the two fitting functions and shown to fit into the experimental data (Figs. 3-6). For the samples that were poorly fragmented or poorly sorted and well-graded (i.e. the Class I rocks) the Rosin-Rammler over-estimated the fines and the Rosin-Rammler function did not fit into the experimental data (Figs. 7-9). The Rosin-Rammler fitting function deviates considerably from the experimental data. The Swebrec function was able to describe the sieve data and fitted into the experimental data (Figs. 7-9). Although the Swebrec function described the fines sieving data better than Rosin-Rammler both have a deficiency in representing fittingly the fines sieving curves.

The strength and elastic properties values are higher for the Class II rocks as compared to the Class I rock types (Table 1). Table 2 shows that the Rosin Rammler function goodness fit (R^2) for the Class II rocks type is higher than the Class I rock types. The Rosin-Rammler function fits better into the experimental data for rock types with characteristic Class II behavior than with rocks types with Class I behavior.

The Rosin-Rammler function over-estimates the fines for the Class I rock types (Figs. 7-9). The value of n is an indication of the shape of the Rosin-Rammler curves. While high values suggest uniform sizing or poor grading. On the other hand, low values suggest a wide range of sizes including both lumps and fines.

The Class II rocks appear to have higher values than the Class I type. The lower the value of 'n' the more the Rosin Rammler curves deviate in the curve fitting of the fines. The factor 'a' of the Swebrec function showed higher values for the Class II rocks (3-5) than the Class I rock types (1-1.2). Similarly, the exponent 'c' of the Swebrec function showed higher values for the Class II rocks (75-666) than the Class I rocks types (37-46). Therefore, it appears that the properties of the Class II rocks have higher values than the Class I rocks included in the work

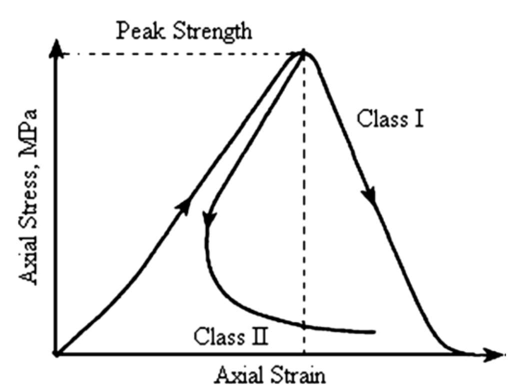

Fig.1. Classification of rock into Class I and Class II behavior in uniaxial compression tests [14]

Table 3. Swebrec parameters and statistics

Rocks /Swebrec Parameters	Gabbro	Norite	Coarse Granite	Fine Granite	Marble	Sandstone	Feldspathic Arenite
a	3.1090784	2.96333	5.146761	3.1524581	1.013766	1.222334	1.220068
b	9.1096482	10.70919	136.31074	25.714163	4.2052	1095.31	2740.876
c	158.92929	75.20527	666.31861	107.96653	46.3247	42.65663	37.5
R^2	0.9983866	0.999586	0.9985607	0.9978619	0.994984	0.999061	0.996597
adj R^2	0.9975799	0.99938	0.9976971	0.996579	0.992834	0.998497	0.994896
std error	1.0668288	0.740004	1.307055	1.5692747	1.698692	0.431224	0.778074
fstat	2165.8288	8457.481	2081.3137	1400.0954	793.4256	3191.509	1025.043

