REINFORCED PLASTICS

T/C TECHNOLOGY CONFERENCES
P.O. Box 842, El Segundo, California 90245

REINFORCED PLASTICS

papers presented at

The Reinforced Plastics Conference

December 2, 1980, El Segundo, California

- Economic Considerations
- Materials Advances
- Directional Reinforcements
- Dual Laminate Constructions for Corrosion-Resistant Containers
- Reinforced Thermoplastics
- Nylon-Fiberglass Composite Sheets
- RIM of Glass Reinforced Polyurethanes
- Processing Developments

arranged by . . . . **TECHNOLOGY CONFERENCES**

P.O. Box 842, El Segundo, California 90245

in cooperation with the So. Calif. Section,

Society of Plastics Engineers

T/C

T/C

TECHNOLOGY CONFERENCES
acknowledges the technical expertise provided by the authors of the papers contained herein.

The papers contained in this publication are based on a conference organized and conducted under the auspices of Technology Conferences with the cooperation of the So. California Section of the Society of Plastics Engineers. Responsibility for the contents and clearance of these papers rests solely with the respective authors.

Technology Conferences
P.O. Box 842, El Segundo, CA 90245

Library of Congress Catalog Card No. 80-53543
ISBN: 0-938648-01-2
Manufactured in the U.S.A.

REINFORCED PLASTICS

Table of Contents

ECONOMIC ADVANTAGES OF REINFORCED PLASTICS/COMPOSITES

IN HIGH-VOLUME APPLICATIONS

by

W. BRANDT GOLDSWORTHY

Goldsworthy Engineering, Inc.
Torrance, Calif.

The last two years have brought a realization to some practicioners and users in the reinforced plastics/composites industry that, if properly exploited, should make these materials the predominant engineering and structural materials in our society. Stong statement? Yes, but let's see if we can develop a rationale to support it.

Forty years of evolution in the science of fibrous reinforced materials has produced a category of basic raw product that has a scope of property availability far broader than any material previously developed. During this evolutionary period, although both product diversity and annual tonnage increased at a healthy rate, the high material costs and hand-craft approach to product manufacture kept these end products confined to specialty items where unique physical properties tended to warrant premium costs.

With the advent of the oil embargo, the fabric of industry began to bias in dramatically different fashions. The escalating cost of energy, coupled with the growing duplicity of ore and oil exporting nations, not only established a whole new priority of values for the transportation industries but has gradually shifted the competitive status of traditional materials as their base costs continue to soar.

This shift in the economy has precipitated a complete reversal in the role of composites in the marketplace. Right now, today, without any further technological breakthroughs or design development evolution, our products can be sold for less money than the same part made in traditional materials! By the way, Mr. Consumer, those same tremendous physical, electrical and thermal property advantages that you were willing to pay a premium for are still there but now as fringe benefits to a less expensive product. It is difficult to see how cheaper and better can result in anything less than an ultimate massive takeover from currently accepted structural materials.

This turnabout has occurred so swiftly and so subtly that most of our own industry still staunchly deny its existence; and, of course, the user is certain that he is being driven to an upward spiraling cost regime by consumer pressure and government mandate to incorporate these strange (and therefore obviously expensive) new materials. In those relatively few cases where this new era has been reduced to product, it is difficult to tell who is the most surprised — the manufacturer or the user. In the short term it is probably going to be about as difficult to convince our own industry as its customers.

Generalizations and blue sky rhetoric are easily dispensed and difficult to refute, so let's get down to hard facts and specific cases to prove our rationale. In order to be certain that we are working in a highly competitive area, let's choose the automotive industry for our case studies. Although the automakers have been steadily increasing their usage of composites in non-structural areas, it is safe to assume that without government-mandated mileage requirements, they would not have considered composites in structural applications. It is their, as yet, tentative entry into these areas that has highlighted the cost savings potential.

