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Combustion characteristics of aluminium-iron oxide in SHS-gravitational process

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Abstract: In order to get high quality of products, the combustion of aluminium-iron oxide thermite in SHS-gravitational process must be under control. The effects of thermite filling density, hole in thermite and inclined angle of pipe on combustion rate were studied. It shows that the combustion rate decreases with the decrease of filling density. The thermite combusts downwards the pipe much more quickly if there are holes in the thermite. And the combustion rate increases with the increase of the inclined angle of pipe. The experiment results show that the combustion of thermite is predominantly controlled by gas phase reaction, which is attributed to the high temperature of the thermite combustion.

Key words: thermite reaction; SHS; chemical synthesis; composites

SHS-centrifugal process can only be used to synthesize linear pipes with a diameter larger than about 20 mm due to some limitations of its principle. The finer pipe and the elbow can not be produced by SHS-centrifugal process.

Sada proposed a method to resolve the above problem [1]. In this method, molten metal and ceramics generated by the highly exothermic reaction between aluminium and iron oxide are separated under the gravity. Subsequently molten ceramics contacting with the inner side of pipe solidifies to form a ceramic layer. Recently, SHS-gravitational process was developed to produce the ceramic lined fine pipe, elbow, tapered pipe and the like with more complicated profile [2,3].

In SHS-centrifugal process, Odawara confirmed that thermite reaction is predominantly affected by a gas phase reaction [4]. But Liu found that combustion rate is controlled by the explosion of fine aluminium powder with particle size smaller than 74 μm (200 mesh) [5]. Based on these results, the quality of ceramic lined steel pipe made by SHS-centrifugal process was greatly improved. In this paper, some experiments were designed to reveal the combustion characteristics of the aluminium-iron oxide thermite in SHS-gravitational process.

1 Experimental

The raw materials used were two kinds of aluminium powder with particle size of 74-149 μm (−100+200 mesh) and <74 μm (−200mesh) respectively, and iron oxide powder with particle size smaller than 45 μm (325 mesh). The thermite was prepared by stoichiometrically mixing the aluminium powder with iron oxide powder according to the formula $2Al+Fe_2O_3=Al_2O_3+2Fe$, and was filled into the carbon steel pipe with a outer diameter of 34 mm, a wall thickness of 3 mm and a length of 150 mm. After the thermite was ignited by a tungsten filament, its combustion time from one end of the pipe to another was recorded by a electro-timer.

2 Results and discussion

2.1 Influences of filling density and particle size of aluminium powder

The filling density refers to the mass of thermite filled in a unit volume of pipe. **Figure 1** illustrates the model of the experiment. The dependence of combustion rate on filling density is shown in **figure 2**. It can be seen that the thermite combusts at a low and stable rate when the filling density is more than 2.1×10^3 kg/m^3. However, the combustion rate increases drastically with decreasing the filling density when the filling density is less than 1.6×10^3 kg/m^3.

The calculated theoretical density (ρ_t) of full dense thermite is 4.20×10^3 kg/m^3. The minimum of experimental filling density (ρ) of the thermite comprising aluminium powder with particle size from 74 to 149 μm (−100+200 mesh) and with particle size smaller than < 74 μm (−200 mesh) is 1.25×10^3 kg/m^3 and 1.24×10^3 kg/m^3, so their relative density equals 29.5%

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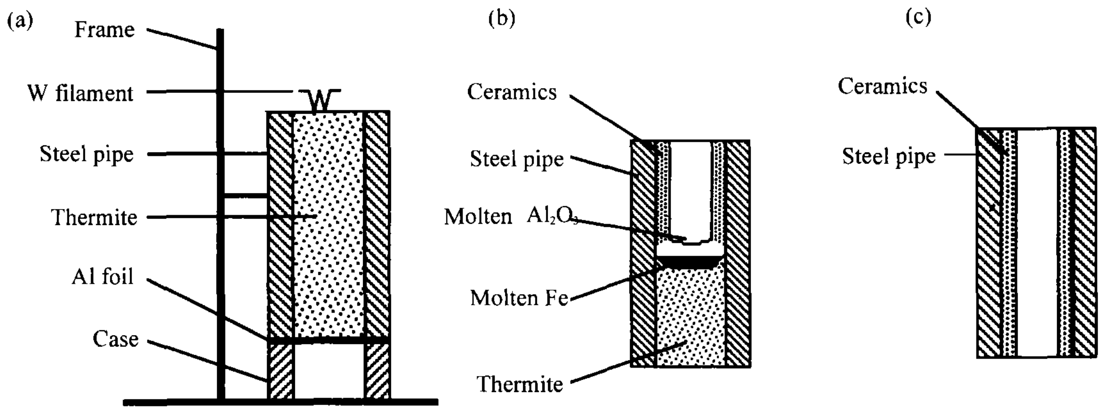