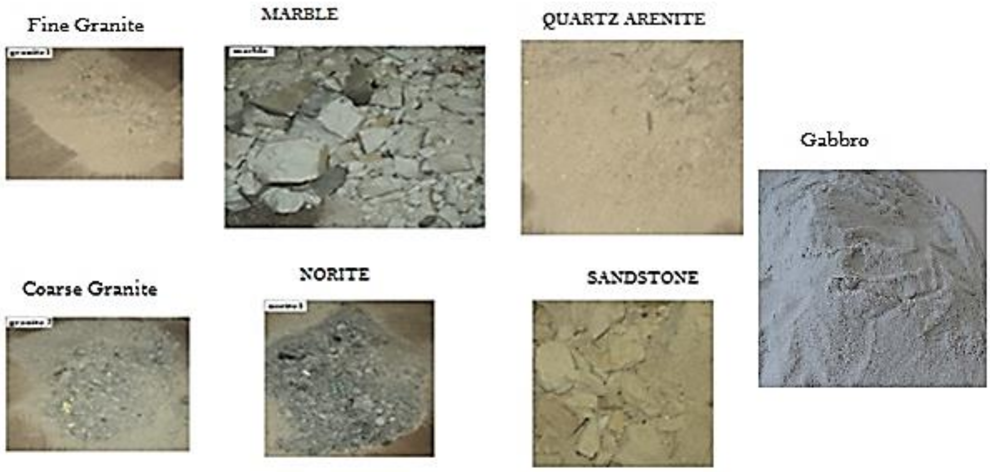

Fig. 2. Fragments of blasted rocks

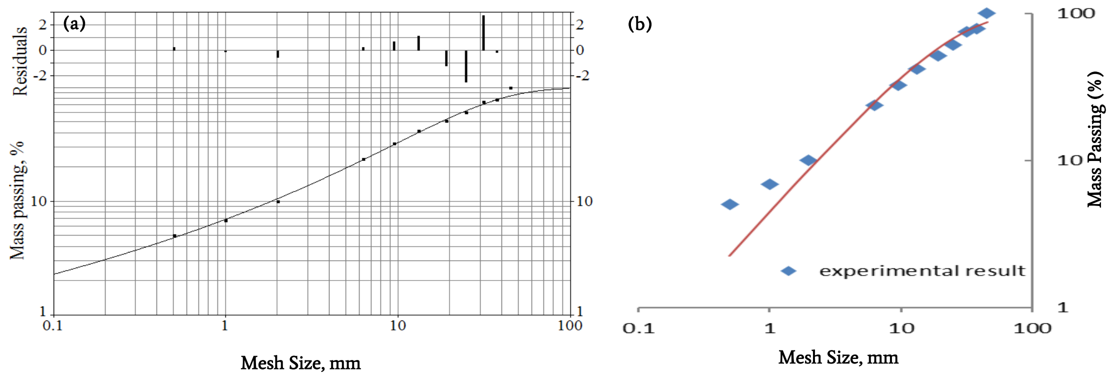

Fig. 3. Mass passing % vs sieve sizes for Gabbro from blast test, (a) Swebrec and (b) Rosin-Rammler

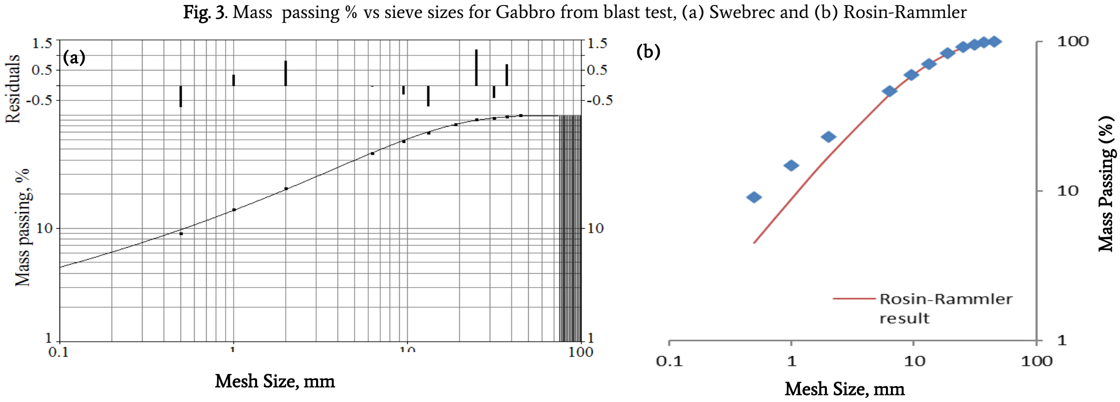

Fig. 4. Mass passing % vs sieve sizes for Norite from blast test, (a) Swebrec and (b) Rosin-Rammler

