UNDERGROUND MINING ENGINEERING 31 (2017) 31-43 UDK 62
UNIVERSITY OF BELGRADE - FACULTY OF MINING AND GEOLOGY ISSN 03542904

Professional paper

ASSESSING THE EFFECTIVENESS OF INERTIZATION OF BROWN COAL DUST WITH LIMESTONE ROCK DUST

Jelena Marković [1], Rijad Šišić [1], Kasim Bajramović [2]

Received: September 5, 2017 **Accepted:** November 22, 2017

Abstract: An assessment of the effectiveness of inertization of coal dust with inert dust is an important step in prevention of coal dust explosions. According to the tests on their explosive properties, coal dusts from all the mines in Bosnia and Herzegovina present an explosion hazard. The measure applied in order to prevent the transmission of deposited coal dust explosion, in both methaneous and non-methaneouspits, is wetting. The prescribed content of solid non-combustible particles in coal dust which makes the dust non-explosive, as defined by BH regulations, is actually based on the figures taken from Polish regulations. In order to get the content of inert component in coal dust which will prevent the transmission of explosion, relevant for BH coals, a research was conducted on brown coal dusts from the three largest producing coal mines in Bosnia and Herzegovina. In this case, limestone rock dust was used to inert coal dust. Tests were conducted in accordance with the methods defined by BAS EN 14034-1 and EN 14034-2. The most important indicator of coal dust explosion is its explosive characteristics (Ek), which describes the interaction between the maximum rate of pressure rise $(dp/dt)_{max}$, maximum explosion pressure p_{max} and duration of the explosion t1.

The tests conducted indicate that the content of inert component in BH coal dusts differs from the amounts defined by the adopted Polish regulations and, consequently, that BAS (Bosnian and Herzegovinian) standards need to be changed accordingly.

Keywords: Brown coal; Dust; Explosive characteristics; Inert dust;

1 INTRODUCTION

Brown coals make 37% of total coal reserves in Bosnia and Herzegovina. Brown coal deposits are tectonically complex and their seams are relatively steep. Mining works usually take place at a depth of 500 meters. Brown coals are mined in methaneous conditions.

The main coal seam of Mid-Bosnian deposit contains the best coal and is the most profitable, so this is where mining works are the most intense.

[1] Faculty of Mining, Geology and Civil Engineering Tuzla
[2] Brown coal mine „Kakanj“ Kakanj
emails: jelena.markovic@untz.ba; rijad.sisic@untz.ba; kasimbajramovic@gmail.com;

According to the parameters defining explosive characteristics of coal dusts (the maximum rate of pressure rise (dp/dt)max and explosive characteristic Ek), the coal dust of the main coal seam falls into the category of highly explosible dusts (Marković et al. 2006).

For many mines, the almost continual deposition of fine-sized float coal dust on the floor, ribs, and roof of mine entries and returns, coupled with the intermittent application of rock dust, has resulted in stratified layers of dust. Over the years, changes in mining technology have produced increased amounts of finer float coal dust, which has additionally affected safety matters (Sapko et al. 1987).

Inertization of coal dust with appropriate inert dusts is customary in many coal mines around the world. This method eliminates the potential hazard of occurrence and transmission of coal dust explosion or reduces it to the minimum.

Early research conducted by Cybulski (1975) has shown that the use of hydrophobic agents in conjunction with conventional limestone-based rock dusts greatly lessened their tendency to cake when exposed to moisture and enabled their dispersibility even in wet mining conditions.

He understood the importance of rock dust dispersibility and conducted quantitative research to characterize the dispersibility relevant to preventing dust explosions.

Sapko et al. (2007) tested large scale mixtures of Pittsburgh high volatile bituminous coal and stone dust for the propagation of an explosion, demonstrating in Figure 1.

Their conclusion was that the finer the coal dust, the higher the amount of stone dust required to inert the mixture.

