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Effect of particle size of iron on reaction velocity of combustion synthesis of Ti-C-Fe system ①

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[Abstract] Four Ti-C-Fe powder mixtures, with a same molar ratio but different particle sizes of Fe and Ti, were used to measure the reaction velocity of the combustion synthesis. The results show that in the case of the finer Ti powder used, the reaction velocity of mixture with the finer Fe powder is higher than that with the coarser Fe powder. However, in the case of the coarser Ti powder used, the reaction velocity of mixture with the finer Fe powder is lower than that with the coarser Fe powder. The effect of particle size of Fe powder on reaction velocity can be explained with the previously proposed mechanisms of the combustion synthesis of Ti-C-Fe system.

[Key words] Ti-C-Fe; combustion synthesis; reaction velocity
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1 INTRODUCTION

Although TiC has an extremely high hardness, a high brittleness restricts its application. However, the brittleness can be improved by an addition of metal such as Ti[1], Al[2~4], Al-Cu[5] or Fe[6~17] to form a TiC-metal cermet. The TiC-Fe cermet has been prepared by a liquid-phase sintering from TiC and Fe powders or a combustion synthesizing from Ti-C-Fe powders[6~17].

It has been known that in the combustion synthesis of TiC, both the combustion temperature and the velocity of wave propagation decreased with increasing particle size of Ti powder[18], but it has not been known that the particle size of Fe would affect the reaction velocity of combustion synthesis of Ti-C-Fe system or not. For the self-propagating combustion synthesis of Ti-C-Fe system, Choi and Rhee[6] had observed that the reaction between Ti and C is more favorable than any other reactions in the Ti-C-Fe system, and the Fe addition mainly serves as a diluent and contributes to the binding of TiC grains in a matrix. For the thermal explosion combustion synthesis of Ti-C-Fe system, Saidi et al[7] and Capaldi et al[8] suggested that the Fe acts as a moderator for the reaction of Ti+ C and leads to a decrease of the combustion temperature. However, Fan et al[10~13, 15, 17] have proved that the Fe addition participates in the reaction for forming TiC in the combustion synthesis of Ti-C-Fe system. Then from this, it can be inferred that the reaction velocity of combustion synthesis of Ti-C-Fe system may be influenced by the particle size of Fe. However, it has not been proved.

In the present work, four Ti-C-Fe powder mixtures, with a same molar ratio but different particle sizes of Fe and Ti, were used to measure the reaction velocity of the combustion synthesis. The experimental results were explained with the previously proposed mechanisms of the combustion synthesis of Ti-C-Fe system.

2 EXPERIMENTAL

30% (in mass fraction) Fe powder with two size ranges (135~ 154 μm and < 45 μm), 56% Ti powder with two size ranges (135 ~ 154 μm and < 45 μm) and 14% carbon black (0.033~ 0.079 μm) were mixed thoroughly to form four Ti-C-Fe powder mixtures with a same molar ratio but different particle sizes of Ti and Fe, as listed in Table 1.

The four mixtures were compressed respectively as a compact (d 18 mm × 36 mm) with a relative density of about 60%. Two pairs of W-3% Re vs W-25% Re thermocouples (0.1 mm in diameter) were set against the outside of the compact with the junctions of the thermocouples 20 mm apart from each other in the axial direction of the compact, and linked with an x-y recorder, as shown in Fig. 1. Then the compact was ignited in a reaction chamber by an incandescent flat of graphite placed 2 mm above the top surface of the compact at a pressure of 0.1 MPa of argon at an initial temperature of 298 K. A combustion wave self-propagated through the compact, and two temperature-time curves were recorded with one x-y recorder. Thus a rate of the wave propagation could be given out from Δt/20 mm, where the Δt is the time interval between the two curves.

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Table 1 Four Ti-C-Fe powder mixtures and their reaction velocities of combustion synthesis

Mixture	Particle size of reactant powder/μm			Average rise rate of reaction temperature /(K•s⁻¹)	Rate of wave propagation /(mm•s⁻¹)
	Ti	Fe	C		
1	< 45	< 45	0.033~ 0.079	1905	9.1
2	< 45	135~ 154	0.033~ 0.079	1510	8.0
3	135~ 154	135~ 154	0.033~ 0.079	602	3.1
4	135~ 154	< 45	0.033~ 0.079	315	2.0

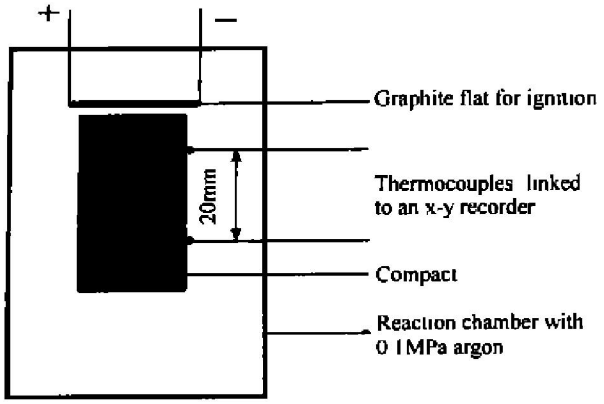

Fig. 1 Schematic of measurement for velocity of combustion wave propagation

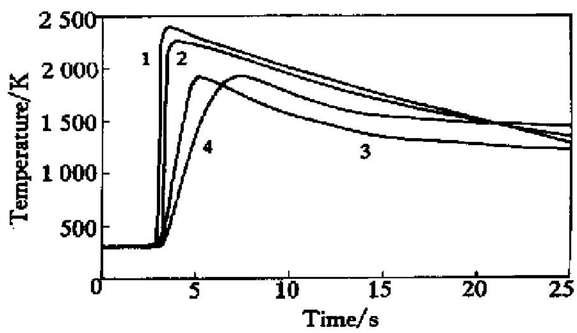

Fig. 2 Temperature-time curves of combustion reaction

1 —For mixture 1 with finer Ti and finer Fe powders;
2 —For mixture 2 with finer Ti and coarser Fe powders;
3 —For mixture 3 with coarser Ti and coarser Fe powders;
4 —For mixture 4 with coarser Ti and finer Fe powders

