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Experimental Studies for the Creation of Composite Materials with Increased Static Mechanical Characteristics

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Abstract. *The aim of the study was to experimentally verify the enhancement of certain mechanical properties of a composite material consisting of unsaturated polyester matrix reinforced with fiberglass, by incorporating specific proportions of sodium aluminosilicate (SAS) powders and talc as fillers for the fabrication of large wind turbine blades. Samples composed of these materials, with varying combinations of the added components, underwent testing for tensile and bending strength, and experiments were conducted to determine their modulus of elasticity. The findings indicate that the inclusion of SAS in the matrix material resulted in increased values of tensile strength and modulus of elasticity up to certain proportions. Solely adding talc to the matrix material led to a rise in bending strength. Increasing the talc percentage in the matrix material reinforced with 20% fiberglass resulted in decreased tensile strength and elastic modulus of the samples, while incorporating a blend of SAS and talc into the matrix material reinforced with 20% fiberglass significantly boosted the elastic modulus and tensile strength of the samples under tensile conditions.*

Keywords*: composite material, sodium aluminosilicatem, talc, polyester, fiberglass*

1. Introduction

Humanity has always grappled with the critical issue of harnessing natural forces as inexhaustible sources of energy, such as water or wind. Presently, there is a particular focus on harnessing wind power, leading to continuous advancements in wind turbine technology, with blades constructed from composite materials reinforced with fiberglass [1-3]. While fiberglass is known for its high strength properties, for the production of higher power wind turbine blades, using it as the sole reinforcing component to the matrix material (even if the materials are unsaturated polyester or epoxy resin) is not deemed sufficient due to its lack of required elastic modulus values [4-7]. Consequently, researchers in this field have been tasked with identifying fillers that can enhance the strength characteristics of composite materials used in turbine blade fabrication. Various methods can be employed to address this issue, such as a German company producing high-power turbines opting for a combination of glass and carbon fibers as one approach, resulting in turbines with output powers of up to 5 MW [8].

The study [9] focuses on the design and utilization of sandwich composite panels made from glass and polyester for constructing wind power system towers with a capacity of 2 MW. The research includes load analysis, proposing coordinated solutions, optimal structural design, and structural analysis of the tower design calculation algorithm. The aim is to optimize the weight and price of the tower while considering parameters such as wind resistance of the blade, aerodynamic loads, and the weight of individual elements and the tower structure itself.

In study [10], tests were conducted to determine the strength properties of a composite material based on processed natural fibers, which could potentially be used for wind turbine blades. Additionally, other materials suitable for composite components were investigated. The results revealed that natural fibers alone cannot be used for manufacturing wind turbine blades without the incorporation of fillers or pre-treatment, such as chemical treatment.

In [11], the influence of fiber materials, their orientation, and layer thickness on the fundamental mechanical properties and stability of wind turbine blades was examined. The study utilized Finite Element Method (FEA) analysis to demonstrate the significant impact of these factors on the blade's

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characteristics. It was found that carbon-based composites with epoxy resin exhibit higher strength and hardness values compared to Kevlar 49-based composites with epoxy resin or epoxy glass.

The aim of the research is to experimentally verify the enhancement of certain mechanical properties of a composite material with an unsaturated polyester matrix reinforced with fiberglass, by incorporating specific proportions of sodium aluminosilicate powders and talc as fillers for the manufacturing of large wind turbine blades without the use of carbon fiber.

2. Materials and methods

In these studies, sodium aluminosilicate powder and talc were used as fillers to enhance certain mechanical properties of a matrix made from unsaturated polyester (UPR). The samples used in the research were made from a composite polymer material, with the matrix being based on unsaturated polyester resin (O-Phthalic anhydride based), produced by the Jordanian company "Intermediate Petrochemicals Industries Co.Ltd". The resin had the following characteristics: dark yellow color, density of 1200 kg/m^3, viscosity of 400 MPa, and a melting point of 288°C. To accelerate the curing process, 0.5 g of cobalt lactate was added as a process accelerator for every 100 g of resin. To solidify the resin, a hardener of the type benzoil peroxide was added in a proportion of 2%. These proportions were chosen based on previous experiments related to curing unsaturated polyesters. It was found that increasing the percentage of cobalt above the value used in previous studies accelerated the reaction to the point where the polyester mixture could only be obtained when all layers of glass fibers were saturated with fillers. Additionally, it was discovered that adding less than 2% hardener to the mixture did not fully solidify the volume due to the formation of a sticky layer on the surface of the fiberglass.

