Stress Strain Characteristics of Glass Fiber Reinforced Plastic as Wind Turbine Blade Materials

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Abstract: Wind energy, which is limitless and clean source, takes first place in alternative energy sources because of its developments last several years. Beside research and development studies of wind turbines produced to transform wind energy to electrical energy increase every day, design and materials of wind turbine blades lead researches carried out intensively at wind turbine constructions.

A study about using composite materials with plastic matrix is chosen because the aim of wind turbine blade studies is producing lighter constructions. In this study, stress-strain characteristics of random short glass fiber mat reinforced polyester or vinylester matrix composite materials produced by using hand lay up molding method are analyzed.

Consequently stress-strain characteristics of composites materials which are manufactured by using different layers of glass fiber mat reinforcement are compared.

1. Introduction

In our world energy requirement increases approximate 4-5% every year. But fossil fuel reserves, which compensate this requirement, increase much more. The most optimistic predictions show that oil reserves will run out at the latest 2030 – 2050 and will not compensate requirements. Also same situation is expected for coal and natural gas. Therefore humankind must tend to renewable energy resources before fossil fuel reserves come to an end. Due to research and development studies, renewable energy resources will be same level with other conventional systems as cost and also efficiency.

Wind energy, which is one of renewable energy resources, is kind of clean, harmonious to environment and economic energy. Using wind power neither consumes fossil fuel nor makes dirty atmosphere. As it is known, in wind turbine constructions wide range of materials are used. Suitable materials must be chosen for each unit to obtain high efficiency
from wind turbines. In Figure 1, components of horizontal axial wind turbine are shown.

Figure 1. Components of horizontal axial wind turbine (Dan A., et al., 2001)

Generally we can prefer five methods for the selection of material in all condition. These methods are; economical and performance characteristics, values of measurement specifications, analysis of values, analysis of damage, analysis of benefit and economical (Eker B., et al., 2004).

Rapid advancements in material technology have created some variations in the structure of wind turbines. That variation primarily provided positive impacts for lowering the prices of wind turbines. Many factors such as mechanical equipment, fatigue resistance, corrosion resistance, breaking toughness, rigidity, weight and appearance have impacts on wind turbine materials. But a major problem influencing the design and operation of wind turbine is fatigue. The lifetimes of most components are gradually reduced by the high number of revolutions that occur at relatively low stress magnitudes. Turbine blades are the components which exhibit the largest proportion of fatigue failure (approximate 50%) (Eker B., et al., 2006). Materials fatigue properties are an important consideration in wind turbine design and materials selection. During the expected 30 years life of a wind turbine, many of the components will
need to be able to endure $4 \times 10^8$ fatigue stress cycles. This high cycle fatigue resistance is even more severe than aircraft, automotive engines, bridges and most other man-made structures (Dan A., et al., 2001). Wind turbines are generally designed to provide requirements of rotor weight control, long time running, main lines of system design and more economic performance. When the other conditions are equal, the most suitable design will be design criterion which makes lighter structures. Accordingly light materials that have proper specifications will provide better performance (Vardar A., et al, 2005).

Worldwide growth in wind turbines since 1994 has been 30% or higher annually (Dan A., et al., 2001). Energy producing cost is decreased owing to using composite materials especially in large wind turbines. Today this kWh value is approximate 90% less than in 1980’s. Namely in 1980’s kWh cost value was 40 US cent but today this value is decreased 3.5-4 US cent. In 2020’s this value is expected to decrease 2.25 US cent.

Composite materials are important not only construction and cost but also efficiency of energy taken from swept area by rotor blades. Even composite materials have a huge effect the developing off-shore systems. On the other hand there must be a specific wind speed for system optimization when wind turbines are considered as aerodynamic. For example; there must be 15 m/s wind speed beside 19-30 rpm for 600 kW wind turbine. Additionally system has to provide stability when there is a storm or windless conditions. Beside proper design of rotor blades, proper material has to be considered to reach these values and conditions and to continue operation. Selection of materials has to be given heed not only low density, proper cost etc. but also adaptation of variable conditions.

