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THE RESEARCH ON EXPLOSION SUPPRESSION EFFECT OF ALUMINUM ALLOY EXPLOSION-PROOF MATERIALS CLEANED BY ULTRASONIC

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Research article

Abstract: Premixed gas explosion pipe system was established to study the change rule of explosion pressure and pressure rise rate of 10% methane/ air premixed gas under four condition that no material was filled, used material was filled, new materials was filled and cleaned materials was filled in explosive pipe. The results show that compared with the used material and cleaned material, the average maximum explosion pressure was reduced by 21.62% and the average pressure rise rate decreased by 84.80%. The results show that the suppression performance of used aluminum alloy explosion-proof materials improved greatly after the used materials is cleaned.

Keywords: Aluminum alloy explosion-proof materials, maximum explosion pressure, pressure rise rate, ultrasonic, free radical.

Introduction

At present, the main barrier explosion-proof materials can be divided into three categories, namely metal, non-metal and composite. Metal barrier explosion-proof materials include mesh aluminum alloy, mesh titanium alloy, mesh copper alloy, mesh nickel alloy and foam metal material. Aluminum alloy is the most widely used metal barrier explosion-proof material; Non-metallic barrier explosion-proof materials are polyester, polyether, foam ceramics, etc. Among them, spherical non-metallic barrier explosion-proof materials are a new type of barrier explosion-proof materials, and mesh polyurethane foam is the most common non-metallic porous explosion-proof material, while foam Ceramic is the best insulation material. Composite barrier explosion protection technology is nanotechnology and coating technology.

Early research on the mechanism of anti-explosion of barrier explosion-proof materials focused on the field quenching in micro-scale space. (Holm, 1933; Birk, 2008) At present, the research on the explosion-proof mechanism of porous materials is relatively mature, but there is no unified conclusion. The viewpoint focuses on the wall effect and cold wall effect of porous materials. The wall effect is that the flame collides multiple times on the surface of the explosion-proof material to cause the destruction of free radicals in the reaction, which leads to the termination of the combustion explosion reaction and prevents the explosion from continuing to spread. The cold wall effect is that after the flame enters the barrier explosion-proof material, since the barrier explosion-proof material has a large specific surface area, the energy of the reaction continues to be lost, and the temperature of the reaction system is lowered, thereby preventing further diffusion of the combustion explosion. (Chen, 2011; Hammel et al., 2014; Nan et al., 2001)

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The related experimental research on the mechanism of barrier explosion prevention mainly focuses on the flame propagation under the condition of explosion-proof and the overpressure distribution of the explosion shock wave, and explores the influence of the parameters such as the aperture, material, packing density and blanking rate of the explosion-proof material on the explosion process. The metal barrier explosion-proof material is mainly a porous material which is made of aluminum alloy as a base material and which is cut and stretched to form a honeycomb network structure. The metal barrier explosion-proof material not only has the advantages of explosion-proof, but also has the advantages of low volume replacement rate and low oil retention rate. The pressure of methane/air explosion decreases 50% when Al_2O_3-SiC foam ceramic is filled in the pipeline. (Nie et al., 2011) The quenching effect of porous nonmetallic materials fails under certain conditions induced by acceleration of flame by obstacles. (Wen et al., 2013) The difference of explosion suppression performance between metal and non-metal explosion-proof material, the effect of material on oil properties, compatibility of polyethylene blocking explosion-proof material with methanol, gasoline and liquid dangerous chemicals are researched and compatibility judgment method of non-metallic barrier explosion-proof material and dangerous chemicals is established. (Lu et al., 2014; Bo et al., 2017) Effect of porous material properties, filling density and geometric size on explosion-proof barrier performance are studied. (Xing et al., 2015) Special three-dimensional mesh structure of foam ceramics is conducive to the destruction of free radicals in gas explosion. (Ma et al., 2013)

