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Characterization and Water Uptake of Reinforced Polymer Blend Using Nanoclay and Rock Wool

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ABSTRACT

The current work focuses on assessing flexural properties, and water uptake of polymeric composites prepared using various reinforcements. These additives consist of kaolinite nano clays and rock wool (RW). In addition to a polymer blend that consists of epoxy and polyester resins as the matrix. The castings were made using a hand lay-up approach. Nanoclay (NC) was added in weight fractions of 5% and 7%, together with RW added in a volume fraction of 10% as reinforcement. The impact test was employed to decide the optimum mixing ratio of the polymer blend that used as a matrix. From the results the blend consisting of 80 wt.% epoxy and 20 wt.% polyester has the highest impact strength value. Thermal analysis was done using differential scanning calorimetry (DSC) as a characterization method to assess the miscibility of the polymer blend. The polyester/epoxy blend showed the maximum flexural strength, which determined as (57.4) MPa. While the hybrid reinforcement using NC (5 wt.%) and RW (10%) lowered the flexural strength to 16.53 MPa. From the water absorption test results showed that, in addition to the standard concentration, the type of material also affects water, in addition to the ratios of its components. Finally, DSC results revealed the presence of two different glass transition temperatures, which indicates that the epoxy/polyester blend is immiscible and there are two distinct phases in this matrix.

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1. Introduction

Nanocomposites acquired a lot of concern due to their notable performance, whether in thermal or mechanical applications at low filler content. This advantage is attributed to the special characteristics of the nano- scale fillers. For instance, the filler's high surface-to-volume ratio greatly enhances the attributes of the nanocomposites. Since the qualities of nanocrystals depend on their shape, chemical structure, size distribution, and phase, in addition to their composition, nanostructures have drawn a lot of attention [1]. The kind of nanofiller, the filler loading levels, and the processing are significant variables that can impact the mechanical and physical characteristics of nanocomposites reinforced with polymer nanocomposites. Numerous studies have identified nanoclay (NC), an affordable natural material, as one of the possible nanocomposite candidates [2]. Many of the examples involve the use of nanocomposite materials, which are created by combining conventional materials with nanomaterials in two different phases: Continuous, like in the case of Portland cement-based concretes and mortars, or dispersed, like in the case of aggregates like nanofibers, nanotubes, and other reinforcements by precipitation. When these materials are added, the result is nanocomposite materials that enhance a number of the physical and chemical characteristics of composite materials [3].

Polypropylene (PP) and polyamide 6/clay nanocomposites (NPA6) were blended to prepare PP/NPA6 blends, which were then melt-drawn into ribbons using a ribbon extrusion technique. The impact of clay on the PP/NPA6 ribbon shape was examined using optical and field-emission scanning electron microscopy. The findings demonstrate that, in a PP/PA6 blend, NPA6 displayed a continuous lamellar structure at low clay contents (3, 5 wt.%), like that of pure PA6. However, at higher clay contents (10 wt.%), only ellipsoids or elongated ellipsoids were seen. Two mechanisms, namely the compatibilization effect and melt rheology, have been considered to explain the morphological difference. It was discovered that both variables, most likely the variance in melt rheology, were responsible for the morphological variations in the blends of PP/NPA6 under the extensional flow field with varying clay concentrations [4].

Melt compounding was used to blend polyamide 6 and polypropylene in 70/30 parts, respectively, containing 4 phr (part per hundred resin) of organophilic montmorillonite (OMMT). Three alkyl ammonium salts were modified to create sodium montmorillonite (Na-MMT). XRD and TEM analysis revealed that PA6/PP nanocomposites with stearylamine-modified montmorillonite formed an exfoliated structure. The 12-aminolauric acid and dodecylamine modified montmorillonite also had an exfoliated and intercalated structure. The addition of OMMT enhanced the PA6/PP blend's stiffness, while ductility and toughness decreased. The PA6/PP nanocomposite with stearylamine-modified montmorillonite exhibited the best tensile, flexural, and thermal properties. The addition of both Na-MMT and OMMT significantly increased the storage modulus and HDT of the PA6/PP blend. The PA6/PP nanocomposite with stearylamine modified montmorillonite had the greatest value in both storage modulus and HDT [5].