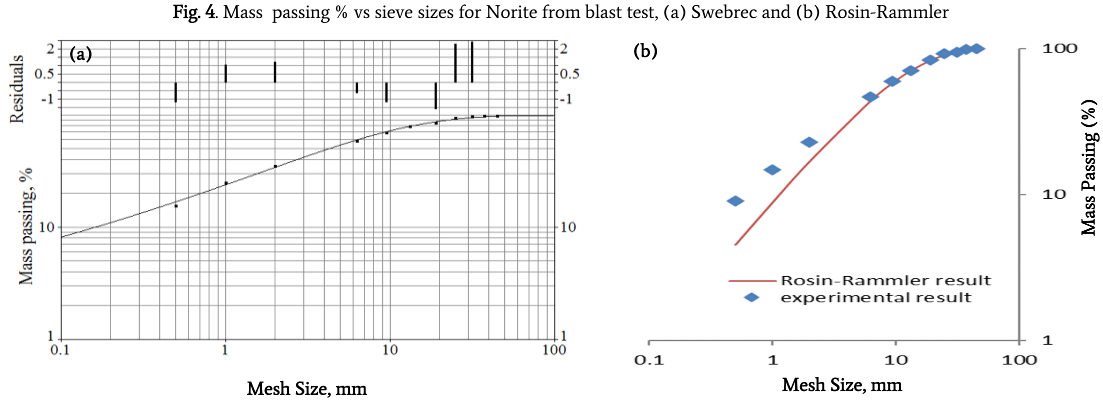

Fig. 5. Mass passing % vs sieve sizes for coarse-grain Granite from blast test, (a) Swebrec and (b) Rosin-Rammler

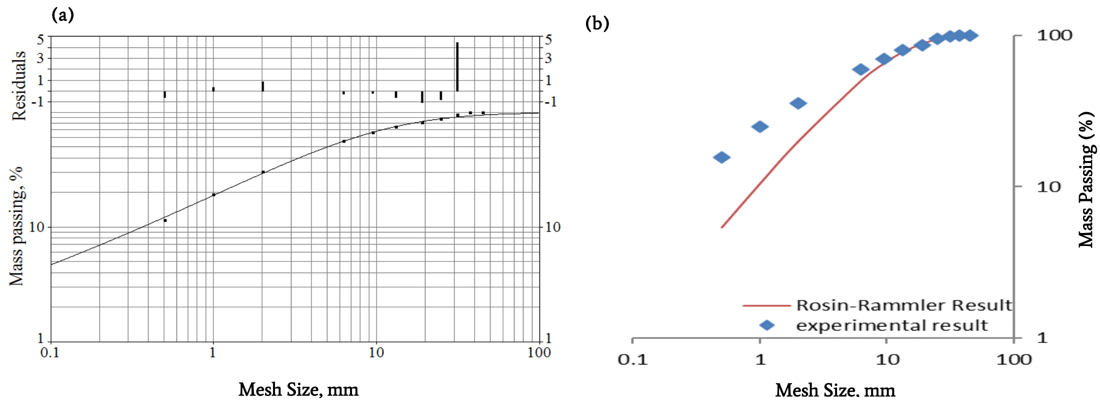

Fig. 6. Mass passing % vs sieve sizes for fine-grain Granite from blast test, (left) Swebrec and (right) Rosin-Rammler

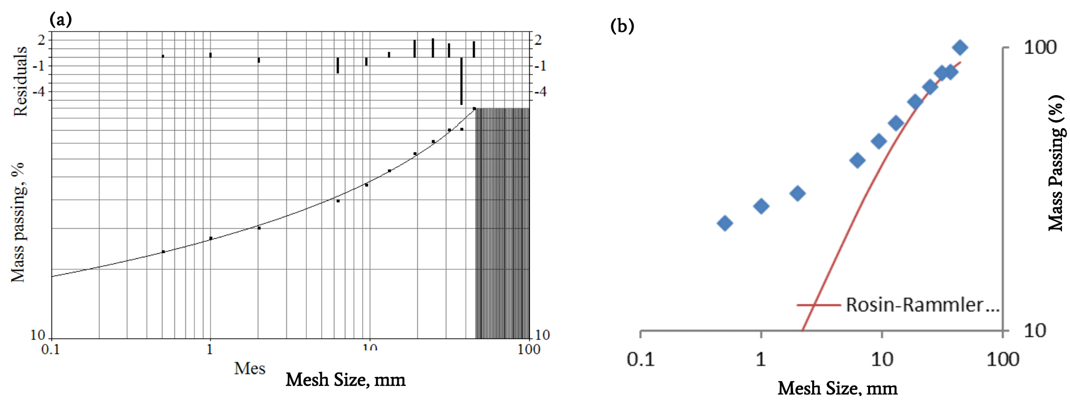

Fig. 7. Mass passing % vs sieve sizes for Marble from blast test, (a) Swebrec and (b) Rosin-Rammler

