The Canister Experiment of the Ti-C Reaction As a Heat Source for Space Chemical Release Experiments

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ABSTRACT

A canister experiment of the Ti-C reaction as the heating technique for chemical release experiments was carried out in the laboratory. A pulse power source was utilized to produce a spark between a pin electrode and the reaction mixture. The heat generated in the reaction was used to heat and vaporize the release material. During the experiment, the temperature and combustion velocity of the reaction, the discharge voltage and current, and the pressure in the canister were measured.

INTRODUCTION

In the past decades, many chemical release experiments have been carried out to test the hypothesis of critical ionization velocity as proposed by Alven [1954]. In the chemical release experiment on the CRRES satellite [M. H. Johnson et al., 1992; Reasoner, 1992; Bernhardt, 1992; E.M. Wescott et al., 1994], the Titanium-Boron thermite reaction was used to heat and vaporize the release metal such as barium and strontium. Since pure boron is expensive and difficult to get, we selected Ti-C reaction as the heat source for our chemical release experiment. As we know, one mole titanium can combine with one mole carbon to yield 44kcal of heat. When the temperature is above 1400°C, heat generated during the reaction will make the reaction continue without any external heat source. Thus, the main issue of the experiment was to ignite the thermite mixture of titanium and carbon and then to utilize the energy generated to heat and further vaporize the diluted release material. When the pressure in the sealed canister exceeded a certain value, the canister was suddenly opened and the metallic vapor of release material was ejected out quickly through a nozzle of the canister. Since the thermodynamic property of Sb is similar to that of barium and Sb is much easier to handle than barium, we used Sb instead of barium as the release material in the experiment. In the experiment, we used electric discharge as the technique to ignite the thermite mixture.

In this paper, the experimental results of the discharge voltage and current, the temperature and combustion velocity of the reaction, and the pressure in the canister are presented.

EXPERIMENTAL SETUP
The experimental setup of the Ti-C reaction is schematically shown in Fig. 1a. A charged capacitor is used as a power source. When the thyristor is triggered, there will be a certain voltage between the pin electrode and the reaction mixture, thereby an electric discharge will be produced between them so as to ignite reaction mixture. The cylindrical canister is made of stainless steel, and its inner radius and length are 48mm and 260mm respectively. To protect the inner wall of the canister from destruction due to high temperature resulting from the heat generated during the reaction, a cylindrical carbon ring which has an outer radius equal to the inner one of the canister is used; the thickness of the ring is 17mm. The mixed powder of Ti, C and Sb is compressed into small columns which are accommodated in the ring. In the mixed powder, the Ti and C have the same mole number.

![Fig. 1. Schematic setup of Ti-C reaction experiment. (a) Circuit to produce electric discharge to ignite the reaction mixture. (b) Arrangement of the two thermocouples to measure the temperature and combustion velocity of the reaction.](image)

A 200A/3V current transducer and a 1000V/1V divider resistance were used to measure the discharge current and voltage, the curves of the resultant signals were shown on the screen of a HP54652A digital synchroscope. Since the temperature during the reaction is very high, two tungsten-rhenium thermocouples shown in fig.1b are used to measure the temperature and combustion velocity of the reaction. These two thermocouples are so arranged that the axial distance between them is about 75mm. When ignition take place at the very place where one thermocouple is located, the output signal from the thermocouple rises suddenly, thus we can determine the temperature as well as the combustion velocity simultaneously. Another diagnostic device includes a 1atm/0.356mV pressure transducer to measure the pressure in the canister. All the signals from these diagnostic and measuring devices except the current transducer and divider resistance are sampled by a 500k/s data acquisition system and then stored in a computer.

**EXPERIMENTAL RESULTS**

In this experiment, the reaction mixture is ignited nearly at the same time as an electric discharge occurs between the electrode and the mixture. Fig. 2 is the temporal evolution of discharge current and voltage displayed on the screen of the synchroscope. From this figure, we find that the discharge lasts about 100μs, and the maximum discharge voltage and current are about 300V and 13A respectively. Thus we can conclude that total discharge energy is less than 0.25J. This means that the igniting technique now used has an obvious advantage over previous resistance heating technique (Xu et al, 1995) which needs a large amount of electric energy and is time consuming.
In the canister experiment, the temperature and combustion velocity of Ti-C reaction play a very important role in determining the mass percentage of the release material and the vaporization speed. The output signals from the two thermocouples during the Ti-C reaction without release material are shown in Fig. 3. The maximum value of about 45mV means that the maximum temperature during reaction is about 2500°C.

Also, it is obviously seen that the time interval between the two upright front edges of the two curves is about 8.3s. Therefore, it can be deduced that the combustion velocity is about 9mm/s.

Fig. 4 shows the time evolution of the pressure in the sealed canister with Ti-C mixed with 20% Sb. The pressure increases quickly and reaches the maximum value of about 18.5atm, then drops down slowly. Fig. 5 is an image of ejection of release metal Sb during an release experiment. Since the diameter of the nozzle is very small (12mm) and the explosion pressure is low, the release process lasts more than 15s, the release efficiency is about 40%. In another experiment where we increase the diameter of the nozzle and the explosion pressure, the release process duration is less than one second.

CONCLUSION

In conclusion, during the canister experiment of Ti-C reaction, the temperature can reach as high as 2500°C without diluent material and the combustion velocity is about 9mm/s. In the sealed canister, the
pressure increases quickly to the maximum value of 18.5 atm, then decreases slowly. The curves of discharge voltage and current indicate that energy needed to ignite the reaction mixture is very small. Also, it is found that the diameter of the nozzle and the explosion pressure are two critical parameters which finally determine the release time. In further experiments, we will use barium as the release material and we will provide an environment similar to where the release will be located so as to model the evolution of barium at high altitude.

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REFERENCES