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INDUSTRIAL APPLICATIONS
OF MULTIAXIAL WARP KNIT COMPOSITES

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Over the past few years, Multiaxial Warp Knit (MWK) fabrics have made significant inroads into the industrial composites arena. This paper will examine the use of MWK fabrics in industrial composite applications (1-10). Although the focus will be on current applications of MWK fabrics in composites, this paper will also discuss the physical properties, advantages and disadvantages of MWK fabrics. The author will also offer possibilities for the future of MWK fabrics in the industrial composites arena.

According to a Frost and Sullivan study, the demand for high performance composite materials in the USA should more than triple between 1987 and 1992 (3). A yearly growth rate of high performance composite materials for this same period has been forecast to be at least 25%. Others predict that the worldwide market for composite materials, currently at \$2 billion, will grow to \$20 billion by the year 2000 (8). One of the biggest reasons for this projected growth is the ever-expanding use of composite structures in industrial applications.

Advanced composite structures, high strength materials combined with a resin system, are being used in the most diverse sectors of the industrial arena. One fabric that is playing an increasingly

important role in this arena is the Multiaxial Warp Knit (MWK). MWK fabrics are ideally suited for this type of end use because of their flexibility and engineerability. MWK fabrics, produced in a one-step process, have properties similar to those of quasi-isotropic layup structures. Besides good handleability, MWK fabric preforms are extremely conformable.

This paper will examine the use of MWK fabrics in industrial composite applications. The focus will be on the MWK fabric itself, and why it is being used as a preform in industrial composites. Current end use applications for the MWK fabric composites will be discussed and possibilities for the future of MWK fabrics in the industrial composites arena will also be offered.

What Is An MWK Fabric Composite

The basic principle of fabric composites is to combine the singular properties of more than one substrate and/or medium to create a single structure that performs much better than any of the individual components. An advanced composite is based on the same principle as using steel reinforced concrete to build a bridge, or straw and mud to make a brick for building a fireplace. In advanced composite structures, reinforcing fibers or fabrics are embedded in resin systems such as epoxy or other binders. Multiaxial warp knitting is a means of manufacturing stable reinforcing fabrics from fibers such as graphite, glass, Kevlar, ceramic, or other textile fibers which have the ability to resist stress and strain from any direction.

MWK fabrics are unique structures which are produced by warp knitting techniques. With these techniques, straight ends of parallel and uncrimped yarns are inlaid into the knitted structure at virtually any desirable angle. Because of the versatility of this process, fabric characteristics can be engineered into the structure to give the ideal combination of mechanical properties at a favorable production cost. This produces MWK fabrics, with the combined advantages of design flexibility, performance, productivity and availability, and the potential to become a major fabric preform for industrial composites.

An industrial composite can be defined as any composite structure that is not being used as a household good such as kitchen utensils, furniture, clothing, jewelry, and/or sporting goods.

THE MWK FABRIC

MWK fabrics generally possess up to four different load bearing yarn systems arranged so that each can take on stress and strain in virtually all directions. Since these load bearing yarns lie straight in the fabric, with no crimp, the physical parameters of the individual yarn system are fully utilized.

From a structural geometry viewpoint (see Figure 1), MWK fabrics consist of warp (0 degrees), weft (90 degrees), and bias (+/- various degrees) yarns that are stitched together during the warp knitting process by a fifth yarn system through the thickness of the fabric structure (4). The warp and weft yarns stabilize the fabric in the machine and cross machine directions while the diagonally arranged or biased yarns absorb tension from any required angle. The fifth yarn precisely binds together all of the load bearing yarn systems. The bias or diagonal yarns in the fabric can be inlaid at any angle along the plane of the machine direction, the most common of which is +/- 45 degrees. It should be noted that all four load bearing yarn systems do not have to be used in a MWK fabric construction. Also, different yarn types and counts can be used in each of the yarn systems. MWK fabrics allow the designer freedom of choice in the arrangement of load bearing yarns in the structure. This provides the fabric designer with a tremendous amount of design flexibility.

Unlike the crimp inserted into the yarn in woven fabrics during weaving, the load bearing yarn in MWK fabrics lies straight and parallel to other yarns in its yarn system. This characteristic of MWK fabrics allows for the yarn properties to be more fully utilized in withstanding in-plane forces. Fabric design is made easier because the designer can more accurately calculate the tensile load of a MWK fabric with a much higher degree of confidence than had been previously attainable with woven fabrics. Testing is still required to verify the estimates, but the starting points can be calculated instead of guessed at. In addition to design flexibility, isotropic stress and strain resistance, excellent tear resistance, and improved conformability to complex shapes are also characteristics of the MWK family of fabrics.