When CO_2 was added in the methane/air mixed gas, the binding reaction of methyl radicals initiated by methane explosion chain are promoted by CO_2, the concentration of methyl radicals is reduced and the methane explosion chain is interrupted, which achieves the purpose of explosion suppression. (Luo et al., 2015) The consumption rate of CH_4 is faster than that of O_2 in the process of explosion. The molar fractions of free radicals of ·H, ·O and ·OH rise sharply during explosion, which instantaneously forms an activation center with very high concentration and promotes gas explosion. (Jia et al., 2017) The addition of water vapor promotes the formation of a large number of ·OH free radicals in gas explosion reaction, and reduces the production of ·H free radicals. Simultaneously, the total heat released by gas explosion reduces, which inhibits the propagation of gas explosion. (Li et al., 2017) The effect of various gases with different properties on gas combustion process is studied by establishing mathematical model of gas explosion in confined space. (Liang et al., 2017)

In 2005, aluminum alloy mesh barrier explosion-proof material was applied in the storage of hazardous chemicals including oil stations in China. After several years of use, the surface will foul and deposit oil, and the explosion-proof performance will be significantly reduced. The cost of replacing the new barrier-proof material is too high. After cleaning the cleaned barrier explosion-proof material by ultrasonic wave, the cleaned aluminum alloy barrier explosion-proof material can be reused.

Materials and methods

Experimental system

The experimental system is a premixed gas explosion pipeline system. The premixed gas explosion pipeline system is mainly composed of a visual premixed gas explosion pipeline, a gas distribution system, a transient explosion pressure system, and a high energy ignition system. The visual premixed gas closed explosion pipeline is mainly composed of a quartz glass pipeline, pressure sensors and a circulation pump. The glass pipeline has a length of 1000mm, an outer diameter of 104mm, an inner diameter of 100mm, and a wall thickness of 2mm. The volume of the gas explosion pipeline is 8L, and the maximum pressure is 2MPa. One side of the pipeline is sealed with a bolted flange, which is fitted with an igniter interface, a vacuum gauge and an outlet pipe with a valve. The other side of the pipeline is sealed with a flange. The flange is controlled by a pneumatic valve. The flange can also be bolted. For the safety of the experiment, a rupture disk is installed on the flange. The critical pressure of the rupture disk is 0.8MPa. The structural diagram of the premixed gas explosion pipeline system is shown in Fig. 1.

Test method

The weight of the explosion-proof material filled with the explosion-proof material is 187g, so as to ensure that the explosion-proof material in the explosion pipeline has a packing density of 25kg/m^3 and a filling rate of 95%. Leave 5% near the ignition head and fill the rest of the space. A certain length of aluminum alloy explosion-proof material is cut and rolled into a cylindrical shape with a diameter slightly larger than the inner diameter of the explosion pipe, and fully filled into the explosion pipe. After the airtightness check, the explosion pipeline is pumped to a vacuum state, and 0.8L

