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The Influence of Ignition Manner on Micropyretic Synthesis of High Exothermic Reaction with Ti+2B

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Abstract: This study investigates the influences of the ignition power on the parameters of the unstable micropyretic synthesis, including the length of pre-heating zone, the propagating velocity and the oscillatory frequency. The results generated in this research can be aided to systematically understand the influence of ignition powers on the unstable micropyretic synthesis.

Key words: Ignition power, micropyretic synthesis, combustion synthesis

INTRODUCTION

The previous study has reported that the ignition manners have the significant effect on changing the length of pre-heating zone and propagating velocity for the stable micropyretic synthesis of Ni+Al compound[1]. For the unstable micropyretic synthesis, the ignition power also influences the oscillatory frequency of the variations in the temperature and propagation velocity, further changing the homogeneity of the structures and properties of the synthesize product.

During the micropyretic synthesis, the compacted powders are ignited either by laser beam, induction coil, electric field, or microwave energy[2]. After ignition, the heat to propagate the combustion wave is obtained from the heat released by the formation of the synthesized product. The unreacted portion in front of the combustion wave is heated by this exothermic heat, undergoes synthesis, wave propagates, thus causing further reaction and synthesis. Since the micropyretic synthesis normally occurs in a few seconds, any small variations in the ignition powers have been reported to dramatically influence the propagation during micropyretic synthesis[3-5]. Thus, an understanding of the influences of the ignition powers on micropyretic synthesis is important. In this study, the numerical calculation was carried out to investigate the correlation of the ignition power with the length of pre-heating zone and the initial propagation velocity during micropyretic synthesis. The unstable TiB_2 micropyretic reaction is chosen to illustrate the effects of the ignition powers.

Numerical calculation procedure: A middle-difference approximation and an enthalpy-temperature method coupled with Guass-Seidel iteration procedure are used to solve the equations of the micropyretic synthesis problems. In the computational simulation, a one-dimensional sample of 1 cm long is divided into 1201 nodes (regions) to calculate the local temperature. This one-dimensional numerical model assumes the following sequence of events: (1) the specimen is gradually heated by a surface heat source in a tiny timestep ($2x10^{-5}$ s) until the combustion front starts to propagate; (2) the reaction is ignited and the combustion front propagates along the specimen; (3) there is only a cooling source at the end. The parameter values used in the computational calculation and the detail numerical calculation procedure have been reported in the previous studies[3-6].

RESULTS AND DISCUSSION

Figure 1 shows the temperature profiles of combustion fronts at various times along the TiB_2 specimen with the ignition powers of 5000, 10000 and 15000 Joule s^{-1}, respectively. The micropyretic reaction is heated by a constant heating rate (power) at the position 0 cm and the heating source is immediately removed after the micropyretic reaction has been ignited. Since the activation energy for Ti+2 B micropyretic reaction is relatively higher than other micropyretic reactions, the combustion front of TiB_2 system has been found to propagate in a rather unstable manner[3]. In such an unstable propagation, the temperature and propagation velocity of the combustion front are periodically changed with the distance, as shown in Fig. 1.

Figure 1 also shows that the different ignition powers change the thermal profiles in the initial stage (0.0-0.2 cm), further influencing the other parameters. Figure 1 shows that the combustion front takes 0.0406 s to start propagating when the ignition power of 5000 J s^{-1} is used. When the ignition powers are further, respectively

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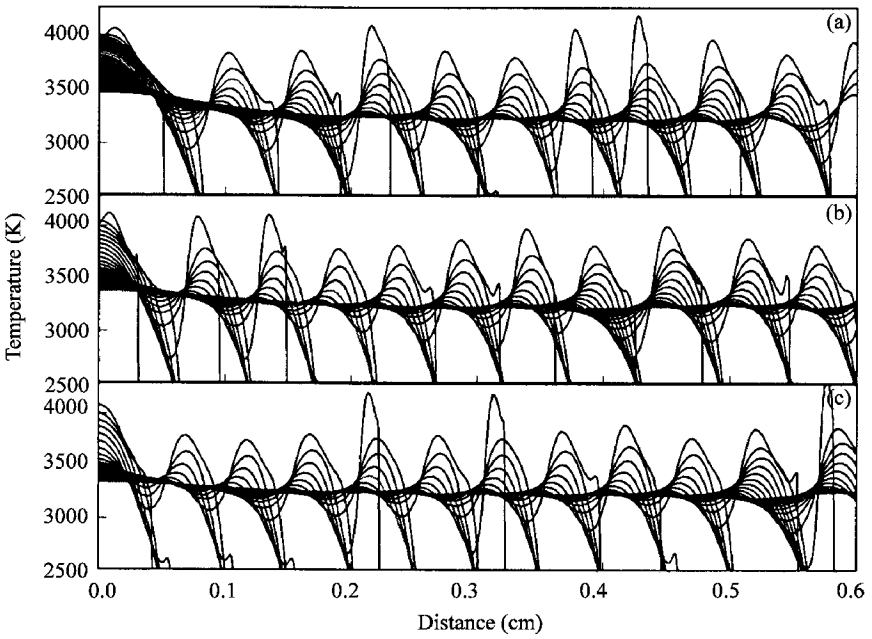

