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Preliminary study of strength of coal composites

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Abstract. Large scale floor convergence and sudden failure of pillars in room-and-pillar underground mining have been reported in various countries over many years. Failure of these mines has been attributed, amongst other causes, to the stiffness criterion used by the mining operators and most importantly mine design practices, that tend to reduce the width-to-height ratio i.e. slender pillars in pursuit of greater coal recovery yields, in order to maximize coal recovery in the seam. It is recorded that the room-and-pillar method can leave behind about 40% of the total coal available for mining. The current study seeks to determine the appropriate width-height ratio for coal composite and stabilized coal pillars. Pure coal was mixed with granular soil and stabilized with cement to form cylindrical composite columns which were crushed to determine their unconfined compressive strength at different width-to-height ratios. The strength increased with the increase in W/H of the columns. Increase in coal percentage in a composite reduces the strength. The stabilized coal pillars mobilized less strength than the composite pillars. Based on limited data, relationships amongst column strength W/H and mix ratios were formulated and are proposed for the estimation of strength of mine support structures. More data is however required to formulate a general regression equation.

Keywords. Pillar failure, cement, unconfined compressive strength, stiffness

Introduction

Coal has been the primary source of energy for many years and continues to be among the dominant sources of energy to date. It provides around 29.9% of global primary energy needs and generates around 41% of the world's electricity. Furthermore, it is used in the production of 70% of the world's steel according to the World Coal Association publication in 2013 [5]. This fossil fuel is formed through plant matter that accumulated over millions of years in swamps and peat bogs over the course of the Phanezoic time period that was buried, compacted and lithified into coal seams. When coal seams are near the surface it is economical to use the open pit method to retrieve the coal, and this method affords the miner the benefit of recovery as much as up to 90% of the coal discovered. However when the seams are formed deep into the ground usually around 100m, depending also on density of the overburden and thickness of the seam, underground mining techniques are used as the method of coal extraction. Among the various methods employed in underground mining to extract coal, the room and pillar mining method is of interest in this study.

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Coal seams are recovered in alternating sections leaving behind rectangular or square portions of in-situ coal as supports to the overburden. This method is normally done in seams that are relatively flat. It is important that the seams as well as the rooms are large enough to allow heavy machinery such as shuttle cars and tractors to pass through with ease [4]. The setback of this method is the valuable material that has to be left behind as supports, this can be up to 40% of the coal seam [5], however depending on the set production targets of the mining operations, the pillars can either be left in place or removed at the later stage of mining [4]. Mining of coal by this method has been dangerous throughout the years due to structural failures of the pillars that tend to occur, one such incident occurred on January 21 1960 at the Coalbrooke colliery in South Africa where 437 miners died from a collapsed mine [3]. The mine collapse was due to cascading pillar failure (CPF). Such tragedies accentuate the importance of understanding the structural and strength properties of coal, and the pillar failure mechanisms, in order to put a stop to the on-going disasters happening in mines [3]. This paper is subdivided into five parts, namely: introduction; materials and methods; results and discussions; and conclusion.

1. Materials and methods

The pure coal (PC) used was sourced from one of the collieries at eMalahleni around Witbank in South Africa and the residually derived granular material (GM) was sourced from Johannesburg. The two materials were mixed and stabilized with Portland cement from Lafarge (Cem) to form the composite column samples. The composite material was split into 2 categories, the 46% PC, 46% GM and 8% Cem mix proportion, and the second consisted of 66% PC, 26% GM and 8% Cem by mass. Category 1 composite mix is referred to as 50/50 composite and the second 75/25 composite. PC was also stabilized with 8% cement and that formed the category 3 of test column samples referred to as stabilized coal (SC).Table 1 shows the different stabilized sample columns prepared for this study. A set of laboratory tests were conducted on the various categories of samples for classification purposes. These categories of soil materials were mixed separately at 30% moisture content and compacted in 150mm diameter moulds to produce several column samples with different heights to generate width/height (W/H) ratio groups of 0.25, 0.5, 1 and 2. The columns were cured in a humidity chamber for 7 days, and then crushed uniaxially under the Instron 5500R compression machine to determine their uniaxial compressive strength, and enabled the estimation of the columns' modulus of elasticity. Representative samples from the crushed material were reserved for moisture content determination at the time of crushing, there were a total of 16 sample columns tested.