Thanks to all these ideas, researchers and manufacturers are focused on using composite materials in wind turbines and so it has been seen that using composite materials provides much more benefit from wind energy. According to some studies, system works efficiently over 3000 hours in one year unless renewing when rotor blades are produced from composite materials. Additionally it has been noticed that effect of rotor to wind turbine generator decreases to harmless level at high revolutions. Also system is stable thanks to power is organized with computer control (Vardar A., et al, 2005).
2. Experimental Studies

Wind turbine rotor blades are incurred the tension by effect of lifting forces. That's why random short glass fiber mat and/or balsa wooden reinforced polyester matrix and vinylester matrix composite materials, which are used to make wind turbine rotor blades, are produced various layers and stress – strain characteristics of these composite materials are investigated.

2.1 Materials

Materials used preparations of test samples have been chosen form materials which are preferred to produce wind turbine rotor blades.

2.1.1 Matrix Materials

As matrix materials are chosen polyester and vinylester resins. Liquid form properties of these resins are indicated in Table 1.

Table 1. Liquid form properties of polyester and vinylester resins (Poliya Polyester and Auxiliary Materials Company, 2007)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Polyester</th>
<th>Vinylester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [g/cm³]</td>
<td>1.128</td>
<td>1.044</td>
</tr>
<tr>
<td>Refraction Index</td>
<td>1.539</td>
<td>1.565</td>
</tr>
<tr>
<td>Acid Value [mg KOH/g]</td>
<td>17</td>
<td>max. 9</td>
</tr>
<tr>
<td>Viscosity [cp]</td>
<td>700</td>
<td>400</td>
</tr>
<tr>
<td>Gel Time [minute]</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>Monomer Content [%]</td>
<td>37</td>
<td>42</td>
</tr>
<tr>
<td>Shelf Life in Months</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Using polyester resin is a reactive, light colored economical general type resin with medium viscosity, low shape deformation. This resin can be used obtaining glass reinforcement plastic (GRP) products in hand lay up and spray up systems.

Using vinylester resin provides excellent adhesion with high corrosion resistance and high resistance to heat during the time of service. Beside the high performance of this resin against acids and alkalis, it provides a high flexibility with high mechanical resistance properties. Owing to these properties it’s used to high static and dynamic loads when reinforced by glass fiber and/or carbon-aramide fiber. Vinylester resins have the best
chemical resistance among the unsaturated resins. As polyester resins generally don’t resist much alkaline – based materials and oxidizing acids, vinyl ester can be used certainly against these chemicals (Poliya Polyester and Auxiliary Materials Company, 2007).

Also Co as catalyzer and Mek-P (methyl ethyl ketone – peroxide) solution as hardener are added to resin.

2.1.2 Reinforcement Materials
Random short glass fiber mat (450 g/m²) and balsa wooden are used as reinforcement components in produced composite materials. Glass fiber is a kind of E-glass which is drawn as micron size filaments with continuous process. Glass raw material is grinded superfine and is blended to obtain a homogenous mixture then it puts to melting furnace operating at approximate 1600 °C. In furnace, mixture turns slowly into liquid melting. Glass filaments which were drawn by wiring system with high speed like 50-70 m/s at 5-20 micron diameters are collected on a bobbin. Before glass fibers are made a bunch they are covered a chemical compound which name is binder. Binder type is one of the most important elements that affect performance of glass fiber in composite material. After glass fibers wrapped on bobbin are dried up, they are subjected to process to obtain glass fiber products which are mat from shorn bunch, filament, discontinuous bunch etc (Camelyaf Company, 2008).

