Experiments and Mechanisms of Gas Explosion Suppression with Foam Ceramics

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1 Introduction

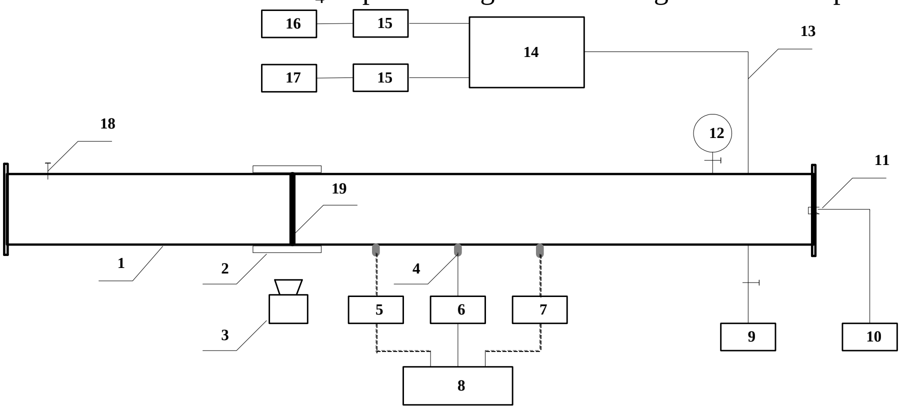
In recent years, coal mines in China get deeper with the continuous expansion of coal production. Then gas pressure in coal seam gets higher and gas emission become larger, thus can increase the potential risk causing gas disaster accident in coal mines. Gas and coal dust explosion accidents, especially continuous and multiple gas explosions are the main disasters that cause serious injuries and death. The traditional water and rock powder shed could not work after the first explosion and the effect is limited, which make rescuers into dangerous conditions.

Many scholars had done much work on propagation law of gas explosion flame, shock waves and the influence of the obstacles to gas explosion. Ellis et al researched flame front from forward bending shape to backward cuspidal point during propagation in closed duct (Ellis, 1997). Matalon et al found that flame front formed a serious vortexes which caused vortexes of the tail gas(Matalon and Metzener, 1997). Clanet et al had found Tulip style structure of flame of propagation in one opened end tunnel(Clanet and Geoffrey, 1996). Chen et al investigated the influence of flame propagation characteristics in different equivalence ratios of CH_4/air premixed gases(Chen, et al, 2008). Bi et al researched the relationship between methane explosion flame speed the presence of coal dust(Bi, et al, 2010). He et al founded the variation tendency of flame front structure, the propagation velocity and the pressure variation over time(He, et al, 2009). He et al established gas explosion flame fractal model and researched the affect of obstacle on the flame front(Yang, 2003; Yang and He, 2003; Yang, et al, 2004; He, et al, 2004). Takeno analysed the the influence law of length, width, and heat loss of porous medium on flame propagation (Takeno and Hase, 1983). Sathe et al found that flame occurred both in the first half and exit of the porous medium burner(Sathe, et al, 1990). Pan et al investigated that the bigger of hole’s equivalent diameter, the faster of flame propagation in porous medium(Pan, et al, 2008).

The development of ceramic foam technology provides a new approach on gas explosion suppression. Gvozdeva, Vasil'ev, Teodoreczyk found that in certain conditions, the porous material can suppress the increase of the pressure wave intensity obviously. The porous material attched to the wall of pipeline can effectively inhibit burst detonation wave(Gvozdeva, et al, 1986; Vasil, 1994; Teodorzyk and Lee, 1995). Nie et al found that the ceramic foam can inhibit the spread of flame and quench it(Nie, et al, 2008). Zhou et al studied the effect of the mesh structure on the flame quenching properties and its suppression on the absorbent of transversal wave(Zhou, et al, 2004). Nie et al found that the ceramic foam had a good three-dimensional connectivity network structure, which could quenche gas explosion flame, and reduce maximum overpressure of gas explosion (Nie, et al, 2008). In this paper, the rule of suppressing gas explosion with ceramic foam was studied and the suppression mechanism of ceramic foam material was analyzed by testing its microscopic pore structure.

