Experimental Research about the Effect of Particle Sizes on the Melt-through Effects of Al-MnO₂ Flame Jet Thermite

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Abstract. The method of ultrasonic dispersion was adopted to prepare reactive materials of Al-MnO₂ flame jet thermite with different components, which was aimed at experimental research about factors on the melt-through effects of Al-MnO₂ flame jet thermite. Based on the single factor experiment, the disposal experiment of the steel plates with 3mm thickness had been carried out. According to the phenomena of experiments, there were many advantages with the form of powder cylindrical charge such as better ignition performance, faster burning rate and firmer combustion process. The charge with the 40um particle size of Al powder and 30-40um particle size of MnO₂ had the best melt-through ability which could penetrate the steel plates with ranging from 1.5cm to 3cm aperture by contrasting and analyzing melt-through effects and molten zones. By contrasting and analyzing melt-through effects and molten zones, it was significant to analyze the accounts for the better performances, with the purpose of providing references for the selections of formula in the future experiments and applications.

1. Introduction
Thermite is one of the high energy density agent which could provide huge chemical heat energy with small volume[1-3] and has many other advantages such as high speed of heat releasing, adiabatic flame temperature and security. It can be widely used in many fields such as metallurgy [4], welding [5], cutting [6], and especially the destruction of by unexploded ammunition[7] due to the use of high energy combustion agent is much more secure, convenient and portable, on the basis of the principle that high energy combustion agent could burn the warhead up steadily via melting through the metal shell of the ammunition. When the traditional thermite is ignited by ignition agent, aluminum thermal reaction will occur to produce alumina and iron which mainly refers to the mixture of aluminum and ferric oxide red powder according to the proportion of 3:2, and release a large amount of heat, and the temperature can reach 2000K. In addition to the type of Al/Fe₂O₃, the concept of thermite has been further promoted, which means other metal oxides like CuO, MnO₂, SiO₂, MoO₃, [8-13] etc. can be used to replace some metal oxides of iron oxide, according to a certain proportion and the mixture is also known as thermites due to the reaction produces enough heat to melt the reduced metal at high temperature and then get metal with higher purity. However, experimental studies [14] have found that it will generate a small amount of slag but an obvious area of flame jet when MnO₂ is used as oxidant, which will not impede the continuous heat transformation in combustion process and improve combustion efficiency, leading some different applications with the type of Al/Fe₂O₃.

In recent years, with the development of material science, many researchers have paid much more attention to the research of micro- and nano-scale super thermites for the reason that in the field of
energetic materials, micro- and nano-scale energetic materials have increased significantly in terms of overall performance especially the aspect of safety compared with traditional energetic materials \[15\]. At present, a large number of scholars have made the preparation, characterization and application of super thermites with micro- and nano-scale materials. For example, Do Kyung Kim\[16\] et al. investigated the thermite reactions between Al/CuO of nanowires and nanopowders, through using field emission scanning electron (FE-SEM) and energy dispersive spectroscopy (EDS), testing the heat flows and energies released from the nanopowders. According to Jia-Xing Song’s research \[17\], thermal properties and kinetics of Al/α-MnO\(_2\) nanostructure thermite could be tested, which has high heat release and low onset temperature.

However, it is rarely mentioned that the effect of the two factors, MnO\(_2\) particle size and Al particle size, on the reaction effect for the flame jet type Al-MnO\(_2\) high heat agent. Aiming at these shortcomings, both MnO\(_2\) and Al powders with different particle sizes were used to conduct the penetration test of 3mm thick steel plate by the single factor experiment method in this research group. According to Chen Chao and Ren Ruie \[18-19\], when the difference of particle size was not large enough, the effect of particle size on the reaction was not obvious. Therefore, it was chosen the different particle sizes of Al powder and MnO\(_2\) powder ranging from 1 to 70um (1,5,10,20,30,40,50,60,70) to explore the effect of the particle size on the penetration effect of the steel plate. During the experiment, it was focused on these two indicators that whether the steel plate was melted through and the size of the melting area.