2.1. Production of samples

The manual molding method was employed for sample preparation, involving pouring the mixture into a glass mold (ensuring it is completely filled) with dimensions of 23 x 12 x 0.5 cm by simple filing. The filling method involved pouring a small volume of the mixture into the mold, followed by laying a layer of fiberglass with random orientation on the polyester layer, applying the mixture with a soft brush, adding a layer of fiberglass mat type, and repeating this process until the mold is fully filled. To achieve the desired thickness of the sample, three layers of fiberglass with random orientation from a Saudi company (Glass Fiber Technology Co. Ltd) and two layers of fiberglass mat type were used. Various percentages of glass fiber reinforcement were tested, ranging from 5 to 30%, with the optimal results achieved at 20% glass fiber reinforcement. However, for the production of wind turbine blades, even this level of reinforcement does not meet the desired criteria, as higher percentages resulted in samples with low hardness and increased flexibility, which is unacceptable in this application.

A number of tests were carried out to identify the properties of the composite material:

Tensile strength tests:

These tests were conducted to determine the mechanical properties of composite materials under axial tensile load on samples. A specialized device was utilized for this purpose, enabling consistent testing with identical samples measuring 21 x 2 x 0.5 cm. This setup was employed not only for the axial tensile tests but also for the bending resistance tests, as illustrated in Figure 1.

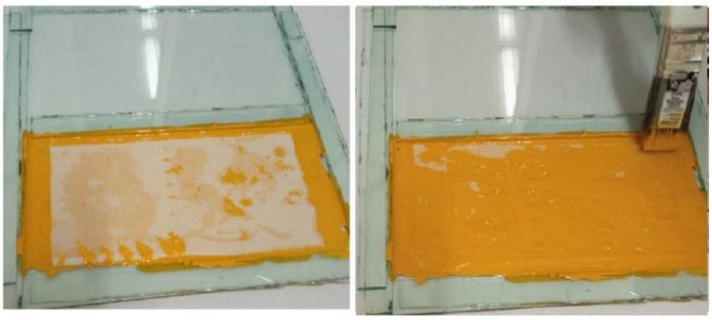

Figure 1. Preparation of the material for the samples

2.2. The strength tests for bending resistance

The bending resistance tests were conducted using the same setup as the tensile experiments, which involved a versatile hydraulic press (Figure 2), but with a modified fixture specifically designed for securing samples of identical geometric dimensions (21 x 2 x 0.5 cm) (Figure 3). These investigations employed a three-point fixture method for applying maximum load to the test samples.

Figure 2. Multi-purpose hydraulic press

Figure 3. The test samples

3. Results and discussions

The results of samples tensile strength tests

Figure 4-1 illustrates the relationship between the tensile strength of unsaturated polyester and the content of aluminosilicate (SAS), showing an increase in strength up to a maximum value of 32 MPa at a 10% SAS content. This enhancement is attributed to the effective distribution of SAS particles within the matrix, promoting the formation of strong surface bonds. However, beyond the 10% threshold, tensile strength decreases due to challenges in SAS penetration into the matrix caused by increased aluminosilicate content. This difficulty is observed practically through higher viscosity of the molding mixture, hindering sample manufacturing. Poor wetting results in reduced adhesion between unsaturated polyester and SAS particles, creating stress concentrators in the composite structure and accelerating its degradation process.