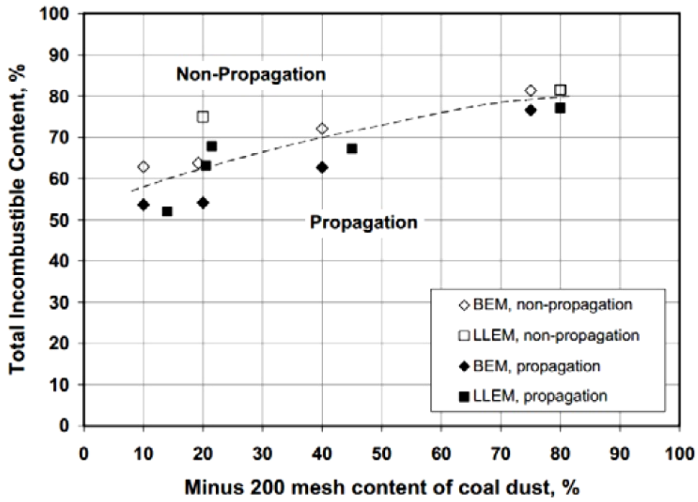


Figure 1 Effect of particle size of coal dust on the explosibility (Sapko et al. 2007)

The development of coal dust explosion on the dust layer was investigated by Sapko, using a specially developed computer program. Calculations of the proportion of dust in raised dust were made in a series of experiments on the transfer of the explosion by a layer of coal dust settled on a rocky substrate.

According to Nagy (1965), modern mines produces much finer dust, requiring an increased total incombustible contents to prevent a propagation of an explosion, leading to the increase in the total incombustible contents in return roadways from 65% to 80% vol.

Richmond et al. (1975) investigate incombustibles contents required to inert coals of various volatile contents, suggested that the 65% total incombustible contents was appropriate for 15% vol. coal, and should be lowered, based on ignitability studies with strong initiators.

Weiss et al. (1989), after series of explosion tests, conclude that total incombustible contents required to prevent propagation in the large rectangular entries at Lake Lynn (79% to 82%) where substantially higher than those required at tests in US Bureau of Mines Bruceton (65%).

The customary measure for prevention of coal dust explosions in underground lignite and brown coal mines in Bosnia and Herzegovina is wetting. In practice, it turned out that wetting is not an effective measure for prevention of ignition, since stronger ignition sources can providean amount of heat sufficient for evaporation of moisture and ignition of the dispersed system (Bašić et al. 1991). In order to prevent ignition, dust would have to be saturated with water to the amount that it prevents any turbulence and cloud formation.

For the purpose of prevention of coal dust explosions, most countries adopted regulations requiring inert dust (usually limestone rock dust) to be added to deposited coal dust in such an amount to make the mixture incapable of transmissing an explosion (Cain 2003).

According to the BAS standards, analogue to the Polish regulations, the prescribed content of the inert solid substance is 80% m/m for methaneous and 70% m/m for non methaneous seams.

The aim of the tests is to make a preliminary determination on whether the numbers taken from the Polish regulations with regards to the content of the solid inert substance at which dust loses its explosive properties are correct and applicable on the dust of brown coals mined in Bosnia and Herzegovina. The tests were carried out on the representative samples from three coal mines which mine in the main coal seam (Bajramović 2011).

The inert agent was selected on the basis of test results for limestone and dolomite rocks obtained from quarries situated near the coal mines.

In accordance with the provisions of PN-G-11020-1994, a regulation defining selection of an inert agent to be added to coal dust in order to inert it, limestone rock dust was selected as the most appropriate, since it meets all the requirements prescribed for an inert agent (Lebecki 2004; Cybulski 2005).

Explosibility of coal dust is defined by the following parameters:

- Maximum developed pressure (p_{max}),
- Maximum rate of pressure rise $(dp/dt)_{max}$,
- Explosion severity (deflagration index), $K_{st.max}$
- Explosive characteristics (E_k)

The first two parameters are tested in laboratory conditions, using the method of measuring pressure explosionin accordance with BAS EN 14034-1and using the method of measuring the maximum rate of pressure rise in accordance with BAS EN 14034-2.

-Explosion severity $K_{st.max}$ and explosive characteristics E_k were calculated from:

$$K_{st} = \left(dp/dt\right)_{max} V^{1/3} \quad \left(mbar/s\right) \tag{1}$$

Where V is the volume of the test vessel (m^3)

$$E_k = \sqrt{\left(\frac{\mathrm{dp}}{\mathrm{dt}}\right)_{\max} \cdot \frac{\mathrm{p_{max}}}{\Delta\tau}}, \quad (bar/s) \tag{2}$$

2 MATERIALS AND METHODS

2.1 Experimental procedure

The tests of explosive characteristics of dust were carried out in laboratory conditions. Testing apparatus is standardized according to BAS EN 14034-1 and includes a 20 dm^3spherical chamber for testing explosive dust, type KSEP 20 with accessories, manufacturer "Kühner" - Switzerland. Coal dust explosion was initiated by chemical igniters with the total energy of 10 kJ.