2 Experiments of foam ceramic suppressing gas explosion

A steel square duct with a length of 18 meters was built in order to test capacity of foam ceramic to suppress gas explosion. The tested samples are made from Al_2O_3 and SiC with different thicknesses and porosities. The concentration of CH_4 in premixed gas is 9.5%. Figure 1 is the experimental system.



1-Gas explosion experiment duct; 2-Glass window; 3-High-speed camera system; 4-Sensor; 5-Temperature measuring system; 6-Pressure measuring system; 7-Velocity measuring system; 8-Dynamic data acquisition system; 9-Vacuum pump; 10-Flame igniter; 11-Spark plug; 12-Vacuum gauge; 13-High-pressure hose; 14-Gas distribution cabinet; 15-Flowmeter; 16-Methane; 17-Compressed air; 18-Air vent; 19-Foam ceramics

Fig 1. The Experimental System

In the explosion suppression experiment, the sample is installed into the pipeline. Different sizes and structures of ceramic foam is tested, each sample has a section size of 200mm×200mm. The thickness of foam ceramic are respectively 15mm, 30mm and 50mm and the pore density are 10ppi, 20ppi and 30ppi, respectively.

The duct has totally 34 measuring holes with 21 holes upside and 11 holes in flank. 11 measuring holes are chose to install pressure sensors and pressure sensors are activated 2 seconds before igniting. The foam ceramic is installed in the middle of sensor 4# and sensor 5# which is 10.338m away from the ignition source. They are shown in Figure 2 and the sensors parameters are in table 1.

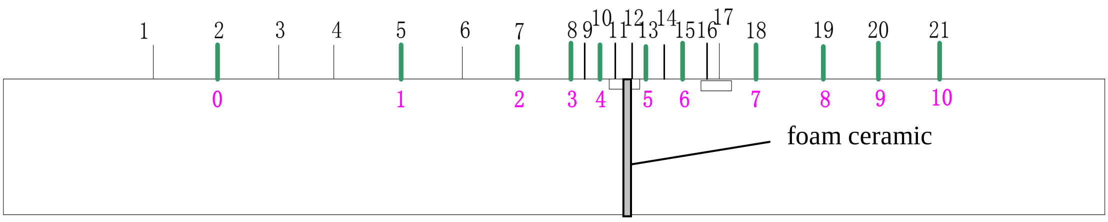


Fig 2. Location of sensors and foam ceramic

Table1: Parameters of each measuring point

Serial Number	0	1	2	3	4	5	6	7	8	9	10
Channel number	101	102	103	104	201	202	203	204	301	302	303
Distance to ignition end/m	3.52	6.52	8.44	9.20	9.73	10.58	11.12	12.38	13.35	14.31	15.38
Sensitivity/ (mV/psi)	62.08	27.59	29.69	28.08	28.74	27.00	28.41	27.97	27.97	27.65	27.70

3 Experimental results

It is noteworthy that the CH_4 in the CH_4-air mixture is of 9.5% and the air used in the experiment is of 21% oxygen and 79% nitrogen (by volume). It is also point out that all the data are gained at the initial condition of 100 KPa and 298 K. In order to study the effect of suppression with foam ceramic sample during blasting, values of sensor 4#, 5# and 6# were selected and analysed according to the sensors' position along the pipe. The results are as follows:

As foam macroporous ceramic with 15mm thickness is testing, the shock wave get through sensor 4# and the corresponding area occurs negative pressure but lasts a very short time. The time is longer when foam ceramic are of mesoporous and microporous structure. The overpressure value of sensor 4# is bigger than of sensor5# and 6# while value of sensor 10# is apparently smaller and more stable. It is gained from figure3-8 that shock wave is significantly suppressed by foam ceramics.

