Experimental and statistical analysis on rate of penetration under the influence of rotational speed for drilling limestone in the open cast mine area

Sarma Kaipa Venkata Subrahmanyam[1], Vardhan Harsha[1], Byra Reddy Raghunatha Reddy[1]*, Shanmugam Bharath Kumar[2] and Hanumanthappa Harish[3]

1. Dept. of Mining Engineering, National Institute of Technology Karnataka, Mangalore, Karnataka-_575025, INDIA
2. Dept. of AI and Robotics. Engg., Dayananda Sagar University (DSU) - Main Campus, Devarakaggalahalli, Harohalli Kanakapura Road, Dt, Ramanagara, Karnataka 562112, INDIA
3. RV University, RV Vidyanikethan Post, 8th Mile, Mysore Rd, Mailasandra, Bengaluru, Karnataka 560059, INDIA

*raghu.bkbreddy@gmail.com

Abstract

In this study, an experimental investigation was carried out to study the rate of penetration for drilling limestone in an open-cast mine. The investigation was also carried out to study the influence of rotational speed. Drilling experiments were carried out with a constant drilling depth of 10m and varying speeds of 40rpm, 45rpm and 50rpm. As the drilling was carried out, the fresh drill bit caused an increase in the rate of drilling penetration. Further, as it reached the optimal level, there was a decrease in the rate of penetration due to the wearing out of the drill bit.

Further, the prediction of experimental results was carried out using the regression analysis using linear and polynomial models. The results show that the polynomial model was found to be in close relation with experimental results.

Keywords: Limestone, Open cast mine, Drilling, Rotational speed.

Introduction

Mining operations are essential for the extraction of valuable minerals and resources, but they come at a significant cost in terms of energy consumption and environmental impact. Drilling is one of the fundamental processes within the mining and mineral process industry. After drilling, some operations such as blasting and material processing operations such as crushing, grinding and screening are carried out on the extracted material[2,8-14]. To address the growing concern over escalating energy costs and the environmental consequences of excessive energy use, it is imperative to optimize these processes.

Drilling, as the initial step in mining operations, involves the making of boreholes, which is a must for blasting. It requires the use of specialized equipment including drills and associated machinery. This process demands a substantial amount of energy, as it involves penetrating a variety of geological structures with different properties. The need for energy optimization in mining is two-fold. First, the escalating costs of energy sources, including electricity and fuel, will have a significant financial impact on the total cost of mining. Hence, reducing energy consumption can result in substantial cost savings and also excessive energy usage contributes to higher costs of production and greenhouse gas emissions cause environmental degradation. Therefore, there is a need to make mining operations more energy-efficient.

The experiments were conducted on percussive drilling in the laboratory and the influence of operational parameters i.e., air pressure, thrust and drill diameter and rock properties on penetration rate was studied[5]. The literature was reviewed on the energy efficiency of drilling operations in mineral industries and recommendations was made for enhancing energy efficiency[6].

Nápoles et al[7] proposed a model to estimate specific energy consumption in grinding, highlighting the role of sliding as the primary mechanism of energy dissipation. Li et al[5] conducted experiments to analyze the influence of parameters on the rock impact efficiency from the views of drilling velocity and specific energy. Tang et al[15] proposed an energy analysis method based on thedrilling process and quantified total energy using the dynamic load influence factor.

From the literature, it was clear that less work has been carried out to investigate the rate of penetration for the variation in rotational speed for drilling limestone. So, the present study deals with the investigation of the rate of penetration for the variation in the operational parameter such as rotational speed. Further, the regression analysis will be carried out for the prediction of the rate of penetration for the variation in rotational speed.

Material and Methods

The present study aimed to investigate the rate of penetration for drilling limestone in an open-cast mine utilizing rotary-percussive drill machines of the RECP-C600H model equipped with a 165 mm diameter drill bit. Figure 1 shows the drill bit used in the present study. Figure 2 shows rotary-percussive drill machines of the RECP-C600H model.