Continuous fibers are produced by bending together lots of fibers. Diameters of bended fibers are approximate 0.065 – 1.40 and they are used glass textile products shaped fabric and filament wrapping technique. Continuous bunches are non-twisted bunch or fibers which are formed from each other parallel filaments. Continuous ribs are obtained by wrapping lots of twisted fibers or non-twisted filament on a bobbin. Ribs are grouped as non-twisted or slight twisted rips. Glass fiber mats are minced fibers which are obtained by cutting twisted or non-twisted rips and length are changing between 3-60 mm. Rips which are used producing discontinuous rips are soft or hard rips.

Glass fiber mats that we were used were thin, flat layers which are consisted of continuous or discontinuous filament bunches. Filaments are scattered irregularly in structure and they are gotten together by a binding resin or mechanical made by needle. Reinforcing effects of mats which are consisted of continuous filament bunches and minced filaments are same but their molded specifications are different. Complex pieces can be molded by continuous filament mats. In Figure 2, random short glass fiber
mat roller is shown. Organic bindings used reinforcing mats might have high or low resolution characteristics showing resolution speed of binding in liquid resin matrix. Reinforcing mats in which binding phase is quickly dissolved are used certain producing methods like hand lay up. Glass fiber mats contained binding phase with low dissolving speed are used pressing mould technique (Akdogan A., 2004).

![Random short glass fiber mat roller](image)

Figure 2. Random short glass fiber mat roller (Camelyaf Company, 2008)

Density of balsa wooden chosen as second reinforcement component in produced composite materials is 80 – 176 kg/m$^3$ but usually 96 – 144 kg/m$^3$ density are used. Problem of this kind of materials is that fluids leak into wooden. Leaked fluids cause corruption of middle material and separation, consequently space is occurred. But balsa wooden in which fibers turn towards wall as vertical is material that do not cause problems happened on other wooden materials and it avoids spreading humidity which occurs around the wall from leaked fluids. Using areas of balsa wooden are various. Because of low cost they are generally used as middle material. Also their strength of cutting and pressing are high. But liquid resistance is lower than foam materials (Camelyaf Company, 2008).

Additionally wax and mould remover are applied on the mould surfaces to take out easily the produced composite material form mould.

### 2.2 Producing of Tensile Test’s Samples

Samples of tensile test were produced at laboratory conditions using hand lay up method. This method was chosen in spite of requiring hard hand-working, because it is suitable for limited products. Wooden moulds were made to produce composite materials intended dimensions and not to overflow resin. Besides, glass material was chosen as mould bottom surface to be composite surfaces smooth and to be applied resin easily.
Before composite materials were started producing, mould were cleaned up and wax and mould remover were applied on the mould surfaces to take out easily the composite material form mould. Additionally, 1/6 ml 6% Co solution and 1 ml 1% Mek-P (methyl ethyl ketone – peroxide) solution were added to polyester resin and 0.2 ml 6% Co solution and 2 ml 1% Mek-P solution were added to vinylester resin, then solutions were blended until obtained a homogeneous solution. After these procedures, random short glass fiber mats were lied down on the mould, resin were applied on it and again one layer glass fiber or balsa wooden were lied down on dampened fibers. Resin ratios of produced composite materials change approximate between 60% - 90% because of using various layers of glass fiber and balsa wooden. During process, it was observed that resin well penetrated to fibers.

Composite materials were produced as 8 different kinds and these were 1 layer random short glass fiber mat + polyester resin, 1 layer random short glass fiber mat + vinylester resin, 1 layer random short glass fiber mat + 1 layer balsa wooden (thickness=1.5 mm) + polyester resin, 1 layer random short glass fiber mat + 1 layer balsa wooden (thickness=1.5 mm) + vinylester resin, 2 layers random short glass fiber mat + polyester resin, 2 layers random short glass fiber mat + vinylester resin, 2 layers random short glass fiber mat + vinylester resin, 3 layers random short glass fiber mat + polyester resin, 3 layers random short glass fiber mat + vinylester resin. Thickness values of produced composite materials are indicated in Table 2. Composite materials were measured with micrometer.