Figure 1 Mode of the experiment, (a) before igniting; (b) during combustion synthesizing; (c) after synthesizing.

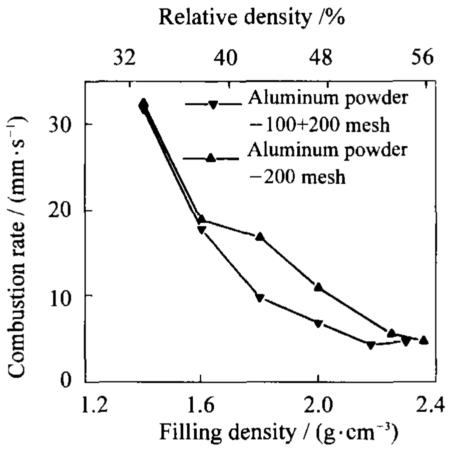

Figure 2 Relationship between combustion rate and filling density.

and 29.8% respectively. Figure 2 also shows the coordinate of relative density. Obviously, compared with the full dense thermite, the thermite filled in pipe is very loose and contains large quantity of pores. The adiabatic temperature of the thermite is 3 622 K, the boiling point of aluminium is 2 748 K, so the aluminium can be evaporated. Furthermore, the reaction temperature is high enough to lead to the decomposition of Fe_2O_3 into FeO and oxygen. Mei observed the deposition of evaporated aluminium and the decomposition of Fe_2O_3 [6]. The gas absorbed on the surface of thermite powders and filled in the pores of thermite will also be released on the combustion front. Thus, there exists a gas phase reactant in the system.

There are two ways for the gas to escape. One is to flow upwards through the layer of molten products, the other is to penetrate downwards through the unreacted thermite. Both molten products and unreacted thermite have the resistance for the gas to escape.

The molten products exert a pressure on the gas. The pressure of the gas should be higher than that exerted by molten products if the gas could be able to escape through the layer of molten products. As for the unreacted thermite, the looser the thermite filled in the pipe, the smaller the resistance for the gas to diffuse through it. The carry-over of molten products was observed when the filling density is more than 2.1×10^3 kg/m^3. This shows that the gas escapes through the layer of molten products from combustion front because the thermite is too dense for the gas to diffuse easily. In the case of the filling density less than 1.6×10^3 kg/m^3, the thermite is loose enough for the gas to diffuse through it easily, resulting in the ignition of the thermite and causing the drastic increase of combustion rate.

Furthermore, the particle size of aluminium can also change the combustion rate, as shown in figure 2. The combustion rate of the thermite comprising the fine aluminium powder is faster than that comprising the coarse aluminium powder, because the fine aluminium powder is of high reactivity.

2.2 Influences of a hole in thermite

When making a hole with a diameter of 6 mm in the thermite of which filling density is 2.0×10^3 kg/m^3, it greatly changes the combustion rate. The experiment model is illustrated in **figure 3**.

The thermite at the top and the bottom of pipe almost combusts simultaneously in the experiment of figure 3 (a). In SHS-centrifugal process, Liu [7] found that the combustion of thermite propagates along the length direction of steel pipe at the rate of 1.5 m/s when the thermite contains a fraction of aluminium with particle size smaller than 74 μm (−200 mesh), but the combustion rate keeps at a relative low level (<0.1 m/s) when the particle size of aluminium in thermite all ranges from 74 to 149 μm (−100+200 mesh). The faster combustion rate can attribute to the explosivity of aluminium with particle size smaller than 74 μm (−200 mesh). Since the particle size of aluminium ranges from 74 to

