Relevance of Shape of Fragments on Flyrock Travel Distance: An Insight from Concrete Model Experiments Using ANN

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ABSTRACT
Flyrock are fragments that travel beyond the acceptable distances in rock blasting in surface mining. Their occurrence poses a great threat to life and property that may or may not belong to the owner of a mine. Hence, it becomes imperative to predict flyrock travel distance (range) that in turn facilitates definition of the blasting danger zone (or secure area) and take necessary safety precautions. The rock properties, blast design, and explosive loading parameters determine the distance travelled by flyrock. The kinematic equations do not work in such predictions owing to air drag that is specific to weight, shape and size of the flyrock. The importance of shape of the flyrock fragment thus assumes importance. In order to assess the importance of the parameters that determine their effect on the flyrock range, experiments on concrete models were conducted. Complete data of these parameters (136 datasets) were analysed using artificial neural networking (ANN). ANN proved to be a good tool to assess the relative importance and sensitivity of parameters. From the analysis, it emerged that the initial velocity, launch angle, and length of the fragments are of prime importance. Since, spherocity is difficult to ascertain, length of the fragments can prove to be a substitute descriptor for flyrock modelling. This will simplify the prediction techniques although launch angle is difficult to predict. Some insights for further R&D in this direction are also included in the paper.

KEYWORDS: Blasting, Concrete Models, Flyrock shapes, Artificial Neural Networks

INTRODUCTION
The primary aim of blasting in mines is to release the ore from the overburden. Since, the process involves release of huge amounts of chemical energy, blasting is supplemented by several
unwanted results. The general objectives of blasting are thus complicated in nature as shown in Figure 1.

![Figure 1: Objectives of blasting operations (after Hustrulid, 1996)](image)

One of the major concerns in blasting thus identified is flyrock. Flyrock can result from unknown or unaccounted rock parameters or lacunae in blast design or its implementation. Thus, flyrock is one of the unwanted ‘design objective’ that needs to be minimized and rather eliminated. Such an exercise shall be possible only when the process of generation and travel domain of flyrock is fully understood. This needs to be emphasized, as it is known to have resulted in accidents ranging from serious injuries, fatalities, and damage to property – belonging and not belonging to the owner of the mine (Jenkins and Floyd, 2000; Rehak, et al., 2001; Bajpayee et al. 2002; Fletcher and D’Andrea, 1987; Verkis, 2011). Flyrock incidents still continue to happen (McKenzie, 2009; Amini et al. 2011; Stojadinovic, et al., 2011; Rezaei, et al., 2011; Kricak, et al. 2012 etc.) and this has resulted into increased attention on the research in the area in recent times (Raina, et al., 2012). One of the major constraints in the prediction of flyrock is non-reporting of such incidents (Davies, 1995) for obvious legal reasons.

Although different studies pertaining to field investigations have been conducted in this regard model experiments have not been much tried except for the work of Lundborg (1974). The study of Lundborg, et al. (1975) were based on the premise to throw the rock to its maximum distance using explosive. This is a serious constraint since blasts are not designed to do so. A variation in blast design parameters within possible domain is possible in mines owing to wrong blast design or its implementation. Such variations at times may result in anomalous blast outcome like flyrock.

In projectile motion, two important parameters viz. initial velocity \( V_0 \), and launch angle \( \theta \) determine the path and range of a trajectory of flyrock. Such an equation assumes a spherical projectile with no air drag. Based on such premise, Chiapetta et al. (1983) and Roth (1979) developed the flyrock range prediction equations. However, the drag free assumption is seriously constrained by the shape of the fragments generated from the blasting which can be a function of in situ block shape and blasting conditions (Chermigovskii, 1985). McKenzie (2009) and Raina et al. (2012) demonstrated that the physical trajectory equations do not work for blast fragments.

Away from the impact (determined by the blast design) with which a flyrock may project from blast face, the size and shape of flyrock are of utmost importance and determine the range of a flyrock. Figure 2 further explains the concept to discern the objectives and form the core of this paper.
Figure 2: Parameters determining the range of flyrock

In this paper it is assumed, and as the case should be, that \( V_0 \) is a function of blast design and
the launch angle is a function of the rock or is unknown. This defines the scope of this paper as
determination of the role of fragment shape in defining the range of flyrock. ANN approach was
selected for analysis in order to determine the relative importance of such post firing parameters
in flyrock range.

