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The mechanical behaviors of polytetrafluorethylene/Al/W energetic composites

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Abstract
The tensile and impact properties of polytetrafluorethylene (PTFE)/Al/W reactive energetic composites were investigated using a universal materials testing machine and an improved pendulum impact tester at room temperature. Samples of four types, all containing W, of differing composition and particle size were prepared by cold pressing and sintering. With increasing W content in the PTFE/Al/W samples, the mass loss during sintering and the density of the materials obtained increased. The addition of microlevel W led to the tensile strength decreasing from 25.3 to 19.8 MPa, while the elongation changed little, but substituting nanolevel W for 5 wt% Al yields a maximal strength of 31.4 MPa. The failure behavior of PTFE/Al/W includes deformation, fracture, disorganization and reaction, in four steps. The addition of 30 wt% of coarse W particles improved the impact strength of the material, but the reactive activity increased and the perfectability of the reaction decreased.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

In recent years, reactive energetic composites based on PTFE (polytetrafluorethylene)/metal such as PTFE/Al received broad attention because of their special response to mechanical shock. Lots of experiments have been performed to investigate the mechanical properties of PTFE/metal energetic composites [1–3]. A better understanding of the impact characteristic of these materials will be useful for their applications in a wide range of shock loading. Several authors have reported the tensile, compression, and impact behaviors, reaction efficiencies and detonation of PTFE/Al [4–9]. Cai *et al* made a detailed study of the mechanical and impact-initiated properties of PTFE/Al/W (tungsten) by using quasi-static, Hopkinson bar and dropped-weight experiments. They have acquired many very important experimental data and set up some models to explain their findings [10–13].

Some applications of these reactive materials require us to develop composites with higher density and strength. The effect of the size of the inclusions and the interface on the mechanical properties such as strength and toughness has been reported for several cases of materials [14–17], but few studies have been conducted to investigate the mechanical behavior and impact initiation of such sintered PTFE/Al/W composites which contain W at different particle sizes and mass ratios. In this paper, the quasi-static tensile and impact properties of these materials at room temperature are presented. Additionally, the impact-initiated characteristics were also investigated by carrying out an impact experiment. The composite containing fine nanolevel W particles had a higher tensile strength than materials with coarse microlevel W particles and samples containing no W particles. The addition of W particles improved the impact strength of the samples, but the reactive activity increased and the perfectibility of the reaction decreased.

2. Experimental procedure

Cold pressing and sintering were used to prepare PTFE/Al/W samples containing four different densities and particle sizes of W particles. The imposed pressure was 20 MPa and the

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Table 1. Information on the initial W particles.

Particle	Density (g cm^{-3})	Size (μm)	W content (%)
W1	19.35	10	99.9
W2	17.83	2.5	95
W3	15.63	10	93.9
W4	11.99	0.1	85

samples were sintered in an Ar atmosphere at 380 °C for 2 h. The initial particles had the following average sizes: Al: 7 μm (JT-4); PTFE: 25 μm (3M, PTFE TFM-1700). The information on the W particles is listed in table 1; W1 was purchased as pure tungsten, and the others (W2, W3 and W4) were compounds of pure tungsten obtained via surface treatment.

In the PTFE/Al/W (PAW for short; for example, PAW2-30% represents the sample containing 30 wt% W2) samples which contain W1, W2 or W3 particles, the W powders were added successively from 0–45 wt% on the basis that the stoichiometric mixture of 73.5 wt% PTFE and 26.5 wt% Al was to be maintained. The nanolevel W4 powder was added to substitute for 0–8 wt% Al.

The mass loss during sintering was obtained by weighing samples before and after sintering. The density of samples was tested by the drainage method according to Archimedes' principle. The typical tensile samples were machined to form GB 16421-1996 type I samples. The testing rate was 10 mm min^{-1} and all the samples were strained to failure. Strain data were obtained by using strain gauges. At least three samples, usually five, for each sample type were tested under the same conditions.