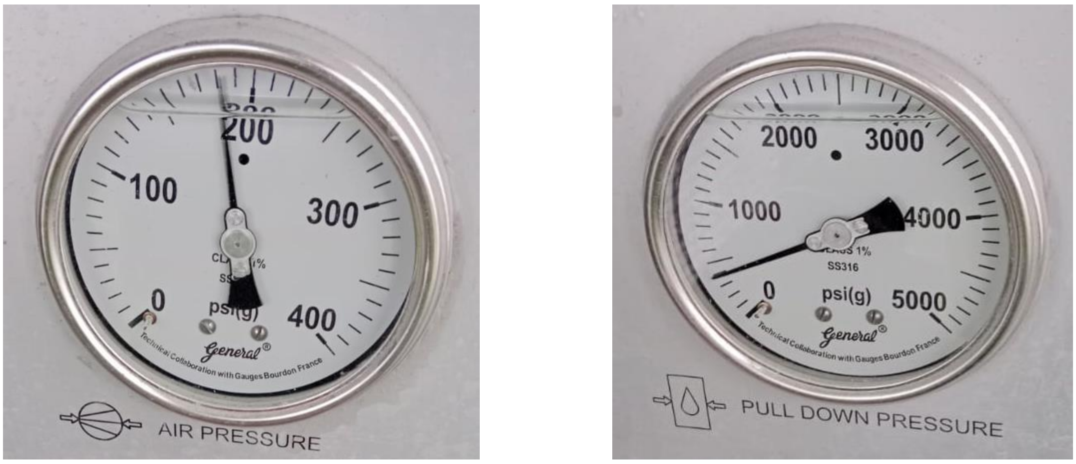
The influence of rotational speed on the rate of penetration will be studied in the present work. The rate of penetration is obtained by varying rotational speed and also maintaining other parameters such as air pressure and pulldown pressure as constant. Figure 3 shows the air pressure and pulldown pressure maintained at 180 PSI and 400 PSI respectively.

The rate of penetration of varying speeds such as 40rpm, 45rpm and 50rpm was used for drilling. Drilling holes of 10m depth were maintained constant for the experimental study. Figure 4 shows the hole measurement taken for maintaining an optimal level of 10m depth. The rate of penetration was recorded for each experimental trial. Further, the rate of penetration was measured for 15 experimental trials using the same drill bit for the variable speed of drilling.

After the experimental trials, the prediction analysis was carried out on the experimental results of the rate of penetration. Further, for prediction, regression analysis was carried out using linear and polynomial regression models. Furthermore, the results of the linear and regression model were compared using the regression coefficient. The regression coefficient shows the percentage of experimental results fitting with the prediction results.

Fig. 1: 165mm Drill bit used in present study

Fig. 2: Rotary-percussive drill machines of the RECP-C600H model equipped with a 165 mm diameter drill bit in the limestone mine



Air pressure maintained at 180 PSI **Pulldown pressure maintained at 400PSI**

Fig. 3: Air pressure and Pulldown pressure maintained constant during drilling

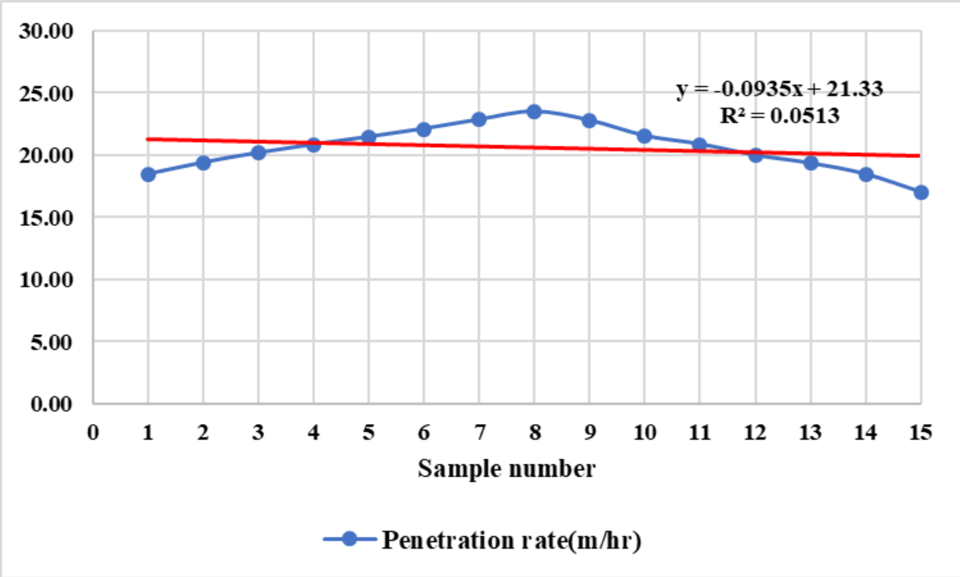
Fig. 4: Hole measurement taken to maintain an optimal level of 10m depth