As it now appears that leaf springs may be one of the first automotive structural applications to reach volume production, let's use it to test our thesis:

1. Raw Material Costs

   As the weight savings on accepted composite spring designs approximates a ratio of five to one over the steel springs they replace and today's ingot prices are greater than one-fifth the composite raw material costs (glass fiber and vinyl ester), it is obvious that the composite raw material cost is less.

   In a recent paper, Gordon Warner of General Motors stated that the raw material cost of composite springs of their design was approximately forty percent of the comparable steel spring.

2. Manufacturing Costs

   Contrasting the relatively labor intensive, multi-operation techniques required for steel spring manufacture to the totally automated single-operation processing of the composite spring, leaves little doubt as to composite spring manufacturing cost reductions over steel.

If manufacturing costs are lower and raw material costs less, then it is obvious that we have a lower cost end product. This, however, is only the beginning in the economics of composite vs. steel springs.

3. Cascading Effect

   With the substantial weight savings and better damping characteristics of composite springs, the cascading effect on the automobile must result in additional cost reduction.

4. Energy Savings

   Both the energy required for reducing ingredients to raw materials and raw materials to end product are heavily in favor of the composite approach.

   According to data compiled by E. F. Bushman, the energy required to get steel from ore to plate is roughly triple the amount used to obtain resin and roving. Energy required to convert the plate to finished leaf spring as opposed to that for resin proving conversion is a far greater multiple.

5. Capital Equipment Costs

The capital equipment cost for producing any base line throughput is several orders of magnitude less for composites than for steel. (Of course the steel equipment and facilities are already in place.)

6. Facility Requirement

For equivalent production throughput, floor space requirements are a startling one-fortieth of steel spring manufacturing needs.

7. OSHA-EPA and Insurance Costs

The automatic manufacture of the composite springs results in a safe, quiet, working environment with some minor styrene emission as the only problem as contrasted to the miniture Dante's inferno of the steel spring line with its high safety hazards and excessive pollution potential.

The iterated cost savings of our test case establish a product that is not just price competitive with the steel it replaces but is dramatically less expensive in all manufacturing and usage facets. Nor is this an isolated case. Our companies' involvement in three other automotive structural components indicate that, although not quite as dramatic as the spring case, each one will be produced for less money than its metal counterpart.

Reasons for lowering costs in composite versus metal products are varied and diverse. In one of these cases, the composite drive shaft, savings are achieved by the elimination of expensive mid-point bearings and univeral joints required for a comparable length steel drive shaft. In another case, the high energy-absorption characteristics of composites result in vastly simplified five-mile-per-hour bumper system as well as providing a substantial weight saving in the critical overhung area forward of the front axle.

Perhaps the most significant current and ongoing factor in the composites vs. metals economic arena is a real shocker. Somehow every American has always believed that manufacturing technology is the backbone of our society and that this technology is constantly being refined and is maintaining its position on the leading edge. Although this has occurred in some facets of industry, the metal working industry only occasionally fits this mold. Unfortunately a large part of the metal working processes and systems were developed thirty to forty years ago and have seen little or no upgrading in that time frame. A classic example of this is a sheet metal component which has multiple usage on every automobile and therefore has been produced in very high volume for many years. Its manufacture involves a profile rolling process, some automatic bending operations, and assembly by flash welding. Simple enough, but the implementation results in a labor intensity entirely out of proportion to the product complexity. At the dictated throughput rate, fifteen men are required on the production line, most employed in tedious hand grinding operations. Further, in spite of years of production experience, the rejection rate is staggeringly high. This is primarily due to grinding away all the strength in the flash weld areas to achieve the necessary esthetics. The alternate to all this in composites is a one-piece unit produced at the same rate by three people with a very low rejection rate. The fortunate result of this stagnation in terms of composite infiltration is that it makes it much easier to compete. Any new, automated process is almost a shoo in.

Now that we have fallen heir to this most fortunate set of circumstances, what can we do to nurture and expand them?