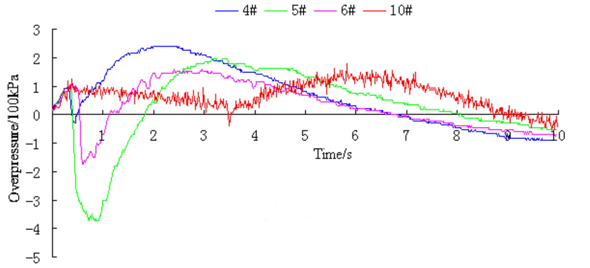


Fig 3. The attenuation of 15mm thickness macroporous Al_2O_3 foam ceramic on blast overpressure

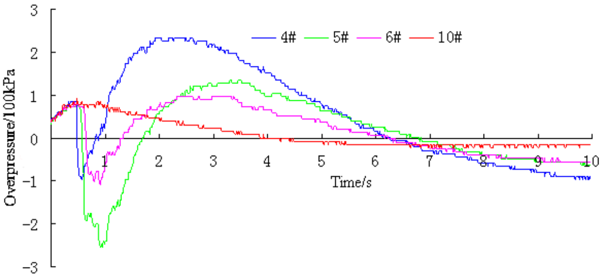


Fig 4. The attenuation of 15mm thickness mesoporous Al_2O_3 foam ceramic on blast overpressure

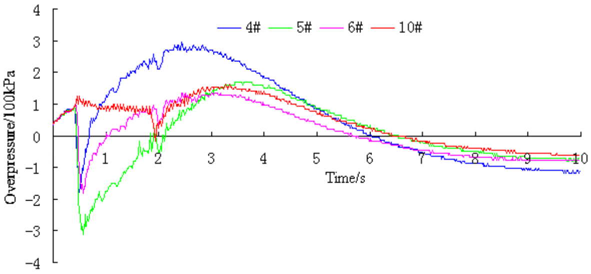


Fig 5. The attenuation of 15mm thickness microporous Al_2O_3 foam ceramic on blast overpressure

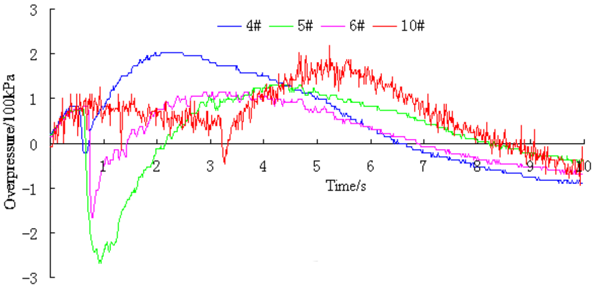


Fig 6. The attenuation of 15mm thickness macroporous SiC foam ceramic on blast overpressure

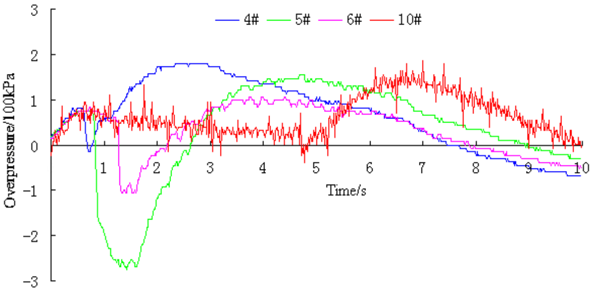


Fig 7. The attenuation of 15mm thickness mesoporous SiC foam ceramic on blast overpressure

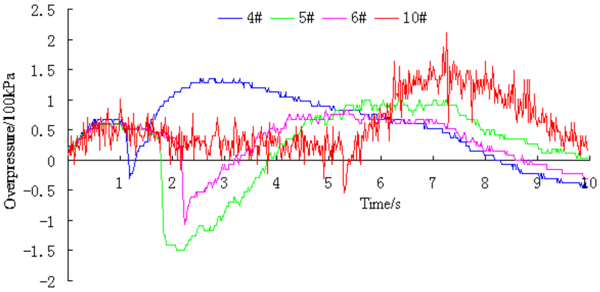


Fig 8. The attenuation of 15mm thickness microporous SiC foam ceramic on blast overpressure

4 Gas explosion suppression mechanism of foam ceramic

The thermal conductivity is an important thermodynamic parameter of foam ceramic for different structural foam ceramic samples have different conductivities, which lead to different suppress effects. As most of the samples were broke, only Mesoporous and microporous Al_2O_3 foam ceramic samples got tested, the size of them are 200mm×200mm×15mm. Results are shown in Figure 6 and 7. It can be seen that conductivity of mesoporous sample is bigger than that of microporous at the same temperature.