Results and Discussion

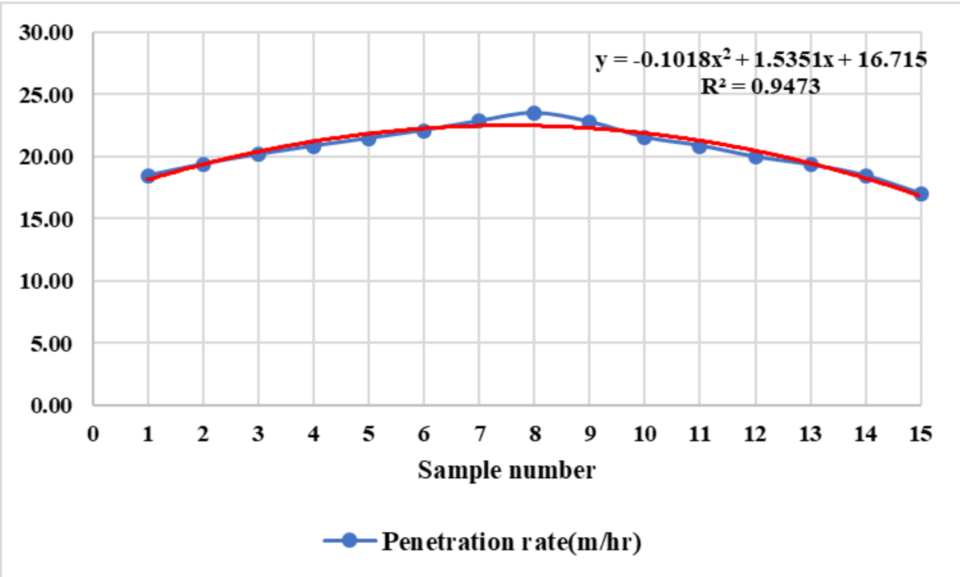
Figure 5 shows the linear and polynomial regression model of penetration rate(m/hr) on drilling rotational speed of 40rpm. The experimental results show the increase in the rate of penetration to an optimal level and there was a sudden decrease in the rate of penetration. This was due to the wearing of the drill bit material with the drilling. From figure 5, it was clear that the fresh drill bit has caused an increase in the rate of penetration. After the increase in the rate of penetration to an optimal level, there was a drop in the rate of penetration due to the wearing of the drill bit. Further, prediction results of linear and polynomial regression models show that the regression coefficient was around 5.13% and 94.73% respectively. From the results, it was also clear that the polynomial regression model has a higher regression coefficient of 94.73%. This shows the closeness in experimental results fitting with the prediction results. This shows that the polynomial regression model is a better prediction model compared with the linear regression for the prediction of rate of penetration (m/hr) on drilling rotational speed of 40rpm.

Figure 6 shows the linear and polynomial regression model of penetration rate (m/hr) on drilling rotational speed of 45rpm. The experimental results show the increase in the rate of penetration to an optimal level and there was a sudden decrease in the rate of penetration. This was due to the removal of the drill bit material with the drilling.

From figure 6, it was clear that the fresh drill bit has caused an increase in the rate of penetration. After the increase in the rate of penetration to an optimal level, there was a drop in the rate of penetration due to the wearing of the drill bit. Further, prediction results of linear and polynomial regression models show that the regression coefficient was around 8.56% and 89.54% respectively. From the results, it was also clear that the polynomial regression model has a higher regression coefficient of 89.54%. This shows the closeness in experimental results fitting with the prediction results. This shows that the polynomial regression model is a better prediction model compared with the linear regression for the prediction of rate of penetration (m/hr) on drilling rotational speed of 45rpm.