Fig. 1: Time variation of the combustion front temperature for the Ti+2B micropyretic reaction. The interval time between two consecutive time steps (profiles) is 0.002 s. The ignition powers in a, b and c are 5000, 10000 and 15000 J s^{-1}, respectively

Table 1: The oscillatory frequency (s^{-1}) of variations in combustion temperature for the Ti+2B unstable micropyretic reaction

Ignition powers	5000 J s^{-1}	10000 J s^{-1}	15000 J s^{-1}
Ignition area	88±15	102±17	111±12
Other areas	94±6	95±14	96±14

Table 2: The required ignition time and the required ignition energy for the specimens with different igniting powers. The pre-exponential factor is taken as $1x10^{10}$ s^{-1}

Ignition powers	5000 J s^{-1}	10000 J s^{-1}	15000 J s^{-1}
Required ignition time (sec)	0.0401	0.0210	0.0145
Required ignition energy (Joule)	200.3000	210.4000	216.9000

increased to 10000 and 15000 J s^{-1}, the energy are quickly accumulated at the ignition (left) end to ignite the reaction. Therefore, the time required for ignition is noted to decrease to 0.0212 and 0.0144 s, respectively. In addition, it is noted that the oscillatory frequency of the temperature variations for the reaction with a higher power is larger than that with a lower power in the initial stage. It is noted that the oscillatory frequency of temperature variations in the ignition area is increased with the increase in the ignition power (Table 1). However, there is no significant difference in oscillatory frequency between the specimens with the various ignition powers after the combustion front propagates far from the ignition spot (Table 1). It is inferred that the ignition power only affects the regions closed to the ignition spot.

A higher temperature gradient is observed as the micropyretic reaction is ignited by a higher ignition power. A higher heat loss is correspondingly to occur, thus, the required energy to ignite the micropyretic reaction is noted to increase with the increase in the ignition power. Table 2 shows that the required energy to ignite the reaction is found to increased in 8.5% (from 200 Joule to 217 Joule) when the ignition power is changed from 5000 to 15000 Joule s^{-1}. At the same increment in the ignition power, the required time to ignite the reaction is decreased in 65% (from 0.0406 s to 0.0144 s).

It has been reported above that a higher ignition power leads to a higher heat loss and the thermal energy is correspondingly to increase in the pre-heating zone. Thus, the length of the first pre-heating zone for the specimen with a higher ignition power is larger than that with a lower ignition power at the beginning of the ignition (Fig. 2a). The zone length for the specimen with a lower ignition power is continuously increased due to a longer ignition time and reaches a maximum value of 0.168 cm. It also causes the combustion temperature and propagation velocity of the combustion front increase to the maximum values[6]. When the combustion front propagates far from the ignition spot, the zone length is gradually decreased to the stable oscillatory values. For the reactions with the ignition powers of 10000 and 15000 Joule s^{-1}, the temperature gradient at the ignition spot is decreased. The heat loss is correspondingly decreased and the temperature profiles at the ignition spot do not display the differences with those in the other area. Thus, the length of the first pre-heating zone is similar with the normal values (Fig. 2b and c).