MWK fabrics are capable of withstanding stresses and strains in an optimum fashion. This is due largely to the parallel and straight arrangement of the load bearing yarns in the MWK fabric. Because the load bearing yarns lie straight in the fabric, their tensile properties are fully utilized and are able to absorb tension without the elasticity that occurs when the yarns are crimped or in a wavelike form, such as in a woven fabric. Because of the arrangement of the yarn systems at various angles (see Figure 1), the MWK fabric is able to withstand shear forces from various angles (7). This isotropic ability is particularly important in many of the advanced composite structures and a primary reason for the use of MWK fabrics.

Due to the parallel nature of the load bearing yarns in the MWK fabric, excellent tear propagation resistance is achieved. If a tear were to occur in the MWK, the yarn layers would shift slightly under the force of the tear and bunch together. The inherent movement of the load bearing yarns and the diagonal element would act to reinforce the area and prevent further tearing (7). This resistance to tear propagation becomes increasingly important when a MWK structure is damaged while in use (such as in a sail, inflatable

structure, or aircraft skin). The damage is minimized by the resistance to further tearing (2).

Because the yarn systems are not interwoven, but rather lie directly on top of each other and are held together by the fifth yarn system, conformability of the fabric is greatly improved. This allows the MWK fabric preforms to conform to many complex geometrical shapes and still maximize the translation of fiber mechanical properties to the composite structure. The conformability of the uncured MWK fabric also provides good shape retention during the laying up and curing process.

By combining a web or nonwoven fabric (usually nylon, polyester or fiberglass) to the MWK fabric during the knitting process, it is possible to control many other physical aspects of the fabric structure. Both the MWK fabric and the web can demonstrate their specific advantages. Because the web is fed into the knitting machine during production of the MWK fabric, it is linked to the load bearing yarns by the stitch yarn, rather than being rigidly bonded. This allows for a certain amount of give to the MWK and web structure.

Adding a web to the MWK structure allows the designer even greater design flexibility. Addition of a web can further control the strength and elongation of the MWK fabric, and at the same time provide variations of fabric cover and density, water and air permeability, stiffness, thickness, initial tear resistance, increased tear propagation resistance, and yarn slippage resistance; all of which can be tailored by the designer to meet the end use requirements of the MWK fabric. The web also provides greater stability of the yarn layers during the further processing stages of creating an industrial composite. It has been shown that the addition of a web to the MWK preform increases the flow of resin during the resinating process in making the advanced composite structure. This results in better processing times and lower production costs (5).

Few, if any other fabric production techniques, offer such a wide range of properties with such versatility in relation to type and count as MWK fabrics. Although a comprehensive data base is not yet available for MWK fabrics due to their relatively recent introduction into the industrial composites arena, several studies have been done and are being carried out to assess their potential (6). The obvious properties that MWK fabric composites offer the industrial composites arena are their incredible design flexibility, isotropic stress and strain resistance, tear propagation resistance, and conformability (9).

End Use Applications of Industrial Composites Using MWK Fabrics

Because the MWK fabrics are relatively new to the industrial composites arena, the number of recognizable end use applications is

relatively small when compared to those of traditional woven fabrics. But when given the head start that woven fabrics have had, some several hundred years, the progress made by MWK fabrics in the industrial composites arena is nothing less than phenomenal.

The majority of current end uses for industrial composites made from MWK fabrics can be separated into two different industries, marine and aerospace. Probably 65 percent of all MWK fabrics currently made are used in marine composite applications, while another 20 percent are used in the aerospace industry. The remaining 15 percent encompass all of the varied end use applications being evaluated with MWK fabric composites. Table I divides many of the current end uses into the three categories.

MWK fabrics are becoming the fabric preform of choice in the marine industry, especially in yachts, sailboats, and high speed racing boats. The MWK fabric composite is generally used in these vessels for the hulls, deck superstructures and substructures, and motor bays.

Because of the isotropic properties of the MWK fabric structure, boat designers are finding that they can use less MWK fabric in the composite structure and still maintain, or often improve upon, the structural integrity and torsional stiffness of the boat. This also means that boat hulls made of MWK fabric composites can withstand greater stresses and strains with less overall weight. Less overall weight obviously requires less energy to power the boat, which translates into fuel savings and/or faster boats. The improved structural integrity makes the boat safer at higher speeds.