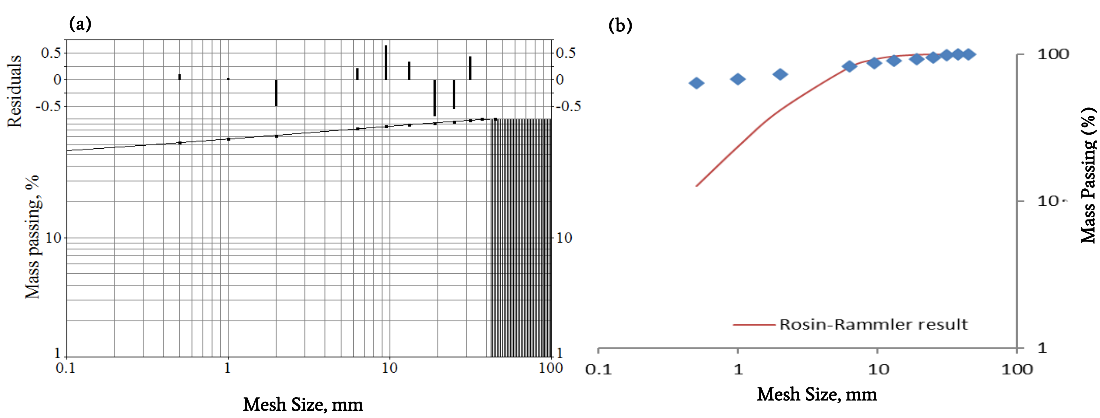

Fig. 8. Mass passing % vs sieve sizes for Sandstone from blast test, (a) Swebrec and (b) Rosin-Rammler

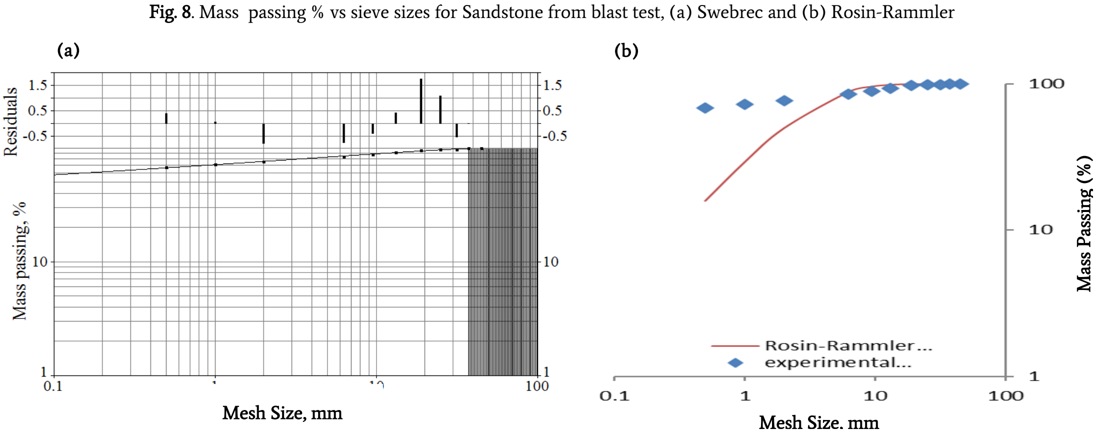

Fig. 9. Mass passing % vs sieve sizes for Feldspathic arenite from blast test, (a) Swebrec and (b) Rosin-Rammler

The Rosin-Rammler and the Swebrec parameters were compared with each other. The comparison shows that the Rosin-Rammler parameters are interdependent. The characteristic size, Xc is related to uniformity index n and the mean size Xm by power form function. The coefficient of correlation is better than 0.9 (Fig. 10). For the Swebrec parameters (factor a, undulating parameter b, and exponent c) only the factor a and exponent 'c' are related. The form of relationship is exponential and similarly, the coefficient of correlation is better than 0.7 (Fig. 11). For both functions (the Rosin-Rammler and Swebrec) parameters, as the value of one parameter increases the other value also increases. As the characteristic size, Xc increases so the uniformity index n and the mean size Xm (of Rosin-Rammler) also increase. Similarly for Swebrec function parameters as the exponent c increases so also the factor increases.

