Research on explosion suppression characteristics of aluminum silicate wool in 90° bend

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Abstract

Experiments were conducted in 90° bend with C₃H₈/Air premixed gas to study the explosion suppression characteristics of aluminum silicate wool in different locations and lengths. The macrostructure of aluminum silicate wool was observed thanks to the scanning electron microscope (SEM for short) before and after the experiment. The suppression mechanism of aluminum silicate wool was analyzed according to both the experimental data and SEM. The results indicate that, explosion overpressures of testing points in the intrados of the bend are lower than those in the extrados positions, which decline firstly and then rise. The overpressure in the bend shows a trend of firstly decreasing and then increasing again with the increase of the distance between aluminum silicate wool and ignition source. The aluminum silicate wool is a kind of three-dimensional porous and skeleton structure with high elastic property and specific area seen from SEM. Moreover, the collapse of the space in the skeleton structure and the fracture of the fibers could absorb energy from explosion effectively and hence attenuate the explosion overpressure.

Keywords: premixed gas explosion; aluminum silicate wool; porous material; explosion suppression; 90° bend

1. Main text

Explosion often takes place during transporting, storing, processing and using of combustible gas, causing great losses to human safety and property. Reducing explosion hazard has been the focus of explosion prevention and protection. In numerous approaches, the porous materials have been paid particularly attention in recently years, such as porous wire-mesh, ceramic foam and so on. The suppression characteristics of the porous materials have been studied by researchers.

Ciccarelli [1–2] studied how the porosity of ceramic foam material affects the explosion. It is found that the flame speed decreased obviously when ceramic foam was placed in the pipe. Lee [3] studied the effect of both the foam material and the metal wires on detonation wave. It is concluded that the transverse wave was absorbed effectively by damping section resulting to the detonation attenuating to the deflagration wave. Vanwingerden [4] found in experiments that the glass wool with high elasticity and compressibility had a suppression effect on explosion overpressure peaks in confined space. Guo [5] studied the attenuation of detonation waves propagating through an absorbing material. The high-speed camera was used to record the structure of flame and detonation wave front during the explosion. Nie [6] conducted experiments to study the suppression effect of ceramic foam on explosion waves. The results demonstrate that ceramic foam could attenuate the explosion overpressure and inhibit the flame propagation by decreasing the flame temperature resulting from the so-called ‘cold wall effect’.

Porous structure could attenuate the explosion overpressure by absorbing the transverse wave. Also, it could decrease the
flame speed owe to the decreasing of the quenching temperature. The elastic and compressible porous material could absorb the energy produced by explosion via the deformation of its macrostructure. Aluminum silicate wool is a typical material with porous, high elasticity and compressibility properties. However, its suppression characteristic on explosion overpressure has not been conducted.

In this paper, the effect of aluminum silicate wool on premixed $C_3H_8$/Air mixture in the 90° bend was studied by experiments. By varying locations and lengths of aluminum silicate wool, the influence of location and length on suppression characteristic was discussed. Finally, the macrostructures of aluminum silicate wool before and after the experiments were observed by SEM.

2. Experiments

The explosion suppression experiments were performed in the pipeline with a $\Phi$ 89 mm × 4.5 mm cross section. The experimental system illustrated in Fig.1 consists of explosion pipeline, gas mixing system, gas distribution system, ignition system, flame and pressure measurement system and data acquisition system.

The explosion pipeline consists of straight pipes and a 90° bend connected by flange-bolt-gasket system. Both the pipes and the bend have a $\Phi$89 mm × 4.5 mm cross section. The curvature radius of the bend is 115 mm. The distance between ignition source and bend is 2100 mm and the value between the outlet end of pipeline and the bend is 900 mm. The pipeline is fixed on a support located 1 m above the ground.

$C_3H_8$/Air (5.5%, $v/v$) mixtures in stoichiometric concentration were prepared by the partial pressure method in an evacuated mixing tank. The gaseous mixture was downloaded into the evacuated pipeline and ignited by a spark plug.

The pressure sensor was MD-HF piezoelectric sensor with maximum range of 2 MPa. The flame sensor consisted of a photoconductive diode and a detector, which is a hollow steel tube with $\Phi$7 mm × 1.5 mm cross section, designed to protect the diode and to gather the flame light exactly passing through the diode.

Seven locations are selected to obtain explosion overpressures, five of which are in the extrados of the bend, distributing in the degree of 0, 22.5°, 45°, 67.5° and 90°; one of which is in the intrados of the bend. The last location is positioned at the outlet end.