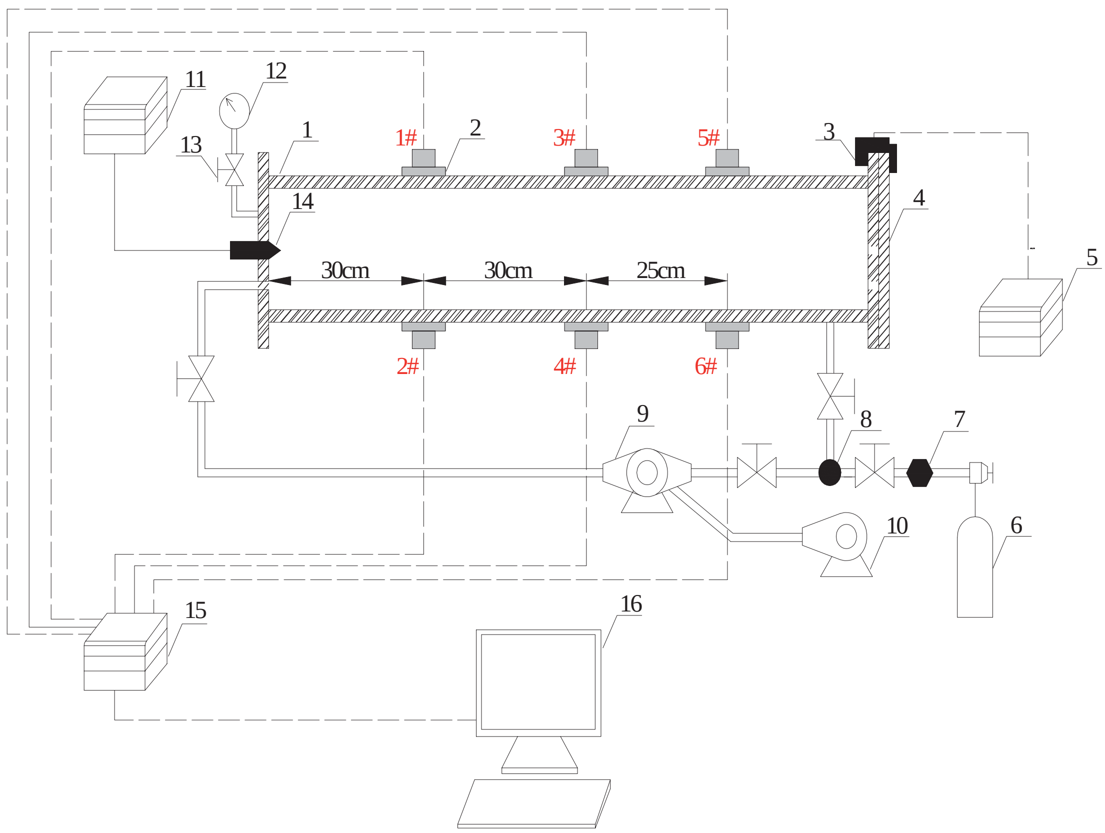

Fig. 1 Structure diagram of the premixed gas explosion pipeline system;
1-non-metallic transparent material premixed gas explosion pipeline 2-transient pressure sensor 3-pneumatic valve 4-removable pneumatic valve control sealing flange 5-pneumatic valve controller 6-gas cylinder 7-rotor flowmeter 8-three Through valve 9-circulation pump 10-air compressor 11-high energy ignition table 12-vacuum table 13-check valve 14-ignition head 15-transient pressure acquisition host 16-data acquisition computer

of methane is injected into the pipeline through the flowmeter, and the air inlet of the explosion pipeline is connected to the atmosphere until the pipeline vacuum gauge reading back to 0MPa, and the pipeline intake valve is closed. The circulation pump was started, and the premixed gas was circulated in the explosion pipeline for 5minutes to complete uniform mixing of methane-air.

Results

Results of tests

(1) Test of methane-air premixed gas explosion unfilled with barrier explosion-proof material

The pressure/time curve of the explosion of 10% methane-air premixed gas unfilled with barrier explosion-proof material is shown in Fig. 2.

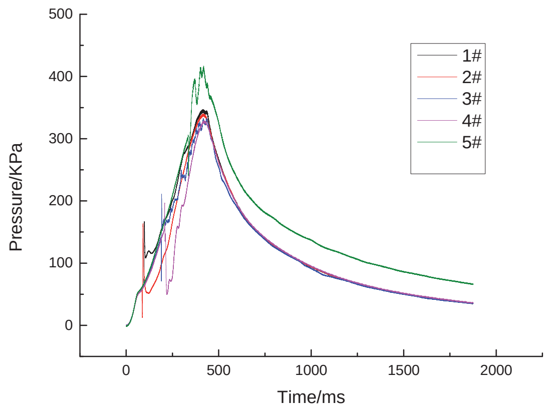

Fig. 2 Explosion pressure/time curve of 10% methane-air gas unfilled with barrier explosion-proof material

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The pressure peak and pressure rise rate obtained by processing the pressure data are shown in Tab. 1.

Tab. 1 Explosion pressure of 10% methane/air gas unfilled with barrier explosion-proof material

Sensor number	Peak pressure/ KPa	Rate of pressure rise/KPa/s
1#	346.875	834.448
2#	339.971	818.025
3#	332.737	761.412
4#	328.463	774.539
5#	416.579	997.837

It can be seen from Tab. 1 that the maximum pressure in the explosion pipeline is 416.579KPa collected by the 5# sensor, and the maximum pressure collected by other sensors is about 330KPa, and the average maximum pressure is 352.925KPa. The 5# sensor pressure rise rate is the largest, and the pressure rise rate of the 1# and 2# sensors close to the ignition head is almost the same. When the pressure is transmitted to the end of the pipeline, the pressure rise rate fluctuates up and down, but the overall trend is decreasing.