In a work carried out by Saravanan *et.al*. (2015), the cyclic olefin copolymer was reinforced with layered organosilicates modified with amino-silane to improve its mechanical, moisture-impermeable barrier, and thermal properties. The ideal percentage of clay (4%) in the nanocomposite raises the film's thermal stability, whereas further loading reduces it. The behaviour of water absorption at 62 °C was observed and compared to that at 48 °C and room temperature. The observed strain to failure for the composite films was less than that of the neat film, and the stiffness of the matrix increased with the amount of clay present. For 2.5–4% weight percentage clay addition, the dynamic mechanical study reveals a higher storage modulus and a low loss modulus. The device encapsulation test and calcium degradation test further demonstrate the need for an ideal clay loading of 4 weight percent for enhanced low transmission rates of water vapour in comparison to alternative nanocomposite films [6].

A study was carried out by Salih in 2022, using nanoclay as a reinforcement for a blend of epoxy and polymethyl methacrylate (PMMA) as a matrix, and studied its thermal and acoustic insulation, in addition to flexural and impact strengths, together with scanning electron microscope (SEM) and differential scanning calorimeter (DSC) as characterization methods. The researchers also suggested a model for the acoustic insulation of this material using previous studies that dealt with the same components. In addition to sound insulation and thermal conductivity, the reinforced specimens demonstrated improvements in mechanical (impact and flexural) qualities. The specimen reinforced with 7% NC had the highest impact strength (97×10~3) KJ/m^2 and the highest flexural values. Thermal conductivity of (0.34) W/m.°C and a sound intensity of 95.6 dB at 10 kHz frequency. The unreinforced blend was seen to have two distinct phases in the scanning electron microscopy pictures. The 7% reinforced specimen, on the other hand, displayed a rough interface between the two polymer phases, indicating that the inclusion of NC improved compatibility. For both reinforced and unreinforced specimens, the differential scanning calorimeter revealed two separate glass transition temperatures that correspond to the glass transitions of both constituents (epoxy and PMMA). The primary difference between the plain and NC/blend composites is the reduced temperature gradient that goes along with the former. Nanoclay had enhanced the mechanical qualities and contributed to the blend's compatibility, even though it remained immiscible [7].

This study aims to assess the influence of hybrid reinforcement on the characteristics and mechanical properties of a blend of epoxy and polyester. The incorporation of rock wool (RW) and kaolinite NC can modify the properties of polymer blends, and the current work provides insight into how these two materials interact with the matrix while focusing on flexural strength, water uptake and thermal analysis. Hybrid reinforcement may impose complexities that are not seen in single reinforcement, and the results can vary accordingly, which can be beneficial when applied whether in research or industry.

2. Experimental Procedure

2.1. Materials

2.1.1. Unsaturated Polyester (UPE)

A thermoset polymer, typically transparent and viscous, that solidifies when hardener (methyl ethyl ketone peroxide, or MEKP) is added in a weight percentage of 1%. The Saudi Industrial Resins Limited Company (SIR)™ provided the unsaturated polyester. **Table 1** lists a few of its properties, and the properties of hardener can also be found in **Table 2** [8].

Table 1: General properties of polyester resin.

Parameter	Value
Density	1 to 1.3 g/cm^3 (25 °C)
Flash point	30 to 33°
Physical state	Liquid (clear)
Viscosity	Dynamic: 400 to 600 MPa.s
Solubility	Insoluble in cold water
Tensile strength of cured resin	33 MPa. (Approx.)
Tensile modulus	1 GPa.
Elongation at break	1.5%
Impact strength	0.4 J/cm^2
Hardness	40 BHN

Table 2: General properties of the hardener (MEKP).

Parameter	Value
State and colour	Clear liquid
Density at 25 °C	1.16 g/cm^3
Solubility	Insoluble in water, soluble in selected solvents, e.g. Ethyl acetone
Viscosity at 25 °C	13.8 mPa.s (cP)
Flash point	95 °C

2.1.2. Epoxy Resin

The epoxy resin utilized in this project was Sikadur-105, produced by Sika™. It is a two-component, low viscosity epoxy resin system that starts as a transparent liquid and solidifies when hardener is added in. a 2:1 ratio. **Table 3** describes the characteristics of epoxy resin [9].

Table 3: General properties of epoxy resin.

