Natural Process Design

Dr. Carolyn Dry
1250 East Eighth Street
Winona, Minnesota, 55987
507-452-9113

Abstract

Self-repairing, fiber reinforced matrix materials consist of a matrix material, which includes inorganic as well as organic matrices, as well as reinforcements disposed within the matrix, hollow fibers having a selectively releasable modifying agent contained therein. The hollow fibers may be inorganic or organic and of any desired length, wall thickness or cross-sectional configuration. The modifying agent is selected from materials capable of beneficially modifying the matrix fiber composite after curing. The modifying agents are selectively released into the surrounding matrix in response to a predetermined stimulus, be it internal or externally applied. The hollow fibers may be closed off or even coated to provide a way to keep the modifying agent in the fibers until the appropriate time for selective release occurs. Self-repair, reinforced matrix materials capable of repairing micro-cracks, and/or releasing corrosion inhibitors or permeability modifiers are described as preferred embodiments in concrete and polymer based materials or products.

This application is a continuation of application Ser. No. 08/189,665, filed Feb. 1, 1994, now abandoned, which is a continuation-in-part of application Ser. No. 08/174,751, filed Dec. 29, 1993, now U.S. Pat. No. 5,575,841, which is a continuation of application Ser. No. 07/540,191, filed Jun. 19, 1990, now abandoned.

Self-Repairing Polymer Composites for Airplanes

Airplanes that are safe to fly or can return home safely even if damaged, bridges that can withstand an earthquake and remain standing, boats that can resist damage to keep afloat, or oil rigs and pipelines that can resist damaging storms – these are the contributions of self repairing composites to the nation's economic and social welfare beyond mere commercial profits. The saving range from lives spared to tax payer savings. On the competitive stage, U.S. industries have been poised to develop many more uses for composites but one technical flaw has hampered their performance, that is, safety and indeed predicable safe performance of composites. Internal damage is not dramatic, but very common in composites. Repair of internal damage is important in order that failures do not progress to ultimate catastrophic failure. Furthermore, micro-scale cracks are hard to detect unless they have developed to macroscopic scale flaws. Non-destructive evaluation techniques have limited ability to detect micro-cracks. Damage can be repaired in the field by hand, but not all of the original strength restored.

The use of polymer composites is receiving much attention from the aerospace community and other vehicle communities such as boats, yachts and automobile manufacturers. Any reduction here is significant because in any one year 20% of all planes are being overhauled or maintained in a major way just to maintain current airplane conditions; the aging fleet will need to be replaced or repaired during the next two decades. [2]

The percentage of composites used in aircraft has grown every year for the past thirty years [1]. Forty percent of that growth is in military aircraft [1]. A major portion of the growth occurs due to the need for composite based specialty items, such as tails, rudders, doors, and flaps. Even though structural composites have found some major applications in aerospace, [2] high costs have blocked use in many applications due to unreliability/inconsistency. Advantages are light weight in relation to strength. For example: glass fiber composite is five times stronger than aluminum [4], carbon reinforcing can give up to 30-40 % structural weight reduction. [1] Boeing's F/A-18 Hornet has 50% of its skin made up of composite material, see figure 2. [5]

In the last decade the use of polymers has grown so much that polymer bridges exist and use of polymers in airplanes had doubled. This, despite the drawbacks of polymers in reliability and consistency, is because polymer composites have so many advantages over steel or concrete. These include: resistance to intrusion of environmental chemicals and water that could cause damage, increased/beneficial vibration damping, energy absorption, electromagnetic transparency, toughness, control of stiffness, high strength to weight ratios, and being lightweight to decrease dead load as well as transport costs. Polymer composites are three times stronger than steel and five times lighter. Composite materials have applications in rehabilitation of existing bridges as complete structural replacement or new construction [5, 6]. The American Association of State Highway and Transportation Officials projected that just to maintain current bridge conditions, 200,000 bridges will need to be replaced /repaired in the next two decades [3].

Figure 1. Polymer composite boat [8]

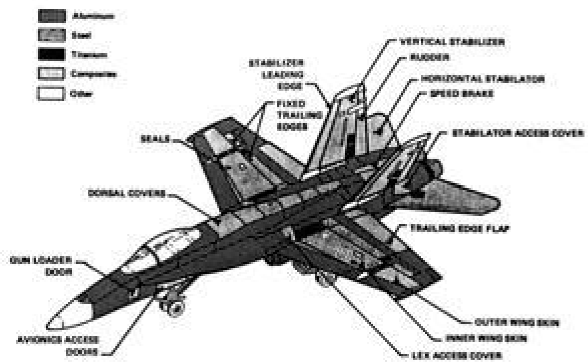


Figure 2. A Boeing F/A -18 Hornet. Fifty percent of the flight surface is carbon fiber [1]

