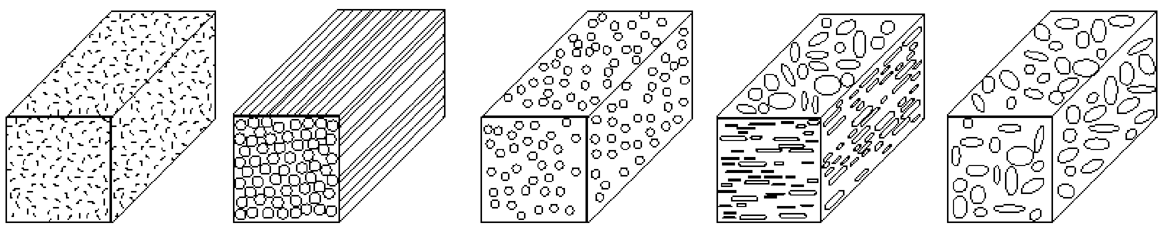
Briefing Paper on Making Stronger Composites with RMT™ Technologies

Individual materials typically are stronger (sometimes substantially stronger) in compression than they are in tension. These materials are called monolithic materials and include metals, plastics, ceramics, and biomaterials. On the other hand, virtually all composite materials are stronger in tension than in compression. Composites are two or more materials organized into a single unit. Fiberglass, glass fibers encased in plastic, is a classic example. Composites are stronger in tension because the reinforcing materials in composites (e.g., the glass fibers in Fiberglass) are stronger in tension, and composites are designed to exploit the tensile strengths of reinforcements, particularly fibers, of which there are several kinds (see Figure 1).



(a) (b) (c) (d) (e)

Figure 1: (a) random fiber (short fiber) reinforced composites; (b) continuous fiber (long fiber) reinforced composites; (c) particulate reinforced composite; (d) flat flakes reinforced composite; and (e) filler reinforced composites.

A shortcoming of composite designs is the tendency to ignore or under utilize the strengths of the monolithic materials which encase the reinforcing fibers. These materials are called matrix materials and, by definition, these materials are weaker in tension than the fibers they hold. This shortcoming traces to the fundamental rationale for the development of modern composite materials. Composites were developed by fiber makers to exploit the superior strengths of promising fiber materials, such as nylons and polyesters. These and other synthetic fibers were originally used to make textiles, e.g., for nylon stockings and polyester suits. Because these fibers could be unusually strong, fiber makers believed synthetic fibers could be used to improve industrial hardware such as parts for automobiles, airplanes, and other major products. Unfortunately, fibers could not be used alone for these purposes.

Matrix Material Keeps it Together

A second material, the matrix material, is required to hold fibers together in the shape of a solid part, to form a steering wheel, for example. The matrix material is required basically as glue; its primary purpose is to serve as an enveloping wrapper to hold bundles of fibers together in a particular shape. An interrelated purpose of the "weaker" matrix material is to transfer applied stress to the reinforcement, the fibers. That's the way a composite works. Thus, putting stronger and lighter fibers in a weaker, and typically heavier, matrix material can result in a very strong material that is lighter than the matrix material alone. Here's a student's explanation of the rational for modern composite design:

> "You may ask, if the fibers are so much stronger than the matrix, why not just use the fibers alone? The answer to that question is simple. Very few parts for products can be made of fibers alone. Usually, a solid piece of material is required to build parts. Wrapping the fibers in the weaker matrix material allows designers to apply the high strength fibers to real-life situations."[1]

The historical bias focusing on reinforcement materials in modern composite designs means that the structural strengths and performance advantages of matrix materials are too often ignored or under exploited. The upshot is that matrix materials are seriously underutilized structurally because matrix materials are treated as ancillary to reinforcement. This incidental inefficiency is large. It means that composites could be much stronger if composites were designed to exploit fully the strengths and advantages of both reinforcements and matrix materials.

Superior RMT Precision™ Composites

RMT™ technologies re-engineer current composite designs to coordinate and exploit fully the structural strengths and performance advantages of both reinforcements and matrix materials. This makes RMT Precision™ composites stronger, stiffer, tougher, lighter, and more economical. The engineering strategy of RMT™ technologies relies on *complementary specialization* of these two basic components of composites. The matrix material is designed to specialize in bearing compression load primarily; while the reinforcement, e.g., RMT™ beaded filaments (see Figure 2), specializes in bearing tensile load primarily. This strategy adds the strength of one to the other, making the most efficient use of both materials to create a stronger and better-performing composite material.

Figure 2. Example of an RMT™ beaded filament.

To achieve this specialization, RMT™ technologies engineer composites steer compression load onto the matrix material and steer tensile load onto the reinforcement. Indeed, RMT Precision™ composites are engineered to minimize tensile load on the matrix material and minimize compression load on the reinforcement. This specialization makes the performance of RMT Precision™ composites substantially superior to that of ordinary composites, because RMT Precision™ composites are engineered to rely on the strengths of each component while mitigating their respective weaknesses. This engineering strategy gives RMT Precision™ composites Stress Steering™ functionality, which is a patented technique exclusive to RMT™ technologies (see US Patents Nos. 5,615,528 and 5,816,009; and *RMT℠ Manufacturing Technologies* at http://unistates.com/randt/rmtmanufacturing.html).

[1]**FRACTURE** (Student Project Web Site: MSE2094), *Virginia Tech Materials Science and Engineering*, 1997.

