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Effects of carbon nanotubes and carbon fiber reinforcements on thermal conductivity and ablation properties of carbon/phenolic composites

Joung-Man Park [a,d,*], Dong-Jun Kwon [a], Zuo-Jia Wang [a], Jeong-U Roh [b], Woo-Il Lee [b], Jong-Kyoo Park [c], K. Lawrence DeVries [d]

[a] Department of Materials Engineering and Convergence Technology, Engineering Research Institute, Gyeongsang National University, Jinju 660-701, Republic of Korea
[b] School of Mechanical and Aerospace Engineering, Seoul National University, Seoul 151-742, Republic of Korea
[c] Agency for Defense Development, 4-R&D Center, Daejeon 305-600, Republic of Korea
[d] Department of Mechanical Engineering, The University of Utah, Salt Lake City, UT 84112, USA

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ABSTRACT

The ablation properties and thermal conductivity of carbon nanotube (CNT) and carbon fiber (CF)/phenolic composites were evaluated for different filler types and structures. It was found that the mechanical and thermal properties of phenolic-polymer matrix composites were improved significantly by the addition of carbon materials as reinforcement. The concentrations of CF and CNT reinforcing materials used in this study were 30 vol% and 0.5 wt%, respectively. The thermal conductivity and thermal diffusion of the different composites were observed during ablation testing, using an oxygen–kerosene (1:1) flame torch. The thermal conductivity of CF mat/phenolic composites was higher than that of random CF/phenolic composites. Both CF mat and CNT/phenolic composites exhibited much better thermal conductivity and ablation properties than did neat phenolic resin. The more conductive carbon materials significantly enhanced the heat conduction and dissipation from the flame location, thereby minimizing local thermal damage.

1. Introduction

Light-weight and multi-functional materials are of interest in and finding may uses in industry [1–3]. Since carbon reinforcements are known to enhance mechanical and thermal properties of high temperature composites, they are viable candidates for us as parts which need to be heat resistant such as engine nozzles for spacecraft applications. In spite of the enhanced performances, thermo-chemical constraints may lead to a recessive degradation of the carbon composite surface by mass loss or ablation. The cause of this mass loss is mainly oxidation, while mechanical erosion may also play a role. Since 1960, several experimental studies on the ablation of carbon composites have been reported [4]. Ablation is an erosive phenomenon that results in part of the material being removed by combined thermo-mechanical, thermo-chemical and thermo-physical influences due to a combustion flame or other heat source at high temperature, pressure and velocity. During ablation appreciable amounts of the heat flux may be converted to an outward mass flux through endothermic sublimation and chemical etching resulting in surface erosion and recession. Ablation may involve oxidation, evaporation and spallation of material. Ablation is controlled by extrinsic conditions (temperature, pressure and flame velocity) as well as intrinsic features of the material such as fiber architecture, matrix microstructure, bulk density and porosity. When carbon composites are subjected to ablative conditions, it is highly desirable that the fiber reinforcement and matrix retain their structure, mechanical properties and shape as long as possible [5–8]. For the evaluation of ablation properties, Laser and flame methods have typically been used to apply high temperatures (typically ~2000 K) to specimens. Flame temperature, pressure and density are important factors, when using a flame [9–11].

Among the materials used as ablatives, carbon reinforcement and phenolic resin have been widely studied [12]. From the viewpoint of oxidation resistance, silicon carbide (SiC) composites are likely superior to carbon composites because SiC exhibits excellent oxidation resistance [13,14]. Nano-sized fillers have also be used in composites and the resulting composites have exhibited improved ablation resistance [15–17].

Recently, multidirectional woven carbon fiber materials have used to produce composites with more or less isotropic properties

* Corresponding author at: Department of Materials Engineering and Convergence Technology, Engineering Research Institute, Gyeongsang National University, Jinju 660-701, Republic of Korea. Tel.: +82 55 772 1656; fax: +82 55 772 1659.

E-mail address: jmpark@gnu.ac.kr (J.-M. Park).

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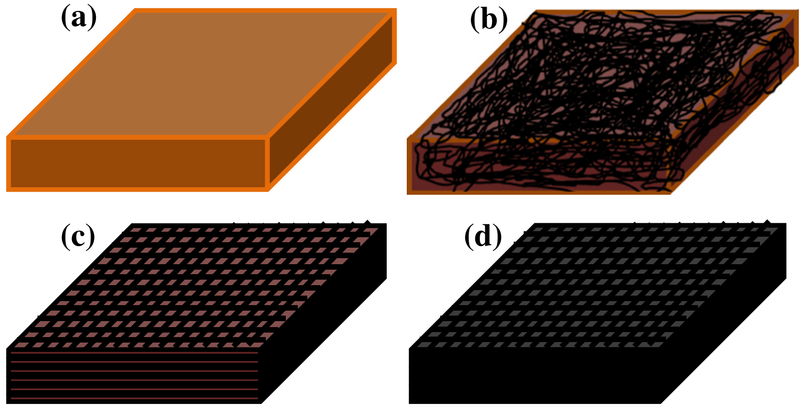

Fig. 1. Experiment specimens: (a) original phenolic plate (PR), (b) random chopped carbon fiber reinforced phenolic composite (RCFPC), (c) weaved carbon fiber mat reinforced phenolic composite (MCFPC) and (d) weaved carbon fiber mat/CNT reinforced phenolic composite (MCF/CNTPC).

