REGARDING THE RESULTS OF ULTIMATE STRENGTH TESTS OF GRP CONSISTING THE STITCHED MULTILAYER ANGLE LAMINAS USED AS A BOAT BUILDING MATERIAL

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ABSTRACT

It has been found that the usage of non-crimp reinforcements merit for achieving acceptable levels of engineering parameters such as strength and stiffness when compared with other glass reinforced structures. Therefore, it is concluded that non-crimp reinforcements are materials for boatbuilding for achieving lighter structures with lesser workmanship. Tensile and flexural tests were conducted on orthophitalic polyester resin with hand – laid E glass stitched multilayer angle laminae with ten different thicknesses and with five different directions (0º, 30º, 45º, 60º, 90º). The assessment of the material was made in light of those experiments, and results are presented together with comparison of other reinforcement fibers (mat and woven roving). It is believed that the presented results are of direct use for the designers.

1. INTRODUCTION

When the boats built in recent years are compared with the boats of former years; it can be seen that the hull structures are made to carry higher loads; no matter the boat is a motorboat or a sailing yacht. This can be attributed to the competitive attitude of people: Boat owners driving motorboats favor ever-faster boats, installing more powerful engines. On the other hand, owners of sail yachts favor larger sail areas, stainless steel rigging, synthetic sail fabrics, shorter fin keels, etc. even though the waves and wind have not changed for millennia. These preferences have resulted on increased stresses on hull material. Moreover, races at sea are made more aggressive manners. Therefore, the designer has to deal with higher structural loads and/or increasingly lighter structures. More accurate calculations are made with smaller margins of error or lesser factors of safety. Those lighter structures are mainly obtained by the use of advanced composite materials technology. The most widely accepted composite material in marine filed is the glass reinforced plastics, due to the fact that it is the optimum choice in terms of durability, workability and cost [1].

It is widely accepted that the modern composite materials are the ideal boatbuilding material for pleasure boats and certain high-speed service craft.

The same can be said for the naval structures. Since the mid-1980s the use of composites has increased considerably as the military strive to reduce the acquisition and maintenance costs and improve the structural and operational performance of naval craft. Other new or potential uses for composites are in the superstructures, advanced mast systems, bulkheads, decks, propellers, propulsion shafts and rudders for large surface combatants such as frigates and destroyers. In submarines, the future applications of composites may include control surfaces, propulsors and mast systems. Navies are also exploring the feasibility of using composites for internal equipment and fittings, such as machinery, heat exchangers, equipment foundations, valves, pumps, pipes and ducts. [2]

However, despite the obvious advantages and the positive experiences obtained so far, it is surprising that composite materials have not enjoyed such popularity in the fishing boat industry.

In South Africa in 1960's; 19 m, pilchard trawlers have been the first examples, followed by the 19 – 22 m shrimp vessels of Florida, USA in 1968. These have been followed by the series production of 28 m purse – seiners in Peru, as well as other sporadic uses during the last three decades [3]. Japan is the country where composite fishing vessels are built most. Those are small and medium sized "pelagic" type fishing boats; and are produced by the engine companies. Those fishing boats are marketed both to the domestic market of Japan and to the Arab Peninsula. In Turkey, as well as other countries; small to medium sizes regional fishing boats, produced traditionally from wood are also built from composite materials and marketed as boats for sports fishing.

However; the usage of composite materials for professional fishermen has been very limited. In Western Europe; where fishing industry is not firmly supported as a state policy and being left for the less-developed members of European Union; aging wooden boats are being replaced by steel boats.

The limited use of plastic composite materials for the fishing boat industry can be attributed to a few reasons; the most important of them being the suspicion and prejudices:

- A stylistic motor yacht design will enjoy a wide acceptance in international arena; but however; a proposed fishing vessel should conform to the regional preferences with respect to form and styling. Imposing a composite material, series production boat possessing a Western European lines to the Turkish fishermen is rather an awkward job. A fisherman will prefer a boat that will be suitable for the regional waters. However, it is believed that these preferences can be overcame by a philosophical design.

