On Minimum Flash Ignition Energy of Energetic Igniter Using Aluminum NanoParticles: Effects of 2D Interparticle Distances

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1 Background

The unique flash ignition phenomenon occurring in nanoparticles has received increasing research interests in recent years. The unique optical-thermal property of nanoparticles makes flash igniter using energetic nanoparticles a possible and promising venue for future applications. The light weight and tiny volume of the system are beneficial in propulsion system used in space. Compared with micro-scale particles, nano particles have lower ignition temperature and higher combustion speed. Moreover, with flash-ignition mechanism, remote and controlled ignition can be achieved. Ajayan et al. found that the stack of single-wall carbon nanotube (SWCNT) can be ignited by the flash light and concluded that it is light absorption causing the flash-ignition [1]. In a later study, Smits et al. found that the flash-ignition cannot be obtained when the carbon nanotube was purified and no metal nanoparticle exist in the CNT. It is suggested that the metal nanoparticle plays an important role in the flash-ignition phenomenon [2]. Chehroudi et al. study the influence of the iron content in the CNT on the minimum ignition energy of the flash-ignition. The increase of iron content reduces the minimum ignition energy [3]. Ohkura et al. discovered the mechanism of the flash-ignition of aluminum nano-powder and confirmed that the melt-dispersion mechanism (MDM) occurs in the flash-ignition with a relatively high heating rate. [4] The outer aluminum oxide layer of the aluminum particle experienced the thermal expansion due to the temperature increase and broke due to the high pressure in the melting aluminum inside the particle. This caused the pure aluminum dispersing to the surrounding air and the aluminum reacted with air quickly. Therefore, the heating rate is a key factor in the reaction of the aluminum nanoparticle.

The objective of this study is to develop a flash igniter by using nitrocellulose (NC) with a different amount of nano-aluminum powder and further to quantify the effects of inter-particle distances on the minimum ignition energy by using simplified 2-D theoretical and experimental analyses. The flash ignition mechanism of this nano-aluminum-nitrocellulose flash igniter is identified and the minimum ignition energy is found to occur when the inter-particle distance is between four and five particle radius as verified by both theoretical and experimental results.

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2 Method

In the sample preparation process, different amounts of nitrocellulose and aluminum nanoparticles are first dissolved and disperse in acetone. Then ultrasonic processor is used to physically and uniformly separate the particles. After the process, the dense solution was dripped and spread onto a slide glass and which is followed by vacuum oven drying process to evaporate liquid content. The overall experimental equipment is shown in Figure 1. After careful calibration of the flash emission energy, energy intensity flux of the flash can be calculated and different flash energy intensities incident on the sample can be achieved by adjusting the position of the flash light. The prepared sample is examined by using SEM (Scanning Electron Microscopy) and TEM (transmission electron microscopy) for the microstructures of alumina in nitrocellulose and for the oxidization layer of thickness of the aluminum naoparticle. The ignition temperature and light absorption efficiency for nitrocellulose and aluminum nanoparticles are identified using Thermogravimetry analyser (TGA) and UV/VIS/NIR Spectrophotometer.

For further theoretical analysis, the flash-ignition process of energetic igniter is first identified experimentally through the high-speed camera observation and TGA analysis. Aluminum nanoparticles are heated up first due to the much higher light absorption and photo-thermal conversion efficiency. Then, thermal conduction between aluminum nanoparticle and nitrocellulose is occur because of the temperature difference. As soon as nitrocellulose reaches its ignition temperature, nitrocellulose burns accompanying exothermic reaction and which will lead to ignition of aluminum nanoparticles as well. According to reaction process mentioned above, a 2D theoretical thermal and heat transfer analysis is developed for the effects of inter-particle distance on minimum ignition energy for the flash ignition process.

