Design and Construction in Mining, Petroleum and Civil Engineering, 1998, Ayres da Silva, L.A.; Quadros, E.F.; Gonçalves, H.H.S. (eds), São Paulo, Brazil

A Nomogram Based Method for Selecting Rock Cutting Parameters on a Simulated Continuous Miner

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Abstract: This paper presents a nomogram-based method for selecting rock-cutting parameters on a simulated continuous miner. Four different bit geometry-related parameters were considered for the development of a nomogram/graphical model. The parameters were bit spacing, cutting depth, cutting drum rotational speed, and bit tip angle. The experimental study was conducted on an Automated Rotary Coal/Rock Cutting Simulator (ARCCS) in Rock Mechanics laboratories at the West Virginia University. An orthogonal fractional factorial experimental plan was utilized to carry out the experiments. Indiana limestone was used as the test material. The model incorporated a normalized shear load factor, defined as a ratio of shear load component required for removing rock lands/ridges to shear strength of the rock, and specific respirable dust generated during rock cutting. A brief description of dynamic shear components in rock cutting process is provided. Details of dynamic shear strength simulation in the laboratory and its effect on rock lands/ridges removal are discussed. The aids of this model to the operators/owners of continuous miners in selecting optimum rock cutting parameters are also discussed.

INTRODUCTION

Coal deposits are often encapsulated in sedimentary rocks such as shale, sandstone, or limestone. During extraction of coal, the roof and floor of the coal seam often consist of one of these rock measures. Therefore, it is a common occurrence to have cut these rock materials in the process of coal cutting. Such a bit-coal/rock interaction has directly caused "black lung" in coal miners. Rock cutting also produces fine dust accretion, resulting in "silicosis." Finally, it ignites sparks, a potential for face ignitions. Millions of dollars are spent on compensation for respirable dust related diseases. The rock/coal cutting also impacts the cutting tools. The impact often results in the wear of the bits, requiring quick replacement. Research suggests many of these factors are directly attributable to improper bit design [1]. Undesirable impacts may be minimized by a proper bit design for continuous miners. The appropriate bit design configuration is accomplished through a maneuver of several bit-related parameters including geometry, mounting configuration on the cutting head, matching tool spacing and cutting depth, etc. In essence, the primary factors influencing the rock fragmentation process by a continuous miner are bit spacing, bit geometry, depth of cut, and cutting drum rotational speed and few other known and unknown parameters.

The mining community has centered its attention on mastering two goals – the minimization of energy required for performance cutting operations and to decrease the amount of respirable dust generated during the cutting process. Unfortunately, these tasks have not been met successfully. There is a need to investigate bit design configuration in more depth in order to perform rock cutting efficiently. Essentially, a better understanding of the influence of several parameters including both machine-controlled and operator controlled during the rock cutting process is required.

The specific respirable dust during the rock cutting process is dependent on various parameters that inter-operate and it influences the performance of a continuous miner [1, 2]. It can be expressed as a function of such parameters as given in Eq. (1.1)

$$\text{Specific respirable dust} = F(d, s, \alpha, z, r, C_0, S, \mu, t) \quad (1.1)$$

where d is depth of cut, s is bit spacing, α is bit tip angle, z is bit tip size, r is rotational speed of the cutting drum, C_0 is the compressive strength, S is the shear strength, μ is the angle of internal friction, and t is the tensile strength of the rock material.

METHODOLOGY

An experimental investigation was carried out in the laboratory utilizing an Automated Rotary Coal/Rock Cutting Simulator (ARCCS) [4] using the Indiana limestone rock material. Tables 1 and 2 show the details of experimental parameters.

Table 1 categorizes the levels and factors involved in the experimental program. The nomenclature x_1, x_2, x_3, and x_4 in Table 2 shows the parameter description of the Table 1.

The factor x_1 is bit spacing in in., x_2 is cutting depth in in., x_3 is tip angle in degrees, and x_4 is drum rotational speed in rpm.