(2) Test of methane-air premixed gas explosion filled with cleaned barrier explosion-proof material

The time/pressure curve of the explosion of 10% methane-air premixed gas with filled cleaned barrier explosion-proof material is shown in Fig. 3.

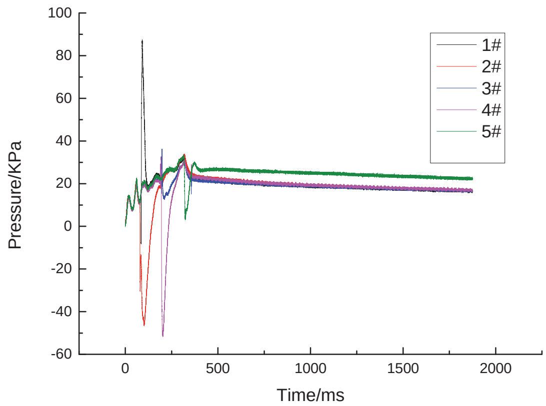

Fig. 3 Explosion pressure/time curve of 10% methane-air gas filled with used barrier explosion-proof material

The pressure peak and pressure rise rate obtained by processing the pressure data are shown in Tab. 2.

Tab. 2 Explosion pressure of 10% of methane/air gas filled with cleaned barrier explosion-proof material

Sensor number	Peak pressure/ KPa	Rate of pressure rise/KPa/s
1#	87.459	853.716
2#	33.866	281.064
3#	36.167	174.039
4#	32.550	148.722
5#	33.537	106.192

It can be seen from Tab. 2 that the maximum pressure of all sensors collected in the explosion pipeline is 87.459KPa, the minimum value is 32.550KPa, and the average pressure peak is 44.716KPa. The maximum pressure rise rate is 853.716KPa/s, and the minimum pressure rise rate is 106.192KPa/s. With the propagation of flame, the pressure rise rate tends to decrease gradually.

(3) Test of methane-air premixed gas explosion filled with new barrier explosion-proof material

The time/pressure curve of the explosion of 10% methane-air premixed gas with filled new barrier explosion-proof material is shown in Fig. 4.

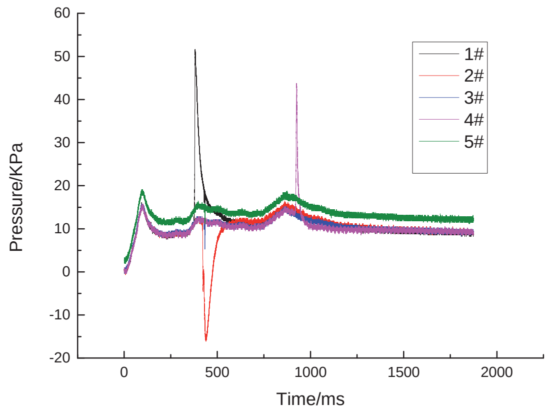

Fig. 4 Explosion pressure/time curve of 10% methane-air gas filled with new barrier explosion-proof material

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The pressure peak and pressure rise rate obtained by processing the pressure data are shown in Tab. 3.

Tab. 3 Explosion pressure of 10% methane/air gas filled with new barrier explosion-proof material

Sensor number	Peak pressure/ KPa	Rate of pressure rise/KPa/s
1#	51.620	132.811
2#	16.440	18.874
3#	15.782	17.269
4#	43.729	46.051
5#	19.070	17.656

It can be seen from Tab. 3 that the maximum pressure in the explosion pipeline is 51.62KPa, the minimum value is 15.782KPa, and the average pressure peak is 29.328KPa. The maximum pressure rise rate is 132.811KPa/s and the minimum pressure rise rate is 18.251KPa/s.

(4) Test of methane-air premixed gas explosion filled with barrier explosion-proof material cleaned by ultrasonic

The time/pressure curve of the explosion of 10% methane-air premixed gas with filled barrier explosion-proof material cleaned by ultrasonic is shown in Fig. 5.