The ANN approach has in recent times found application in prediction of flyrock. Several
workers as presented in Table 1 have used ANN or related methods in flyrock prediction.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Method used</th>
<th>Prediction domain</th>
<th>Conclusions</th>
<th>Flyrock model</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amini et al.</td>
<td>2012</td>
<td>Support Vector Machine (SVM)</td>
<td>Copper mine, Iran</td>
<td>SVM works better than ANN but ANN is an alternative approach</td>
<td>implicit</td>
<td>Limits not defined</td>
</tr>
<tr>
<td>Stojadinovic et al.</td>
<td>2011</td>
<td>Approximate numerical solution</td>
<td>Quarry in Serbia</td>
<td>Maximum throw obtained at a launch angle of 45(^\circ). The impulsive approach of Little (2007) contradicted powder factor is the most contributing and density the least contributing factor in flyrock prediction</td>
<td>implicit</td>
<td>Flyrock assumed to be spherical; contrasts with findings of McKenzie (2009) and Raina et al. (2012) contrast with the classical study of Lundborg (1974) and Lundborg and Lundborg et al. (1975)</td>
</tr>
<tr>
<td>Rezaei et al.</td>
<td>2011</td>
<td>Fuzzy modelling</td>
<td>Iranian Mine</td>
<td>implicit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mohamad et al.</td>
<td>2013</td>
<td>ANN</td>
<td>Granite quarry, Malaysia</td>
<td>implicit</td>
<td></td>
<td>Limits defined</td>
</tr>
</tbody>
</table>

In most of the publications the shape of the fragment and hence air drag is almost neglected as a parameter.
The uncertainty with ANN predictions is that the explicit model is not known and that variation in number of data sets defines the boundary conditions for the models. It is not clear whether such flyrock prediction models can be extended by extending the learning. Moreover, the validation of the models in the same data set does not improve despite of significant learning cycles. Although specific to certain problems and generally classified as a black box, the ANN tool is quite helpful in determining the relative importance and sensitivity of independent parameters on an output.

DESIGN OF EXPERIMENTS

The primary objective as mentioned earlier was to determine the most influencing parameters on flyrock range (with above said assumption) and find whether it is possible to have a simpler parameter other than spherocity that could be defined easily for use in prediction of flyrock range. In line with the above seventy-five (75) concrete models of 18" x 18" x 6” were blasted with single hole while varying the blast design and strength parameters. A significant variation in the blast design was observed during the trials to achieve a reasonable variation in the input and output data. The range of the blast design data generated is thus provided in Table 2 (Raina et al. 2012).

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Parameter</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strength, MPa</td>
<td>12.9</td>
<td>7.32</td>
</tr>
<tr>
<td>2</td>
<td>Diameter, mm</td>
<td>12.75</td>
<td>8.07</td>
</tr>
<tr>
<td>3</td>
<td>Hole depth, mm</td>
<td>70.51</td>
<td>98.49</td>
</tr>
<tr>
<td>4</td>
<td>Burden, mm</td>
<td>36.7</td>
<td>114.0</td>
</tr>
<tr>
<td>5</td>
<td>Charge per hole, kg</td>
<td>0.45</td>
<td>0.97</td>
</tr>
<tr>
<td>6</td>
<td>Charge length, mm</td>
<td>74.6</td>
<td>37.2</td>
</tr>
</tbody>
</table>

The flyrock fragments were physically measured for different dimensions and weight. Most of the pre- and post-blast parameters were recorded. The blasts were conducted in a calm atmosphere to minimize the effect of air velocity.

The following parameters, relevant to this paper, were determined and compiled for analysis:

1. The initial velocity of fragments launched post firing were measured with the help of high-speed camera at 1000 frames per second.
2. The launch angle was also determined from high-speed video.
3. The range and weight of the flyrock was logged with physical measurements.
4. The dimensions of flyrock viz. length, width, and thickness were also measured physically.
5. The spherocity of the flyrock fragments was calculated from flyrock dimensions using the equation of Sneed and Folk (1958).
6. Use of ANN to decipher the importance and sensitivity of \( V_0 \), \( \theta \), and sphericity parameters in flyrock range.
7. Define most significant parameters of shape for assessing the flyrock range so that the predictions become easier from ANN results.