In an attempt to compare the Swerec parameters with Rosin-Rammlers parameters, only the undulating parameter b show relationship with Rosin-Rammler parameters. Both factors a and exponent c show no form of relationship with Rosin-Ramler parameters. The form of relationship between the undulating parameter b of Swebrec and characteristic size, Xc, and the uniformity index, n of Rosin-Rammler are power form. The coefficient of correlations between b of Swebrec and n and Xc of Rosin-Rammler are 0.815 and 0.917 respectively (Fig. 12).

The Rosin-Rammler parameters were compared with the rock strengths (UCS, BTS). The uniformity index, n correlated with the BTS and UCS. The uniformity index shows a power form relationship with rock strength with a correlation coefficient better than 0.7 (Fig. 13). As the uniformity index increases so also the strength property values also increases. However the characteristic size, Xc correlated only with the UCS with a correlation coefficient of 0.663 (Fig. 14a). As the values of the UCS of the rock increase so the characteristic size increases by power form.

Similarly, the Rosin-Rammler parameters were compared with the elastic properties (E and *v*) of the rocks. The comparison shows that both parameters of Rosin-Rammler (Xc and n) were related to elastic parameters (Figs. 14b & 15). As shown for strength properties, the elastic properties were related with Rosin-Rammler parameters by power form. The relationship was stronger with elastic properties than shown for strength properties with uniformity index having a high correlation coefficient of 0.956 with the elastic modulus (Fig. 15). Unlike strength properties, the elastic properties show a dual relationship with Rosin-Rammler parameters. The relationship of the parameters with elastic modulus is not the same as shown with Posson's ratio. As the elastic modulus increases both the uniformity index and characteristic size values also increase. This is not the same with the Poisson ratio, as the Poisson's ratio value increases the Rosin-Rammler parameters (Xc and n) values decreases (Fig. 16)

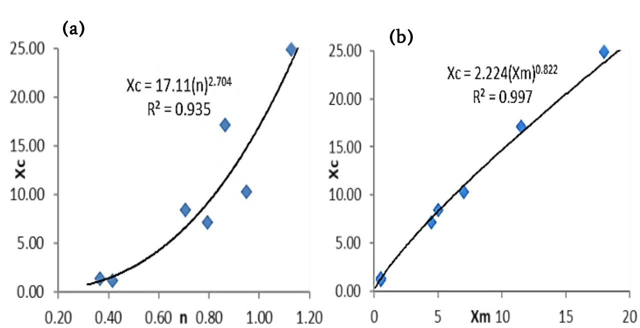

Fig. 10. Characteristic size, Xc against (a) n and (b) Xm

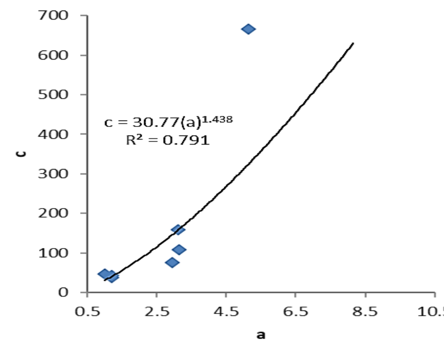

Fig. 11. exponent c and factor a parameters of Swebrec

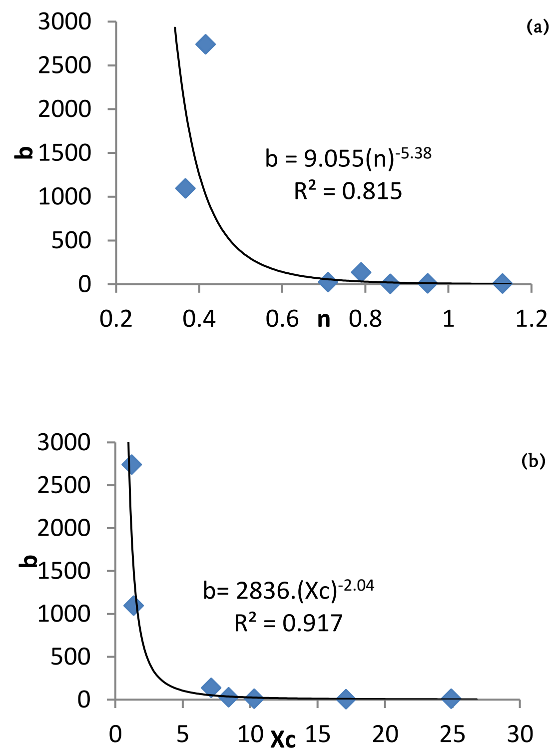

Fig. 12. undulation parameters b of Swebrec against Rosin-Rammler parameters (a) n and (b) Xc