Figure 1 depicts the sequence in which the cuts were made in orthogonal experimental plan [3] on the ARCCS. Bit #1 first attacks the rock block, followed by bit #2 and then bit #3 during one revolution of the drum. R_{12} and R_{23} are the ridges/lands between the grooves made by bits 1 & 2 and 2 & 3 respectively.

EXPERIMENTAL RESULTS AND ANALYSIS

A graphical model was developed based on the experimental trials. This model considered all four of the parameters. The model incorporated both the respirable dust generated during rock ridge breakage and the normalized shear load factor at each level.

Normalized Shear Load Factor

The indentation during the initial phase of rock cutting causes rock fracture development underneath the bit tip and ahead of the zone of impact. During the indentation process, the force applied on the bit overcomes the compressive strength of the rock. Beyond

Table 1. Description of parameters used in the orthogonal experimental study.

Serial Number	Parameter Description	Levels of Parameter
1	Bit spacing	1 in., 1.5 in., and 2 in.
2	Cutting depth	0.4 in., 0.8 in., and 1.2 in.
3	Bit tip angle	60°, 75°, and 90°
4	Cutting drum rotational speed	50 rpm, 70 rpm, and 90 rpm.

Table 2. Factors and levels used in the orthogonal experimental study.

Factor	Level		
	0	1	2
x_1	1.0	1.5	2.0
x_2	0.4	0.8	1.2
x_3	60°	75°	90°
x_4	50	70	90

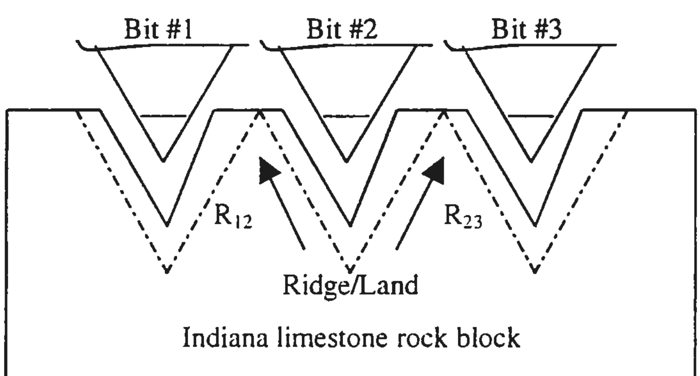

Figure 1. Sequence of cuts used in orthogonal experimental plan.

this stage, adjacent cuts interconnect when fractures extend from the crushed zone. As the cuts deepen, ridges are narrowed and chipped away. The cutting pressure applied on the cutting bit is partially expended on creating a crushed zone underneath the bit tip. It is partially used in exerting shear load on the ridges/lands between the grooves. The shear component of the applied pressure removes the ridges/lands off the rock surface. Figure 2 describes the shear components of the applied force on a cutting bit in a typical rock cutting process. A particular instance of this dynamic process [2] can be considered as a static case and analyzed for force components and break out angle. A part of the shear load exerted on the rock ridge/land is absorbed in overcoming the cohesive strength of the rock. However, a major part of the shear load is expended on removing the failed rock; hence, over-coming the friction between the failed rock material and the unaffected rock block.

A *normalized shear load factor* [1] was defined as a function of the shear load component. It typically represented the ratio of shear load component of the applied load on the bit to the shear strength of the rock. This factor was calculated for all the experimental trials in the orthogonal experimental plan. Finally, a graphical model was developed using the normalized shear load factor and specific respirable dust. All four of the parameters of interest were plotted against the normalized shear load factor and the specific respirable dust in this model.

Breakage of rock ridges/lands between the grooves occurs when cutting advances. Rock chips are formed during this process. Ridge removal also results in fine dust generation. In order to understand the dust generation process, a comprehensive analysis of the forces that cause rock ridge/land removal is necessary. The ridge breakage process is mainly due to the shear component of the applied force on the cutting bit. The spacing to depth ratio was monitored during the ridge breakage process.

