The Dripping Behaviors of PE Metal Sandwich Panel Insulation material at Different Powers

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Abstract—An experimental study on the characteristics of molten drop and flame spread of metal polyethylene (PE) cladding panel is presented. The parameters investigated include mass loss rate, the mass of the melting part and the average flame height. The effects of fire source power on the flame spread and melt drop are studied. The results show that the sandwich panel combustion can be divided into the surface of the sandwich panel and the dripping combustion. With the increase of power, the time interval between melting drops becomes smaller and the flame pulsation frequency increases, which causes the temperature change range getting larger, the mass loss rate and mass of the melting part and the average flame height increase under all conditions. The mass loss rate and the area of combustion of the metal sandwich panel depend on the degree of surface burning. There is a certain relationship between oil pool fire average flame height, and the distance between sample and the oil pan (D). It is found that when D ≤ 1.4m, with the rise of D, oil pool fire average flame height decreases. However, when D ≥ 1.4m, the fire flame intensity of the oil pool is determined by the number of extinguished droplets before the drops hit the oil pan, and the flame parameters of the oil pool are basically stable. The influence mechanism and law of oil pool fire burning of PE metal sandwich panel insulation materials are revealed.

1. INTRODUCTION
At present, there are few studies on the fire behavior and evolution mechanism of metal-faced PE sandwich panels at home and abroad. Jelle studied the PE and XPS fire spread behaviors at different altitudes in Hefei and Lhasa. The fire spread rate of PE and XPS will increase with the increase of the tilt angle. With the rise of sample with, the flame height of the pool fire zone is greater than the flame height of the surface flame zone for PE and XPS in the plain test[1]. Oleszkiewiczl explored the fire spread characteristics of exterior insulation materials of full-size exterior wall and analyzed the fire hazard of different types of insulation materials. The fire spread distance and the maximum heat flux were measured, and the fire spread characteristics of the materials were classified accordingly[2]. Sun Jinhua studied the combustion of samples of insulation materials placed under different angles of inclination and the different pressures caused by different altitudes of Hefei and Lhasa. The variation rules of the characteristics of the pool fire length, fire spread rate, average flame height and preheating zone length during the fire spread of the two materials were obtained [3]. Lie made a full-size EPX metal sandwich panel. The study found that if the fire spread rate of the PE sandwich layer is lower
than 18mm/s, the entire sandwich panel will not have the effect of burning around[4]. Griffin carried out the ISO9705 standard test, studied the fire behavior of PE sandwich panels, and discussed the influence of core material thickness, PE grade and construction mode. The study found that reasonable core thickness and construction can effectively prevent the fire spread of the sandwich panel [5]. Liu Aijing studied the PE fire spread of insulation materials with different widths and different preheating angles through a self-made test platform. The study found the effect of width and preheating angle on its fire spread and used linear simulation. The relationship between the width and the preheating angle is established[6]. Huang Xinjie conducted small-scale combustion characteristics tests on EPS insulation materials of different widths and densities. It was found that as the density decreases or the width increases, the fire spreads is faster and the fire area of the oil pool is larger [7]. Zhou Yang studied the fire spread characteristics of rigid polyurethane and polystyrene insulation materials, revealing the two factors of material collapse and melt flow in the combustion process under different pressures and placement angles[8]. Suo Xiao used the FDS fire simulation software to simulate the fire spread of the student apartment, and studied the rate of the PE insulation material during the fire spread process and the characteristics and motion of the smoke-generating components and smoke[9]. You Fei conducted a fire spread study on the polystyrene foam sandwich panel. The variation of internal temperature of different installation methods shows that the temperature of different measuring points on the horizontal and vertical reliefs at the same time shows the first-order exponential decay distribution. The application of external wall insulation panels has positive reference significance [10].

2. Material and Methods

2.1. Experiment System
This experiment is carried out by using a self-made small-scale combustion experimental platform. The test device is shown in Figure 1.