The tests of brown coal dust inertization were conducted for two particle sizes: fine dustd100 (100% of particle size up to 75 µm) and medium dust d25 (25% of particle size up to 75 µm).

Before adding the inert limestone rock dust, the explosive properties of the coal dust were tested in a dust-air mixture, in order to determine the dependency of such properties on dust concentration i.e. to determine the stoichiometric concentration of dust.

The tests were performed for five different concentrations of coal dust: 125 g/m^3, 250 g/m^3, 500 g/m^3, 750 g/m^{3}and 1000g/m^3.

Then, the limestone rock dust (particle size 20 µm) was added to the coal dust-air mixture in steps of 5% and the explosive properties of the mixture with the inert agent were tested.

2.2 Properties of the tested samples of the mixture of dust and limestone rock dust

Coal samples used for testing explosive properties were taken according to the Standard BAS 103:2002, from three coal mines, marked as A, B and C, all of them conducting mining operations in the main coal seam.

Table 1 shows the immediate analysis of coal dust as "zero measurement"for the total natural content of inert substance. The analysis of dust in the underground rooms of the brown coal mines indicates that the average content of fraction with particle size of up to 75µm in the deposited dust is 25% (Bajramović, 2011). Therefore, the tests were conducted for dusts d100 and d25.

Table 1 Immediate analysis of coal dust

Coal Mine	**Parameters of immediate analysis (% m/m)**							
	Hygroscopic moisture (Wh)		***Ash(A)***		***Total non-combustible (n)***		***Volatile matter (V^{daf})***	
	d100	d25	d100	d25	d100	d25	d100	d25
A	6,09	7,44	25,40	20,46	31,49	27,90	58,22	54,32
B	4,57	4,99	33,32	24,81	37,89	29,80	51,11	46,86
C	9,12	8,37	12,16	10,83	21,28	19,20	46,46	45,29

The chemical analysis of the limestone rock that was selected as an inert agent for the tests is presented in Table 2. The analysis was conducted using an XRF spectrometer.

Floating capability tests in laboratory and underground conditions indicated the good floatability of this dust (Bajramović, 2011).

Table 2 Chemical analysis of limestone rock

Test sample particle size	20 µm
	Mass content, % m/m
Annealing loss	43,15
SiO_2	<0,035
Al_2O_3	0,08
Fe_2O_3	0,06
CaO	52,79
MgO	3,72
SO_3	0,07
Na_2O	<0,1
K_20	0,02

3 RESULTS AND DISCUSSION

3.1 Results of the explosive characteristics test (mixture coal dust – air)

Based on the testing of explosive properties of brown coal dust on prepared referent samples from the three coal mines, we obtained the curves of explosion pressure and rate of pressure rise, depending on the concentration of dust with total natural content of inert substance, for d100 and d25. Figures 2 and 3 show the results for d100.The paper does not include the results for d25 since the values of stoichiometric concentrations are the same as for d100.