3 Results

From the theoretical analysis in Figure 2 and experiment result in Figure 3, two main results are obtained: (1) The relationship between minimum ignition energy and aluminum inter-particle distance, and (2) The collective effect of agglomeration of different numbers of nanoparticles on the minimum ignition energy. The inter-particle distance for minimum flash ignition energy can be theoretically obtained by plotting the total enthalpy release from nitrocellulose after ignition, h, light absorption, nitrocellulose temperature after light exposure for 2ms, T_NC_2ms, and temperature increase of aluminum nanoparticle(△T_al) after receiving nitrocellulose combustion temperature, versus interparticle distance. The optimum point of inter-particle distance can be identified to be about four times the particle radius from Figure 2. It is supposed that ignition of the nAl/NC includes several process illustrated below: 1) The nano-aluminum particles absorbed the energy from the flash light by photo-thermal effect. At the instant, the temperature aluminum particle is increased to a certain temperature which is unable to ignite the aluminum. 2) The heat of the aluminum particle was transferred to the nitrocellulose by radiation and conduction. 3) The nitrocellulose was then ignited with the relatively low temperature, which can be verified in the TGA. 4) The heat of the exothermic reactions induced the temperature increase of the aluminum particle and finally ignite them. For collective condition, the thermal transfer equations was modified and still obtain the same trend as compared to the uni-particle uniform dispersion. In Figure 3, it is clearly found from experiments that the lowest MIE falls between four to five times the particle radius in agreement with the theoretical prediction.

4 Conclusion

In this study, we use nitrocellulose and nano-aluminum powder to make the igniter that can be ignited by camera flash. The experiment and theoretical analysis are carried out in a two-dimensional way to study the effects of inter-particle distances on the minimum flash ignition energy.

The results from experiment and theoretical analyses show that the effect of inter-particle distance on minimum ignition energy is the results of a trade-off among three parts of major contributors, (1) the light absorption of nanoparticle; (2) thermal transfer between nanoparticle and nitrocellulose; (3) the exothermic heat from nitrocellulose combustion. It is also found the minimum ignition energy for the flash igniter is the inter-particle distance being four or five times the particle radius.