The ranges of data of input parameters in this paper for analysis are presented in Table 3.
Table 3: Data range of the flyrock fragments considered for analysis

<table>
<thead>
<tr>
<th>Values</th>
<th>Weight (gm.)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Thickness (mm)</th>
<th>Spherocity</th>
<th>V0 (m/s)</th>
<th>Alpha (θ)</th>
<th>Trajectory throw (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0.38</td>
<td>8.60</td>
<td>6.40</td>
<td>4.52</td>
<td>0.47</td>
<td>4.52</td>
<td>8.88</td>
<td>6.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>250.00</td>
<td>90.22</td>
<td>61.81</td>
<td>53.17</td>
<td>0.99</td>
<td>56.48</td>
<td>99.34</td>
<td>28.00</td>
</tr>
</tbody>
</table>

Alpha was resolved into radians before analysis

MODELLING WITH ARTIFICIAL NEURAL NETWORKS

An artificial neural network (ANN) or a neural network is a mathematical model inspired by biological neural networks and an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation (www. Wikipedia). An adaptive system, the neural networks are used to model complex relationships between inputs and outputs or to find patterns in data. The theory and practical application have been explained in many a research papers available on internet and those referred in Table 2. In order to avoid the redundancy, the theory, and rationale of ANN analysis is omitted in the text.

EasyNN-Plus™ software that uses a back-propagation algorithm to analyse the data was used for analysis. The software has many options to optimize the learning and network, freezing, cloning, jog weights and trimming of the data. The automatic node and network generation routine of the software were used to train the network. The net generated in this way (Figure 3) presented the optimum solution for training. The parameters 1 to 7 in Table 3 were used as input and the flyrock trajectory distance was taken as the output.

RESULTS AND DISCUSSION

The network got trained in 14800 learning cycles (Figure 4). The resulting correlation between the normalised- observed and predicted values is shown in Figure 5.
The validation of the results is shown in Figure 6.
The analysis yielded the following results for importance (Figure 6) and sensitivity (Figure 7) of the parameters with respect to the flyrock range.

![Figure 6: Relative importance of independent parameters](image)

![Figure 7: The sensitivity of independent parameters](image)

The summarized data of relative importance and the sensitivity of independent parameters in determining the flyrock range are given in Table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Relative Importance</th>
<th>Parameter</th>
<th>Relative Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Velocity</td>
<td>0.20</td>
<td>Initial Velocity</td>
<td>0.46</td>
</tr>
<tr>
<td>Launch angle</td>
<td>0.17</td>
<td>Width</td>
<td>0.18</td>
</tr>
<tr>
<td>Spherocity</td>
<td>0.16</td>
<td>Length</td>
<td>0.15</td>
</tr>
<tr>
<td>Weight</td>
<td>0.14</td>
<td>Weight</td>
<td>0.14</td>
</tr>
<tr>
<td>Length</td>
<td>0.13</td>
<td>Spherocity</td>
<td>0.03</td>
</tr>
<tr>
<td>Width</td>
<td>0.11</td>
<td>Launch Angle</td>
<td>0.03</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.08</td>
<td>Thickness</td>
<td>0.01</td>
</tr>
</tbody>
</table>

As is evident from the Figures 6&7 and Table 4, the initial velocity, launch angle and weight of the fragments are the most influencing parameters in determining the range of the fragments and are in tune with the basic trajectory equations. The weight and spherocity of the fragment assume almost equal importance. The next influencing parameter is length of the fragments. Thus, the length of the fragments can be a better substituting parameter in determining the throw of the fragment and can replace the spherocity that is very difficult to measure in actual field conditions.
This appears to be logical as during the flight of the fragments these will tend to orient along the length owing to its dominance in the centre of gravity of the fragments. The analysis is expected to open new avenues for R&D in flyrock prediction with some further insight provided below.

**FUTURE VISTAS**

The estimation of the launch angle is a difficult proposition in actual field conditions. Since this is an important parameter in determination of the range of a flyrock, some in depth studies are required to estimate the possible angle. The launch angle has a different relationship with the flyrock range since it is an angular function. This aspect is also important and may be one of the reasons to show less sensitivity in predictions. A proper mathematical model can address the issue in a better manner. In addition, there is a need to include velocity of air in future tests.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


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