Similarly as done for the Rosin-Rammler parameters, the Swebrec parameters (factor a, undulating parameter 'b', and exponent c) were compared with the strength and elastic properties of the blasted rocks. Only factor a and undulating parameter b show form of relationship with the strength properties of the rocks. While factor a shows power from a relationship, the undulating parameter b shows the logarithm form of relationship with the strength properties of the rocks. In all cases, the coefficient of correlation is better than 0.6. The factor a and strength property values are directly related (i.e. as one value increases the other value also increases), Fig. 17. However undulating parameter b and strength property values are inversely related (i.e. as one value increases the other value decreases) see Fig. 18.

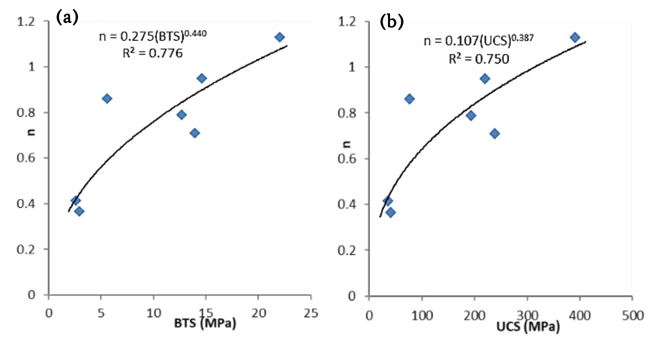

Fig. 13. uniformity index of Rosin-Rammler, n against Strength properties (a) BTS and (b) UCS

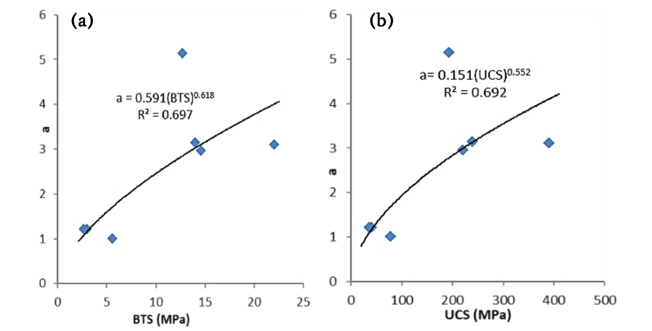

Fig. 17. factor 'a' parameters of Swebrec against Strength properties (a) BTS and (b) UCS

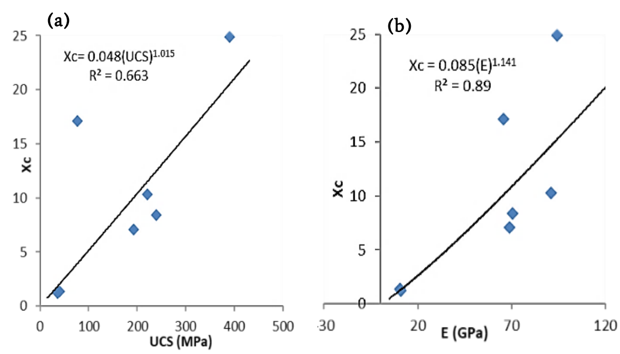

Fig. 14. characteristic size, Xc of Rosin-Rammler against (a) UCS and (b) E

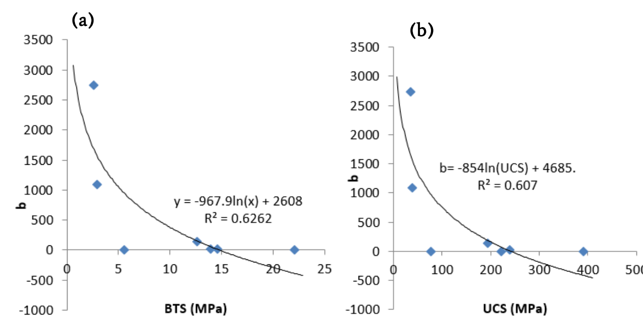

Fig. 18. undulation parameters b of Swebrec against Strength properties (a) BTS and (b) UCS