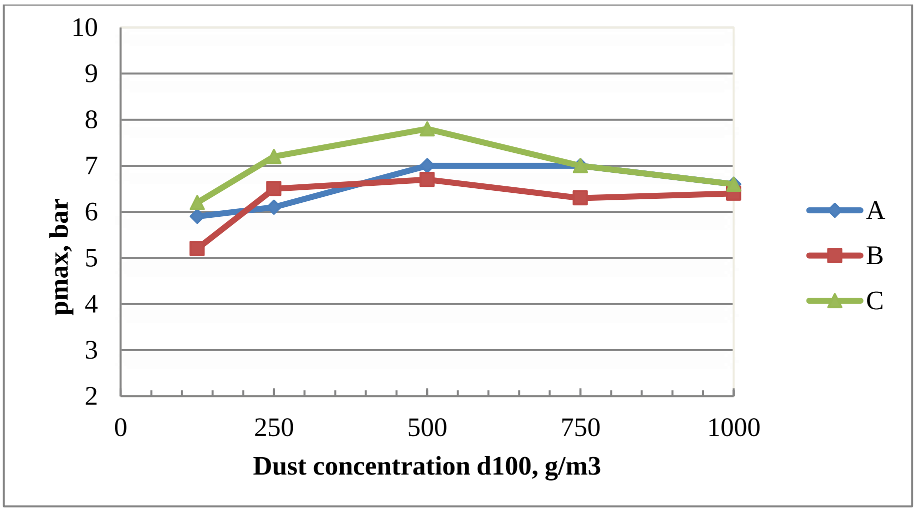


Figure 2 The dependence of the explosion pressure on dust concentration

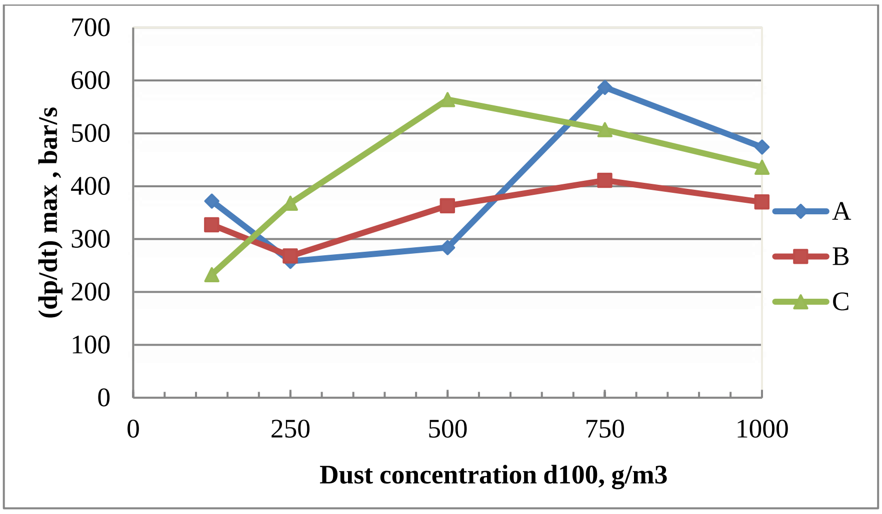


Figure 3 The dependence of the rate of pressure rise on dust concentration

The analysis of these diagrams indicates that the optimum explosion pressures p_{max} and the rate pressure rise $(dp/dt)_{max}$ are reached when dust concentration is 500 g/m^3 and 750 g/m^3, respectively.

The maximum rate of pressure rise is from 411 to 587 bar/s, which places the brown coal dust of the main coal seam into the category of highly explosive dusts..

In addition, it was found that the dispersion of the dust highly influencesan explosion in a spherical chamber. The explosibility of coal dust is observed through its most important indicator, explosive characteristics (E_k), which describes the interactions between the maximum rate of pressure rise, maximum developed pressure and duration of the explosion (Marković et al. 2015). The norm JUS B.Z1.065 on the coal dust explosion hazard defines that: "Dust of an open coal seam is considered explosively non-hazardous if the highest explosive characteristics (E_k), observed in laboratory testing, does not exceed 70 bar / s".

The value of the explosive characteristics (E_k) was from 244,7to 370,8 bar/s for fine coal dustandfrom127,5 to 159,2 bar/s for medium coal dust.

3.2 Results of the explosive characteristics test (with addition of limestone rock dust)

Figures 4 and 5 show the influence of added limestone rock dust on the explosibility parameters of fine coal dust (d100) for stoichiometric concentration. The diagrams for d25 are the same as the ones for d100, the only difference being fewer steps taken within the test (the values not resulting in an explosion are presented in Table 3). The test results indicate that, for different individual brown coal dusts, we need to add different percentages of limestone rock in order to prevent explosions, depending on the quality of individual coal seamsi.e. thetotal natural content of inert substance (moist and ash). Such differences are less notable for fine coal dust (8%) and more pronounced for medium dust (17%), indicating a significant influence of particle size dispersion conditions on the explosive characteristics.