2. Experiments

2.1. Materials

All chemicals were analytical reagent grade and were used without any further treatment or purification, including Al and MnO\(_2\) were supplied by Naiou Nano technology Co., Ltd. (Shanghai, China) while C\(_2\)H\(_6\)O was purchased from Sinopharm Chemical Regent Co., Ltd. (Shanghai, China).

2.2. Sample preparation

According to the thermo chemical reaction equation:

\[
3\text{MnO}_2 + 4\text{Al} \rightarrow 3\text{Mn} + 2\text{Al}_2\text{O}_3 + 1759.4\text{kJ}
\]

The mass ratio of could be calculated to MnO\(_2\): Al=29:12, and the average heat released per gram of high heat agent is 4.768kJ, which produces 0.45g manganese matrix. The steps following as that firstly the reagents were dispersed in the anhydrous ethanol, then the mixture is carefully stirred and concussion in the ultrasonic wave concussion for about 1h; Secondly the mixture was transferred to the evaporating dishes in a vacuum oven drying at 60°C for 18h; Last but not least the evaporating dishes were removed and scraped carefully to get the black gray solid which need to be transferred in a mortar and grinded to powder. Finally, the weight percent of all samples can be available in the following table 1&2.

| Table.1 the samples and formulations used for the experiment |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Numb. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Al size | 1 | 5 | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
| MnO\(_2\) size | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |

| Table.2 the samples and formulations used for the experiment |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Numb. | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| Al size | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| MnO\(_2\) size | 1 | 5 | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
2.3. Combustion experiments
In this experiment, the thickness of 3mm steel plates were used to carry out the penetration test. The experimental settings, as shown in Figure 1, were placed under the steel plate for loading the high energy combustion agent. The experiment device were used with electric ignition mode.

![Sketch Map](image1)

![Physical map 1](image2)

![Physical map 2](image3)

Fig 1 the sketch of steel plates ablated by thermite

3. Results and Discussion
Figure 2 shows the processes of experiments of thermite with different Al particle sizes while Figure 3 shows the processes of experiments of thermite with different MnO₂ particle sizes. The 1#-18# charges were ignited respectively during the experiment process. In each group of experiments, the reaction was extremely intense with bright flame, dazzling white light, dark smoke and little noise. As shown from the figures following, the samples marked Numb.5, 6 and 15 could melt through the plates. After the penetration of the steel plate, the heights of the flame were range from 0.8 to 1.1 meters.

![Fig 2](image4)

![Fig 3](image5)

Fig 2 the processes of experiments of thermite with different Al particle sizes

Fig 3 the experimental results of steel plates ablated by thermite with different MnO₂ particle sizes
According to the phenomena, by the increase of the particle size of both Al and MnO$_2$, the combustion time had been getting longer, which means the decrease of reaction rate. The reason that the reaction rate would be negative correlation with the specific surface area could account for the phenomena.

Fig 4 the combustion time of experiments of thermite

Fig 5 the results of experiments of thermite with different Al particle sizes
As shown from the pictures and table above, with the increasing of the particle size, the areas of molten area had decreased in different ways ranging from 447cm² to around 180cm² that the decline of Al was much faster than that of MnO₂. However, to melt through the steel plates, the best particle sizes were about 30 to 40mm, which may be explained by the reason that when particle sizes were small, a large number of powder in the processes of heating with flame jet carried out in the reaction while the larger particle size could reduce the specific surface area, resulting the decline of reaction rate. It could also account for why the larger the particle sizes were, the smaller the areas of the melting area were. On the other hand, due to the molar mass of manganese dioxide is far greater than that of aluminum, the influence of MnO₂ contrast group on particle size was less than that of aluminum contrast group.

4. Conclusions
According to the penetration test of 3mm thick steel plate carried out by 18 groups of different particle sizes of Al and MnO₂, it was found that 5#, 14# and 15# charge (the average particle size of Al powder is 40um, MnO₂ powder is 30-40um) had the best penetration ability. Through comparative analysis, we can draw the following conclusions:

1. The particle size of both Al and MnO₂ are supposed to moderate instead of too small or large, with the aimed for the best melt-through effect;
2. The particle size of and Al has a more important role in the reactions of thermites than that of MnO₂, which means the select of Al powder will be stricter than MnO₂ powder.

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