2.2. Temperature Acquisition System
The K-type thermocouples and Keysight 34970A temperature inspection instrument are used to record the temperature change of the middle position of the metal sandwich panel during the combustion, as shown in Fig. 2.
2.3. **Metal Sandwich Panel Sample**

Test sample is from Shanghai JiXiang LTD. bought in the construction market. The model number is JXPE802(1.22m×2.44m×0.004m), the surface is aluminum alloys, and the core is PE. Five powers of 4kw, 6kw, 8kw, 10kw, and 12 kw are studied, respectively. In this experiment, each experiment lasts for 30 minutes. Each sample with the same size was repeated three times under the same condition to minimize experimental error.

3. **TEST RESULTS AND ANALYSIS**

3.1. **Metal sandwich panel burning phenomenon**

The PE pyrolysis temperature is usually about 280℃, and the porosity of the PE thermal insulation board is relatively large, and shrinkage melts when heated to cause deformation, which increases the distance between the surface of the PE and the fire source. When heated by the fire source, the test found that the combustion zone can be divided into two parts, one part is the surface burning area, because the PE material is a thermoplastic material, and the temperature of the pyrolysis is rapidly increased when heated by the gas source. After the ignition, the PE sandwich panel is heated, which is defined as the preheating stage of combustion before the first droplet happens. After that, there will be intermittent droplets, however the time interval of droplets is different. in this process will produce volatile low molecular chain liquid substances and flammable gases, in a sufficient oxygen environment, the flammable volatile gases will preheat the combustion behavior. The other part is the oil pool fire burning area, because the PE thermoplastic material melts and drips during the heating process to produce a pool fire, as shown in Fig. 3. Two different forms of combustion are thus available: one is solid surface burning, which is the burning of the surface of the metal sandwich panel. The other is drip combustion, which is divided into two ways: one is PE droplet drip combustion, the other is PE block drip combustion. The initial phenomenon is that the sandwich layer has a very weak flash of fire, but it does not produce a distinct flame. When the flame continues to burn for about 3 minutes, the flame starts to be generated. The middle of the plate burns first. Then, the two sides began to burn quickly, and finally the bottom of the plate began to burn as a whole, and the burning of the metal sandwich panel continued to expand, and the molten PE material quickly became fluid and dripped downward, drip on the surface of the metal disk to form a sump fire. The area of the sandwich panel will be larger, and the droplets are dripping more and more, so the resulting oil pool fire begins to slowly increase. Since the droplets drip in the metal disk, the surface of the sandwich panel is not in direct contact with the oil pool fire region, so the oil pool fire does not provide thermal feedback to the surface of the sandwich panel, there is no burning effect on the sandwich panel. At the peak of the burning, the fire rapidly and continuously increases, the burning of the metal plate reaches the peak. The dripping frequency of the droplet increases accordingly. At this time, under the action of heat, the remaining material on the surface of the sandwich panel will be slightly deformed. When it falls into the oil pool fire, the oil pool fire will weaken briefly, but it will continue to increase again. then, it will reach the highest peak of the oil pool fire. At this time, the oil pool fire area is the largest. Finally, as the fire of the sandwich panel gradually weakens, the droplets gradually decrease, finally the fire gradually decreases until it is extinguished. From the beginning to the end, the surface metal only changes in color blackening and deformation.
3.2. Sample mass loss rate

The traditional thermoplastic insulation material in the combustion process will indirectly enhance the heat transfer from the combustion zone to the preheating zone or even the pyrolysis zone because of the nature of droplets and dripping. The droplets accumulate at the bottom of the insulation board to form obvious features. The droplets accumulate at the bottom of the insulation board to form obvious features. The PE metal sandwich panel insulation material is different from the traditional insulation material. Due to the constraint of the metal panel, the burning of the thermal insulation material is difficult. The mass loss rate of sample under the conditions of 4kw, 6kw, 8kw and 10kw are shown in Fig. 3. It can be seen from the figure that as the power of the fire source increases, the ignition time of the metal sandwich panel shorter. However, the mass loss rate is gradually increasing, the difference between the 4kw and 12kw mass loss rates is relatively obvious. When the metal sandwich panel is heated by the gas source, the temperature of PE material of the sandwich layer of the metal sandwich panel will rise rapidly. When the temperature rises to a certain temperature, the softening and shrinkage of the material will occur until the melting behavior [12].