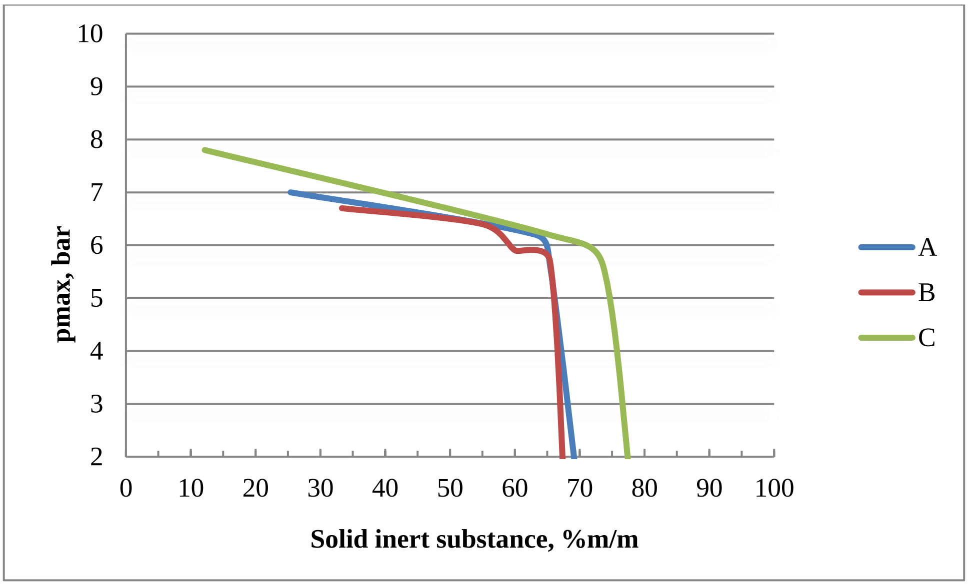


Figure 4 The dependence of the explosion pressure on the content of solid inert substance for d100

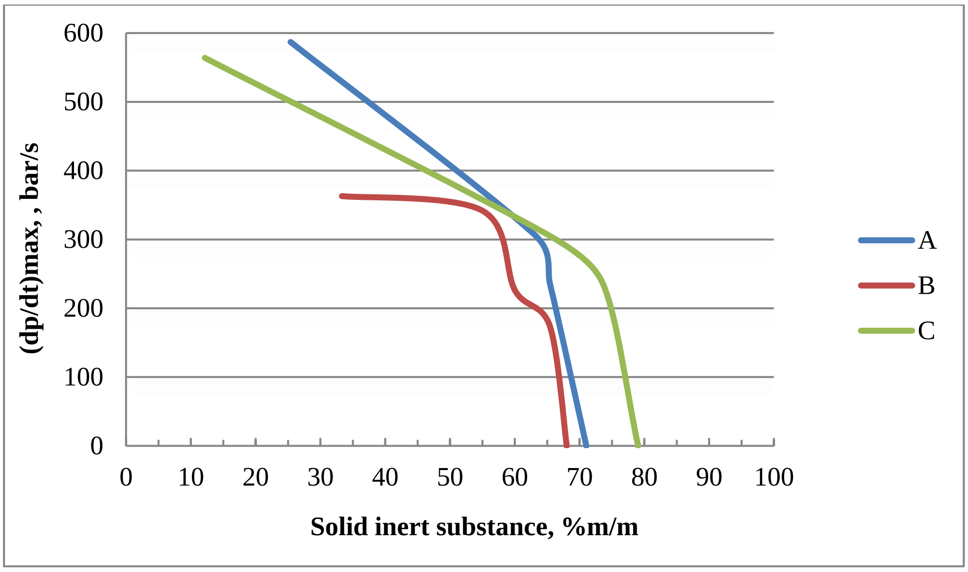


Figure 5 The dependence of the rate of pressure rise on the content of solid inert substance for d100

Table 3 shows the immediate analysis of brown coal dust with addition of limestone rock dust which did not result in an explosion.

Table 3 The immediate analyses of samples in an explosion

Coal Mine	*Parameters of immediate analysis* (% m/m)*							
	Hygroscopic moisture (Wh)		*Ash (A)*		*Total non-combustible (n)*		*Volatile matter (V^{daf})*	
	d100	d25	d100	d25	d100	d25	d100	d25
A	2,51	5,07	71,05	44,75	73,56	49,82	74,13	59,72
B	2,20	1,59	68,02	49,25	70,22	50,84	58,53	52,44
C	1,50	3,47	79,04	51,23	80,45	54,70	56,68	50,94

Figures 6 and 7 show the dependence of the explosive characteristics on the content of inert solid substance for fine and medium dusts.