In Figure 4-2, the results demonstrate that an increase in talc percentage leads to a decrease in the tensile strength of unsaturated polyester. This can be attributed to the incompatibility between the matrix and talc materials, which reduces the effectiveness of load transfer within the composite. As the talc content increases, the composite material collapses under lower stress.

Figure 4-3 examines the effect of SAS content on the tensile strength of unsaturated polyester, while keeping the talc content fixed at 5%. The SAS content ranges from 5% to 20%. As the SAS content increases, the tensile strength limit also increases and reaches its peak value (33 MPa) at a 10% SAS and 5% talc content. This value surpasses the tensile strength limit achieved by adding only 10% SAS to the matrix material. However, when the SAS content exceeds 10%, the tensile strength values decline. This decrease can be attributed to the challenges faced in the penetration of SAS and talc particles into the matrix material's structure. In practical terms, this was confirmed by the difficulty encountered in sample manufacturing due to increased viscosity of the molding mixture. The formation of numerous stress concentrators within the composite structure accelerates the degradation process.

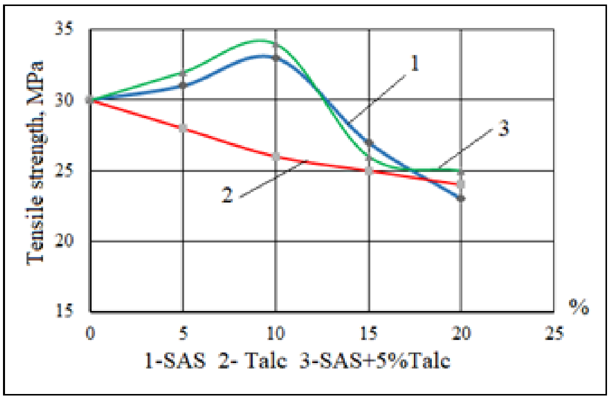

Figure 4. The SAS and talc additives effect on the tensile strength of unsaturated polyester: 1- SAS, 2- Talc, 3-SAS+5%Talc

In Figure 5-1, the results demonstrate that increasing the SAS content in unsaturated polyester reinforced with 20% fiberglass leads to a decrease in tensile strength. This can be attributed to the difference in properties between the matrix and fiberglass materials under tensile conditions.

In Figure 5-2, the results show that increasing talc content in unsaturated polyester reinforced with 20% fiberglass leads to a reduction in tensile strength. This is due to the incompatibility of the strength properties of unsaturated polyester and fiberglass under tensile conditions.

Figure 5-3 examines the effect of SAS and talc additives on the tensile strength of unsaturated polyester reinforced with 20% fiberglass. The SAS content ranges from 5% to 15%, while the talc content is fixed at 5%. The results indicate that with an increase in SAS content in the composite mixture, the tensile strength of the samples increases and reaches its maximum value (108.8 MPa) at 5% SAS and 5% talc. However, beyond this point, the tensile strength begins to decrease. This can be explained by the fact that SAS and talc materials consist of oxide groups, which have a similar structure to fiberglass. This compatibility between the matrix material, fiberglass, and added components contributes to the increase in tensile strength. However, when the SAS content exceeds 5%, the adhesive gap between the surfaces of the matrix material, fiberglass, and additives decreases during sample manufacturing. This incomplete wetting process weakens the adhesive bonds between the particles, leading to the formation of numerous defects and stress concentrators in the composite structure, accelerating the degradation process.

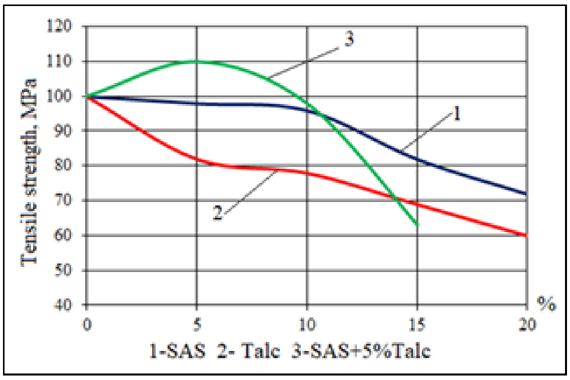

Figure 5. The SAS and talc additives effect on the tensile strength of unsaturated polyester reinforced with 20% fiberglass (UPR/glass fiber/talc:70%/20%/5%)