The most immediate need is for educating industry personnel at all levels. Remember, no individual is going to work with these materials unless he is comfortable with them. Today there are relatively few who are.

Existing and upcoming composites design people must be dissuaded from their current romance with property optimization and place economics of manufacturing at least on a par with this factor. Let's get on with the real world--we've long since proven that almost anything can be made from composites.

We are equally guilty of manufacturing process stagnation. A preponderance of our products are still made by hand with the help of a few simple mechanical aids. Even where machinery is employed, it is primarily equipment that was designed with a great deal more emphasis on versatility than productivity. Although learning and evolutionary curves cannot be eliminated, we can substantially shorten their time frames by departing from traditional thinking. Remember, there was a village smithy era in metals too and it was the breaking away from this established approach that precipitated the industrial revolution and established the U.S. as the prime world power. The current need for reindustrialization provides the opening wedge for establishment of composites in the main stream. The key to keeping it there is automated processing.

This rise to dominance will not come free. In order to achieve it, manufacturers must be willing to spend at least equivalent amounts for capital equipment as they would in traditional materials. This is the only way to abandon the craft and achieve an industry. Further this capital equipment must be developed to meet specific needs. You cannot build an automobile or an airplane with a filament winder, a pultruder and a tape placement machine anymore than you could build today's models with a lathe, a drill press and a milling machine.

One of the worst barriers that we must overcome in this era of high product liability judgments is the understandable reluctance of manufacturers to increase their exposure by using new materials. Fibrous structures have a lower potential for catastrophic failure, greater fatique life, and electrical and thermal properties that mitigate toward greater consumer protection. It is important that your potential customer has this information going in. Even Ralph Nader could become an ally.

The primary buzz word for all politicians these days is reindustrialization. The need is certainly very real if this country is to remain a world power. Just how extensively this will be accomplished depends on the vagaries of domestic and world politics and even more heavily on the will and energy of our people. Our industry and we as individuals can play the major role in this effort by insuring that this program is characterized by replacing the old with the new, not simply rehashing the old. It is a fact, that although our industry carries a much lower profile than some of the glamour disciplines like electronics, that we represent the only new basic structural material to come along in several hundred years. It is, therefore, no flight of fancy to say that we are on the leading edge of the Composites Age. We are only at the base of the evolutionary curve in high-strength fiber development — thermoset, thermoplastic, metal and other inorganic matrix research — automated fabricating and process machine development. Certainly this industry contains the potential for virtually unlimited usage scope as these disciplines mature.

THE EFFECTIVE USE OF DIRECTIONAL REINFORCEMENTS

by

MARVIN LUGER

Proform, Inc.
St. Paul, Minn.

The Effective Use of Directional Reinforcements

by Marvin Luger

Proform, Inc.

Introduction

For many years designers of reinforced plastic products have recognized that their laminates were dissimilar to metals and other crystaline materials in several important ways. One of these differences is that, unlike metals, a laminate is "non-isotropic"; that is, the strength and stiffness change with the change in direction within a laminate. Although nearly everyone recognizes this fact, the great majority of designs are made using a single set of property values which ignores the fact. An important minority, meanwhile, have developed some very advanced mathematical techniques (eg. directional finite element computer analysis) to optimize laminate designs permiting sophisticated designers in those industries (eg. aerospace) to design laminates that become the most efficient product components possible today. Between these two extremes there seems to be a great knowledge gap. This presentation is designed to give those designers who have no experience with directional materials some simple design approaches that will improve their designs while introducing them to directional materials.

In addition to presenting simplified design approaches, I will introduce a number of our Knytex Division directional reinforcement products. Most of these products are already in use by large firms using computer designs. They have also been in volume use in applications where low cost and high handling volume are prerequisites. As the original large user of Knytex reinforcements, Proform/Xerxes, Inc., large structural product laminating plants have perfected the structural applications and the placement of these materials with impregnators and chop/hoop winders.