As the power of the fire source increases, the heat absorbed by the PE material will also increase, and the temperature rise rate will also increase. With the rise of power, the heat that PE absorbs and temperature increase upon most occasions[13]. The thermal properties of the material cause a rapid rise in temperature, causing the chemical bonds on the molecular chain to begin to break, resulting in an increase in the rate of thermal decomposition to produce flammable gases. in the same air environment, the flammable volatile gas will quickly spread with oxygen. With the rise of power, the degree of thermal decomposition and fire spread rate of sandwich panels increases, resulting in a reduction in burning time and an increase in mass loss rate.

3.3. Oil pool fire mass and area

Oil pool fire is a part that should not be ignored in the process of fire spread. It often plays a role in controlling fire growth during the actual fire spread process. The oil pool fire is inseparable from the heat transfer relationship between the flame and the melting zone. The heat transfer includes thermal convection and heat radiation. The oil pool fire of the metal sandwich panel depends largely on the combination of heat radiation and heat convection, the relationship between heat transfer and combustion rate can be expressed by Equation:

\[ m = C(q_{\text{conv}} + q_{\text{rad}}) \]  \hspace{1cm} (1)

\[ m \propto h(T_f - T_p) + \sigma(T_f^4 - T_p^4)(1 - \exp(-k_f/l_f)) + q_{\text{ex}} \]  \hspace{1cm} (2)

Where \( h, T_f, T_p, m, \sigma, k_f, l_f \) and \( q_{\text{ex}} \) are convective heat transfer coefficient, flame temperature, pyrolysis temperature, total mass loss rate, Stefan-Boltzmann constant, smoke absorption coefficient, average flame height and external radiant heat flow respectively. As an important parameter to measure the degree of fire hazard, the oil pool fire can indirectly reflect the change process of heat release rate in the fire spread. Figure 4 depicts the pool fire mass variation curve for different conditions. It can be seen from the Figure 4 that with the rise of power, the ignition time, mass of the oil pool fire mass
increase, the time for the droplets to be produced decreases. Whether it is the mass and the rate of the droplets, in the experiment both are 12kw drop mass, production rate >10w drop mass, production rate >8kw drop mass, production rate >6kw drop mass, production rate. The same is true for the material burning area rule of the metal sandwich panel. Therefore, the law can be summarized as follows: with the rise of power, the intense the sample burns area increases, and the resulting oil pool fire mass increases.

![Fig.4 Oil pool fire mass change under different working conditions](image)

3.4. Oil pool fire area

The area of the pool fire depends on the rate of drop dripping and the fire spread rate and burnout rate of the sump fire. The burnout rate is the rate at which the burnout striker advances during the fire spread of the metal sandwich panel. The burnout rate can be divided into the lateral burnout rate $V_A = L_1T_1^{-1}$ (where $L_1$ is the distance spread by the striker in unit time, $T_1$ is the transverse fire spread time). The longitudinal burnout rate $V_B = L_2T_2^{-1}$ (where $L_2$ is distance that the longitudinal striker spreads in the unit time, $T_2$ is the longitudinal fire Spread time[15]), the oil pool fire area is

$$S = (V_{f1} - V_A)(V_{f2} - V_B)T_1T_2$$ (3)

where $V_{f1}$ is average rate of the transverse fire spread, $V_{f2}$ is the average rate of the longitudinal fire spread. It can be seen from the Figure 4 that with the rise of power, the fire pool area will increases. because the power will cause the droplets to drip, the rate and quantity increase, resulting in more droplets of concentrated droplets burning, whether the horizontal or vertical fire spread rate will be faster, through the curve of the droplet mass, it is found that the power increases, whether vertical or horizontal, the rate of increase of the fire spread rate is greater than the growth rate of the burnout front, resulting in an increase in the fire area of the oil pool, as shown in Fig. 5.