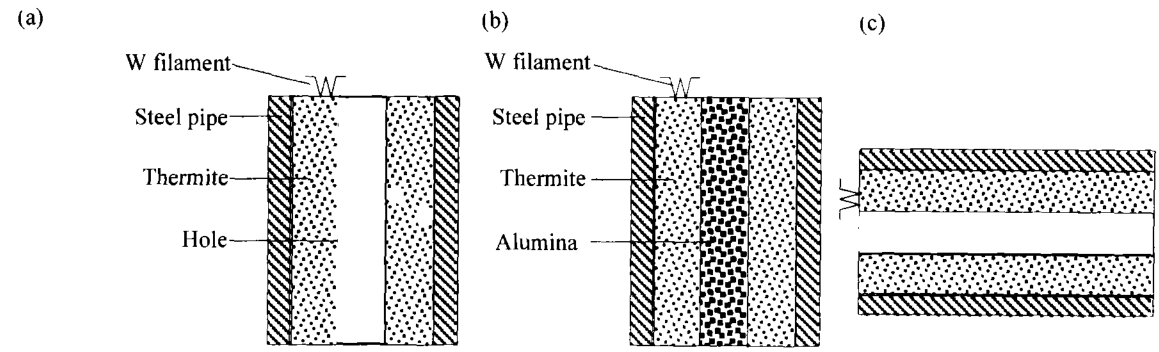

Figure 3 Schematic of experiment, (a) making a hole in thermite; (b) the hole filled with alumina; (c) putting the pipe horizontal.

149 μm (−100+200 mesh) in this experiment, the reason of the explosivity with finer aluminium may be exclusive.

When the hole is filled with alumina of which particle size is 1-2 mm in the experiment of figure 3(b), the thermite reaction steady propagates along the pipe passing over about half length of pipe. The average combusion rate is 20.6 $mm \cdot s^{-1}$. After that, the thermite in the rest of pipe combusts simultaneously. In the experiment of figure 3(c), the pipe is horizontal and other conditions are the same as that in the experiment of figure 3(a), but the result is the same as that in the experiment of figure 3(a).

Comparing these experimental results with each other, the suspect, that a drop of molten products dropping downwards along the hole ignites the thermite reaction simultaneously, is cleared up, and the conclusion that the thermite reaction is predominantly affected by a gas phase can be drawn.

2.3 Influences of inclined angle

In order to further study the movement of the gas phase in SHS-gravitational synthesis, a inclined angle θ between flame and steel pipe is held in the experiment.

The result shown in **figure 4** demonstrates that the combustion rate increases with the increase of inclined angle. At the small inclined angle, the layer of molten products can not fully cover the thermite, so the gas easily escapes from the combustion front to the ambient. While the inclined angle is 90°, *i.e.* the pipe being vertical, the gas phase goes downwards through the unreacted thermite under the pressure of the layer of molten products and accelerates the reaction. Accordingly, the combustion rate at 90° of inclined angle is much faster than that at the small inclined angle.

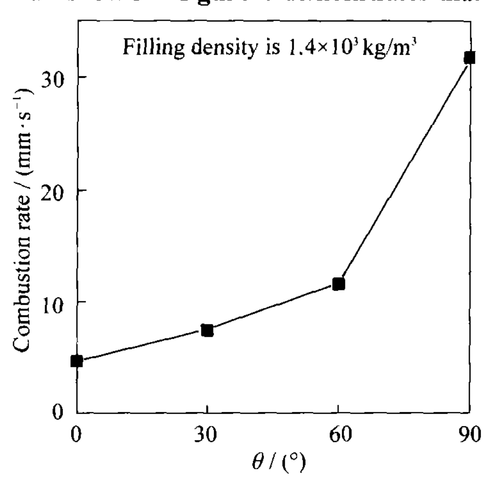

Figure 4 Relationship between the combustion rate and the inclined angle of pipe.

3 Conclusions

In SHS-gravitational process, the combustion of thermite is controlled predominantly by a gas phase reaction. If the thermite is loosely filled in pipe or there are holes in the thermite, the gas phase diffuses through the thermite under the pressure of molten products, resulting in the rapid combustion rate. While the thermite is densely filled in pipe and there is no hole, the diffusion of gas phase is hindered with the increase of filling density, resulting in the slow combustion rate. Furthermore, the combustion rate increases with increasing the inclined angle of pipe.

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