Types of Directional Reinforcements

The directional reinforcements of interest in this presentation are variable in two ways: They vary in their fiber arrangement and they vary in the material from which the fibers are made. Figure 1 is a chart showing the various constructions and materials currently available and the typical fiber properties that these materials have. Figure 2 shows some of the structural advantages of non-woven fiber reinforcements compared with woven ones. If we assume each fiber is loaded horizontally with a tension force "T", the maximum woven fiber force becomes $T/\cos\alpha$ which is greater than T of the straight fiber. The average stress T/area of the straight fiber becomes $T/(\cos\alpha \times \text{area})$ in the woven case, which is also greater; but, in addition to that disadvantage, the stress in the woven fiber, unlike that of the straight fiber, is non-uniform; thus the woven fiber stresses reach limiting values at lower values of T. The geometry of the weave also creates shear and bending moment values which are absent in the non-woven construction.

The chart in Figure 3 shows some average values for strength and stiffness of laminates made from various Knytex reinforcements. This data should not be used for design purposes since many factors affect laminate properties, but they provide an indication of the levels of strength and stiffness attainable with the materials and constructions available. You will notice the crossply material properties exceed the woven properties and this would be true in both the warp and weft fiber directions. The unidirectional properties are highest, of course, in the fiber direction and that is the property direction shown. Unidirectional materials are the most efficient supplementary stiffening and strengthening reinforcements to use in the frequently occurring case where a laminate is deficient in only one direction. Our objective in this paper is to show several methods to use directional materials as partial or total replacements for standard laminates. It should be noted that other values (eg. shear, bearing, etc.) are needed in most designs and some of these values differ considerably with directional materials. The methods shown can be extended to cover these considerations.

Design Approach Proposed

In considering the substitution of more efficient directional materials into a design, we should first identify the values in a design equation that we wish to alter. Figure 4 shows these for a series of typical problems. In Figure 5 we have indicated the general form of the equation for stress and deflection in the most frequently occuring types of problems. Also shown are the factors which we will change with changing reinforcement. In designs of one reinforcement, one merely uses the allowable stresses and modulus values for the substitute material. These will show immediate improvements with directional materials in most cases. Improvements are mostly linear with property value improvements.

It is in the combining of directional materials with standard laminates that some of the greatest economies occur. Figure 6 shows a very old but simple technique for computing an "equivalent area" or an "equivalent moment of inertia" for a combined material.[1] The word "equivalent" in this case means an area or moment of a single material which would perform in the structure in the same way as the combined material. You will notice that the directional material is better in proportion to its improved stiffness. For improved moment of inertia values, the placement of unidirectional materials, for example, at the greatest distance from the area centroid will contribute the greatest improvement in moment of inertia. It should be noted that all materials used in combination should have ratios of strength to stiffness that are about the same magnitude. Stiff but weak materials must be carefully evaluated for maximum stress. Fortunately all Knytex reinforcements currently available have high strength as well as high stiffness.

Equivalent Property Costs

The equivalent material concept can be expanded to develop an equivalent cost. The equivalent cost of a proposed replacement material is the cost of the quantity of that material which, compared to a base material, can give equal performance. In Figure 7 material cost assumptions are shown. Several typical laminates are listed and column one shows the assumed reinforcement-to-resin ratio. Costs per pound and per cubic inch are then easily computed. The "E" glass chop mat laminate is used as a basis of comparison.

Equivalent strengths are then computed by multiplying the cost per cubic inch of each laminate type by the ratio of the strength of the basis material to that of the laminate type being compared. Equivalent costs can be found for any strength of interest but only tensile, compressive and flexural strengths are shown in the example. The logic of this approach is quite simple: if a material is twice as strong, then it takes only half as much of the material to carry the load. Figure 8 is a chart computed in a similar manner for stiffness, ie. the laminate cost of each type is multiplied by the ratio of the basis material stiffness to that of the laminate being compared. Cost comparisons for Kevlar and hybrid materials are not extended for strength and stiffness. Although stronger and stiffer than glass, they are not cost justified on a single property basis. If one is interested in weight saving, impact strength, fatigue resistance or other of the high performance properties of these materials, then similar performance ratios for each property can be formed and a weighted percentage for each according to its relative importance used to determine the most cost effective laminate overall. It is even possible to consider handling qualities, drapability and any other considerations if it is possible to quantify the relative performance of each laminate.