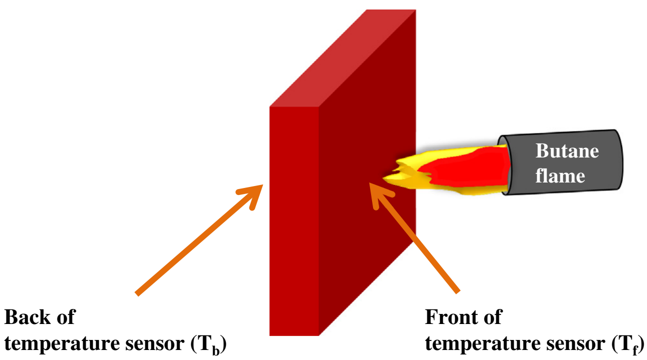

Fig. 2. Experimental set up for the flame retardant rest.

in relatively high density carbon composites. 3D woven composites, especially those with orthogonal configurations, have been pursued in the aerospace industry as a way of reducing the vulnerability to delamination under impact and local buckling failure under in-plane compression, which is commonly exhibited by 2D

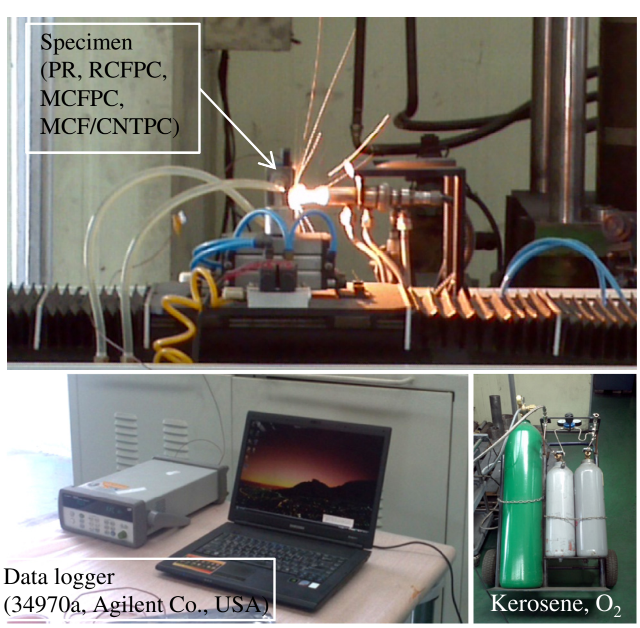

Fig. 3. Experiment set up of ablation test of specimens.

composites [18]. The formation of a coating on the carbon fibers used in a composite has been shown as an effective method of improving ablation-resistant. $TaCl_5$–Ar–C_3H_6, which has been used as such a coating, is characterized by high hardness, and a high melting point, as well as resistance to chemical attack, thermal shock and oxidation. It also has good thermal and electrical conductivity. These properties make it a very attractive candidate as an ablation-resistant carbon-fiber-coating for high temperature applications [19]. A goal of the research, describe in this paper was to explore how increases in the ease of heat transfer and dissipation, improves ablation stability. Heat can be dissipated by more highly thermal conductive materials thereby reducing thermal damage [20]. Surface roughening also effects heat transfer, resulting in an acceleration of surface recession [21,22].

In this study, the effects of orientation of CF and CNT reinforcement on thermal conductivity for ablation applications were investigated. Four specimen types were fabricated for the flame tests, i.e. (1) neat phenolic resin (PR), (2) a random chopped carbon fiber reinforced phenolic composite (RCFPC), (3) a woven carbon fiber mat reinforced phenolic composite (MCFPC) and (4) a woven carbon fiber mat/CNT reinforced phenolic composite (MCF/CNTPC). The following tests were conducted on these specimens: (a) flame retardant test, specimens were exposed to a butane gas flame at 1300 °C followed by a damage analysis of the specimen's surface including inspection of the cracks produced; (b) ablation testing, using an oxygen–kerosene flame torch at 2300 °C, of the specimens with different reinforcement materials and orientations; and (c) Thermogravimetric Analysis (TGA) tests were performed for material from both the front and back sides of the test specimens. These test results were used in an evaluation and comparison of the ablation properties and stabilities of the four different specimen types.

2. Experimental

2.1. Materials

Multi-wall carbon nanotubes (Hanhwa Nantech Co., Korea, Carbonation >95%, aspect ratio 444.5), produced by a chemical vapor deposition process, were used as reinforcing materials. Phenolic resin (RESINOX SC-1008, Monsanto Chemical Co., U.S.A.) based on a phenolic resole-type resin was used as the composite matrix. Acetone (Dae Jung Chemical, Co., Korea) was used as the CNT dispersing solvent. CF (CF3327NON (Plain), Hankuk carbon Co., Korea) was used in the WTR-3K type yarn. The dimension of the CF mat was 50 × 50 × 0.27 mm, and the chopped CF was clipped from CF mat with a length of approximately 30 mm.