Improved Nanoreinforced Composite Material Bonds with Potential Sensing Capabilities

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ABSTRACT

Dramatic increase in the bond strength of composite/adhesive interfaces of nanoreinforced composite material joints and structures has been achieved using laser-assisted fabrication of Micro-Column Arrays (MCA) on the surface of the two materials prior to bonding.

Several advantages of the MCA technology resulting in drastic improvement of virtually any bond include: interlocking of the adhesive material between micro columns, about 10-fold increase of the specific surface area, inherent elasticity of the micro columns, enhanced resistance to hydrothermal failures, substantially improved wettability, and control over the surface chemistry.

In order to take advantage of the unique electrical properties of both composite materials and the Carbon Nanotube (CNT) reinforced adhesive, experiments were performed to evaluate the potential of using electrical response of the bonded material to applied stress.

Keywords: nanoreinforced composites, laser-assited surface modification, micro-column arrays, electrical properties, sensing capabilities.

1 INTRODUCTION

Several industrial and aerospace applications require novel and reliable material systems and structures to meet the increasing requirements of innovative designs. Fiber reinforced composite materials have a high potential for applications in the areas of increased payload, reduced costs, and better survivability.

One of the very important issues in the aerospace industry is bonding of dissimilar materials, since high bond resistance to high and rapid thermal and mechanical loads is required.

Composite materials have very different coefficients of thermal expansion. In addition, structural properties and thermal conductivities are different too, which actually adds to the problem. Aerothermic heating, and high mechanical loads caused by ultra-high speeds, is one area targeted by the current research.

The main focus of this work is achievement of a dramatic increase of the bond strength in the adhesive and composite/adhesive interfaces of existing fiber reinforced composite material joints and structures suitable for various industrial, military, and NASA applications.

The technology developed at Integrated Micro Sensors Inc is based on laser-assisted fabrication of micro-column arrays on the surface of the two materials prior to bonding.

There are several advantages of the MCA technology in the drastic improvement of any bond: (i) mechanical strength increases due to interlocking of the adhesive or brazing material between micro columns, (ii) the bond strength increases due to the increase of the specific surface area by more than an order of magnitude, (iii) stability increases due to the inherent elasticity of the micro cones during a deformation, (iv) increase in the bond durability because of the repeated bend contours of the surface preventing hydrothermal failure, (v) wettability of the material surface significantly improves due to the highly developed surface morphology at the micro and submicron level and changes in local chemistry as a result of surface oxidation.

The MCA technology is efficient, highly scalable, reproducible, environmentally safe, and can be applied virtually to any solid state material. Our recent results show that MCA enhanced bonding process can be extended to heterogeneous relatively low melting point materials, like Reinforced Plastic Composites (RPC). The type, quality, number and orientation of the fibers in such materials can be selectively chosen to provide custom structural properties. These lightweight high strength versatile materials are increasingly important in numerous industrial arenas.

2 EXPERIMENTAL RESULTS

2.1 Fabrication of MCA structured surfaces on fiber reinforced composite materials

Previously employed MCA structured surfaces have remarkably improved the bonding between similar and dissimilar high melting point homogeneous materials such as titanium, silicon, and various ceramics, using metallic and organic bonding media [1-3].

It is currently anticipated, that the MCA enhanced bonding process can be extended also to heterogeneous relatively low melting point materials, like Fiber Reinforced Plastic (FRP) and Carbon Fiber Reinforced Plastic (CFRP) composites.

Experimental work conducted on various types of RPC materials indicated, that, while MCA technology is not well suitable for processing heterogeneous microfiber reinforced composites due to the size of the fiber comparable with the size of micro columns, it can be successfully applied to composites with reinforcing fibers on the nanoscale, such as, for example, carbon nanotubes, nanoparticles, or graphene. For this reason the efforts have shifted away from woven fiber materials toward those material types, which demonstrated the potential for increased bond strength, like RPC with unidirectionally and randomly oriented fibers.

As a result, a new laser assisted surface preparation technique has been introduced. This process removes the relatively weak binding resin at the surface of the composite leaving a dense mat of undamaged strong structural fibers able to be incorporated into and reinforce the bonding media.

Figure 1 below illustrates the dramatic effect of this new surface preparation technique on CFRP material with unidirectional fibers.

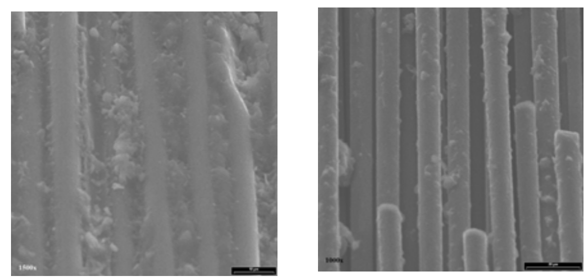

Figure 1: SEM (150X) images of unidirectionally carbon fiber reinforced sample surface before (left) and after (right) laser processing.

On RPC material with unidierectionally oriented fibers, a 30% average increase in bond strength over traditionally prepared samples was achieved, and the bond strength of the Devcon Epoxy was surpassed.