Among the most promising material alternatives are some of the hybrids which can be mixed within a strand or by alternating strand materials. These materials frequently out perform single material reinforcements and provide considerable design flexibility.

Other Design Considerations

It should be noted that this discussion is not a complete coverage of all important design considerations. It is meant to show some simple approaches that will introduce directional materials into a design. Figure 9 lists a few other thoughts that should be of interest to a designer. One point of caution in handling shear forces: directional materials tend to resolve shear forces in the fiber direction. As a result, crossply shear planes should be examined more carefully than shear planes between woven roving layers.

Some Examples of Directional Material Uses

Proform, Inc. is a fiberglass manufacturer specilizing in large structural products. Many of these have included directional materials in their design. Figure 10 is a photo of a dome covering a wastewater tank. The drawing in Figure 11 shows how directionalmaterials have been used in this type of dome. Figure 12 is a rail car cover photo. On this type of structure, unidirectional materials contribute stiffness to the arch ribs. The Lash barges shown in Figure 13 consist of a series of low corrugations whose height is limited by stacking requirements as can be seen in Figure 14. Figure 15 shows how stiffness and strength can be obtained using directional materials rather than rib height. Figures 16 and 17 show another corrugated product incorporating unidirectional reinforcements. Figures 18 and 19 show large tanks wound using directional materials (see Figure 20). Use of a weft unidirectional reinforcement contributes greater axial strength to the tank for resistance to seismic loads or the vertical drag loads occuring when the tank is used as a bin or silo. Warp unidirectional materials used on ribs improve rib stiffening and add greater hoop strength and stiffness.

Conclusion

It is our hope that this presentation will convince those who have never considered the use of directional reinforcements that they can obtain many useful benefits and efficiencies by such use. Although truly optimum results require fairly complex mathematical analysis, it is nonetheless possible to make major design improvements on many simple and ordinary products by using the methods outlined.

[1]Laurson & Cox, Mechanics of Materials, Wiley, New York. 1947.

Types of Directional Reinforcements

I — Various Constructions
1. Unidirectional
   a. Warp
   b. Weft
   c. Biased (by user)

2. Bi-Directional
   a. Woven roving & fabric
   b. Knitted unidirectional plies

3. Multi-Directional
   a. Random (various mats)
   b. Oriented triaxial knitted plies

Typical Fiber Properties

II — Various Fiber Materials	Tensile Strength (PSI)	Youngs Modulus (PSI)	Specific Gravity
1. "E" Glass	2.2×10^5	10.5×10^6	2.55
2. "S" Glass	2.9×10^5	12.4×10^6	2.49
3. Kevlar (duPont) type 49	4.0×10^5	19.0×10^6	1.45
4. Graphite	3.5×10^5	35.0×10^6	1.70
5. Hybrids (ex: Kevlar/Glass)	3.2×10^5	15.0×10^6	2.00
6. Other hybrids	Can often be tailored to needs		