Figures 2 – 5 show the Normalized Shear Load Factor (NSLF) as a function of spacing to depth (s/d) ratio. It is observed that the NSLF increased with decrease in s/d ratio for all different levels of spacing used. At larger spacing, the shear force component required to inflict ridge breakage is higher if the cutting depth is smaller. However, as the cutting depth increases for the same level of bit spacing, the shear force effort required to inflict breakage has drastically plumped.

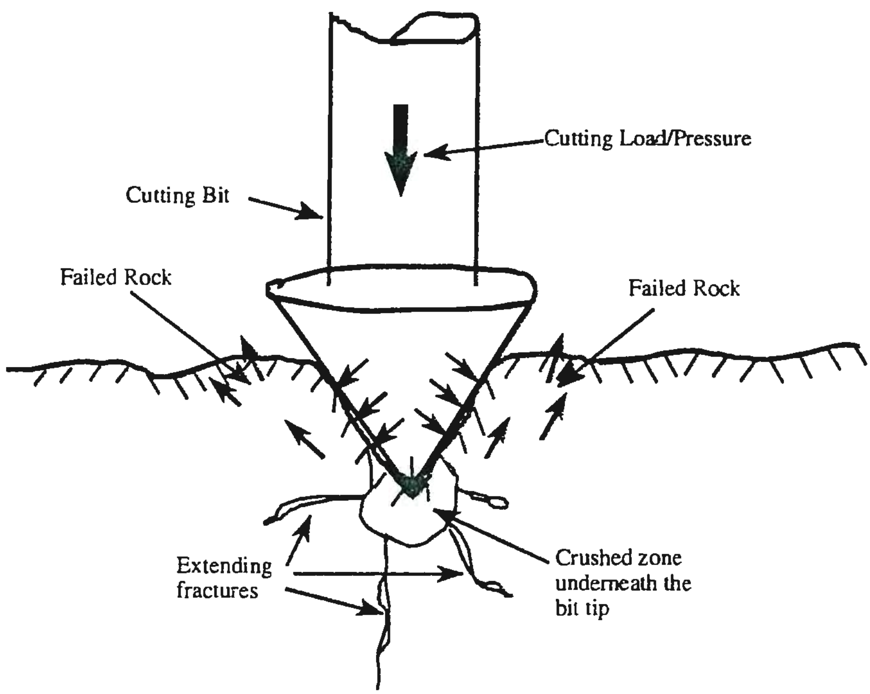

Figure 2. Force components shearing the rock ridges/lands during the cutting process.

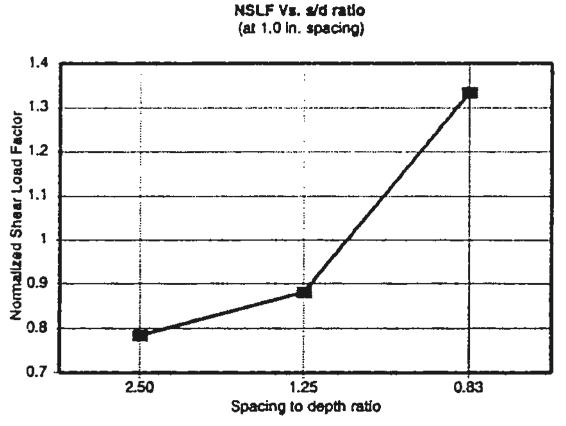

Figure 3. Normalized Shear Load Factor as a function of s/d ratio at 1.0 in. spacing.