### Table 2. Thickness values of produced composite materials

<table>
<thead>
<tr>
<th>Samples</th>
<th>Thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 layers fiber + polyester (C)</td>
<td>3.35</td>
</tr>
<tr>
<td>3 layers fiber + vinylester (G)</td>
<td>3.04</td>
</tr>
<tr>
<td>2 layers fiber + polyester (B)</td>
<td>2.13</td>
</tr>
<tr>
<td>2 layers fiber + vinylester (F)</td>
<td>1.82</td>
</tr>
<tr>
<td>1 layer fiber + polyester (A)</td>
<td>1.06</td>
</tr>
<tr>
<td>1 layer fiber + vinylester (E)</td>
<td>0.93</td>
</tr>
<tr>
<td>1 layer fiber + 1 layer balsa + polyester (D)</td>
<td>2.56</td>
</tr>
<tr>
<td>1 layer fiber + 1 layer balsa + vinylester (H)</td>
<td>2.41</td>
</tr>
</tbody>
</table>

### 2.3 Preparing of Tensile Test’s Samples

Composite materials, which were produced as various layers random short glass fiber mat and/or balsa wooden reinforced vinylester resin and
polyester resin matrix, were prepared proper form and structure to be performed tests.

Samples of tensile test were prepared according to ASTM D 638 “Standard Test Method for Tensile Properties of Plastics”. In Figure 3, dimensions of tensile test’s samples are shown according to ASTM D 638. Composite materials were cut with a handsaw and then grinded with machine. At the end their edges and corners were grinded with sandpaper.

Figure 3. Dimensions of tensile test’s samples according to ASTM D 638

Meanings and values of symbols, which are in Figure 3, are given below;
b₁ (width of narrow section): 13 mm ± 0,5
L₁ (length of narrow section): 57 mm ± 0,5
b₂ (width overall): min. 19 – max. 25,4 mm
L₃ (length overall): min. 165 mm
L₀ (gage length): 50 mm ± 0,25
L (distance between grips): 115 mm ± 5
R (radius): 76 mm ± 1

2.4 Tensile Test

Tensile test were applied to samples at 50 mm/min test speed and obtained data of tensile stress, yield point, breaking strength and elasticity module which are given in Table 3 and also in Figure 4 – 7. During tests, 5 N/mm² pre-load is applied to eliminate cavity of grips.
Table 3. Tensile test data of polyester matrix composite materials and vinylester matrix composite materials

<table>
<thead>
<tr>
<th>Samples</th>
<th>Yield (Re) Force [N]</th>
<th>Point (Re) Stress [N/mm²]</th>
<th>Tensile (Rm) Force [N]</th>
<th>Breaking Strength [N/mm²]</th>
<th>Strain mm %</th>
<th>Elasticity Module (E) [N/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>476,10</td>
<td>41,50</td>
<td>717,67</td>
<td>699,67</td>
<td>60,97</td>
<td>2,67</td>
</tr>
<tr>
<td>B</td>
<td>1394,67</td>
<td>46,75</td>
<td>2220,00</td>
<td>2119,33</td>
<td>71,04</td>
<td>2,98</td>
</tr>
<tr>
<td>C</td>
<td>2472,40</td>
<td>61,05</td>
<td>3532,00</td>
<td>3221,67</td>
<td>79,55</td>
<td>4,71</td>
</tr>
<tr>
<td>D</td>
<td>547,33</td>
<td>15,84</td>
<td>846,67</td>
<td>826,00</td>
<td>23,90</td>
<td>6,7</td>
</tr>
<tr>
<td>E</td>
<td>769,53</td>
<td>61,30</td>
<td>1099,33</td>
<td>1046,00</td>
<td>83,31</td>
<td>2,91</td>
</tr>
<tr>
<td>F</td>
<td>1476,97</td>
<td>71,04</td>
<td>2303,67</td>
<td>2027,33</td>
<td>97,52</td>
<td>3,50</td>
</tr>
<tr>
<td>G</td>
<td>2616,83</td>
<td>81,10</td>
<td>3738,33</td>
<td>3427,00</td>
<td>106,21</td>
<td>4,92</td>
</tr>
<tr>
<td>H</td>
<td>839,67</td>
<td>25,81</td>
<td>1047,00</td>
<td>983,33</td>
<td>30,22</td>
<td>5,34</td>
</tr>
</tbody>
</table>