Determination of the elasticity modulus

In Figure 6-1, the results demonstrate the impact of increasing the sodium aluminosilicate (SAS) content on the elastic modulus of unsaturated polyester. The findings indicate that the elastic modulus increases and reaches its peak value (2640.4 MPa) at a SAS content of 10%. This can be attributed to the SAS particles' ability to withstand applied stresses in the composite material. The uniform distribution of SAS particles within the matrix material structure restricts its mobility, resulting in reduced deformation of the composite material and higher values of the elastic modulus at a given SAS content.

In Figure 6-2, the results reveal a decrease in the elastic modulus of unsaturated polyester as the talc content increases. This can be explained by the difference in elastic properties between the matrix material particles and talc. Talc particles do not possess a sufficient modulus of elasticity compared to unsaturated polyester. Consequently, an increase in talc content leads to a decrease in the elastic modulus due to the contribution of the unsaturated polyester material.

Figure 6-3 presents the effect of SAS content ranging from 5% to 20% on the elastic modulus of unsaturated polyester with a fixed talc content of 5%. The findings illustrate that as the SAS content in the matrix material increases, the elastic modulus also increases and reaches its maximum value (2750.5 MPa) at a content of 10%. However, beyond 10% SAS content, the elastic modulus starts to decrease. Similar to Figure 6-1, this behavior can be attributed to the ability of SAS particles to withstand applied stresses in the composite material. The uniform distribution of SAS and talc particles within the matrix material structure limits its mobility, resulting in reduced deformation of the composite material and increased values of the elastic modulus at a given SAS content. Additionally, it is worth noting that with a ratio of 5% talc and 10% SAS, the elastic modulus value was higher compared to when only 10% SAS was added to the matrix material. This can be attributed to the significant reduction in deformation achieved by the combined presence of talc and SAS particles in the composite material.

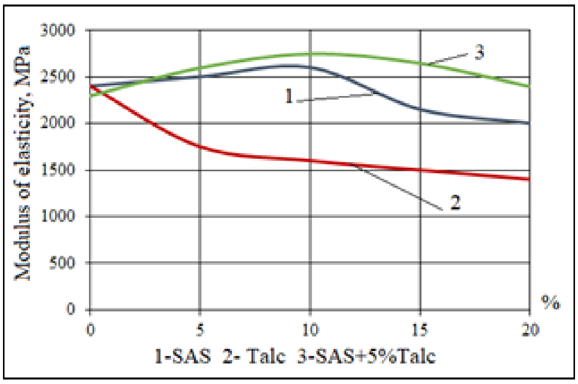

Figure 6. Effect of SAS and talc additives on the elastic modulus of unsaturated polyester: 1- SAS, 2- Talc, 3-SAS+5%Talc

Figure 7-1 illustrates a decrease in the elastic modulus of unsaturated polyester reinforced with 20% fiberglass as the SAS content increases. This decrease can be attributed to the incompatible elastic properties of SAS and fiberglass particles, which prevent the matrix material from effectively restricting mobility as the composite material deforms. Additionally, the elastic modulus decreases as the percentage of SAS increases.

In Figure 7-2, the elastic modulus of unsaturated polyester reinforced with 20% fiberglass decreases with an increase in talc content. This decrease is due to the incompatible elastic properties of talc particles, fiberglass, and the matrix, which hinder the matrix material's ability to limit mobility as the composite material deforms. The modulus of elasticity also decreases as the percentage of talc increases.