References

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Figure

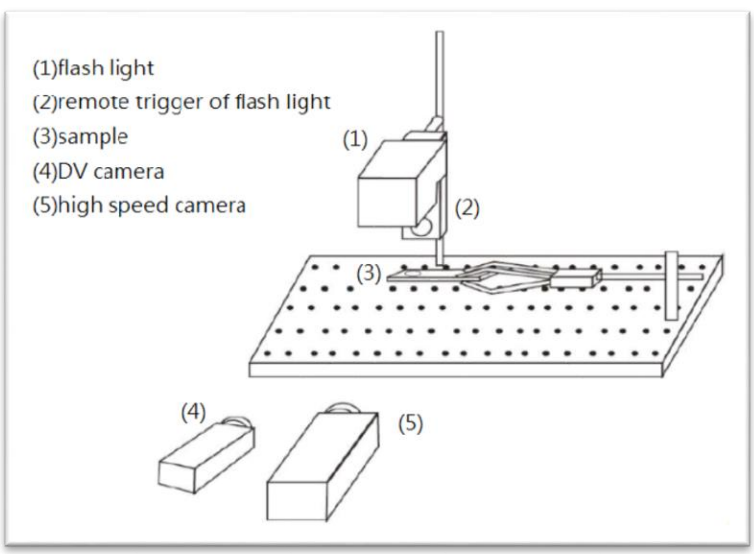

Figure 1. Schematic diagram of the experimental setup for flash-ignition

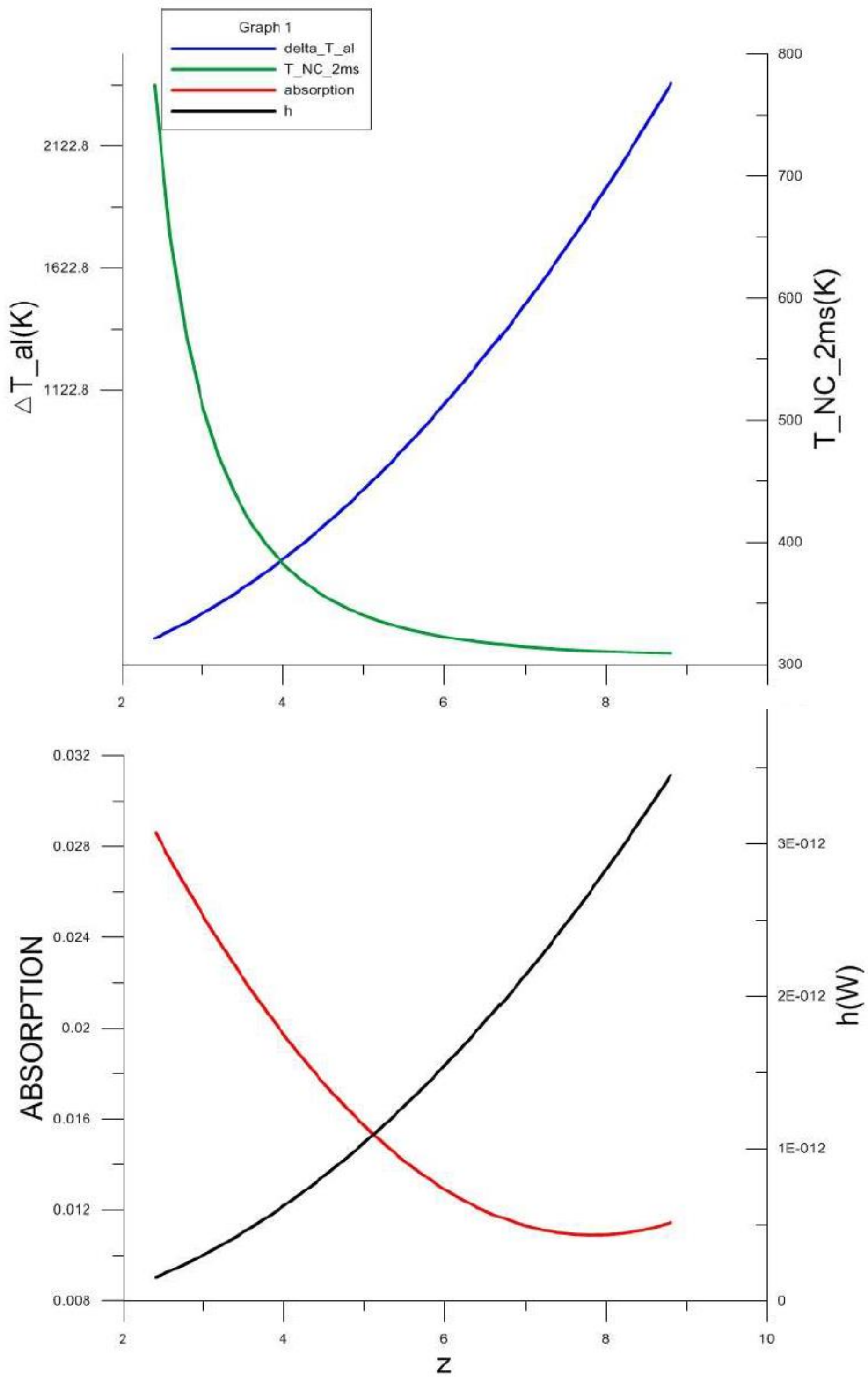

Figure 2. Results from theoretical analysis with well-distributed aluminum nanoparticle