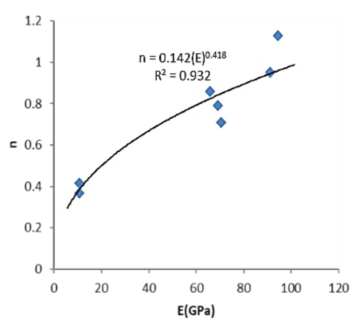

Fig. 15. uniformity index of Rosin-Rammler, n against Elastic parameter E (GPa)

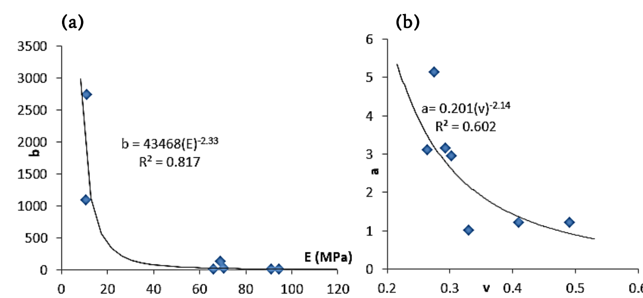

Fig. 19. undulation parameters b and factor a of Swebrec against elastic parameters (a) E and (b) ν

The comparison of the Swebrec parameters with the elastic properties of the rocks shows that they are related (Fig. 19). As shown for Rosin-Rammlers, the elastic properties are related to Swebrec parameters by a power function. Only factor a and undulating parameter b show form of relationship with the elastic properties while exponent c did not relate with either E or ν. The relationship is stronger with elastic modulus than shown for Poisson's ratio having a correlation coefficient of 0.817 (Fig. 19).

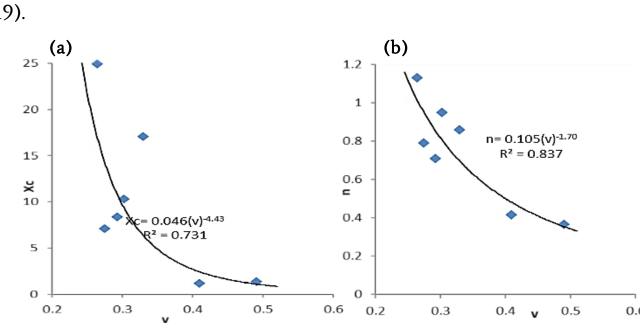

Fig. 16. Poisson's ratio ν against (a) characteristic size and (b) uniformity index of Rosin-Rammler

4. Conclusion

The Rosin-Rammler model fits well into the experimental data especially for fragments with poorly graded or uniformly sorted fragments of the Class II rock types included in this work. Both the experimental curve and the Rosin-Rammler curves are quite similar. It fitted well into the ranges of the data set. The exception is for the Class I rocks Marble, Sandstone, and Feldspathic arenite that is poorly fragmented. The lower part of data of the characteristic curves for the Class I rocks suffers fitting at the expense of the remaining upper data that fit well. While the Rosin-Rammler model tries to fit the data down to the lowest mesh sizes where no data exist causing the whole data to suffer fitting altogether. The value of n is an indication of the shape of the Rosin-Rammler curves. While high values suggest uniform sizing or poor grading. On the other hand, low values suggest a wide range of sizes including both lumps and fines. The n values for Class II appear higher than the Class I and therefore Class II rocks fragments fit better in the Rosin-Rammler function.

It can be intuitively concluded that there exists a comparable relationship among Rosin-Rammler parameters and similarly among Swebrec parameters. Also, there exist comparable relationships between

Rosin-Rammler and Swebrec, and these relationships can best be described by power form functions. Furthermore, the results show that there exists a trend in the relationship of the two functions parameters with the strength and elastic properties of the rocks included in this study. Besides, the result shows that the form of relationship and curvature of the curves are similar among paired compared parameters for each function parameter. The Rosin-Rammler shows a stronger correlation coefficient among its parameters than Swebrec parameters. In all cases, the comparison of the two functions parameters with strength properties indicated that BTS is always with stronger correlation coefficients than the UCS. Similarly, E shows a stronger correlation coefficient than v. this work implies that though Kuz-Ram formula looks simpler it performs creditably well when compared to more complex functions of the Swebrec function

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