Table 1. Sample preparation

Column Height (mm)	Column Diameter (mm)	Stabilized Material Composition	Material Composition ratio	No. of Columns
600	150	PC/GM	50/50	2
300	150	PC/GM	50/50	2
300	150	PC/GM	75/25	2
300	150	PC	100	2
150	150	PC/GM	50/50	2
150	150	PC/GM	75/25	2
150	150	PC	100	2
75	150	PC/GM	50/50	2
75	150	PC/GM	50/50	2
75	150	PC	100	2

Note: PC-pure coal, GM-granular material

2. Results and discussions

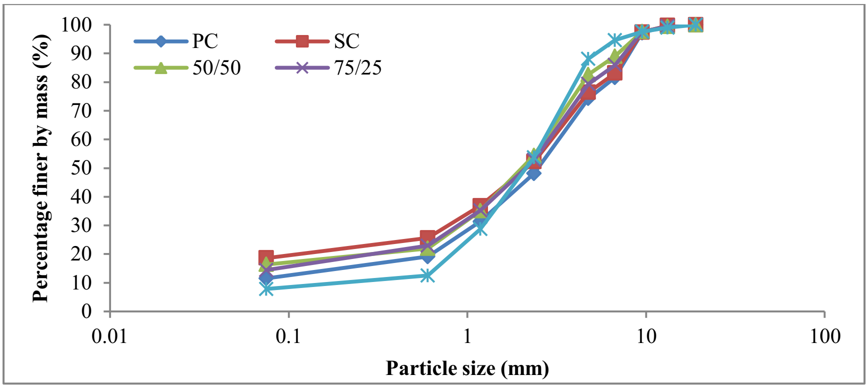

Figure 1. Particle size distribution

The PC and GM's particle size distribution exhibited a narrow envelope, classified by Unified Soil Classification System (USCS) as poorly graded Sand with silt and gravel, which are non-plastic [1]. The Instron compression machine produced the stress – strain relationship shown in Figure 2 for all columns cast. The 75mm high columns showed a greater peak stress for a composite sample of 50/50 material. As the width of the columns was kept constant, an increase in height of column reduced the strength, ie the as the W/H ratio increases so does the compressive strength and this behavior was also observed by [2] in his study. [3] states that the shorter columns would retain most of their load even after failure, and also states that designing pillars with an adequate stability factor (greater than 2) minimizes risk of failure and that W/H ratios should be high enough to satisfy local mine stiffness criterion. Modulus of elasticity (E) being a measure of stiffness of the stabilized column and obtained as the ratio of uniaxial stress over the uniaxial strain from the unconfined compressive strength tests, as can be seen in Table 3 that increasing W/H ratio reduces the E.

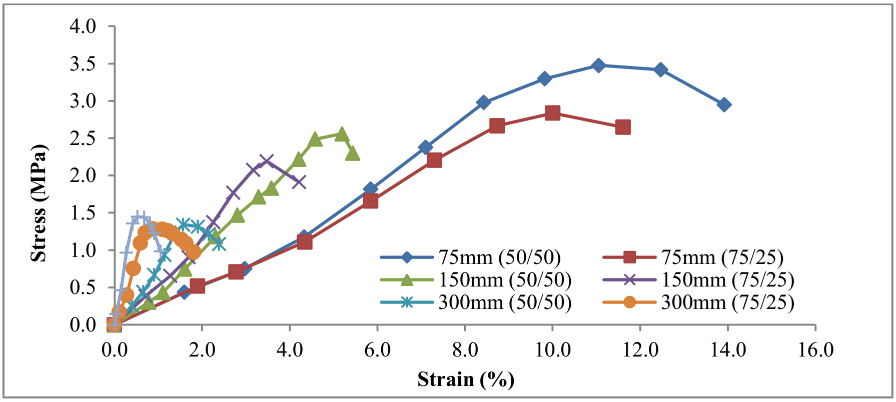

Figure 2. Stress-Strain relationship of columns with different heights

Table 2. Peak stress and estimated Modulus of Elasticity

Sample height (mm)	W/H	Peak Stress (MPa)			Modulus of Elasticity (MPa)	
		50/50	75/25	SC	50/50	75/25
600	0.25	1.45	1.21	0.88	319.12	37.23
300	0.5	1.34	1.28	0.86	119.47	21.94
150	1	2.56	2.20	1.44	58.56	65.30
75	2	3.48	2.84	1.64	43.89	37.01

Note: SC – stabilized coal

$$\mathbf{Sp} = 1.123\ \mathbf{W/H} - 0.1625\ \mathbf{CR} + 1.316 \qquad (R^2 = 0.928) \qquad (1)$$

The pure coal stabilized with 8% cement achieved less compressive strength when compared to the stabilized composite as shown in Table 3; the cementation was more effective in holding together the composite particles than in the pure coal. A model with a coefficient of determination of 0.928 is proposed to predict the compressive strength (Sp) of pillars of varying W/H and composite ratio (CR). This indicates that though the strength of the pillar is dependent on the W/H ratio the composite variable contributes to the strength, with a negative slope coefficient where CR is defined as the ratio PC/PM. Figure 5 shows the quality of the fit between predicted values for Sp and the actual values from the laboratory. Figure 3 and 4 show the comparison of the actual results of this study to those from the empirical formulae from literature. The stabilized composite column strength is defined amongst the rest of the columns with same size specimen for the investigated W/H. However the witnessed lower strengths for 75/25 composite are attributed to higher content of PC in the composite.