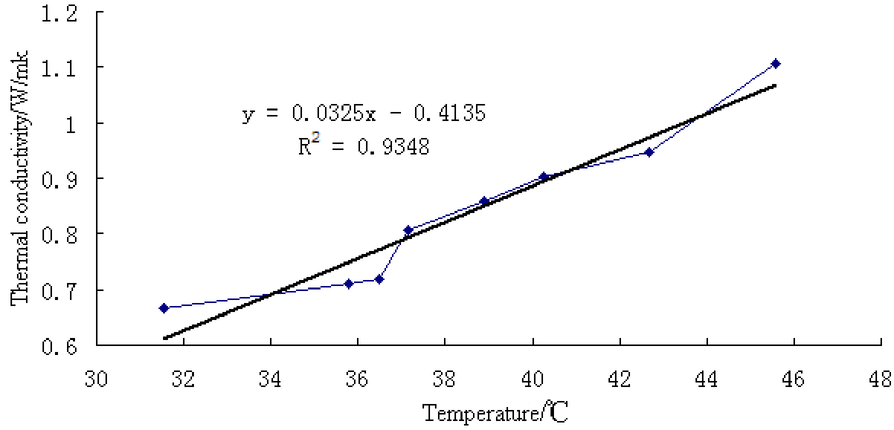


Fig 9. Thermal conductivity variation of microporous Al_2O_3 foam ceramic with temperature

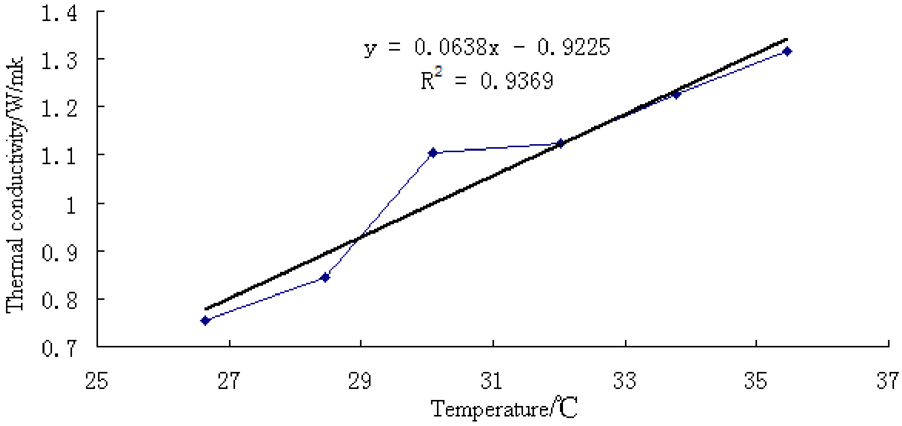


Fig 10. Thermal conductivity variation of mesoporous Al_2O_3 foam ceramic with temperature

Microscopic structure of Al_2O_3 and SiC foam ceramic are obtained by using scanning electron microscope. Figure 8 is the image of 500 times magnified of original foam ceramic structure. Result shows that foam ceramics is formed by foam struts and foam pores. Foam strut is formed by triangle pores located in tendons and pore walls which are similar to three-dimensional interconnected network. The pores of the foam ceramic are relatively evenly distributed and pore edges are relatively regular which make a good interconnectivity.