The impact tests were performed using an improved pendulum impact tester; the pendulum impacts a surface of a 10 × 10 × 10 mm cubic sample directly. So besides the impact strength, we could also get deformed and impact-initiated property values. One of the hypotheses for this behavior was that the sample absorbs all the loaded impact work.

3. Results and discussion

The mass loss during the sintering process and the density of samples after sintering are shown in figure 1. The PTFE/Al composite only had a mass loss of about 0.01% after sintering, but with the addition of pure W1 particles, the mass loss increased to at most 0.25%. At the sinter temperature of 380 °C the tungsten element is more chemically reactive with PTFE than aluminum, so the added W reacted with trace amounts of hydrofluoric acid (HF) present at the sintering temperature and produced more highly volatile products. The PAW samples containing W4 have the maximum mass loss because of their maximal surface area. The mass losses of PAW samples containing W2 or W3 are the lowest, because the surface treatment of the W particles decreases their reactive activity.

The density of PAW samples increases linearly with the addition of all kinds of W particles, which ranged from 2.28 to 3.09 g cm^{-3} and 94.8–95.5% of the theoretical maximum density. The depressed reactive activity of W favors increase of the W content in PAW samples and yields higher density materials.

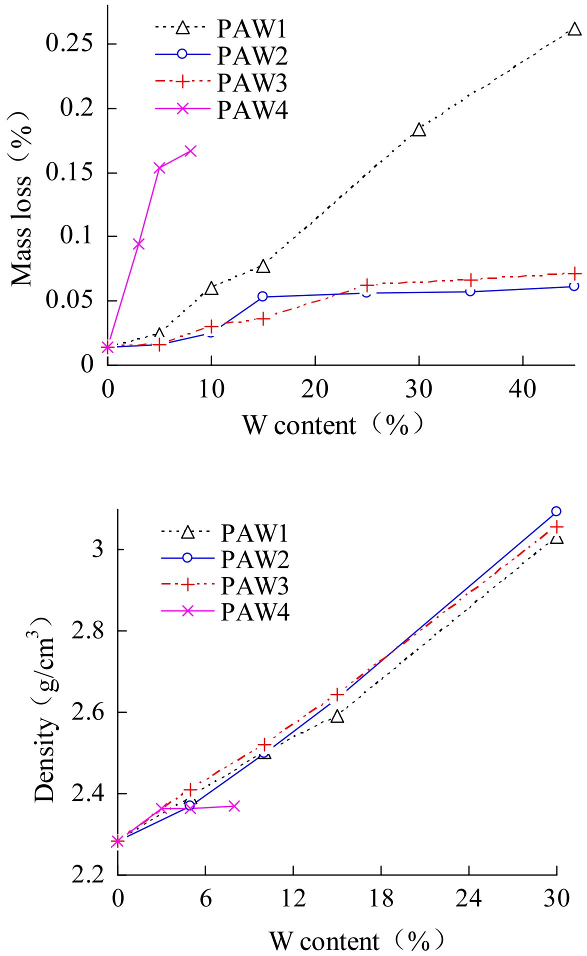

Figure 1. The mass loss and density of PAW samples.

The tensile stress–strain curves of PAW samples containing W2, W3 or W4 particles are displayed in figure 2. The 0–30 wt% addition of W2 or W3 results in the tensile strength and elongation of the materials decreasing from 25.3 MPa and 395% to 19.8 MPa and 350% or 21.2 MPa and 328%. With the increasing of the nanolevel W4 content in PAW, the tensile strength is enhanced and then decreased, with 31.4 MPa achieved at the content of 5 wt%. The elongation is decreased linearly from 395% to 235%.

The tensile property decline of PAW materials with coarse W particles could be attributed to the weak interface between the matrix and the tungsten filler and the decreased volume content of PTFE matrix, which makes the major contribution to the strength of these composites. After substituting fine nanolevel W for partial Al, the surface of the filler increases and the interface improves and is thus able to support stresses transferred from the matrix. Furthermore, the increase in particle amount is beneficial to the crystallization of PTFE and thus decreases the plasticity of materials (figure 3).