- The most important barrier retarding the use of plastic composite materials is the extremely high cost compared to the wooden and steel counterparts. In the Turkish boat market, up to 100% difference of cost between the steel and plastic composite material can be observed. This high cost of initial investment will cause the investor to divert to wood or steel even at the first sight.

  The inherent advantages of composite boats such as their insusceptibility to fungal attack, not being subject to galvanic corrosion, rotting, to attacks of marine borers and gribble, reduced operating costs over the years due to minimal maintenance and dry – docking requirements are surpassed by the excessive initial investment. However, in the hot waters of Eastern Mediterranean, it is a popular practice to cover the traditional wooden hull with a layer of GRP sheathing against boring organism – an approach not totally betraying the traditional prejudices; but making use of some of the obvious advantages of composite materials.

  In order to eliminate the above discussed disadvantage of high initial cost, a design of maximum 15 – 20 m range should be selected and be mass – produced to lower the cost. Although plastic composite material is the ideal material for vessels smaller than the above – mentioned size; the relevant market in Turkey is dominated by the extremely cheap wooden boat construction. However; when the fact that wooden boat construction is almost a forgotten art in the West is taken into account, fishing boats of this category can be produced in Turkey and exported to Europe at reasonable prices.

The reason of selecting the 15 – 20 m range for the mass production of composite hulls is that the manufacturing of a steel boat less than that range is not feasible due to difficulties in manufacturing; as well as the fact that a composite boat of above the 20 m range cannot compete with a steel boat of the same size in terms of the manufacturing cost.

- Until recently, users approached to plastic composite boats with some suspicion in terms of stamina; but now, it can be observed that this attitude has been diminishing.

- Another source of prejudice that is prevalent among the users is the lack of stability and seaworthiness of the composite hulls due to their lightweight. The first thing that can be said against this statement is to look at the well – known stability formula: BM = I/V and note that neither the moment of inertia (I) of the waterline area nor the displacement volume (V) of the hull are parameters that are only determined by the weight of hull. When the data prepared by Lloyd's Register of Shipping is referred; one can see that the lightest material for a one square meter panel with frames, satisfying the regulations for a 12.6 m fishing boat is the composite material; (21 kg) when compared to the wood (45 kg) and steel (56 kg) [4]. Hence; the weight of the plastic composite material built hull will obviously be the lowest.

  If the same underwater form (with the same prismatic coefficient) with no ballast is to be used; the saving in weight can either be used as an extra space for tank storage or for extra equipment <u>or</u> for the choice of a finer form (i.e.; lower midship section coefficient). Here, one should state that the Turkish users are not keen on using ballast in their hulls.

  The other factor affecting the seaworthiness besides the metacentric radius and metacentric height is the vertical accelerations, determined mainly by heaving. Vertical velocity and accelerations related to heaving directly depends on the waterplane area buoyancy [5]. In other words; waterplane loads per unit area is the governing factor in terms of the magnitude of the vertical accelerations. A successful design; as seen in various traditional designs, should provide the vertical acceleration related ride comfort. Once a hullform with less vertical accelerations is obtained; seaworthiness can further be enhanced by a higher freeboard and a suitable flare.

- One of the drawbacks against the composite materials is that they are susceptible to abrasion. In order to eliminate deterioration by abrasion, working surfaces should be covered with abrasion – resistant coatings.

The purpose of this paper is to contribute to the technology of composite materials; by the study of non-crimp reinforcement elements for hull construction. Engineering constants of plastic composites have been found by a series of experiments and presented in this paper. Advices for material thickness and directions shall also be made based on the assessment of experiments performed.

Although the evaluation of the elastic constant for unidirectional multi-layer laminates is analytically possible, for design purposes, ultimate strengths of unidirectional multi-layer laminates are needed.

The scope of this study is to establish the results of tests performed to determine some important engineering constants (modulus) and ultimate strengths of GRP panels, consisting of standard production series of stitched multilayer angle laminas embedded in a polyester matrix, prepared in which area systematic approach based upon thickness, and material direction.