Parameter	Value
Flexural properties	14-day 7900 psi (54 MPa)
Viscosity (mixed)	200 cps
Pot life	30 minutes. (60 gm mass)
Tensile properties	14-day 4500 psi (37.2 MPa)
14-day tensile strength	54 MPa
Elongation at break	3.1%
Modulus of elasticity	1400 MPa

2.1.3. Kaolinite Nanoclay

Kaolinite NC was purchased from Intelligent Materials Pvt. Ltd. ™ for this study. Properties are displayed in **Table 4** [10].

Table 4: General nanoclay properties.

Parameter	**Value**
Chemical formula	Al_2O. 2SiO. $2H_2O$
Molecular weight	258.2 g/mol.
Appearance	White powder
Specific gravity	~2.6
Melting point	>1500 °C
Solubility	Insoluble in cold water
Elongation at break	3.1%
Modulus of elasticity	1400 MPa

2.1.4. Rock Wool

Also known as stone wool, it is a kind of inorganic fiber. The rockwool used in the study was purchased from Saudi Rockwool™ in the form of loose rockwool. It is generally used in automobiles, houses, and other industrial equipment for thermal and acoustic insulation. It is remarkable that insulating qualities are complemented by its high tensile strength and modulus, good chemical resistance, and high dimensional stability. **Table 5** displays the general characteristics of RW [11].

Table 5: General properties of rockwool.

Parameter	**Value**
Appearance	Loose woolly-filler
Desired properties	Reduction of transferred heat, and transmitted noise
Appearance	Mixed black and yellow
Packing	Loose wool supplied in PE bags

2.2. Methods

The samples were prepared using the hand lay-up process with a mold size (100 mm× 50 mm). Epoxy was blended with unsaturated polyester to create a matrix. Five distinct epoxy and polyester ratios were combined, ranging from 90:10 to 50:50 each.

The impact test results on the above-mentioned blends were taken as a parameter to choose the blend with the optimum mixing ratio (OMR). The impact test determined the optimal polymer blend ratio, revealing that an 80% wt. epoxy and 20% wt. polyester mixture had the highest impact strength. This blend ratio was chosen as the composite's matrix and strengthened with two weight fractions: 5% and 7.5% of NC, followed by the addition of rockwool to create two further castings with a volume fraction of 10% each, which were hybridized with the weight fractions of nano-sized clay. For comparison, a single casting consisting only of an epoxy/polyester blend was prepared.

After all castings had been allowed to cure for a full day to reach primary solidification, they were removed from the mold and placed in a dryer oven to remove any remaining tension. The molds are displayed in **Fig. 1** below, with the numbers denoting each specimen shown in **Table 6**. The water uptake test specimens are shown in **Fig. 2** below.

Table 6. Casting component details of specimens for Figure 1.

Cast number	**Composition**
1	Pure (unreinforced) blend.
2	Blend+ 5% wt. NC
3	Blend +7.5 % wt. NC
4	Blend+5% wt. NC+10% vol. RW
5	Blend+5% wt. NC+10% vol. RW

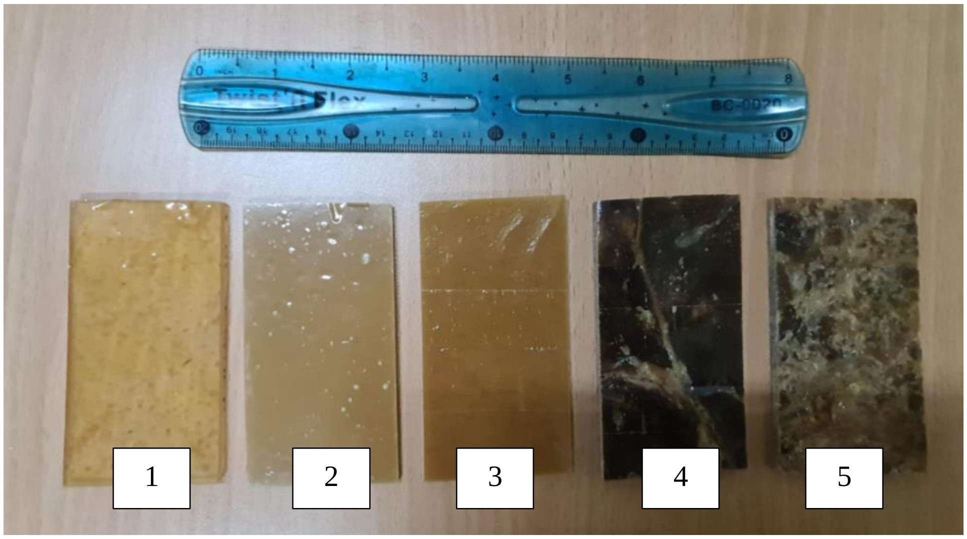

Figure 1: The castings used in the current work.