Figure 1

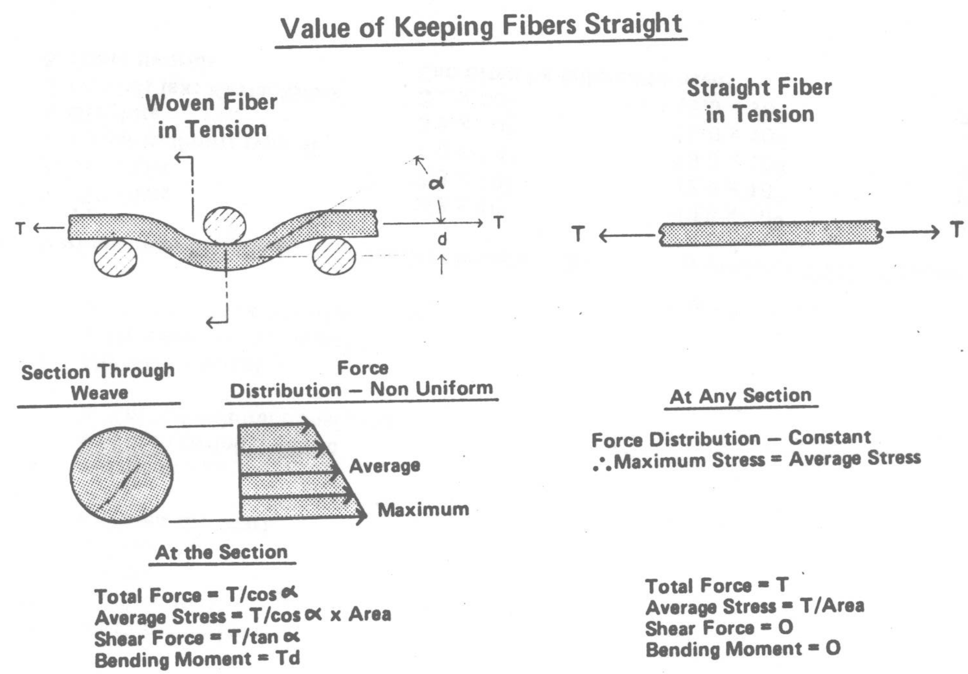
Value of Keeping Fibers Straight
Woven Fiber in Tension
T
α
d
T
Straight Fiber in Tension
T
T
Section Through Weave
Force Distribution – Non Uniform
Average
Maximum
At the Section
Total Force = T/cos α
Average Stress = T/cos α x Area
Shear Force = T/tan α
Bending Moment = Td
At Any Section
Force Distribution – Constant
∴ Maximum Stress = Average Stress
Total Force = T
Average Stress = T/Area
Shear Force = O
Bending Moment = O

Figure 2

Laminate Physical Property Comparison

	Strength (PSI)			Stiffness (PSI)		
	Tensile Strength	Compressive Strength	Flexural Strength	Tensile Modulus	Compression Modulus	Flexural Modulus
A. "E" Glass						
1. Chop Mat Laminate	15,000	18,000	25,000	0.8×10^6	0.9×10^6	1.0×10^6
2. Woven Roving Laminate	25,000	25,000	40,000	1.8×10^6	1.5×10^6	2.0×10^6
3. Unidirectional Laminate	60,000	40,000 (20,000)*	80,000	3.5×10^6	3.1×10^6	5.0×10^6
4. Crossply Laminate	30,000	30,000	45,000	2.0×10^6	2.0×10^6	2.5×10^6
B. Kevlar						
1. Woven Roving Laminate	55,000	21,500	42,000	2.7×10^6	2.7×10^6	2.3×10^6
2. Unidirectional Laminate	88,500	20,000	47,000	4.5×10^6	3.9×10^6	3.3×10^6
3. Crossply Laminate	70,000	25,000	44,000	3.6×10^6	3.3×10^6	3.0×10^6
C. Hybrid (Kevlar/Glass)						
1. Woven Roving Laminate	40,000	22,000	42,000	2.2×10^6	2.1×10^6	2.2×10^6
2. Unidirectional Laminate	71,800	31,200	65,000	3.8×10^6	3.5×10^6	3.3×10^6
3. Crossply Laminate	50,000	25,000	44,000	2.8×10^6	2.6×10^6	2.9×10^6

*Low Compression Strength results can be improved by avoiding unbraced column loading.

Figure 3