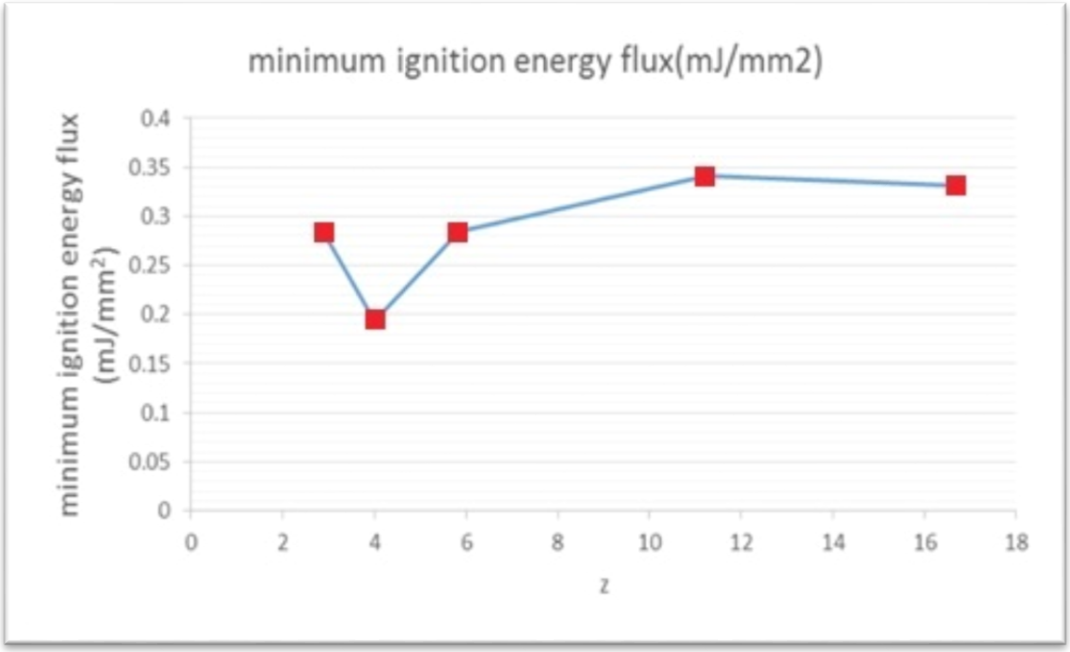

Figure3-a. Minimum ignition energy as a function of the aluminum interparticle distance —sample1

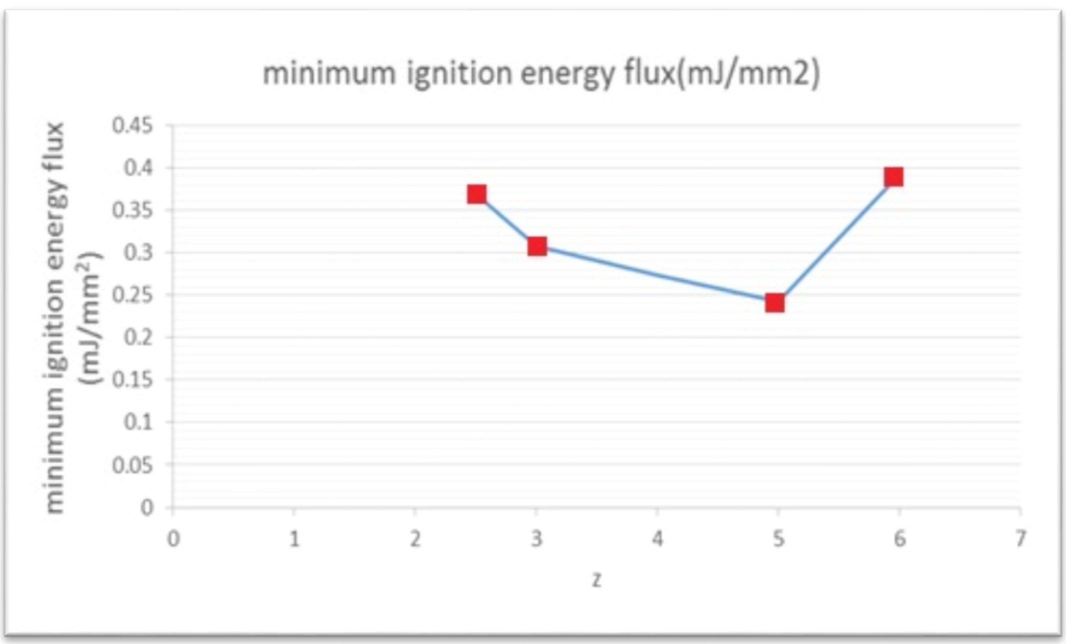

Figure3-b. Minimum ignition energy as a function of the aluminum interparticle distance —sample 2