Both the distance $L_x$ between ignition source and aluminum silicate wool and the length $L$ of aluminum silicate wool are selected as the alterable variables. Distances of 300, 600, 900, 1 200 and 1 500 mm are chosen. Lengths of 300, 600, 900 and 1 200 mm are selected. The internal diameter and thickness of aluminum silicate wool are 60 mm and 10 mm respectively.

The aluminum silicate wool was put in the selected position before experiment. Then the pipeline was closed by bolts-gaskets-flanges. After being evacuated by vacuum pump, the pipeline was filled with $C_3H_8$/Air premixed gas. The spark plug was activated to ignite the combustible gas. When pressure wave propagates through the testing points, the pressure signals were recorded by data acquisition system.
3. Results and analysis

3.1. Explosion overpressure in the bend without aluminum silicate wool

Fig. 2 shows the peak pressures at different testing points in the extrados of 90° bend when the premixed C₃H₈/Air explosion propagates in the pipeline without aluminum silicate wool.

![Fig. 2. Peak pressures at different points in the extrados of 90° bend.](image)

It is shown that when deflagration propagates through bend, the explosion overpressures differ from each other at different points in the extrados of 90° bend. During the degree of 22.5° to 45°, the explosion overpressure decreases from 85 kPa to 40 kPa. Whereas, when the degree varies from 45° to 67.5°, the explosion overpressure increases from 40 kPa to 72 kPa. The position in degree of 45° gets the minimum explosion overpressure.

This phenomenon differs from the conclusion of detonation conditions under which the position of 45° obtains the maximum value. The possible reasons for this phenomenon are analyzed as follows. First, curvature radius and diameter of bend have a certain impact on overpressure. Larger curvature radius and diameter may result in the movement of the position obtained the maximum peak pressure. Second, high flame speed occurs at the position of 45°. According to the Bernoulli equation, the position at a higher speed has a lower pressure.

3.2. Effect of locations of aluminum silicate wool on explosion suppression

Fig. 3 shows changes of explosion overpressure when the distance $L_X$ changes from 0 to 1500 mm.

![Fig. 3. Influence of porous media position on peak pressure.](image)

![Fig. 4. Influence of porous media length on surge pressure.](image)
It can be seen from Fig.3 that explosion overpressure increases then decreases as distance gets larger. Overpressure is obviously larger compared to experiments without aluminum silicate wool, demonstrating the obstacle effect of increasing pressure in the pipeline. The obstacle effect is most significant when $L_X$ equals to 300 mm as the increment of pressure ranges from 30 kPa to 70 kPa. When 900 mm $< L_X <$ 1400 mm, porous material could obviously decrease the explosion overpressure. When the distance is 1100mm, the pressure of every testing point reaches the minimum value. Hence, the distance of 1100mm is the optimal location where the suppression effect of aluminum silicate wool is most evident.

In addition, the location of 1100mm is the mid-point between ignition source and 90° bend. The overpressure increment $\theta = \frac{(P - P_0)}{P_0} \times 100\%$ is defined to evaluate the effect of suppression. Table 1 is the calculated results at every point.

<table>
<thead>
<tr>
<th>Degree/(°)</th>
<th>Distance/mm</th>
<th>300</th>
<th>600</th>
<th>900</th>
<th>1200</th>
<th>1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>76.94%</td>
<td>-1.33%</td>
<td>-54.95%</td>
<td>-80.39%</td>
<td>20.61%</td>
<td></td>
</tr>
<tr>
<td>22.5</td>
<td>22.55%</td>
<td>57.29%</td>
<td>-54.46%</td>
<td>-75.83%</td>
<td>8.75%</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>77.63%</td>
<td>-2.96%</td>
<td>-58.89%</td>
<td>-81.31%</td>
<td>31.69%</td>
<td></td>
</tr>
<tr>
<td>67.5</td>
<td>108.55%</td>
<td>95.76%</td>
<td>-27.80%</td>
<td>-76.30%</td>
<td>16.62%</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>33.49%</td>
<td>-44.86%</td>
<td>-83.58%</td>
<td>-92.03%</td>
<td>-25.32%</td>
<td></td>
</tr>
<tr>
<td>-45</td>
<td>44.89%</td>
<td>83.99%</td>
<td>-63.85%</td>
<td>-77.49%</td>
<td>36.79%</td>
<td></td>
</tr>
<tr>
<td>Outlet</td>
<td>30.11%</td>
<td>11.48%</td>
<td>-87.30%</td>
<td>-84.38%</td>
<td>-55.63%</td>
<td></td>
</tr>
</tbody>
</table>