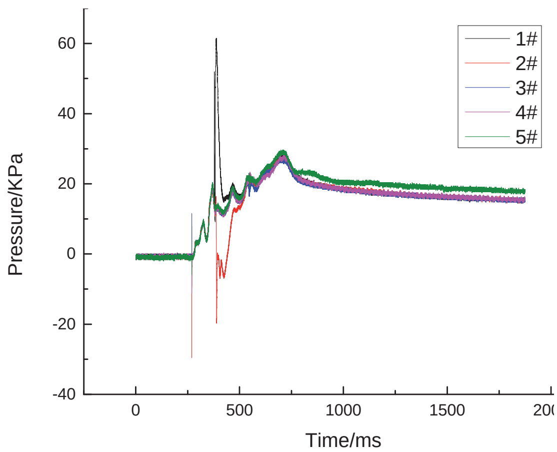

Fig. 5 Explosion pressure/time curve of 10% methane-air gas filled with barrier explosion-proof material cleaned by ultrasonic

The pressure peak and pressure rise rate obtained by processing the pressure data are shown in Tab. 4.

Tab. 4 Explosion pressure of 10% methane-air gas filled with barrier explosion-proof material cleaned by ultrasonic

Sensor number	Peak pressure/ KPa	Rate of pressure rise/KPa/s
1#	61.484	148.535
2#	28.605	22.208
3#	27.285	20.919
4#	28.276	21.669
5#	29.591	24.397

It can be seen from Tab. 4 that the maximum pressure in the explosion pipeline is 61.484KPa, the minimum value is 27.285KPa, and the average pressure peak is 35.048KPa. The maximum pressure rise rate is 148.535KPa/s and the minimum pressure rise rate is 20.919KPa/s.

Analysis of test results

Through the analysis of the maximum pressure data of 10% concentration methane-air premixed gas explosion under the four conditions: unfilled barrier explosion-proof material, filled cleaned barrier explosion-proof material, filled with new barrier explosion-proof material, and filled barrier explosion-proof material cleaned by ultrasonic. Compared with the cleaned barrier-proof explosion-proof materials, the average explosion pressure of the new barrier-proof explosion-proof materials is reduced by 34.41%, and the average pressure rise rate is reduced by 85.12%, indicating that the performance of aluminum alloy barrier explosion-proof material reduced seriously after it was soaked by oil for many years. Compared with the cleaned barrier-proof explosion-proof materials, the average explosion pressure of the barrier-proof explosion-proof materials cleaned by ultrasonic is reduced by 21.62%, and the average pressure rise rate is reduced by 84.80%, which indicates that the explosion-proof performance of used barrier explosion-proof material reduces dramatically because of corrosion. Compared with the barrier-proof explosion-proof materials cleaned by ultrasonic, the average explosion pressure of the new barrier-proof explosion-proof materials is reduced by 16.32%, and the average pressure rise rate is reduced by 2.13%. It shows that the explosion performance of the cleaned aluminum alloy barrier explosion-proof material cleaned by ultrasonic is similar to the explosion-proof performance of the new barrier explosion-proof material. It can be seen from the above analysis that the inhibitory effect of the barrier explosion-proof material on the pressure rise rate is significantly greater than the suppression effect on the maximum pressure. In the four cases, pressure and pressure rise rate of 10% methane/air premixed gas explosion measured by different sensors are shown in Fig. 6 and Fig. 7 separately.

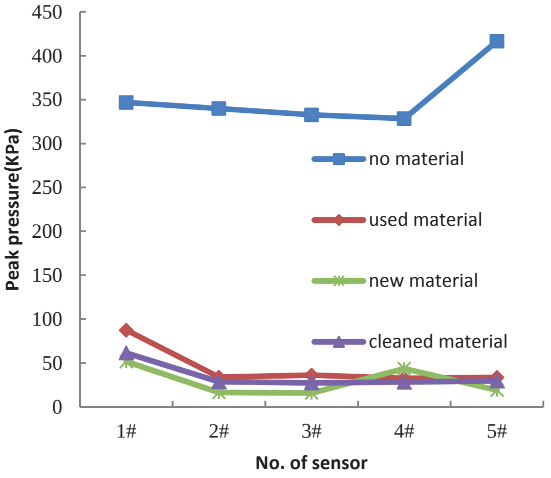

Fig. 6 Peak pressure of each sensor with 10% concentration of methane/air premixed gas in four cases