MWK fabric composites are being used in most of the fastest ocean going racing boats and yachts because of their increased stability and weight savings. The hulls and masts of several of the sailboats used in the America's Cup competition were made of MWK fabric composites because of the performance edge experienced by using these composite structures. Partially as a result of using MWK fabric composite structures, speed boats and racing boats are achieving speeds previously thought to be unreachable with any degree of safety.

Another example of improved performance as a result of using MWK composite structures in marine applications was seen in a new generation of racing shells used by some of the top rowing teams in the country. The shells (long narrow row boats, usually powered by 8 rowers) were found to give a greater translation of power into speed because of the improved torsional stiffness. This allowed energy to be translated more directly into speed rather than being absorbed by the shell when flexing.

MWK fabrics are also being looked at for applications in sails. In this case, however, the composite structure is the MWK fabric combined with a plastic film, usually through laminating. Because of the lack of crimp in the yarn in the MWK composite structure, the force of the wind is immediately translated into power and not

absorbed at all by the crimp deformation associated with woven fabric structures.

Fabric composites of all types are being used in the marine industry because of their inherent resistance to corrosion. This saves on the manufacturing cost because expensive metal treatments and repeated paintings are not needed to protect the craft from the corrosive nature of salt water.

In the aerospace industry, which includes the military, aerospace and commercial aircraft industries, MWK fabric composites are being used more and more. Relatively speaking, they are being used in this industry for many of the same reasons as in the marine industry, namely reduced weight, and increased strength and integrity. Because of the flexibility and tailorability of mechanical and physical properties, MWK fabric composites can be customized for the application and specific properties can be emphasized to suit the particular need.

Currently, there are very few aircraft that use MWK fabric composites in critical structures such as the fuselage or wings. Most current applications center around the skin of the aircraft. Other areas of use are in the top and side tail units, fuselage paneling, leading edges on side rudders, and engine paneling. MWK fabric composites are also being evaluated for rotor blades, outer skin, and ballistic protection for helicopters. It is thought that the use of MWK composites is also being evaluated in the new military plane/helicopter, the V-22 Osprey, and the all-composite Beech Starship business plane (8).

The lower weight achieved through the use of MWK composite structures means that less fuel is consumed by the aircraft, which translates into significant energy savings for the user. Also, because of the improved structural integrity offered by the MWK fabric composite, it is believed that safety is enhanced.

Other various applications for MWK fabric composites can be found in the industrial composites arena. In Europe, MWK fabric composites are being used for flooring in sports halls where the combination of multi-directional force distribution and excellent tear resistance are beneficial. The MWK fabric composite also helps to improve the sound damping characteristics of the flooring. MWK fabrics coated with rubber are also being used in the industrial roofing industry.

The Future of MWK Fabric Composites In Industrial Applications

The main obstacle in gaining acceptance for MWK fabric composites in the industrial composites arena has been the lack of confidence derived from inexperience and a lack of sustained performance data for MWK composites. With the advent of time, these obstacles will undoubtedly be overcome and MWK fabric composite usage will dramatically increase (1).

Numerous end use possibilities exist for MWK fabric composites. They can not only be used to replace traditional materials, but also to improve the performance of many new industrial composites which seem to have reached their performance limit. MWK fabric composites can be used to replace traditional structural materials such as concrete, wood, and steel, thus creating new possibilities in various industries and end uses.

The advantages of using MWK fabrics in composite structures are clearly the flexibility and freedom of choice in the desired properties in all directions which can be matched to individual needs. As a result, MWK fabric composites are uniquely suited to a wide range of industrial applications.

MWK fabric composites incorporating a nonwoven structure are ideally suited for many high strength geotextile applications, where isotropic strength, resistance to tear and tear propagation, good water permeability, low creep, and good fabric/soil interaction are required.

With the flexibility of fiber placement and potentially high productivity, MWK fabric composites are ideally suited for many structural load bearing applications in the automotive and aerospace industries. MWK fabrics, because of their structural makeup, have good flexibility which allows them to be formed during molding into virtually any desired shape. The through thickness reinforcement provided by the stitching process helps to reduce the possibility of delamination of layers in the composite structure.

Numerous applications for MWK fabric composites also include protective helmets and armored protection of vehicles, buildings, and people. Various drive belts, V-belts, fan belts, and conveyor belts will benefit from the availability of diagonal load bearing yarns in the composite structure. Inflatable rafts, cushions, balloons, and fuel cells are ideal applications due to the MWK fabric composite's isotropic strength and tear resistance.

There are probably hundreds or even thousands of other areas that could benefit via the use of MWK fabric composites. The flexibility of the MWK fabric system provides endless potential end use applications. All that is needed is for the designers and engineers of the world to dare to improve upon what they already have and open their minds to the future.

