Influence of Mechanical and Aggregate Properties of Rock on Powder Factor in Rock Blasting

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Abstract

Profit margins in metal quarrying have drastically reduced in Sri Lanka due to high powder factors recorded in recent rock blasting activities. Importance of analysing the influence of mechanical and aggregate rock properties on the powder factor arises in this context to determine suitable rocks in which expenditure on blasting is minimal during the production stage.

Eight quarries operated under the close supervision of qualified Mining Engineers were selected for this study to ensure that a proper blasting geometry and configurations have been properly managed during the period of study. Random core samples were obtained from each quarry site and tested for Density, Uniaxial Compressive Strength (UCS), Tensile Strength and Aggregate Impact Value (AIV) and Rock Mass Rating (RMR). Explosive consumption and drilling records for the past six months were obtained from each quarry for the calculation of powder factor.

Powder factor was plotted against each selected rock property and regression analysis was performed to understand their standalone influence. Results of the analysis concluded that the aggregate rock properties, especially Aggregate Impact Value (AIV) have a greater influence on the powder factor. Relationship established in this research can be used to predict powder factor of a fresh rock before conducting any blasting activity.

Keywords: Mechanical/Aggregate properties of rocks, Powder factor, Rock blasting

1. Introduction

Quarry metal or construction aggregates are a vital requirement to carry out infrastructure development projects. Emerging mega projects such as the Port City Development, highway extension and multi-story residence and hotel complexes have drastically increased the demand for construction aggregate during the last few decades. On the other hand, metal quarrying industry is challenged by various technical as well as non-technical issues directly impacting the economics of operations. Such technical issues are the difficulties encountered in finding suitable rocks for construction works, comparatively low metal yield achieved per blast and rock fragmentation control issues. Protests made by environmentalists against environmental impacts as a result of blasting, complaints and objections made by the inhabitants in the surrounding areas, increasing expenditure on environmental remediation and impact mitigation measures are a few of the non-technical issues faced by the local metal quarrying industry at the moment.

Technical issues over and above non-technical issues finally affect the cash flow of the business. Profitability issues of the business will discourage the quarry operators and investing in the quarry metal industry leading to supply shortages in the future.

Therefore, sustainability and smooth operation of the metal quarry industry is an essential need for the continuation of ongoing and upcoming mega development projects in Sri Lankan.

Profit = Sales – Total cost

Profit = Sales – (Fixed cost + Variable cost)..(1)

Fixed cost is the capital expenditure such as Crusher plants, Track drills, Excavators, Loaders etc. The variable costs cover operational costs such as explosives cost, drilling cost, salaries, secondary blasting, and breaking etc. The variable cost is more sensitive to the profit than the fixed cost. The drilling cost, salaries, wages are less than the fixed cost in the present situation in Sri Lanka and the secondary blasting and breaking can be controlled by proper handling of explosives. Therefore, the explosive and metal yield directly affects the profit of the quarry. In mining engineering it is recognized as the powder factor.

$$Powder\ factor = \frac{Explosive\ usage\ of\ the\ blast}{Insitu\ volume\ of\ the\ blast}$$ .....(2)

(S. C. Bhanwar 2013)

Therefore, it is Important to research on the factors influencing the powder factor in rock blasting. There are many empirical formulae dealing with powder factor and blasting configurations. Therefore, it is important to study the influence of mechanical and aggregate rock properties on powder factor.

2. Methodology

Eight quarries with close supervision by qualified mining engineers in the Western province of Sri Lanka were selected for the research project. It was assumed that the blasting geometry and configurations have been properly optimized by the responsible engineers during the time period in which the powder factors were recorded.

Explosive usage and drilling data were collected from the selected quarries in the course of nearly six months. The mean powder factors were calculated for each quarry.