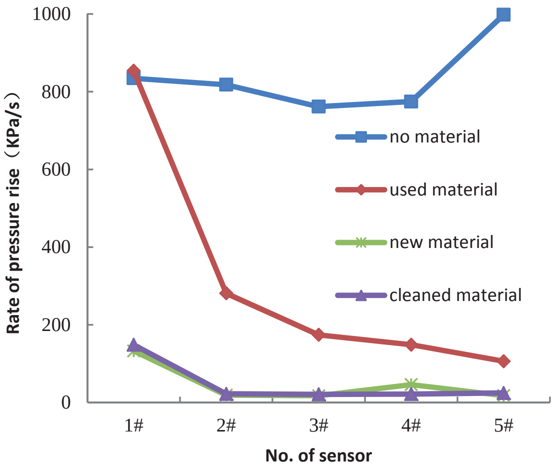

Fig. 7 Pressure rise rate of each sensor with 10% concentration of methane/air premixed gas in four cases

It can be seen from Fig. 6 that when no barrier explosion-proof material is added in the pipeline, the peak pressure of premixed gas explosion is much higher than that of other three cases, which indicates that barrier explosion-proof material plays an important role in suppressing gas explosion pressure. Compared with filling new materials and cleaned materials, the peak pressure of premixed gases explosion filled with cleaned barrier explosion-proof materials is about 20KPa higher. It shows that the explosion suppression performance decreases with the prolongation of the time of barrier explosion-proof materials. The peak pressure of the pre-mixed gas explosion is basically the same when the new material and cleaned material is filled, which indicates that the anti-explosion performance of the material after cleaning basically reaches the anti-explosion performance of the new material.

It can be seen from Fig. 7 that in four cases, the pressure rise rate at the 1# sensor near the ignition head is the maximum value, wherein the maximum pressure rises in the case of not filling the barrier explosion-proof material and filling the cleaned barrier explosion-proof material. The rate is above 800KPa/s. In the case of filling the new barrier explosion-proof material and the explosion-proof material cleaned by ultrasonic, the explosion pressure rise rate curve is basically consistent, the maximum pressure rise rate is very close, both are less than 200KPa/s, and the pressure rise rate measured by other sensors is less than 30KPa/s. The pressure rise rate at 1# sensor is much higher than the pressure rise rate at other sensors because the 1# sensor is close to the ignition head. In order to ensure that the premixed gas can be ignited smoothly, leave 5cm at the ignition head end, and the explosion of the empty space is sufficient. The explosion caused the pressure collected at the 1# sensor to be larger.

Discussion

Wall effect is one of the mechanisms of anti-explosion of barrier explosion-proof materials. The wall effect is that the flame collides multiple times on the surface of the explosion-proof material to cause the destruction of free radicals in the reaction, which leads to the termination of the combustion explosion reaction and prevents the explosion from continuing to spread. The surface of the explosion-proof material is polluted by oil and oil sludge. And scale is formed on the surface which can affect the wall effect significantly. ·O, ·H, ·OH, ·HO, ·HCO are key free radicals in gas explosion chain reaction. After the aluminum alloy explosion-proof materials is cleaned by ultrasonic, the scale on surface disappears. The free radical consumption rate increases and the growth rate of free radicals decreases which terminate chain reaction.

Conclusion

(1) After being used for many years, the aluminum alloy barrier explosion-proof material is oxidized by the oil, and the explosion-proof performance is seriously degraded.

(2) The explosion performance of the cleaned aluminum alloy barrier explosion-proof material after ultrasonic cleaning is greatly improved, and the explosion-proof performance is similar to the new barrier explosion-proof material.

(3) The inhibitory effect of the barrier-proof material on the rate of pressure rise is significantly greater than the suppression effect on the maximum pressure.

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