Figure 4. Datas of breaking strength, tensile stress and yield point of polyester matrix composite materials

Figure 5. Datas of elasticity module of polyester matrix composite materials

1 1 L G F + P : 1 layer glass fiber + polyester, 2 L G F + P : 2 layers glass fiber + polyester, 3 L G F + P : 3 layers glass fiber + polyester, 1 L G F + 1 L B + P : 1 layer glass fiber + 1 layer balsa + polyester
3. Results and Discussion

In result of applying tensile tests; when quantity of random short glass fiber mat added as reinforcement material were increased, stress – strain characteristics of polyester matrix composite materials and also vinylester matrix composite materials increased. When random short glass fiber mat and balsa wooden were used together as reinforcement material to produce composite material, strength values decreased but strain values increased well. In Figure 8 – Figure 11, these results are given.

\[ \text{1 L G F + V : 1 layer glass fiber + vinylester, 2 L G F + V : 2 layers glass fiber + vinylester, 3 L G F + V : 3 layers glass fiber + vinylester, 1 L G F + 1 L B + V : 1 layer glass fiber + 1 layer balsa + vinylester} \]
In two or three layers glass fiber reinforced composite materials, strength values can not be high in proportion to layer quantity, because in these composite materials, a surface section occurred between layers. In this surface section, shear stress occurs and loads are transferred one layer to another layer by the shear stress. Section, which is between layers, is characteristic in terms of composite strength. Strength values required from composite materials can be provided when matrix material is changed (for example; from polyester to vinylester) and/or quantity of glass fiber mat is increased. Decreasing of strength value is observed at balsa and glass fiber reinforced composite materials. When Figure 11 is examined, it said that there was not main different between strain values of vinylester matrix composites and polyester matrix composites which have the same layers requirement compound.

![Figure 8. Yield point comparison of various layers random short glass fiber mat and/or balsa wooden reinforced polyester or vinylester matrix composite materials](image)

3 1 L G F + P : 1 layer glass fiber + polyester, 1 L G F + V : 1 layer glass fiber + vinylester, 2 L G F + P : 2 layers glass fiber + polyester, 2 L G F + V : 2 layers glass fiber + vinylester, 3 L G F + P : 3 layers glass fiber + polyester, 3 L G F + V : 3 layers glass fiber + vinylester, 1 L G F + 1 L B + P : 1 layer glass fiber + 1 layer balsa + polyester, 1 L G F + 1 L B + V : 1 layer glass fiber + 1 layer balsa + vinylester
Figure 9. Tensile stress comparison of various layers random short glass fiber mat and/or balsa wooden reinforced polyester or vinylester matrix composite materials

Figure 10. Breaking strength comparison of various layers random short glass fiber mat and/or balsa wooden reinforced polyester or vinylester matrix composite materials

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1 L G F + P : 1 layer glass fiber + polyester, 1 L G F + V : 1 layer glass fiber + vinylester, 2 L G F + P : 2 layers glass fiber + polyester, 2 L G F + V : 2 layers glass fiber + vinylester, 3 L G F + P : 3 layers glass fiber + polyester, 3 L G F + V : 3 layers glass fiber + vinylester, 1 L G F + 1 L B + P : 1 layer glass fiber + 1 layer balsa + polyester, 1 L G F + 1 L B + V : 1 layer glass fiber + 1 layer balsa + vinylester
Figure 11. Strain values comparison of various layers random short glass fiber mat and/or balsa wooden reinforced polyester or vinylester matrix composite materials