MATERIALS

This study concentrated on the E-glass reinforced polyesters. The fibers in the form of layers known as stitched multilayer laminae or as non-crimp reinforcements were supplied by Cotech industries (Table 1).

Table 1: Fibers used.

Product type (Abbrevation)	Weights in each axis [g/m^2]				Dry thickness [mm]
	0°	- 45°	90°	+ 45°	
EBX 446 (A)		223		223	.4
EBX 936 (B)		468		468	.8
ETLX 751 (C)	283	234		234	.6
ETLX 1169 (D)	567	301		301	.9
EQX 868 (E)	283	150	283	150	.65
ELT 850 (F)	425		425		.7
EQX 1168 (G)	283	301	283	301	.9
ELPB 425 (H)	425		40		.45

These types of reinforcements are believed to make the production of lighter structures possible by the use of lesser layers or alternatively, to achieve higher levels of strength for the same weight of material used [7]. The main factor that deters the producer from the usage of stitched multilayer reinforcements (non-crimp reinforcements) is the higher cost of those materials. Although the usage of lesser layers will cause a reduction in the costs of workmanship; material cost is still high in developing countries where the cost of workmanship is less when compared to industrialized countries. Therefore, the usage of non-crimp reinforcements is generally limited to the inner shell and to outer shell (2-3 mm) of the sandwich-type hulls where strength and stiffness are required.

The resin used is orthophitalic polyester form the Dewilux Inc. This polyester resin, produced as a general purpose resin, is widely used in boat building and is readily available on the market. Panels from which the specimens were taken were produced by hand lay-up in workshop of a boat builder in Izmir. The same person laid the glass fibers to overcome possible differences of workmanship practice. Hand lay-up was the preferred method since both it is used widely in the boat building industry due to its lower cost and the ease of obtaining uniform thickness throughout the lamination. Production with this method is sufficient where medium-strength characteristics are satisfactory.

A series of panels were prepared with thicknesses varying from 1 mm to 10 mm with increments of nominally 1 mm to represent the scantlings of a hull of single skin construction. The curing of panels was made at the room temperature and they were left for one month at the ambient indoor conditions before being tested.

Since the aim of this job was to obtain a spectrum of results representing the tensile and flexural stresses of the material; test specimens (five for each test) were cut in each direction for each of the panels.

The tests were performed for tensile and three-point flexural loads at the Laboratory of Offshore Structures and Shipbuilding Materials of the Technical University of Gdansk Faculty of Maritime Engineering and Ship Technology. Tensile and flexural tests were performed according to the standards PN-EN ISO 527 and to PN-EN ISO 178, respectively.

RESULTS AND DISCUSSION

The starting point of this experimental research was to determine the strength characteristics of unidirectional, multilayer angle laminas and to submit the results for the use of designers. Clearly if the designer does not aim to attain increased strength values in a specific direction, then when dealing with these kinds of anisotropic materials, accepts minimum strength value anticipated in any direction as the theoretical design strength value. The reason for the preference of multilayer unidirectional laminas over chopped strand mat and woven roving combinations is by eliminating the effect of crimp angle, thus attaining higher strength values. As a matter of fact, if the increased strength values yield a uniform distribution in x-y plane then material is ideal for implementation (Figure 1.).