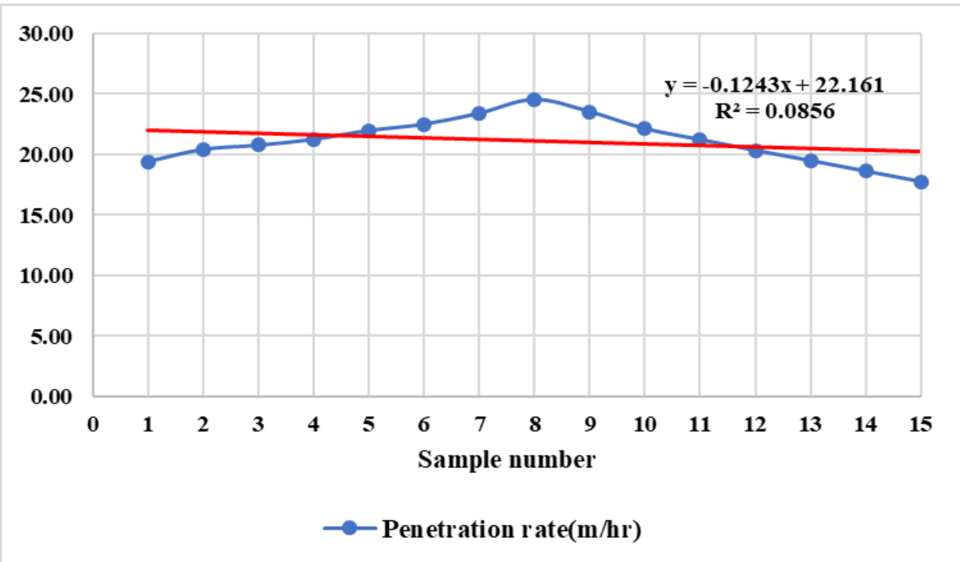


Linear model

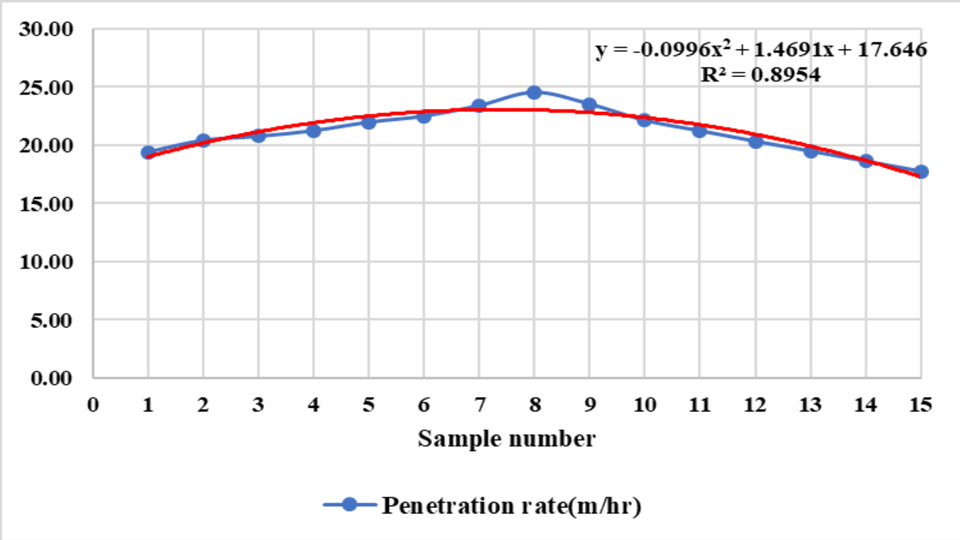


Polynomial model

Fig. 5: Linear and polynomial regression model of rate of penetration (m/hr) on drilling rotational speed of 40rpm