Conclusions

The MWK process offers limitless possibilities for the formation of new fabric preforms for the composites industry. By varying the angle of the load bearing yarn systems, and the type and count of yarn used, the strength in any fabric direction can be tailored to the requirement, rather than the requirement being tailored to the fabric available. Because of the complete versatility of the MWK fabric, design flexibility is virtually limitless.

MWK fabric composites offer many never before realized advantages to the industrial composites arena, giving the designer flexibility that he or she has never before had. The ability to design a composite structure with the load bearing systems aligned precisely where they are needed provides opportunities to make better, more cost efficient structures.

The use of MWK fabric composites in many of the areas mentioned earlier shows that their development is worthwhile. New end uses are being developed daily and in many cases MWK fabric composite structures are being used to replace expensive, heavier or technically inferior constructions produced from other materials. Many times these replacements are converted directly into cost savings. Also, with each new application, comes more experience and an addition to that ever-expanding data base, which so many engineers and designers require. All that is needed is for them to open their minds and give MWK fabric composites a try.

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Table I. Listing of MWK Composite Applications by Category

INDUSTRY	MARINE	AEROSPACE	OTHER
Estimated % of MWK Fabric Composite Market	65%	20%	15%
Applications	<ul style="list-style-type: none"> -hulls -decks superstructure substructure -support beams -motor bays -sails -racing shells 	<ul style="list-style-type: none"> -aircraft skin -tail units -fuselage paneling -leading edges on wings and rudders -engine paneling -rotor blades -ballistic protection 	<ul style="list-style-type: none"> -flooring -geotextiles -wall panels -automotive applications -protective helmets -industrial belting -inflatables

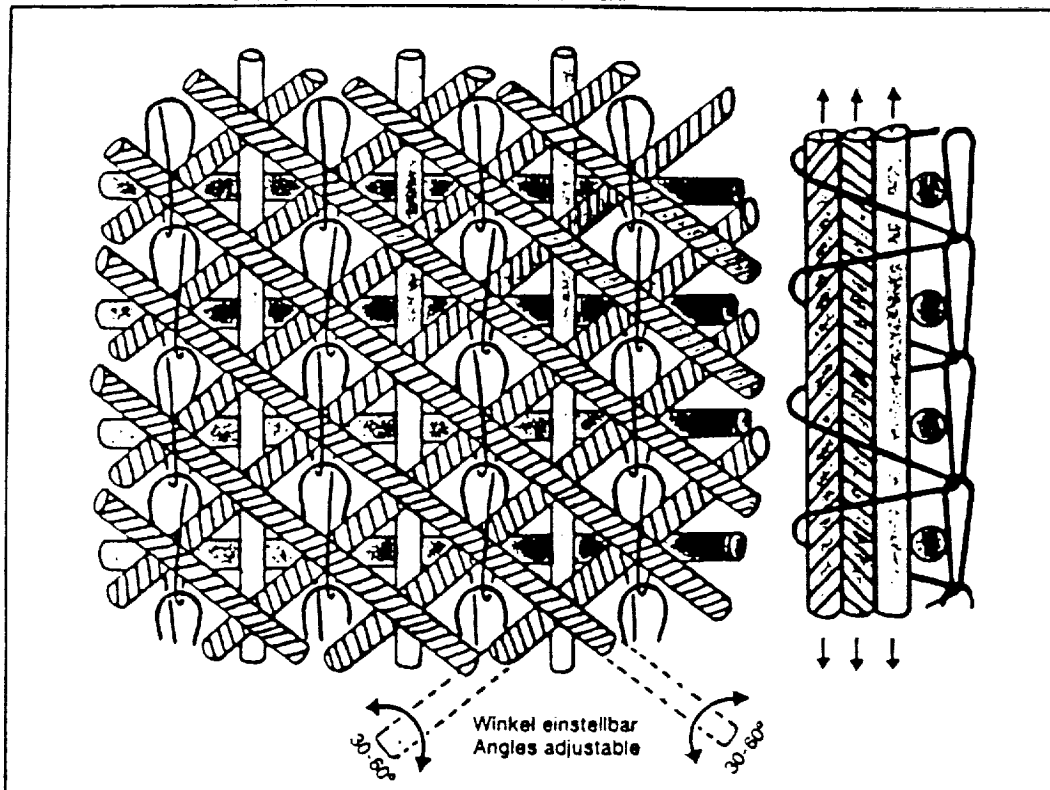


Figure 1: Structural Representation of MWK Fabric (10)