Figure 3. Pultruded polymer beams by Strongwell [9]

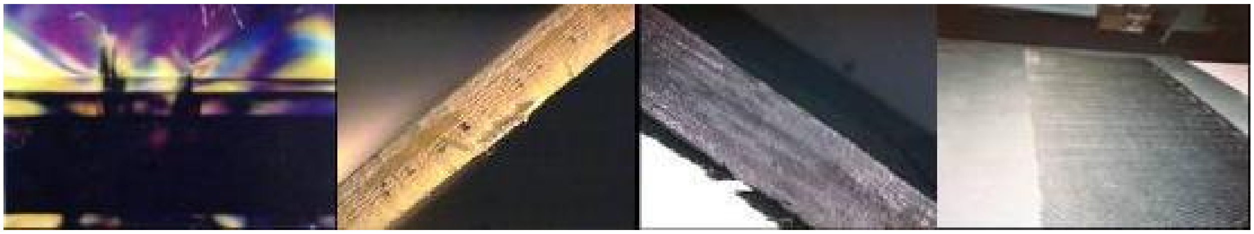
Figure 4. Carbon tube for the oil industry [10]

Self-Repairing Polymer Composites for Airplanes

Airplanes that are safe to fly or can return to home base safely even if damaged, is the main contribution of self repairing composites to the nation's economic health. Advantages include savings and weight reduction. These savings range from lives spared to profits saved to taxpayer savings. Also, the weight of the planes could be reduced by use of less over designed, thick laminates, while the expense is reduced by use of cheaper, less toughened prepregs. On the competitive stage, U. S. aircraft industries have been poised to develop many more uses for composites but one technical flaw has hampered their performance, that is, safety and indeed predictable safe performance of composites. Damage, which is internal, is very common in composites. Repair of this damage is important in order that failures do not progress to catastrophic failure. However, delaminations are hard to detect. Damage is usually repaired in the field by hand, but not all of the original strength is restored.

The Solution: Self-Repair - The Answer to Damage in Polymer Composites

The solution is to develop polymer composites with unique toughness and strength by self-repair, which occurs at material interfaces and at damaged areas. This is not by hand repair, but by release of repair chemicals from within the composite itself. The hollow fibers are embedded in the matrix, and the chemicals they carry are released wherever and whenever cracking or other matrix damage occurs. The repair chemical flows into the crack, and crack faces are rebonded.



(Far left) A microscope photo of release of adhesive into polymer. Next a self-repaired fiberglass laminate in which the delams filled with yellow repair chemical flanking the center impact site. Next is a sample of self-repairing graphite laminate which shows repair lenses. Note that the repair chemical goes to all layers of the composite. Far right is a large airplane wing piece showing a continuous array of repair vessels. Self-repair of composites is a concept that Dr. Carolyn Dry invented. There are seven patents issued.

Recent Research on Self-Healing Polymer Composites by NPD

The work, under the Air Force Small Business Innovative Research (SBIR) program, on self-repair in impacted composite laminates processed by lay-up and autoclaving at 250F for fiberglass and at 350F for graphite laminates, was successful. It yielded restoration of flexural modulus of the non-damaged, not-impacted controls of 94% in fiberglass and 74% and 88% of the non-impacted samples for the epoxy and free radical repair chemicals, respectively. Further the chemical penetrated to all layers in the fiberglass and graphite composite laminates.

Recently, very fast adhesive systems for repairs have been developed. Photos taken from a video of the dynamic system of impact and repair shows very fast delamination and fiber break, chemical release, flow into damage site and repair chemical cure, all in less than a minute.

Far left is a photo of dyed pink repair chemical that vacated the tubes and filled the delamination and crack caused by an impact. Next is an outside view of the laminate 1 second after impact (the repair chemical has already filled the damaged area) and next is the same repaired area, backlit, at 5 seconds after impact. Note that the repair chemical flows into delaminations and cracks, as well as broken fibers as seen on the right. Far right is a sample that was impacted twice. The repair chemical is dyed red. The light color in the release vessels reveals that half of the repair chemical had been used.

Acknowledgements

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Related Patents

	Patent Number	Title
#1	6,527,849	Self-repairing, reinforced matrix materials
#2	6,261,360	Self-repairing, reinforced matrix materials
#3	5,989,334	Self-repairing, reinforced matrix materials
#4	5,803,963	Smart-fiber-reinforced matrix composites
#5	5,660,624	Self-repairing, reinforced matrix materials
#6	5,575,841	Cementitious materials
#7	5,561,173	Self-repairing, reinforced matrix materials
#8	5,660,624	