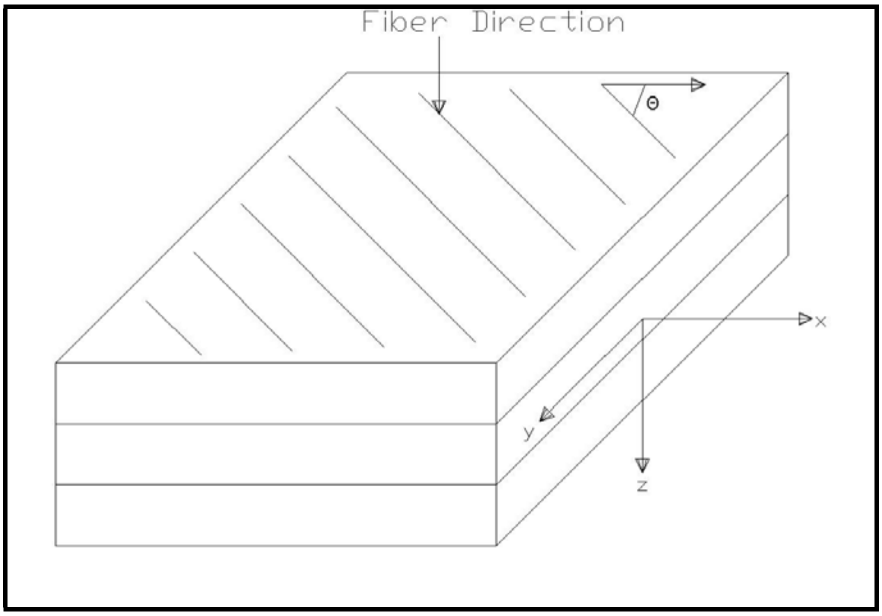

Figure 1: Axes of a panel.

As far as the test results are concerned, either the results of the burning test or the thicknesses obtained indicate high quality production in terms of industrial standards. The properties of the panels and the results obtained were summarized in the Table 2.

Comparison between the glass contents of 50 - 51 % of Panel 4, 5 and 9 with the 52 - 56 % glass content of the other panels can be explained by the low glass content of unidirectional ELPB 425 fabric used in lamination sequence of the above panels. This unidirectional lamina has very loose stitching characteristic. Besides, all the other fabrics of producer are certified except the latter.

As much attention as intention was paid to obtain a uniform strength distribution in x-y plane, similar precautions were taken also for similar distribution in x-z plane.

When the strength values of panels in x and y axis, in other words "fill" and "warp" strengths are studied; the ratio of fill strength / warp strength as 0.80 for the panels of aspect ratio 1, and 0.61 for the panels of aspect ratio 2 as requested by classification societies are not met by most of the panels [8, 9, 10].

In order to apprehend the phenomenon, weights of glass building up thickness at every angle should be assessed.

It is obvious that it has been failed to obtain uniform angular distribution of glass weights. Although the glass weight distributions are expected to follow the pattern of strength, they do not usually fit this form; even sometimes they establish just the opposite of the expected form. For example, Panel-1 does not contain any glass in 90° direction. In the same manner Panel-2 and Panel-4 do not have glass in 90° direction either; on the contrary these panels have some strength in this direction.

Regarding Panel-3, the reverse effect of the low glass weight in the 45° direction shows high strength in this direction. When the other results are studied similar situations are encountered with. First of all Panel-3 will be concluded: the higher strength in 45° direction in spite of the low glass weight can be explained such that 45° layers are always supplied as +45° and -45° pairs of the same weight. Low mechanical properties of +45° layer in transverse direction to the material axis are counter balanced by the high strength properties of -45° layer's material axis in coincidence with +45° layer's transverse axis. Hence +45° layer's strength also in transverse direction is increased and vice versa. If can briefly be stated that due to above reason in all panels 45° direction is advantageous.

Having some strength in 90° direction in spite of no glass or low glass is caused by transverse strength of 0° and 45° laminas. Here, it is clearly seen the enveloping effect i.e. coverage of this directions by the layers of other directions. Eventually it should be stated that glass weights in 0° and 90° directions should properly be balanced.

Panels 8, 9 and 10 also betray a good aspect. Whereas, in these panels a balanced strength distribution in 0°, -45°, -90° directions is present, in 30°- 60° directions a reduction in strength is observed. This revives the importance of 30° and 60° laminas.