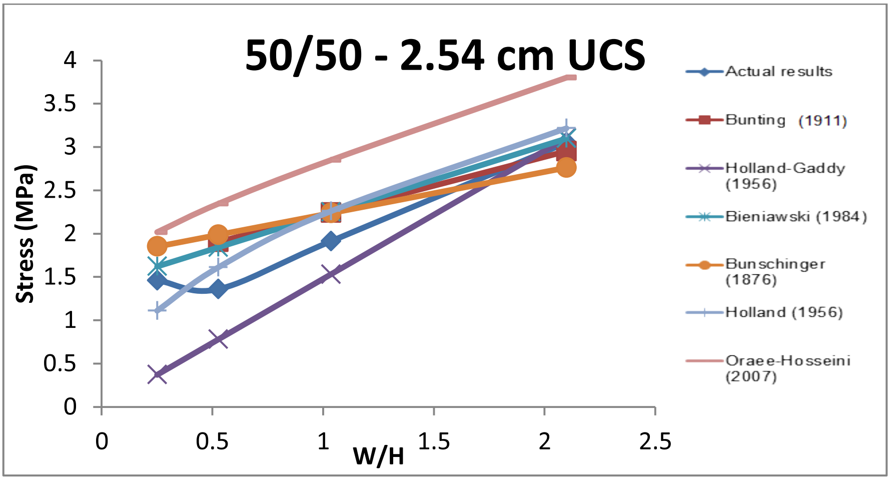

Figure 3. Comparison between actual results to empirical formulae for 50/50 – 15cm UCS specimen

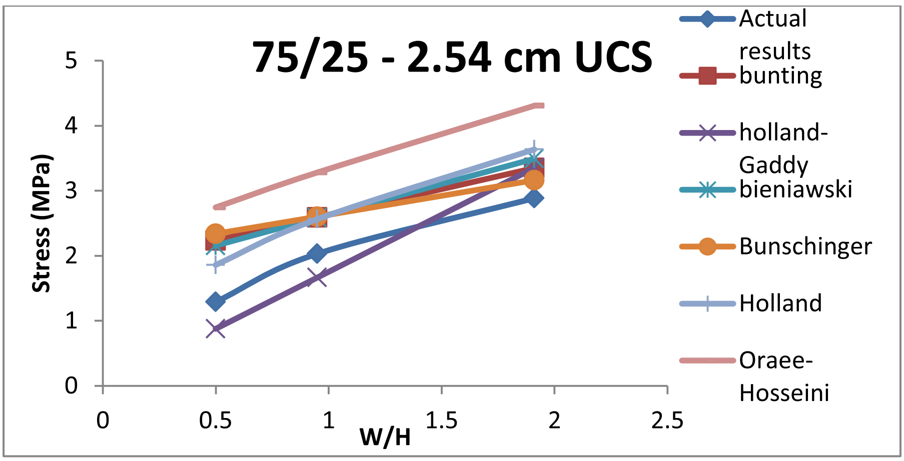

Figure 4. Comparison between actual results to empirical formulae for 75/25 – 15cm specimen

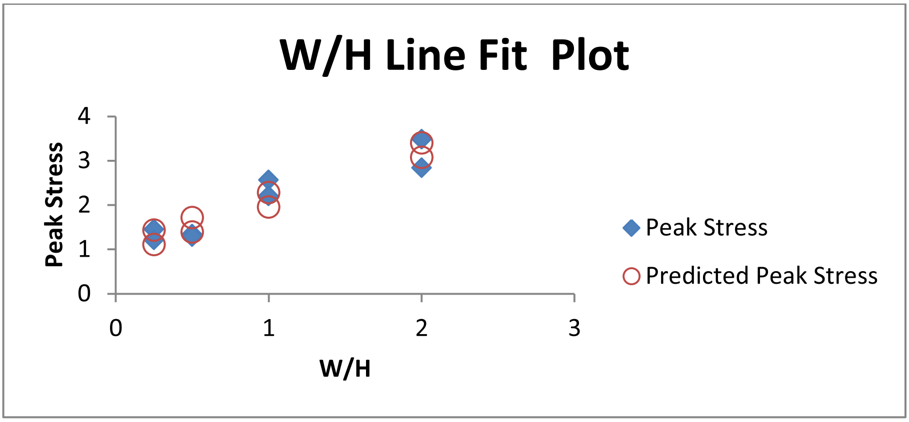

Figure 5. W/H best fit plot

3. Conclusions

Failure of pillars in the mining activity can be catastrophic. It occurs as a sudden collapse of supporting pillars leading to a transfer of load to the following pillars and thus a consecutive failure of remaining pillars. The strength of the pillars can be improved by as shown in literature as well as the current study increasing the W/H ratio and creating a composite of PC and GM and stabilizing it with cement. Shorter pillars have higher strength however lower E. Equation (1) with a coefficient of determination of 0.928 is proposed as an approximate expression to predict the compressive strength by W/H and CR.

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