3 RESULTS

The measured rates of the wave propagation are listed in Table 1. It can be seen that the wave velocities of mixtures with the finer Ti powder are much higher ($9.1\,mm\cdot s^{-1}$ and $8.0\,mm\cdot s^{-1}$) than those ($3.1\,mm\cdot s^{-1}$ and $2.0\,mm\cdot s^{-1}$) with the coarser Ti powder whether the Fe powder is finer or coarser. This indicates that the effect of particle size of Ti is greater than that of Fe on the rate of wave propagation. However, the wave velocity of mixture with the finer Fe powder is higher ($9.1\,mm\cdot s^{-1}$) than that ($8.0\,mm\cdot s^{-1}$) with the coarser Fe powder when the finer Ti powder is used, whereas the wave velocity of mixture with the finer Fe powder is lower ($2.0\,mm\cdot s^{-1}$) than that ($3.1\,mm\cdot s^{-1}$) with the coarser Fe powder when the coarser Ti powder is used.

Fig. 2 shows the temperature-time curves of the combustion reaction of the four mixtures. It can be seen that there are remarkable differences among the maximum temperatures, i.e. the combustion temperature, T_c, and the rise rate of reaction temperature to T_c from the initial temperature, T_0. An average rise rate of reaction temperature can be calculated from $(T_c - T_0)/\Delta t$, where the Δt is the time interval in which the reaction temperature rises to T_c from T_0, and the calculated results are listed in Table 1. Both the average rise rate of reaction temperature and the rate of the combustion wave propagation indicate the reaction velocity of the combustion synthesis, and the experimental results show that the dependence of them on the particle sizes of Ti and Fe is consistent with each other.

4 DISCUSSION

In the combustion synthesis of Ti-C-Fe powders mixture, if the Fe powder does not participate in the reaction for forming TiC, then the particle size of Fe will affect the reaction velocity of the combustion synthesis only by means of changing contact area of the Ti powder with the carbon black. Thus the reaction velocity of mixture with the finer Fe powder is lower than that with the coarser Fe powder due to a decrease in contact area of the Ti powder with the carbon black. This is contrary to the results obtained in the case of the finer Ti powder used, where the reaction velocity of mixture with the finer Fe powder is higher than that with the coarser Fe powder. Therefore, the assumption, that the Fe powder didn't participate in the reaction for forming TiC, is not correct.

In fact, it has been proved that the Fe powder does participate in the reaction for forming TiC in the combustion synthesis of Ti-C-Fe system[10~13, 15, 17]. In the combustion synthesis, the reaction of Ti+ C takes place in Ti and Fe particles respectively, and the reaction in the Ti particle occurs earlier than that in the Fe particle. In the case of the coarser Ti powder used, the combustion reaction takes place by a ternary-reaction-diffusion/dissolution-precipitation mechanism whether the Fe powders is coarser[11] or finer[12], namely, the reaction in the Ti particle occurs in the solid state and by a ternary-reaction-diffusion mechanism, and the reaction in the Fe particle is in the liquid state and by a dissolution-precipitation mechanism. In the case of the finer Ti powder used, the combustion reaction takes place by a dual-dissolution-precipitation mechanism when the coarser Fe powder is used, namely, both the reactions in the Ti and in the Fe particles takes place in the liquid state and by a dissolution-precipitation mechanism[17], and it can be deduced that the combustion reaction will occur by the dual-dissolution-precipitation mechanism too when the finer Fe powder is used.

From the mechanisms stated above, it is not difficult to understand the effect of the particle size of Fe on the reaction velocity of combustion synthesis of Ti-C-Fe system. Because the reaction in the Ti particle is earlier than that in the Fe particle, the effect of the Ti particle size is greater than that of the Fe particle size on the reaction velocity, and the reaction velocity of mixture with the finer Ti powder is much higher than that with the coarser Ti powder due to the liquid-state reaction in the finer Ti particle and the solid-state reaction in the coarser Ti particle. In the case of the finer Ti powder used, since both the reactions in Ti and Fe particles occurred in the liquid state and by the dissolution-precipitation mechanism, and the reaction in the finer Fe powder is more favorable than that in the coarser Fe powder, then the reaction velocity of mixture with the finer Fe powder is higher than that with the coarser Fe powder. While in the case of the coarser Ti powder used, the reaction in the Ti particle takes place in the solid state and by the ternary-reaction-diffusion mechanism, and the reaction in the Fe particle takes place in the liquid state and by the dissolution-precipitation mechanism. And what is more important that, the finer Fe powder caused the reaction in the Ti particle more difficult due to a decrease in contact area of the Ti powder with the carbon black, so the mixture with the finer Fe powder gave the lower reaction velocity than that by the mixture with the coarser Fe powder although the decrease in the Fe particle size was benefit to the reaction in the Fe particle.

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