Table 2: Results from all tests

Panel no.	Sequences	Fiber content by weight [%]	Thickness [mm]	Direction	Tensile strength [MPa]	Tensile modulus [GPa]	Flexural strength [MPa]	Flexural modulus [GPa]
				Result from tests (CV=coefficient of variation expressed as percentage in brackets)				
1	[H/A]	52.3	1.36	*0º*	211.3 (8.6)	8.56 (6.5)	304.8 (10.4)	3.38 (10.8)
				30º	147.5 (11.0)	8.17 (3.9)	266.4 (6.8)	3.30 (7.5)
				45º	134.4 (3.3)	6.80 (3.1)	276.6 (13.2)	3.55 (16.6)
				60º	91.0 (4.5)	6.74 (15.8)	205.6 (5.7)	2.60 (14.8)
				90º	62.3 (6.5)	5.25 (6.6)	165.8 (12.9)	2.36 (10.6)
2	[C/B]	53.5	2.12	*0º*	132.3 (10.4)	6.46 (10.9)	251.2 (15.6)	6.09 (10.3)
				30º	170.6 (2.8)	12.35 (3.0)	300.6 (7.9)	5.05 (8.1)
				45º	233.6 (4.3)	13.02 (10.9)	345.6 (11.8)	5.68 (12.0)
				60º	222.3 (3.1)	9.58 (12.4)	302.0 (13.5)	5.09 (10.7)
				90º	75.0 (2.7)	5.31 (6.9)	192.6 (7.5)	3.78 (9.4)
3	[F/D/C]	52.4	3.36	*0º*	324.9 (5.3)	15.81 (16.1)	450.6 (11.4)	11.22 (12.2)
				30º	177.5 (3.6)	11.13 (5.1)	337.4 (11.2)	9.20 (0.7)
				45º	175.5 (8.3)	9.93 (2.1)	334.4 (6.3)	9.13 (4.6)
				60º	117.6 (5.9)	9.52 (8.8)	269.8 (6.9)	7.56 (4.5)
				90º	119.6 (8.1)	9.06 (25.7)	200.8 (3.4)	5.22 (5.2)
4	[D/A_2/D/H]	51.4	4.31	*0º*	315.1 (8.7)	14.94 (3.4)	547.4 (7.0)	13.37 (7.3)
				30º	207.4 (1.9)	13.84 (2.3)	340.2 (10.5)	9.32 (9.0)
				45º	210.5 (4.6)	11.51 (2.7)	298.0 (3.6)	7.07 (3.8)
				60º	154.5 (3.6)	9.38 (5.1)	195.2 (2.7)	5.32 (10.2)
				90º	104.5 (2.9)	7.23 (4.5)	152.6 (7.3)	4.60 (6.2)
5	[D/A/F/A/D/H]	50.6	5.77	*0º*	319.3 (2.3)	15.01 (9.2)	653.4 (7.7)	15.60 (11.4)
				30º	191.0 (3.6)	11.55 (2.9)	286.6 (9.5)	10.72 (12.1)
				45º	191.1 (5.4)	9.76 (3.2)	215.5 (12.5)	5.17 (6.0)
				60º	154.8 (2.3)	9.15 (4.4)	207.2 (11.6)	5.43 (16.5)
				90º	155.4 (3.7)	8.92 (6.8)	168.4 (10.4)	4.82 (8.4)
6	[D/B/G/B/D]	56.4	6.09	*0º*	225.5 (4.8)	11.43 (10.6)	417.6 (6.1)	12.20 (5.5)
				30º	196.4 (7.6)	16.06 (14.5)	354.4 (10.7)	11.20 (3.3)
				45º	253.7 (2.1)	14.43 (2.5)	332.6 (5.8)	10.57 (2.1)
				60º	204.7 (3.5)	13.58 (24.9)	267.4 (4.1)	9.00 (5.1)
				90º	143.8 (2.2)	8.23 (12.8)	191.2 (4.0)	6.45 (3.9)
7	[D/B/G/E/B/D]	53.1	7.00	*0º*	254.2 (1.2)	12.00 (1.3)	418.6 (3.8)	12.51 (2.4)
				30º	214.0 (4.6)	13.81 (2.4)	346.6 (3.0)	11.88 (2.9)
				45º	210.3 (5.3)	11.92 (4.0)	320.0 (8.1)	11.06 (6.0)
				60º	209.4 (4.8)	10.81 (9.4)	247.2 (3.8)	8.93 (4.4)
				90º	156.3 (2.9)	9.34 (1.5)	201.2 (7.5)	7.25 (2.8)
8	[D/B/G/F/E/B/D]	53.8	8.30	*0º*	226.3 (4.7)	11.85 (2.3)	397.2 (6.3)	12.16 (5.5)
				30º	172.4 (4.8)	13.91 (8.4)	286.0 (4.7)	12.06 (3.3)
				45º	218.6 (6.3)	12.07 (6.7)	362.0 (5.5)	10.48 (6.7)
				60º	181.2 (1.7)	11.77 (8.5)	308.6 (4.5)	8.96 (5.7)
				90º	177.0 (1.5)	9.34 (4.5)	304.8 (6.5)	9.92 (4.1)
9	[H/D/B/G/F/E/B/D/H]	51.3	9.51	*0º*	258.2 (5.4)	14.39 (1.5)	428.4 (2.7)	13.92 (4.5)
				30º	170.2 (1.5)	11.97 (3.0)	308.0 (3.6)	12.97 (6.0)
				45º	212.8 (2.9)	11.17 (3.5)	322.6 (6.2)	10.69 (8.1)
				60º	170.6 (2.1)	9.26 (3.0)	241.6 (3.5)	7.64 (6.1)
				90º	163.1 (3.5)	10.26 (2.9)	181.4 (7.7)	7.35 (5.6)
10	[H/D/B/F/G/F/E/B/D/H]	52.6	10.69	*0º*	266.8 (3.5)	15.34 (2.2)	417.0 (3.5)	10.37 (4.3)
				30º	167.8 (5.1)	12.89 (11.7)	272.0 (4.3)	7.97 (5.8)
				45º	198.9 (1.6)	11.31 (2.8)	284.4 (2.2)	6.94 (6.4)
				60º	160.5 (5.6)	9.71 (8.7)	216.6 (8.7)	5.77 (8.9)
				90º	167.7 (5.7)	8.26 (10.6)	165.8 (5.7)	5.03 (6.0)