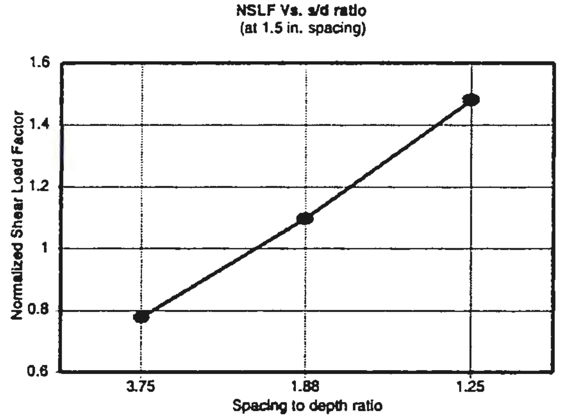

Figure 4. Normalized Shear Load Factor as a function of s/d ratio at 1.5 in. spacing.

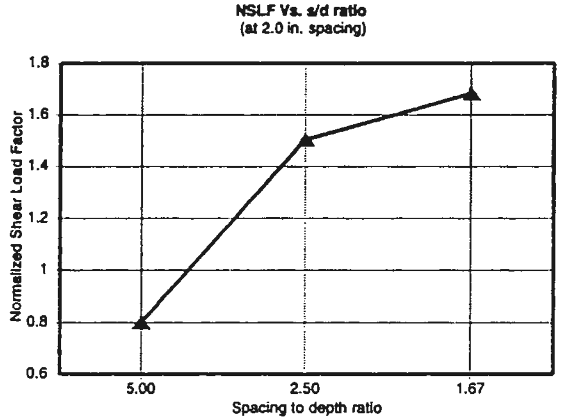

Figure 5. Normalized Shear Load Factor as a function of s/d ratio at 2.0in. spacing.

Development of a Graphical Model

Using the test results obtained in orthogonal experimental study, a direct estimation of each parameter was conducted. Besides, the rock breakage process under dynamic conditions was analyzed. Based on these results, a graphical model/nomogram was developed to better represent the effects of various parameters that were investigated. Figure 6 shows the details of the graphical model. The normalized shear load factor (NSLF) is represented on primary vertical axis where as the specific respirable dust (srd) is represented on secondary vertical axis. The effects of four of the primary parameters are shown on the horizontal axis as levels 0, 1, and 2. The levels of parameters are described in Tables 1 and 2. For a chosen NSLF, required levels of parameters and expected specific respirable dust can be estimated using this model.

The NSLF increased significantly with increasing levels of cutting depth and bit spacing. It decreased with the increasing drum speed of cutting head. A marginal reduction in NSLF required to inflict rock ridge breakage was visible when the bit tip angle increased from 75^0 to 90^0. The effects of bit geometry parameters on specific respirable dust were directly estimated using variance analysis [1,3].

For example, in order to select a suitable level of cutting depth trace a point or a level of this parameter on the nomogram that would produce acceptable levels of specific respirable dust and would require a low NSLF. Approximation is necessary when the acceptable levels of NSLF and specific respirable dust do not fall on a specific level of a parameter in the model. A similar criterion can be applied when choosing levels for the other bit geometry parameters as well.

CONCLUSIONS

Analysis of the results in the orthogonal experimental plan indicated that the average specific respirable dust increased with increase in bit spacing, decreased with increase in cutting depth, increased with the increase in drum speed of the cutting head. A rotational speed of 70rpm resulted in low specific respirable dust generation.

A nomogram/graphical model was developed using the results from orthogonal fractional factorial experiments and shear force component analysis during ridge breakage. The model incorporated the effect of all four of the primary parameters (e.g., bit spacing, cutting depth, drum seed of cutting head, and bit tip angle). A normalized shear load factor (NSLF), defined for the purpose of interpreting shear breakage nature of rock material, was represented on the primary verti-