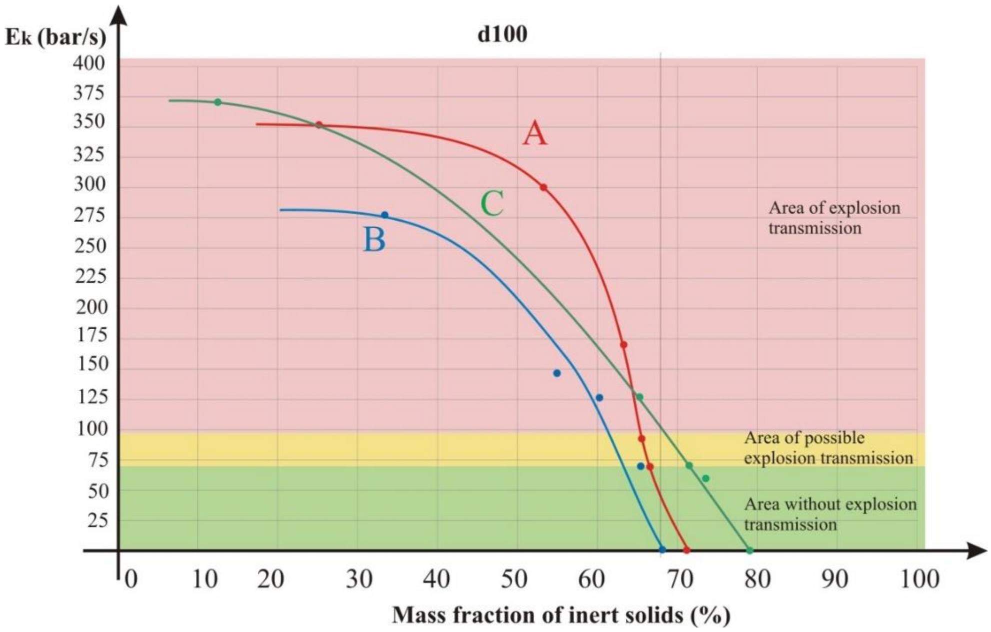


Figure 6 The dependence of the explosive characteristics on the content of solid inert substance for d100

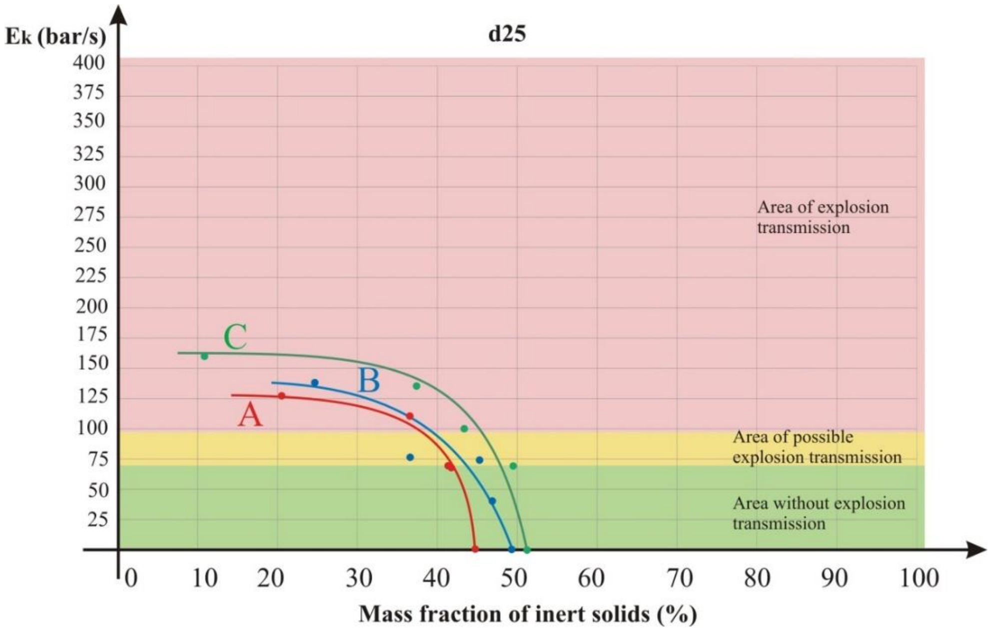


Figure 7 The dependence of the explosive characteristics on the content of solid inert substance for d25