CONCLUSION

It was previously said that the main advantage of non-crimp reinforcements is that they offer the possibility of achieving higher strengths with panels of less thickness. Lesser amounts of layers contribute both to merit lighter structures and saving in workmanship.

However, the structure has the strength characteristics of shear strength, bending strength and stiffness closely related to material thickness and the specialists of this field stress that lessening of the material thickness is not advisable. Schofield stresses that mat and woving roving layers should be reverted to especially in middle sections which include mat reinforcements. The high resin content of the mat renders the laminate effectively to a lower density "core" material that could bring the panel strength and stiffness up to design standards [11].

The experimental work of Devies and Petton [12] present the results of strength experiments of mat and woven roving fiber reinforced polyester specimens. The method and the conditions of production are the same as this work. A comparison of results obtained for numbered as 4 are presented in Table 3.

Table 3: Comparison of the tests' results

	Woven rowing + Mat [9]	**None-crimp**	**Increments [%]**
0º tensile strength, MPa	229.2 (5.9)	315.1 (8.7)	37
0º flexural strength, MPa	354.5 (7.6)	547.4 (7.0)	54
45º flexural strength, MPa	257.8 (-)	298.0 (3.4)	16
0º tensile modulus, GPa	14.99 (1.9)	14.94 (3.4)	-
0º flexural modulus, GPa	13.34 (3.3)	15.60 (7.3)	16

As can be observed from Table 3: the 16% increase in flexural strength in the 45° direction is the same as reported by Steggal [7].

It is interesting that although 30° and 60° directions of fiber orientation exist in the related scientific literature, they do not appear in the producers' catalogues to the authors' knowledge. If layers with those orientation angles are laminated, they would offer the advantage of the elimination of the strength reduction in the 90° fiber direction. Although unidirectional laminae in the 30° and 60° angles can be hand-laid; taking the peculiarities of workmanship in fabrication and the form of hull, it is suggested that the glass fabric producers should give a consideration to produce fabrics with those orientation angles.

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