Figure 7-3 examines the effect of SAS content, ranging from 5% to 15%, on the elastic modulus of unsaturated polyester reinforced with 20% fiberglass and 5% talc. The results indicate that as the SAS content increases, the modulus of elasticity also increases. The maximum value of 6376.9 MPa is achieved with a content of 5% SAS and 5% talc. This increase in the elastic modulus can be attributed to the good compatibility between the matrix materials, SAS, talc, and fiberglass, which creates a strong adhesion force within the composite material. This adhesion force limits movement within the structure, resulting in a lower deformation value and an increase in the elastic modulus. However, when the SAS content exceeds 10%, the adhesion force decreases due to a decrease in adhesion strength, leading to higher deformation values.

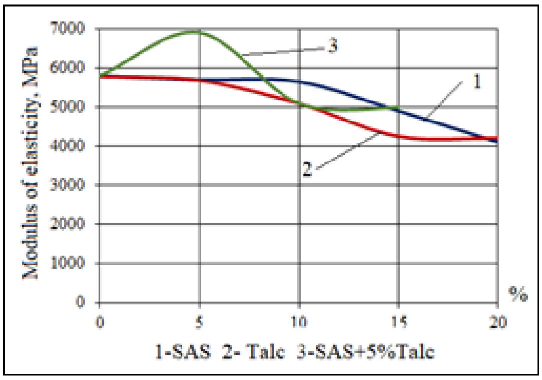

Figure 7. The SAS and talc additives effect on the elastic modulus of unsaturated polyester reinforced with 20% glass fiber (UPR/glass fiber/talc:70%/20%/5%)

The tests samples results for bending strength

Figure 8-1 illustrates the relationship between the content of sodium aluminosilicate (SAS) and bending strength. It shows that an increase in SAS content up to 10% leads to a corresponding increase in bending strength, reaching a maximum value of 0.065 GPa. Additionally, it is worth noting that this increase in SAS content also results in higher elastic modulus and tensile strength.

During bending strength tests, samples are exposed to three simultaneous stresses: tensile stresses on their external surfaces, compressive stresses on their internal surfaces, and shear stresses at the interface. The composite material can be destroyed by any of these three types of destruction, depending on the materials used (matrix, reinforcing material, filler) and the adhesion strength between them.

Figure 8-2 demonstrates the effect of talc content on bending strength. As talc content increases up to 10%, bending strength also increases, reaching a maximum value of 0.0662 GPa. Talc exhibits a high modulus of elasticity in bending.

Figure 8-3 focuses on the influence of SAS content on the bending strength of unsaturated polyester, with a fixed talc content of 5%. As SAS content increases from 5% to 20%, bending strength also increases, reaching its highest value of 0.0729 GPa at 10% SAS and 5% talc. However, further increases in SAS content result in a decrease in bending strength. Notably, the combination of talc and SAS yields high values of elastic modulus and bending strength.

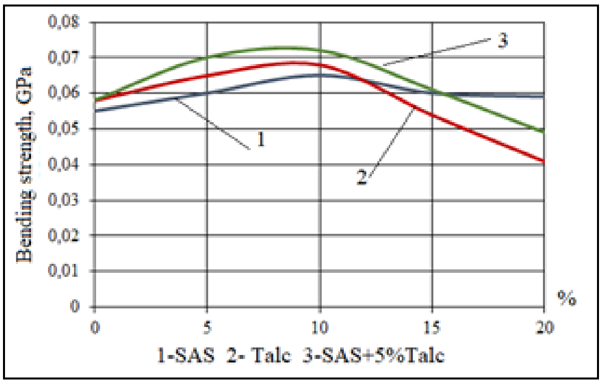

Figure 8. The SAS and talc additives effect
on the bending strength of unsaturated polyester:
1- SAS, 2- Talc, 3-SAS+5%Talc

Figure 9-1 illustrates a decrease in the bending strength of unsaturated polyester reinforced with 20% fiberglass as the SAS content increases. This is attributed to the incompatible properties of the matrix, SAS, and fiberglass materials during bending. With each increase in SAS content, the adhesion strength between the matrix and fiberglass materials decreases.