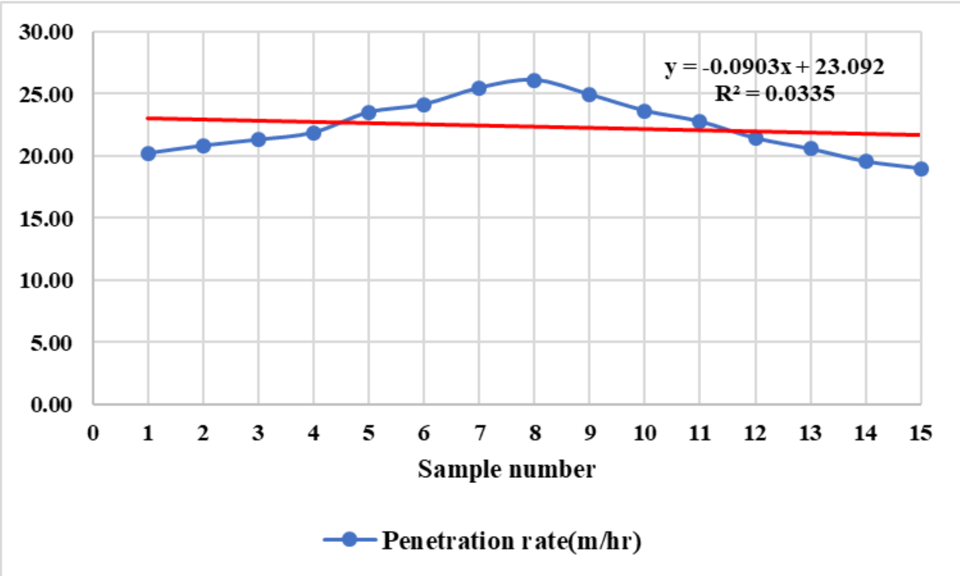


Linear model

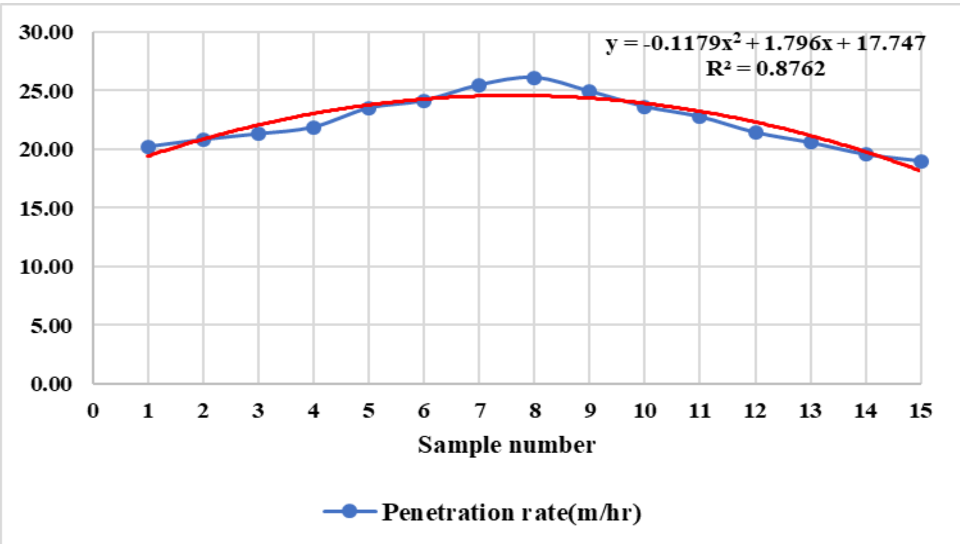


Polynomial model

Fig. 6: Linear and polynomial regression model of rate of penetration (m/hr) on drilling rotational speed of 45rpm



Linear model



Polynomial model

Fig. 7: Linear and polynomial regression model of rate of penetration (m/hr) on drilling rotational speed of 50rpm

Figure 7 shows the linear and polynomial regression model of penetration rate(m/hr) on drilling rotational speed of 50rpm. The experimental results show the increase in the rate of penetration to an optimal level and there was a sudden decrease in the rate of penetration. This was due to the removal of the drill bit material with the drilling.

From figure 7, it was clear that the fresh drill bit has caused the increase in the rate of penetration. After the increase in the rate of penetration to an optimal level, there was a drop in the rate of penetration due to the wearing of the drill bit. Further, prediction results of linear and polynomial regression models show that the regression coefficient was around 3.35% and 87.62% respectively.

From the results, it was also clear that the polynomial regression model has a higher regression coefficient of 87.62%. This shows the closeness in experimental results fitting with the prediction results. This shows that the polynomial regression model is a better prediction model compared with the linear regression for the prediction of the rate of penetration (m/hr) on a drilling rotational speed of 50rpm.

From figures 5,6 and 7, it was clear that the highest rate of penetration was obtained for the rotational speed of 50rpm. This shows that with the increase in the rotational speed from 40rpm to 50rpm, there was an increase in the rate of penetration. From figures 5,6 and 7, it was also clear that the polynomial regression model provided a higher regression coefficient compared to the linear regression model.

Conclusion

The rate of penetration for drilling limestone in an open-pit mine was investigated experimentally in this study. Additionally, an investigation was conducted to examine the impact of rotating speed. Drilling tests were conducted at varied speeds of 40 rpm, 45 rpm and 50 rpm while maintaining a constant drilling depth of 10 m. The new drill bit increased the rate of drilling penetration as the drilling was being done. Additionally, when the drill bit wore out, the rate of penetration decreased as it reached the ideal level.

Additionally, regression analysis employing linear and polynomial models was used to predict the experimental results. The polynomial regression coefficient for rotational speeds of 40rpm, 45rpm and 50rpm was 94.73%, 89.54% and 87.62% respectively. The findings indicate that there was a strong correlation between the polynomial model and the experimental results.

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