In order to observe the microstructure of foam ceramics, the three-dimensional digital microscope (VHX-600) is used to conduct microscopic analysis and test Al_2O_3 foam ceramic structures. The three-dimensional images of foam ceramics are shown in figure 12 that before and after explosion experiments.

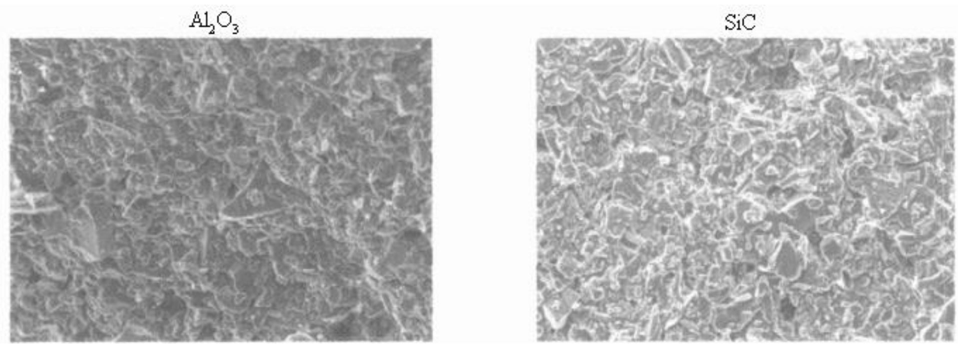


Figure 11. SEM of Al_2O_3 and SiC foam ceramics

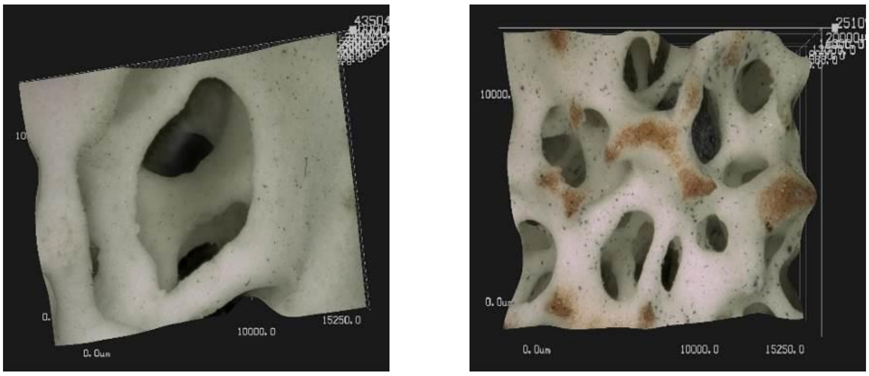


Fig 12. The image of three-dimensional Al_2O_3 foam ceramic before and after the experiment

When the flame arrives at the surface of foam ceramic and tries to pass it through, it would be divided into large numbers of flame streams immediately because of the pores of foam ceramic. As the flame temperature is obviously higher than the skeleton of foam ceramic, the heat of flame would be transferred to the skeleton and the flame temperature would drop sharply. When the flame temperature declines below the quenching temperature, the flame would extinguish. In a word, the thermal conductivity of foamed ceramics plays a critical role in quenching flame.

The influence of thermal conductivity of foamed ceramics on gas explosion suppression is mainly achieved by wall effect. When the flame is passing through, the temperature of foamed ceramics with high thermal conductivity would increase more quickly which enhances the probability of collision between free radicals and walls. The free radicals to collide with porous walls are more likely to be eliminated. Therefore, the chemical chain reactions are prevented and gas explosion is suppressed.

5 Conclusion

(1) Foam ceramics that made from two materials with different thickness and porosity are studied experimentally. The results show that the foam ceramic has a significant suppression effect on gas explosion overpressure.

(2) Gas explosion suppression mechanism is gained by analyzing the foam's microscopic pore structure and its thermal conductivity. It is wall effect that prevent chemical chain reactions, the heat of flame would be transferred to the skeleton and free radicals are reduced. Flame temperature drops sharply until it bellows the quenching temperature, then the flame would extinguish in the end.

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