Figure 9-2 demonstrates an increase in the bending strength of unsaturated polyester reinforced with 20% fiberglass as the talc content increases. The bending strength reaches its maximum value of 0.1427 GPa at a talc content of 5%. This suggests that talc particles exhibit high resistance to compression and shear stresses, which can be attributed to the sufficient compatibility of matrix materials, fiberglass, and talc in bending conditions. However, as the talc content exceeds 5%, the bending strength decreases due to a decrease in the adhesion strength between the matrix and talc materials.

Figure 9-3 focuses on the effect of SAS content on the bending strength of unsaturated polyester, with a fixed talc content of 5%. As the SAS content increases from 5 to 15%, the bending strength also increases, reaching its highest value of 0.1597 GPa at 5% SAS content and 5% talc. However, when the SAS content exceeds 5%, the adhesive gap between the surfaces of the matrix material particles, fiberglass, and additives decreases. This incomplete wetting process before curing leads to the formation of numerous stress concentrators in the composite material structure, accelerating the destruction process.

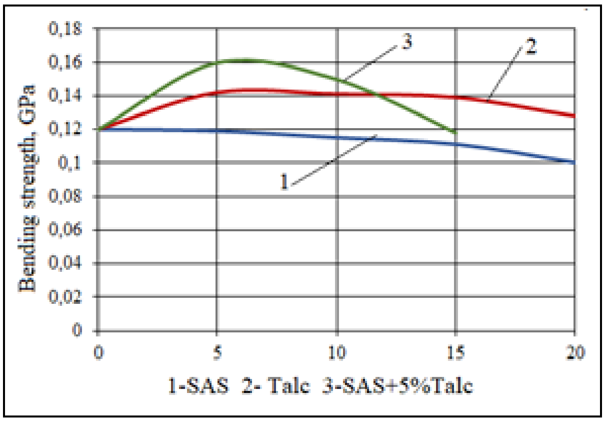

Figure 9. The SAS and talc additives effect on the
bending strength of unsaturated polyester reinforced
with 20% glass fiber (UPR/glass fiber/talc:70%/20%/5%)

4. Conclusions

The tensile strength and modulus of elasticity increased with the addition of sodium aluminosilicate (SAS) to unsaturated polyester. The tensile strength reached its maximum value (32 MPa) and the modulus of elasticity reached 2640.4 MPa at a 10% SAS content. However, as the SAS content increased, the tensile strength and elastic modulus of unsaturated polyester reinforced with 20% fiberglass decreased.

Increasing the talc content in the matrix material of unsaturated polyester reinforced with 20% fiberglass resulted in a decrease in the tensile strength and elastic modulus of samples made from the composite material.

Adding a mixture of sodium aluminosilicate and talc to the matrix material increased the values of the elastic modulus and tensile strength of the manufactured samples. The maximum values of tensile strength (33 MPa) and elastic modulus (2750 MPa) were achieved with a ratio of additives to the matrix material: 10% SAS and 5% talc. Furthermore, adding a mixture of SAS and talc to the matrix material reinforced with 20% fiberglass significantly increased the values of the elastic modulus and tensile strength of the samples. The maximum values of the tensile strength (108.8 MPa) and modulus of elasticity (6367.9 MPa) were obtained with a ratio of additives to the matrix material of 5% SAS and 5% talc.

The tests carried out proved that the addition of only sodium aluminosilicate (SAS) to unsaturated polyester increased the bending strength, reaching its maximum value. However, when added to the matrix material reinforced with 20% fiberglass, the bending strength decreased with each increase in SAS.

The analysis of the results showed that adding only talc to unsaturated polyester and the matrix material reinforced with 20% fiberglass increased the bending strength by up to 10%.

The tests carried out showed that adding SAS and talc to the matrix material led to an increase in bending strength, with the maximum value (0.0729 GPa) achieved at a content of 10% SAS and 5% talc. Adding 5% SAS and 5% talc content to the matrix material increased the bending strength of the composite material, reaching a maximum value of 0.1597 GPa.

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