To investigate the impact behavior of PAW materials thoroughly, the pendulum impact tester was rebuilt and the pendulum impacted the surface of samples directly. The impact work was adjusted to make the PAW fragment samples with specific shape bring about different degrees of failure, including deformation (plastically deformed), fracture

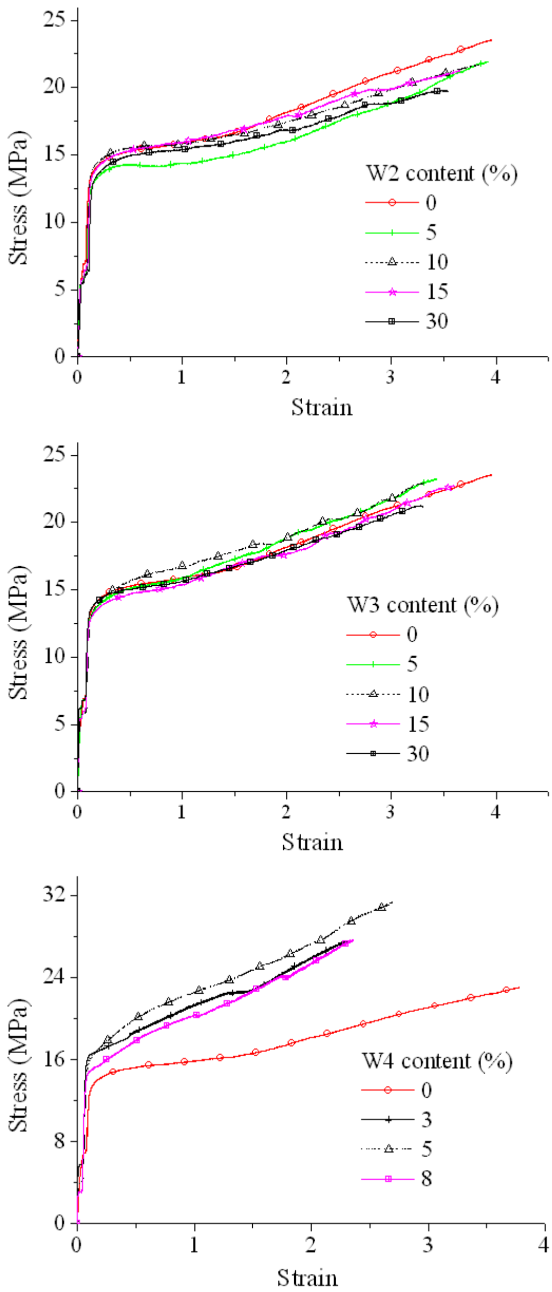

Figure 2. The tension response of PAW samples.

(covered with fine cracks), disorganization (separated into pieces) and reaction (producing a flame, smoke or sound), as shown in figure 4.

The impact testing results for three kinds of PAW samples are presented in table 2. The samples containing 30 wt% W2 or W3 have higher fracture work and disorganization work than the samples with no W particles. Tungsten particles have higher strength than Al particles and PTFE. When the material was impacted, the samples with W particles produced tinier cracks and the stresses could be transferred from the matrix to the metal filler, so the PAW samples could absorb more loaded impact energy.

The impact work needed to initiate the reaction of samples decreases with the addition of 30 wt% W particles in materials.