3.5. Sample average flame height

The flame height is an important parameter affecting the spread of fire. It is closely related to the degree of fire hazard. The flame height is the distance from the top of the flame to the front edge of the flame. Then using the camera to record the phenomenon of fire and flame combustion in the oil pool, using matlab software to image it to obtain the flame height under stable combustion conditions. Because the flame floats during the combustion process, we define a function $F(Z)$ that represents the probability of the flame length appearing, and when $F(z) = 50\%$, $z = H_f$, the $H_f$ is average flame height[14].Figure 6 shows the correlations between experimental flame height and power. From Fig.6. it can be observed that average flame height increases with in the increasing of power,With the increase of power, the amount of air entrainment increases as well. The subsequent increase of initial air momentum in the pyrolysis in turn drives up the upward movement rate of air vaporized fuel mixture.
In addition, the temperature near the combustion area goes up with the presence of power and the flame height stretches further because of the buoyancy effect, which occurs when the inside and outside of the combustion region are different in density.

3.6. Oil pool fire average flame height

We define the distance between sample and oil plate as D. Figure 7 shows the correlations between experimental flame height and D under the 12kw. With the rise of D, the average flame height and the decrease in most cases, the gap of three working conditions of 0.4m-0.8m is great. But at D belong to 0.8m-1.2m, the curve of the three working conditions gradually tends to be straight, so it can be predicted that the average flame height will not change with the increase of the distance at a distance of about 1.2 m. The reason for the change of five working conditions is the time for the droplets to drip from the layer of the sandwich panel to the oil pan increases as the D increases, when D is increased, the shape of the droplet flame gradually becomes a slender shape during the dripping process, which will increase the contact area of the droplet with the air environment to make it fully burn, and the mass loss increase, which will occur in the air.

The fuel in the sump fire is reduced and the required droplets are transferred to the extinguished droplets for combustion. This will be the reduction of the heat of the oil pool fire, which also leads to the reduction of the oil pool fire area, the average flame height and the maximum flame height. With the rise of D, the droplets are extinguished before contacting the oil pan. The change will be small, at the same time, the proportion of the combustion mass of the droplets will gradually increase during the dripping process, but the flame intensity will tend to be constant, It can be seen that the strength of the oil pool fire flame is determined by the number of extinguished droplets before they contact the oil pool fire.
4. CONCLUSIONS

Through the self-made combustion platform, the behavior of the droplets of the PE metal sandwich panel was studied. The key parameters such as mass loss rate, flame height and oil pool fire area were measured. The results of this work are summarized as follows:

Under the five conditions of 4kw, 6kw, 8kw, 10kw and 12kw, the burning behavior of metal sandwich panels can be divided into two forms: one is surface burning and the other is dripping combustion. The degree of surface burning is a factor affecting pool fire forms. In most cases, with the rise of power, the mass loss rate of the metal sandwich panel, the mass and area of oil pool fire increase, the ignition time of the sandwich panel decreases as the power increases.

Under the 12kw condition, the distance D between the droplet and the oil pan will affect the flame intensity of the average flame height of oil pool fire. When \( D \leq 1.4 \text{m} \), with the rise of D, the pool fire area and the average flame height decrease. When \( D \geq 1.4 \text{m} \), the amount of extinguish of the droplet in the air determines the fire flame intensity of the oil pool. Although the mass fraction of the droplets burning in the air will increase, the amount of the droplets will not change, so the oil pool fire flame height changes are not obvious.
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