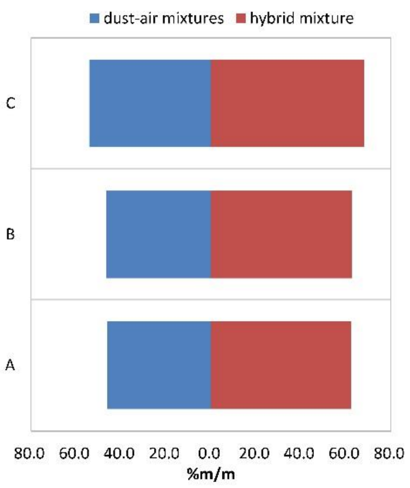
Since the coal is mined in methaneous pits and the explosive characteristics tests were conducted in dust-air mixtures, we need to take into consideration the presence of methane in the explosive mixture of dust and air i.e. observe the hybrid mixture, coal dust -1,5% CH_4-air (Bartknecht 1989). The results are corrected using the formula by T.N. Maso and R.V. Wheeler, taken over by Cybulski W. (1973). According to the formula, per each percentage of methane in the air, the total content of inert substance (n) in the dust-air mixtures hould be increased by (Δn) :

$$\Delta n = \frac{100 - n}{c_{\min}} \tag{3}$$

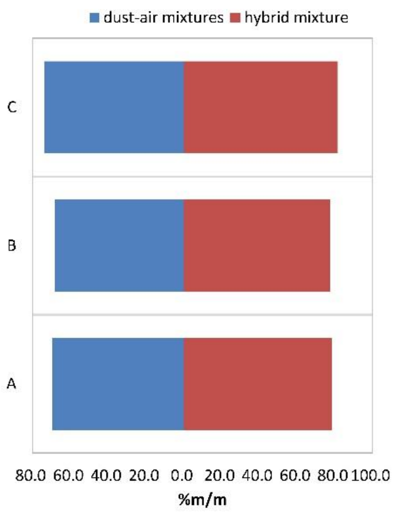
Where:

c_{min} - is the lower explosion limit of methane

Since it is the deposited coal dust with average content of d25 is what actually takes part in explosions, the relevant results are the ones gained by tests on medium coal dust, whose explosive characteristics is much lower in comparison to fine coal dust, Figure 8 (b). The percentage of inert solid substance in the hybrid mixture which makes the brown coal dust non-hazardous in terms of explosion in this case is from 57,23 to 64,46%m/m. In terms of total inert substance content (moisture and inert solid substance) this percentage is from 62,30 to 67,93%m/m.



a) d100



b) d25

Figure 8 Total content of inert substance which makes the dust non-hazardous in terms of explosion

4 CONCLUSIONS

The preliminary results of the research presented in this paper show how a brown coal dust explosion develops depending on the content of inert solid substance and what are the effects of the inert substance on the explosion.

The test results establish the limit below which an explosion cannot develop. The established dependency of coal dust explosive characteristics on the content of solid inert substance can be used for defining rock dusting control and protection measures against hazardous coal dust.

The tests on the brown coal dust, in the optimum concentration area (worst-case principle), notwithstanding their preliminary character, show deviations from the applicable standards and indicate the necessity of continued research and introduction of changes into the BAS standard, in terms of definition of the optimum quantity of solid inert substance for all kinds of coal in Bosnia and Herzegovina.

5 REFERENCES

BARTKNECHT W. (1989) *Dust Explosions.* New York: Springer Verlag.

BAŠIĆ A. et al. (1991) Eksplozivnost mokre ugljene prašine- dileme i pitanja. In: *XIV međunarodna konferencija Zaštite u rudarstvu, Donjeck, SSSR.* Amsterdam: A.R.Green.

BAJRAMOVIĆ K. (2011) *Sadržaj inertne čvrste materije i eksplozivne karakteristike nataložene ugljene prašine starijih miocenskih ležišta,* Thesis [PhD]. University of Tuzla Faculty of Mining, Geology and Civil Engineering.