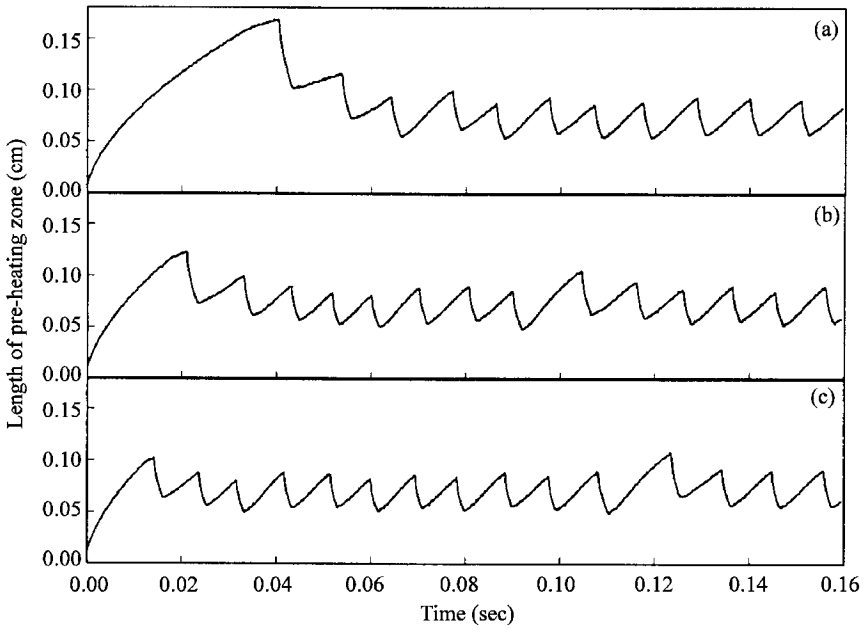

Fig. 2: Plots of the length of pre-heating zone with the reaction time during TiB_2 micropyretic reaction. The ignition powers in a, b and c are 5000, 10000 and 15000 J s^{-1}, respectively

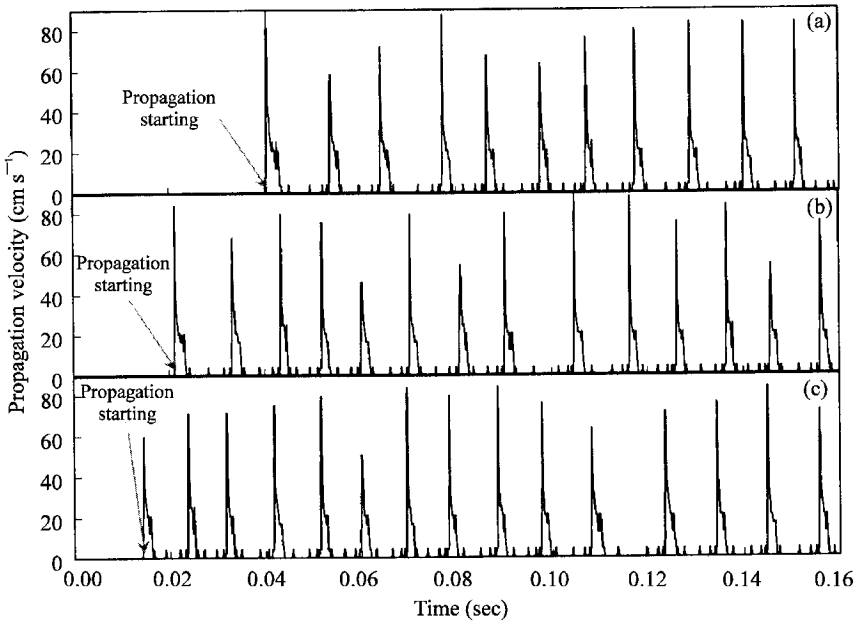

Fig. 3: Plots of the time variation of the instant propagation velocity of the TiB_2 specimens. The ignition powers in a, b and c are 5000, 10000 and 15000 J s^{-1}, respectively

It has been reported that an increase in the initial temperature in the pre-heating zone increases the instant propagation velocity[7]. The previous numerical results have indicated that a lower ignition power increases the ignition time and causes the more thermal energy to transfer to the pre-heating zone. The initial temperature in the pre-heating zone is expected to increase. It is noted from Fig. 3 that the propagation velocity is correspondingly increased. The start propagation velocity reaches the maximum value, 95.8 cm s^{-1}. After the micropyretic reaction has been ignited, the exothermic heat quickly triggers the new reaction. Thus, the

propagation velocity is gradually decreased to the normally values. When the ignition powers are further increased to 10000 and 15000 Joule s^{-1}, the start propagation velocities are found to respectively decrease to 83.3 and 58.3 cm s^{-1} (Fig. 3b and c).

CONCLUSIONS

The above numerical results show that a lower ignition power takes a longer time to ignite the specimens. Thus, the length of pre-heating zone is correspondingly increased, further dramatically changing the temperature (Fig. 1) and the velocity (Fig. 3) at the initial propagation. The calculation indicates that the standard deviation of the length of the pre-heating zone for the reaction with a lower ignition power (5000 Joule s^{-1}) is 2.5 times more than that for the reaction with a higher ignition power (15000 Joule s^{-1}). Such a larger variation may result in the non-homogeneous microstructure and properties at the ignition spot. The numerical results also indicate that the specimen may be quickly ignited by a higher ignition power to prevent from the heterogeneous structures. However, a higher ignition power also results in higher heat conduction and consumes the additional energy required to ignite the specimens. There are 8.5% increments in energy and 65% decrements in the required time to ignite the specimen when the ignition power is increased from 5000 to 15000 Joule s^{-1}. The results generated in this study suggest that the optimal ignition power should be carefully chosen in order to reduce the processing cost and obtain the homogeneous synthesized product.

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