Five tests on Uniaxial Compressive Strength were performed for each quarry using prepared core samples. It was repeated for all the selected eight quarries. Values were calculated by using the following equation;

$$UCS = \frac{4P}{\pi D^2} MPa$$ ....(3)

UCS - Uniaxial Compressive Strength (N)
P - Failure Load (N)
D - Diameter of the sample (m) (F.G.Bell 1992)

Five tensile strength tests were performed for each quarry and it was repeated for all the eight quarries using core-disk samples. The mean tensile strength values were obtained from the following equation;

Tensile Strength= $\frac{2P}{\pi Dt}$MPa ....(4)

P = Failure Load (N)
D = diameter of the sample (m)
T = Thickness of the sample (Z.T. Bieniawskiet al 1978)

Five tests were carried out for density values for each quarry and obtained the mean values for the density of each quarry.

obtained. The aggregate Impact values were calculated as follows.

$$AIV = \frac{\text{(Weight of fines passing 2.36mm sieve after test)}}{\text{(Weight of the sample)}} \times 100$$

(C. J. Konya et al 1991)……………(5)

During the field visits, data for Rock Mass Rating values were obtained and RMR values (D.U. Deere et al 1988) were calculated for eight quarries.

After calculating the relevant indices, rock properties and powder factor values were plotted and statistically significant relationships were established.

3. Results

Summary of the results are given as in Table 1.

Table 1 - Summary of the test results

Quarry	Powder Factor	Density (Kg/m3)	UCS (MPa)	Tensile strength (MPa)	AIV	RMR Value
01	0.22	2805.2	51	22	20	70.7
02	0.21	2653.7	77	14	22	74.7
03	0.20	2756.8	76	5	22	74.0
04	0.29	2721.4	124	16	17	77.0
05	0.20	2718.3	151	11	22	66.2
06	0.20	2701.6	62	16	27	62.0
07	0.18	2663.7	48	34	23	70.0
08	0.26	2696.6	81	15	18	70.0

Five aggregate samples were collected from each quarry to find the mean Aggregate Impact Values. It was repeated for all eight quarries and the mean Aggregate Impact Values were

All the prepared graphs are statistically insignificant other than the Powder Factor vs. Aggregate Impact Value show quadratic and cubic model as follows;