Figure 2 below is a stress/area (psi) vs elongation graph illustrating the single lap shear test results with the unidirectionally reinforced material. The first three samples were non laser processed and the last three were laser processed.

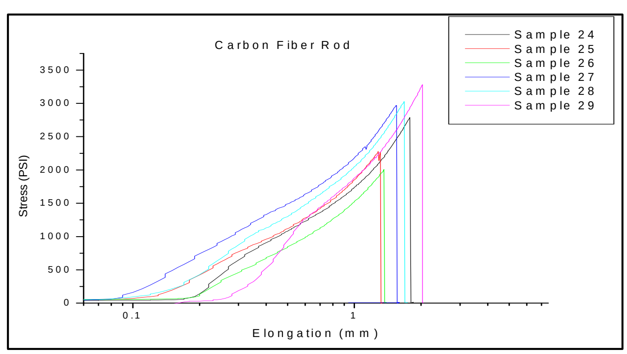

Figure 2: Stress-elongation graphs from testing of a unidirectionaly carbon fiber reinforced material.

These results were further confirmed (>40% strength increase was achieved) using Eponex, a CNT reinforced high strength epoxy adhesive and a RPC with randomly oriented fibers. The SEM image of laser processed surfaces of such a material is shown in Figure 3 below.

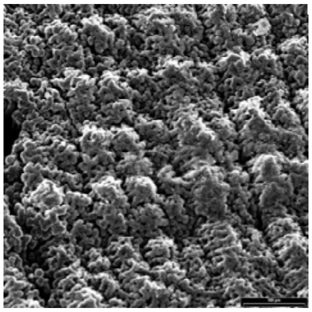

Figure 3: SEM (200X) image of a randomly carbon fiber reinforced composite material.

Figure 4 illustrates the stress (psi) vs. elongation of the RPC samples with randomly oriented carbon fibers. Samples 42, 43, and 44 were laser processed, and samples 45, 46, and 47 were not laser processed.

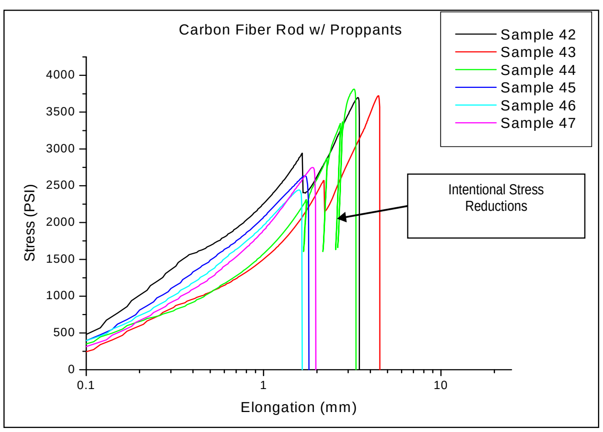

Figure 4: Stress-elongation graphs from testing samples of a randomly oriented carbon fibers.

2.2 Electrical properties of the bonded structures

In order to take advantage of the unique electrical properties of both composite materials and the CNT reinforced adhesive, experiments were performed to evaluate the potential of using electrical response of the bonded material to applied stress.

It was found, that the used Zyvex Epovex CNT reinforced epoxy adhesive was not electrically conductive even at applied voltage of 1.0 kV. Nonetheless, samples were prepared, and the current flow through the electrically conductive RPC samples was measured as they were shear stressed to failure. There was a very measureable change in current flow as stress was applied, however, reversibility remains an issue that requires additional study. Figure 5 below illustrates the current flow vs. pressure relationship.

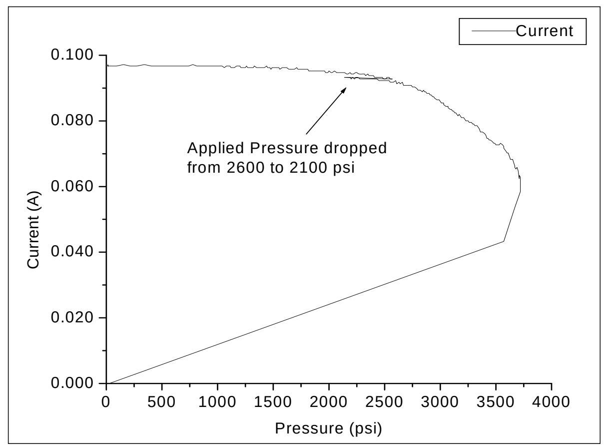

Figure 5: Current flow vs. pressure applied on bonded sample 43.

Tests were also conducted to investigate the relationship between capacitance and applied pressure. The capacitance of a carbon fiber reinforced sample was approximately 68 pF. And, while the capacitance increase with an increase in applied pressure was also small (~3 pF), it was measureable and appeared to display a well behaved and reversible relationship.

The above results indicate that the development of embedded bond interface transducers for "smart" monitoring of the bond health is a viable concept. Future work should be directed towards optimization of the MCA fabrication on composite materials reinforced by fibers with nanoscale dimensions and investigation of the potential of using various electrical responses including resistance, capacitance, and impedance, as a bond health sensor indicator.

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