CAIN. P (2003) *The use of stone dust to control coal dust explosions: A review of international practice*. [Online]. Available from: *http://www.ugcoal.ca.*

CYBULSKI W.G. (1973) *Wybuchy pyłu węglowego i ich zwalczanie*. Katowice: Wydawnictwo" Śląsk".

CYBULSKI W.G. (1975) *Coal Dust Explosions and Their Suppression*. Washington: Bureau of Mines, US Department of the Interior and the National Science Foundation.

CYBULSKI K. (2005) *Zagorżenie wybuchem pułu węoraz ocean skuteczności działań profilaktycznych w polskich kopalniash węgla kamiennego*. Katowice.

INSTITUT ZA STANDARDIZACIJU BOSNE I HERCEGOVINE (2011) *BAS EN 14034-1:2004+A1:2011: Determination of explosion characteristics of dust clouds. Part-1. Determination of the maximum explosion pressure p_{max} of the dust cloud*. Sarajevo: Institut za standardizaciju Bosne i Hercegovine.

INSTITUT ZA STANDARDIZACIJU BOSNE I HERCEGOVINE (2011) *BAS 14034-2:2011: Determination of explosion characteristics of dust clouds. Part-2. Determination of* *the maximum rate of explosion pressure rise dp/dt_{max} of the dust clouds.* Sarajevo: Institut za standardizaciju Bosne i Hercegovine.

INSTITUT ZA STANDARDIZACIJU BOSNE I HERCEGOVINE (2002) *BAS 103:2002: Metode uzimanja uzoraka uglja za određivanje eksplozivnosti prašine*. Sarajevo: Institut za standardizaciju Bosne i Hercegovine.

INSTITUT ZA STANDARDIZACIJU BOSNE I HERCEGOVINE (2011) *BAS ISO 5068-1: Brown coals and lignites –Determination of moisture content – Part 1: Indirect gravimetric method for total moisture*. Sarajevo: Institut za standardizaciju Bosne i Hercegovine.

INSTITUT ZA STANDARDIZACIJU BOSNE I HERCEGOVINE (2010) *BAS ISO 1171: Solid mineral fuels – Determination of ash.* Sarajevo: Institut za standardizaciju Bosne i Hercegovine.

INSTITUT ZA STANDARDIZACIJU BOSNE I HERCEGOVINE (2013) *BAS ISO 5071-1: Brown coals and lignites –Determination of volatile matter in the analysis sample – Part 1: Two-furnace method*. Sarajevo: Institut za standardizaciju Bosne i Hercegovine.

JUGOSLOVENSKI STANDARD (1990) *JUS B.Z1.065.:Metode određivanja eksplozivnosti ugljene prašine*. Beograd.

LEBECKI K.(2004) *Zagrożeniapyłowe w górnictwie,* Katowice.

MARKOVIĆ J. et al. (2006) Emisije ugljene prašine pri širokočelnom otkopavanju i ocjena opasnosti od eksplozije. In: *Monografija Zbornika radova RGGF-a Univerziteta u Tuzli XXXII.* Tuzla*:* University of Tuzla Faculty of Mining, Geology and Civil Engineering, pp. 112-114.

MARKOVIĆ J. et al. (2015) Testing of dust explosion characteristics of brown coal at reduced oxygen content. *TTEM*, 2, pp.150-155.

NAGY J. (1965) *Float Coal Hazard in Mines: A Progress Report*. U.S. Department of Interior, Bureau of Mines.

RICHMOND J. et al. (1975) *Effect of rock dust on the explosibility of coal dust*. U.S. Department of Interior, Bureau of Mines.

SAPKO M. et al. (1987) Explosibility of Float Coal Dust distributed over Coal-Rock Dust Substratum.In: *Proceedings of the 22nd International Conference of Safety in Mines Research Institutes.* Beijing, China: Coal Industry Publishing House, pp. 459–468.

SAPKO M. et al. (2007) Coal Dust Particle Size Survey of U.S. Mines. *Journal of Loss Prevention in the Process Industries,* 20, pp. 616-620.

WEISS E. et al. (1989) Recent results of dust explosion studies at the Lake Lynn experimental mine. In*: Proceedings of the 23rd international conference of safety in mines research institutes, U.S. Department of the Interior, Bureau of Mines.* Washington*:* pp. 843-856.