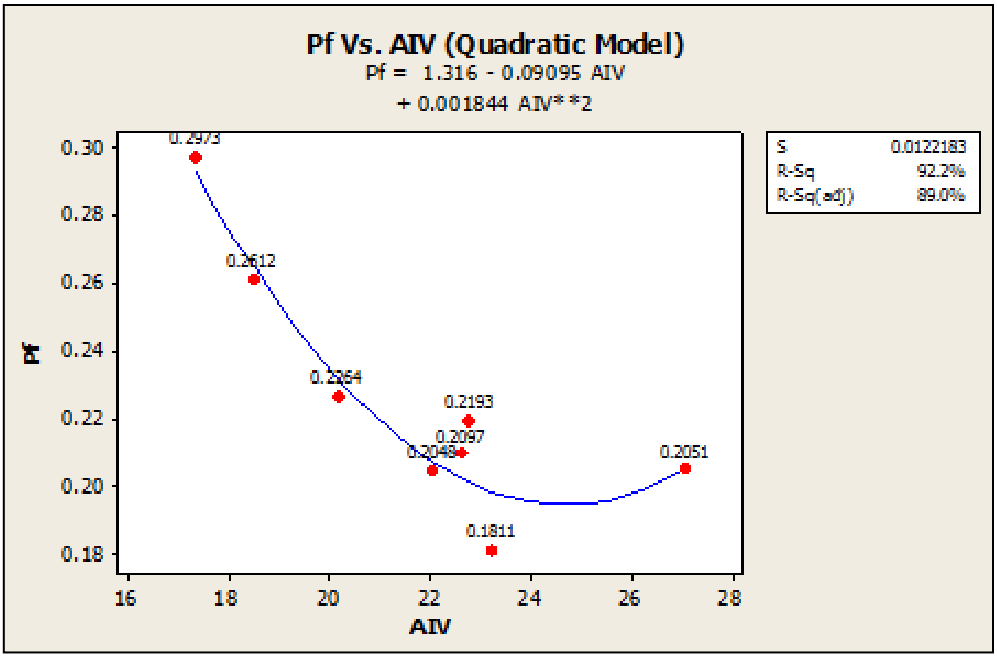

Figure 1 - Quadratic model in between powder factor and AIV

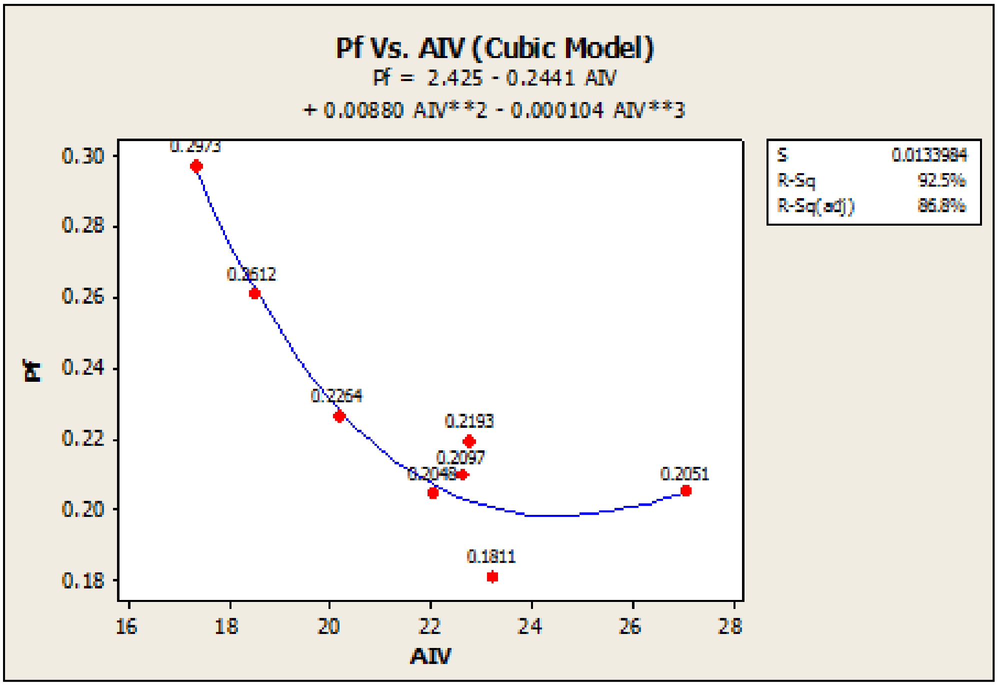

Figure 2 - Cubic model in between powder factor and AIV

4. Discussion

By using the regression analysis in the mini tab software, all the tests data were analyzed. After analyzing the rock properties such as the Density, Uniaxial Compressive Strength, Tensile Strength, Rock Mass Rating values, they were found to be statistically insignificant. But the most significant relationships were found between the powder factor and Aggregate Impact Value.

Statistically significant quadratic model is as follows;

Pf= 1.326-0.09095AIV+0.001844 AIV^2 ……………………………………….(6)

By using another quarry sites in Sri Lanka, the above quadratic (Eq 06) equation could be validated as follows;

Table 2 - Validation results

Quarry	AIV	Powder Factor (Predicted)	Powder Factor (Actual)
Q9	25	0.1948	0.20
Q10	32	0.2939	0.28
Q11	18	0.2764	0.26

By using the Aggregate Impact Values of the above three quarries, the powder factor values could be predicted from equation (Eq 06). The powder factor values can be found by using the actual explosive data and drilling data. Actual powder factor values and predicted powder factor values were closer to each other.

The statistically significant cubic model is as follows.