Stress – strain characteristics of same layer random short glass fiber mat and/or balsa wooden reinforced vinylester matrix and polyester matrix composite materials are given in Figure 12 – Figure 15. According to these results, it is understood that stress and strain values of vinylester matrix composites are higher than polyester matrix composites’. Stress – strain curves of just glass fiber reinforced composite materials are like linear but light waving are seen at plastic area of balsa and glass fiber reinforced composites materials’ diagrams. These waving occur because of breaking firstly balsa wooden then glass fiber material during tensile tests. Besides, some discontinuities, which occur all these curves, are seen due to producing composite materials by using hand lay up method. When composite materials are produced by using this method, air might enter composite structure during producing and make some emptiness’s.

5 1 L G F + P : 1 layer glass fiber + polyester, 1 L G F + V : 1 layer glass fiber + vinylester, 2 L G F + P : 2 layers glass fiber + polyester, 2 L G F + V : 2 layers glass fiber + vinylester, 3 L G F + P : 3 layers glass fiber + polyester, 3 L G F + V : 3 layers glass fiber + vinylester, 1 L G F + 1 L B + P : 1 layer glass fiber + 1 layer balsa + polyester, 1 L G F + 1 L B + V : 1 layer glass fiber + 1 layer balsa + vinylester
Figure 12. Stress – strain characteristics comparison of 1 layer random short glass fiber mat reinforced polyester matrix and vinylester matrix composite materials\(^6\)

Figure 13. Stress – strain characteristics comparison of 2 layers random short glass fiber mat reinforced polyester matrix and vinylester matrix composite materials\(^7\)

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\(^6\) 1 L G F + P : 1 layer glass fiber + polyester, 1 L G F + V : 1 layer glass fiber + vinylester

\(^7\) 2 L G F + P : 2 layers glass fiber + polyester, 2 L G F + V : 2 layers glass fiber + vinylester
Consequently, stress – strain characteristics of vinylester matrix composite materials are superior to polyester matrix composite materials.’.

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8 3 L G F + P : 3 layers glass fiber + polyester, 3 L G F + V : 3 layers glass fiber + vinylester

9 1 L G F + 1 L B + P : 1 layer glass fiber + 1 layer balsa + polyester, 1 L G F + 1 L B + V : 1 layer glass fiber + 1 layer balsa + vinylester
4. Conclusion

Wind energy is one of renewable energy resources which are suitable the using and developing. It does not damage the ecology and its external costs are low. Wind station costs and wind energy prices decrease regularly. There is not only one fact to define the wind energy price because of changing wind speeds, station costs and amortization periods in everywhere. But wind energy prices cope with other energy resources’ prices when there is adequate wind intensity. Technology that transforms wind energy to electric energy requires high capital but expenses of combustible and operating are pretty low. When wind turbine’s aerodynamic and materials are developed, energy costs decrease.

In this study; stress – strain characteristics of random short glass fiber mat and/or balsa wooden reinforced polyester matrix and vinylester matrix composite materials were examined. These reinforcement and matrix materials are used at industry as wind turbine blade materials.

In result of applying tensile tests; it was seen that tensile stresses and strain values of vinylester matrix composite materials were higher polyester matrix composites’. But polyester resins are chosen as matrix material to produce rotor blades up to 3 meters length. Because polyester resins provide enough strength and decrease cost in small wind turbines. Vinylester or epoxy resins are needed to use as matrix material to produce rotor blades more than 3 meters length. Because strength values of these resins are higher than polyester resins’.

When layers of random short glass fiber mat were increased, stress – strain values of composite materials produced as polyester or vinylester matrix also increased.

In random short glass fiber and balsa wooden reinforced composite materials, tensile strengths were decreased because of using balsa wooden but strain values were increased. Balsa wooden is usually preferred to profit from cost and lightness advantages. In industry, glass fibers are used main reinforcement material and balsa wooden is preferred as second reinforcement material. So produced composite materials have optimum specifications.
References