It can be found from Table 1 that when the distance is short, pressures at intrados 45° and extrados 45° of the bend increase obviously. Pressures decrease up to about 76%–92% when the distance is 1 200 mm, representing a significant suppression effect. It is concluded that the aluminum silicate wool has two effects on explosion overpressure: increasing or decreasing the explosion overpressure. First, aluminum silicate wool can increase explosion overpressure because of the contractible section area of pipeline and the turbulence to combustion reaction. Then, aluminum silicate wool can also absorb the pressure wave for its characteristics of porosity and large specific area. However, the combination effect is different at different testing points. For instance, porous material mainly plays an increasing effect at the point 67.5° but decreasing effect at 90°.

Explosion begins from the ignition source and develops insufficiently in the front section of pipe. Thus, the pressure wave and flame absorbed by porous material is quite limited when the porous media is placed at the initial stage of explosion. The increasing effect is dominant. When the pressure wave and flame is fully developed, the wave-absorbing and overpressure-suppression effect of porous material is dominant and decrease the explosion overpressure compared to the experiments without porous material.

Fig.4 is the pressure changes versus length of aluminum silicate wool at different testing points. It can be seen that length has a remarkable impact on explosion overpressure. The aluminum silicate wool could reduce the explosion overpressure at all testing points when length varies from 0 to 400 mm. However, it would promote the explosion severity at the length of 600 mm. The aluminum silicate wool has suppression effect at some of the points, some of which is not obvious when length varies from 900 to 1 100 mm.

3.3. Explosion suppression mechanism of aluminum silicate wool

Traditional porous materials such as foam ceramic and porous iron could attenuate explosion waves because of their porous structure which could reflect and scatter shock waves and hence consume the energy. Teodoreczyk [7] believed that porous material could absorb the transverse wave in the detonation wave. Aluminum silicate wool is a kind of typical porous material with high elasticity and compressibility. The microstructure is observed thanks to scanning electron microscope before and after explosion in order to find out its explosion suppression mechanism on the microscopic level. Results are shown in Fig.5.
The fiber of aluminum silicate wool is isscross with diameter of 5–10 μm, forming a three-dimensional skeleton structure in microcosmic view in Fig.5(a) and Fig.5(b). Large quantities of gaps exist in the macro structure. Fibers fracture and smash during the explosion, as shown in Fig.5(c) and Fig.5(d). The numerous gaps or spaces inside the aluminum silicate wool are compressed and collapsed in the explosion. It means that the aluminum silicate wool could not only reflect the explosion wave, but also absorb the explosion energy by breaking the fibers and compressing the inner spaces. According to the chain reaction theory, the internal structure of aluminum silicate wool could increase the area in which activated molecules contacts.

Fig.6 shows the impulse at different points when porous material length is 300mm and the distance is 1 200 mm.

It is found that the impulse decrease obviously up to from 600 Pa·s to 200 Pa·s if the aluminum silicate wool is located in the right position. The aluminum silicate wool could largely attenuate the impulse of explosion.

Fig.7 [8] is the P-I diagram of half timber house. It is clear that the damage magnitudes at 0°, 45° and 90° have been reduced from 5 to 2. It can be concluded that aluminum silicate wool could decrease the explosion impulse, absorb the explosion energy and reduce the damaging effects on equipments and personnel casualties.

4. Conclusions

Suppression experiments of aluminum silicate wool were conducted in pipeline with 90° bend using C3H8/Air premixed mixture. The influence of aluminum silicate locations and lengths on explosion overpressures is discussed. It is found that explosion overpressure obtained at different points on the 90° bend is different. As the length of aluminum silicate increases, the explosion overpressure shows a trend of firstly decreasing then increasing from testing point of 0° to 90° in the extrados of bend. The overpressure can be attenuated nearly up to 80% when the distance of aluminum silicate wool from ignition source is 1 100 mm and the length is 300 mm. The macro structure of the aluminum silicate wool is a kind of three-dimensional skeleton structure with large quantities of gaps resulting from the isscross fibers. Because of the porosity of aluminum silicate wool in microscopic view, the pressure waves could be reflected and scattered. Moreover, the porous material absorbs explosion energy during explosion process by compressing the skeleton structure and breaking its fiber structure.
Acknowledgements

Supported by the Natural Science Foundation of China under Grant (No 50974027).

References