Pf= 2.425=-0.2441AIV+0.00880 AIV^2 -0.000104A/V$^{3.}$……………………..(7)

By using the above Q9, Q10, Q11 quarries, the cubic relationship could be validated as follows;

Table 3 - Validation Results

Quarry	AIV	Powder Factor (Predicted)	Powder Factor (Actual)
Q9	25	0.1975	0.20
Q10	32	0.2171	0.28
Q11	18	0.2759	0.26

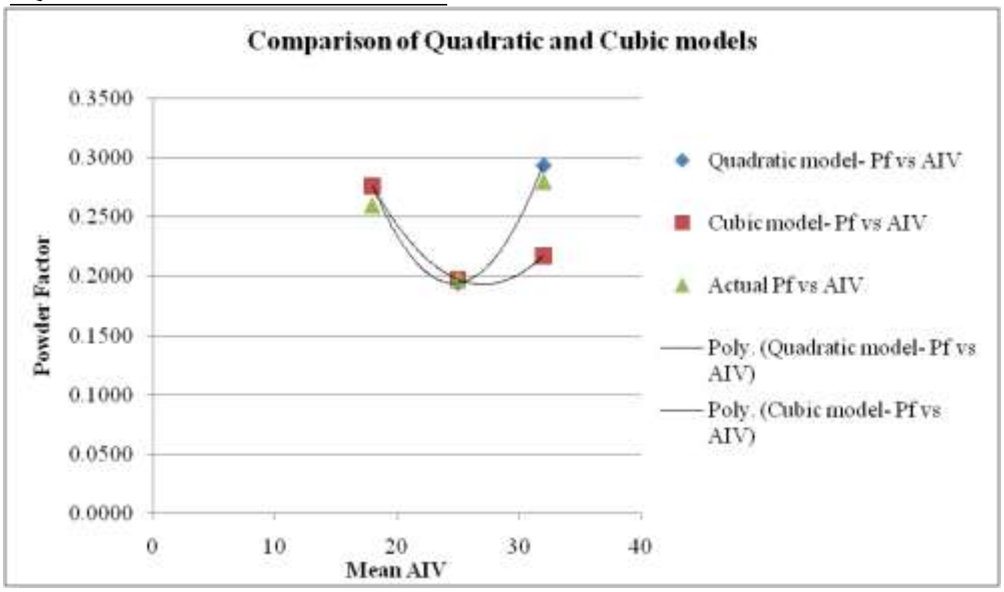

Figure 3 - Comparison of quadratic model and cubic model

In the cubic model validation, the actual powder factor values and predicted values were very close.
The quadratic relationship and cubic relationships were compared as follows;
Both quadratic and cubic relationships agree with the actual powder factor values very closely at low Aggregate Impact Values according to Figure 03. But the predictions of cubic model deviate considerably from the actual in the case of higher Aggregate Impact Values.

5. Conclusions

Though the research model targeted five mechanical and aggregate rock properties such as Density, Uniaxial Compressive Strength (UCS), Tensile Strength, Aggregate Impact Value (AIV) and Rock Mass Rating (RMR) which were supposed to have direct relationships with the Powder factor, the statistical test outcome concludes that the influence of all those rock property factors are insignificant other than the AIV.
The quadratic and cubic models between powder factor and Aggregate Impact Value relationships are statistically significant. It can be concluded that the quadratic relationship derived in this research between Powder factor and Aggregate Impact Value (AIV) predict powder factors of a fresh rock with a high level of accuracy.

6. Recommendation

Results of this research introduces a new dimension to select a suitable rock mass for a quarry site among several available options based on expected Powder Factor of rock blasting. The quadratic relationship between Powder Factor and Aggregate Impact Value (AIV) derived in this research is recommended for the use by mining engineers to select the rock which produces good fragmentation while giving out lower Powder Factors in rock blasting operations. The use of the above model is recommended for investors on metal quarrying to project their future potential operational costs and forecast cash flows as well as profits from the same site. Outcome is an indirect invention to control fragmentation as well as cost of the blasting operations while operational cost controlling methods for the metal quarry industry. Further, the model recommends predicting powder factors of any operating quarry using Aggregate Impact Value (AIV) and deriving metal production using explosives consumption data. Hence, it will be a useful tool for the mining engineers in Sri Lanka to forecast quarry production with higher accuracy.

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