Coordinated specialization means that each component, i.e., the matrix material and the reinforcement, is essentially activated according to the type of load applied to the overall composite. Provided that the reinforcement material is "less stiff" or "softer" than the matrix material, activation can be sequential (see US Patent No. 6,767,619). This performance-enhancing Sequential Stress Management System is built into RMT Precision™ composites exclusively. This patented Sequential Stress Management System coordinates and optimizes the structural performance of both matrix materials and reinforcements for superior overall performance by RMT Precision™ composites, which are not only stronger, but also lighter, stiffer, tougher, and more economical than conventional composites.

Continuous Fibers

RMT™ technologies further enhance the performance of RMT Precision™ composites by using continuous reinforcement in the form of RMT™ beaded filaments (see Figure 3). Generally speaking, composites of all types, including RMT Precision™ composites, which use continuous reinforcement, have superior mechanical properties. As a general rule, discontinuous reinforcement, such as short fibers, for example, can have tensile strengths that approach only 50% of the tensile strengths of continuous fiber counterparts (i.e., fibers of the same material and design parameters, e.g., same diameter); and they can have moduli of elasticity that approach 90% of that of continuous fiber counterparts. Some RMT Precision™ composites include both continuous and discontinuous reinforcement, capitalizing on the bests of both.

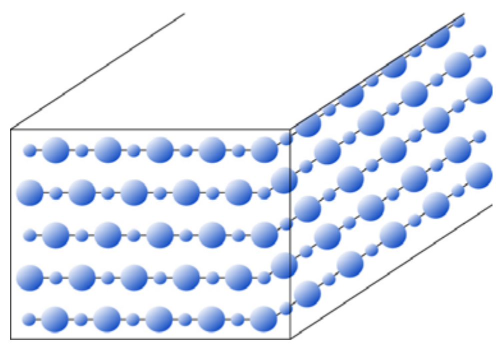


Figure 3. RMT Precision™ composite with RMT™ beaded filaments as continuous reinforcement.

RMT™ Beaded Filaments Localize Load

RMT™ technologies further enhance the performance of RMT Precision™ composites by not only steering but also by localizing the applied stresses of load, particularly tension and compression. In RMT Precision™ composites, permanent RMT™ beaded filaments carry tensile load primarily. The beads also shape the matrix material into a framework, which optimizes the capacity of the matrix material to carry compressive load and minimizes the threat of tensile and shear stresses in the matrix material (see *RMT℠ Manufacturing Technologies* at http://www.unistates.com/randt/rmtmanufacturing.html). Along each RMT™ beaded filament, strands of the filament connect the beads. These strands are called "ligaments," and these ligaments are the "workhorses" of the RMT™ beaded filaments, carrying the bulk of the tensile load on the overall composite.

One ligament connects two beads. With beads on either end, the ligament is separated from other ligaments along the RMT™ beaded filament. This separation isolates, or localizes, the ligament. Under stress, this has the effect of localizing tensile load into small components within the overall composite (see Figure 4). This localization of tension is very important, because this parceling of tensile load precludes the concentration of tensile stress at any one place in the RMT Precision™ composite. The concentration of tension is the single greatest threat to most composites. A similar, but less effective, localization of tension is achieved by the age-old practice of tying knots periodically along a rope or net, e.g., fishing net.

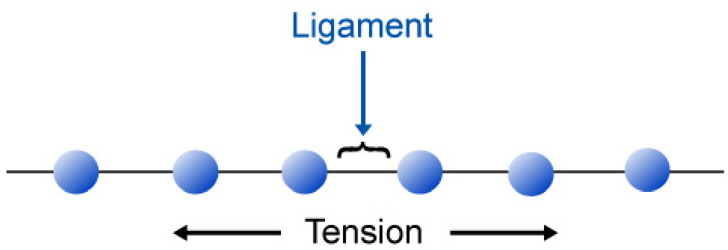


Figure 4. Example of an RMT™ beaded filament ligament between beads.

Just as RMT™ beaded filaments localize tensile load, the framework of the matrix material created by the RMT™ beaded filaments localizes compressive load (see *RMT℠ Manufacturing Technologies* at http://www.unistates.com/randt/rmtmanufacturing.html). Addressing load locally spreads and diffuses the threat of load and uses the material mass of a composite more efficiently. This more efficient use of the structural strengths of all sturdy materials is what makes RMT Precision™ composites superior to other composites. This more efficient management of load thwarts the threat of the concentration of stress, which is the primary reason for the failure of virtually all products of all kinds made with all materials.

	Conventional Composites	RMT Precision™ Composites
Optimizes tensile strength	✓	✓
Matrix material transfers applied stress to reinforcement	✓	✓
Matrix material holds together reinforcements	✓	✓
Optimizes tensile and compression strengths		✓
Exploits strengths of reinforcement and matrix material		✓
Coordinated specialization of materials		✓
Stress Steering™ functionality		✓
Sequential Stress Management System		✓
Localized load management		✓

Chart I. Comparison of the attributes of conventional composites vs. RMT Precision™ composites.

RMT Precision™ Hybrid Composites

Some RMT Precision™ composites include both continuous and discontinuous reinforcement, capitalizing on the best of both. These hybrid composites combine a distinct matrix material system with a distinct reinforcement material system. For example, the matrix material of an RMT Precision™ composite can be reinforced with discontinuous fibers, particulates, and flakes (see Figure 1) while the RMT™ beaded filaments can be strengthened with wrappings, coatings, coils, and even carbon nanotubes, among other construction strategies. Also, in an RMT Precision™ composite, various RMT™ beaded filaments can be composed of different materials as a means to tailor the composite for optimal performance in a specific application.

Simple Efficiency

In sum, at the heart of RMT™ technologies are simple innovations that use materials more efficiently, thereby making ordinary materials into extraordinary materials measured by today's standards (see US Patents Nos. 5,615,528; 5,816,009; 6,767,619; and related patents worldwide).