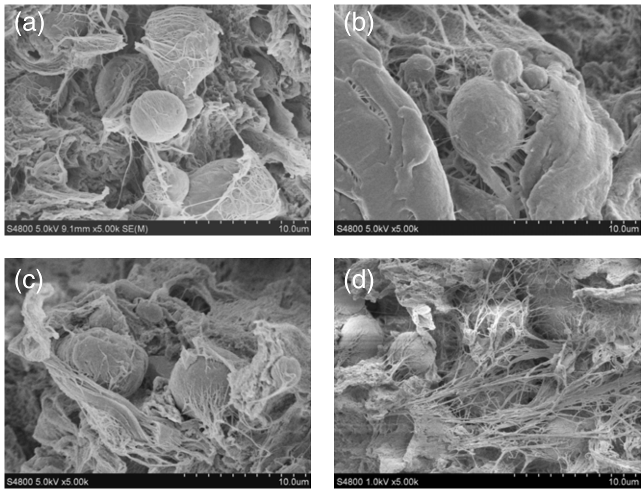

Figure 3. SEM images of the samples after tensile testing: (a) PAW1-0%; (b) PAW2-30%; (c) PAW3-30%; (d) PAW4-5%.

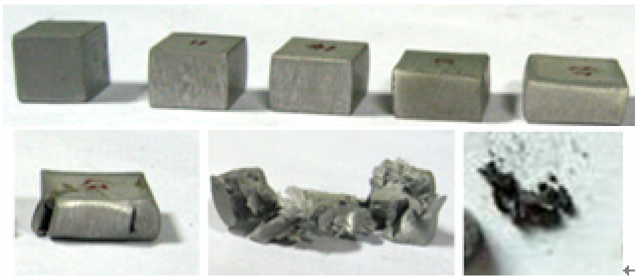

Figure 4. The deformation, fracture, disorganization and reaction phenomena for PAW specimens.

Table 2. Failure work of PAW samples.

Samples	Fracture ($J\ cm^{-2}$)	Disorganization ($J\ cm^{-2}$)	Reactive ($J\ cm^{-2}$)
PAW1-0%	55.91	66.59	116.59
PAW2-30%	74.87	90.13	101.27
PAW3-30%	70.03	86.74	106.16

As discussed in the above paragraphs, the reaction activity of PTFE with W is stronger than that with Al. Therefore the samples with W particles are easier to initiate reactions in under the some impact conditions. The reaction work of the PAW3-30% sample is higher than that of the PAW2-30% sample for the more chemically inert W3 particles.

The addition of W to materials had a great influence on the reaction characteristics of the samples. Figure 5 shows three video frames for the reaction climax for different samples. The reaction of PAW1-0% with no tungsten was the most violent and had a light range of about 12 inches × 12 inches with a lot of smoke produced; the burning lasted for 5 s and almost no sample remained. The other two samples containing W particles showed little reaction light; the reaction lasted no more than 100 ms and only a little of the sample was burnt. The reaction of the PAW3-30% samples was so faint that it could not be judged by eye.

At the initial stage of impact, the heat energy caused the aluminum element to be oxidized; Al oxidation will accelerate

Figure 5. The reaction climax for different PAW samples.

PTFE decomposition upon proceeding with impact in PAW mixtures, and fluorine-containing products in turn benefit Al oxidation. The PAW1-0% sample is a stoichiometric mixture of PTFE/Al (73.5/26.5 wt%), so the reaction is more easily spread. The reaction of samples with 30 wt% content of tungsten is incomplete for rich fuel.

4. Conclusions

Quasi-static tensile and impact-initiated properties of sintered energetic composite systems consisting of PTFE, Al and W particles were investigated. Four kinds of samples with different W particles and varying mass ratio were tested to determine the effect of different W particle and mass ratios on the tensile and impact-initiated properties of these materials.

The addition of W led to increase of mass loss during sintering and of the densities of the materials obtained, and this increase is in direct proportion to the W content in materials. Appropriate surface treatment of W particles can improve the compatibility of PTFE/Al/W, evidently. The fine nanolevel W particle-filled samples have a higher tensile strength than coarse microlevel W particle-filled ones and samples containing no W particles.

The rebuilt pendulum impact tester can be used to investigate the failure process of the PTFE/Al/W materials obtained clearly and simply. The failure behavior includes deformation, fracture, disorganization and reaction in four steps, along with increase of the impact energy. The added 30 wt% of coarse W particles increases the impact strength of the material, but results in a greater tendency to react, with the reaction lasting only a few milliseconds and being incomplete.

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