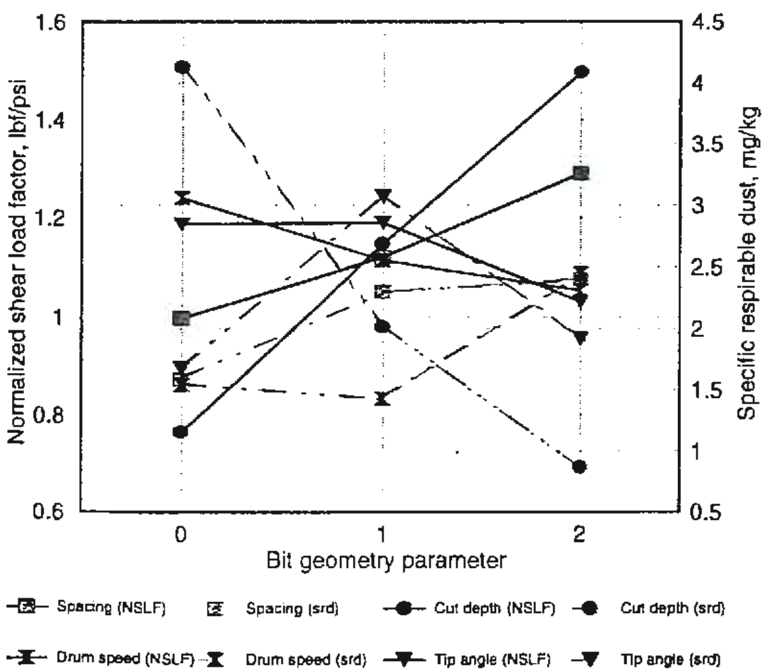

Figure 6. Graphical model showing the effects of primary parameters.

cal axis of the model. The specific respirable dust was represented on the secondary vertical axis of the model. For a chosen NSLF, the model will provide insights into expected levels of specific respirable dust and a comprehensive knowledge of the effect of four of the primary parameters.

ACKNOWLEDGEMENT

The research was supported by the US Department of the Interior's Mineral Institute Program administered by the former Bureau of Mines through a subcontract from the Pennsylvania State University Generic Mineral Technology Center for Respirable Dust under the grant number G1125141. Thanks are due to the supporting agency. The authors would also like to extend their thanks to Mr. Ahmad Zia, a graduate research assistant in the Department of Mining Engineering, West Virginia University, for his assistance in the experimental work.

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PROCEEDINGS OF THE FIFTH SOUTH AMERICAN CONFERENCE IN ROCK MECHANICS AND SECOND BRAZILIAN CONFERENCE IN ROCK MECHANICS - SAROCKS'98
SANTOS/SÃO PAULO/BRAZIL/22-25 NOVEMBER 1998

Design and Construction in Mining, Petroleum and Civil Engineering, 1998

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Suporte Financeiro:
FUNDAÇÃO DE AMPARO À PESQUISA
DO ESTADO DE SÃO PAULO
FAPESP

Edição:
ESCOLA POLITÉCNICA DA
UNIVERSIDADE DE SÃO PAULO
EPUSP

SÃO PAULO/1998

Design Edition and Cover by Daniel Cohenca, *Brazil*
Logotype by Adilson Claro *and* Roberto Temin , *Brazil*

South American Congress on Rock Mechanics (5 : 1998 : Santos)
SARocks'98: Design and construction in mining, petroleum and civil engineering; proceedings / ed. by L.A.Ayres da Silva, E.F. de Quadros, H.H.S. Gonçalves. São Paulo, EPUSP, 1998.
526p.

1. Mecânica de rochas 2. Engenharia de minas 3. Engenharia civil 4. Petróleo I. Ayres da Silva, Lineu Azuaga II. Quadros, Eda Freitas de III. Gonçalves, Heloisa Helena Silva IV. Brazilian Symposium on Rock Mechanics (2 : 1998 : Santos) V. Universidade de São Paulo. Escola Politécnica VI. t.

CDU 624.121
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622.323

The texts of the various papers in this volume were set individually by typists under the supervision of each of the authors concerned.

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Published by
Escola Politécnica da Universidade de São Paulo, São Paulo, Brazil (Fax: +55 11 818 5721)

ISBN 85-86686-02-6

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