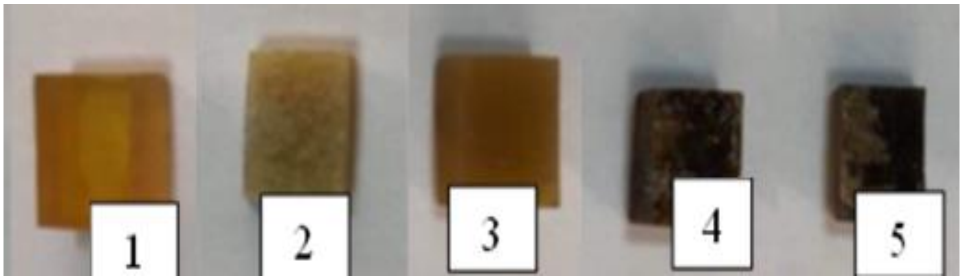

Figure 2. The water uptake test specimens.

2.3. The Tests

2.3.1. Flexural Strength

Flexural strength was tested using Jianqiao testing equipment™, manufactured in China. The set is shown in **Fig. 2**, and according to the ASTM D790 standard specification [12]. The test is used to assess the material's ability to withstand bending until a fracture happens, using a load applied in the middle of a standard specimen. In the current work, the three-point bending test was used, in which the specimen is mounted on two supports, and the load is applied in the middle of the specimen until breakage takes place. To calculate the value of F.S, three- point bending method was used by applying the following **Eq. (1)** [13]**:**

$$\mathbf{F.S} = \frac{3PL}{2bd^2} \tag{1}$$

Where F.S is the flexural strength (MPa), L is the distance between the two supports (mm), P is the applied load (Kg), b is the width (mm) and d is the thickness (mm).

2.3.2. Water Absorption

Water absorption test was conducted to ascertain the water content of polymeric-based chemical samples, as per the standard specification ASTM D570 [14], where specimens measured 10×10×10 mm in length, width, and height were immersed in distilled water for over five months, and weekly weight measurements were taken during this time, and the results were compared to the sample's pre-immersion weight. As in **Eq. (2)** shown below [9].

$$\textbf{Weight gain\%} = \frac{\textit{Weight of wet specimen} - \textit{weight of dry specimen}}{\textit{weight of dry specimen}} \tag{2}$$

The specimens measure 10×10 mm squares, with the thickness varying according to the thickness of the cast they were cur from. The specimens were first dried in an oven for 4 hours prior to immersion in water, to evaporate as much humidity as possible, which might have been created during preparation and storage. After that, they were cooled in a desiccator, and then the initial dry weight was taken (W_o). The specimens later were immersed in distilled water at ambient temperature (The immersion started in winter with an ambient temperature at around early 20 °C). Specimens were taken out of water weekly, gently wiped with a clean tissue and left to be dried and remove surface water, prior to their weighing again, and this time the weight is considered a wet weight ($W_{1,2,3..}$), where 1,2,3, … are the number of the week of immersion. Every week, the process is repeated, and the weight is subtracted from the initial dry weight (W_o) that was measured at the beginning of the test, to monitor the changes that take place and how the material responds to the immersion. Since temperature and other parameters remained unchanged throughout the test, the time was the only variable parameter, as this helped consistency and ability to compare the results and their interpretation.

2.3.3. Thermal Analysis

A differential scanning calorimeter (DSC) was used to carry out thermal analysis of the blend. The test was performed according to the specification ASTM D3418 (Standard test method for transition temperatures of polymers by DSC) [15] and the apparatus used in this characterization is DSC PT1000 by Linseis™. The weight of the specimen is about 5-10 mg, and is put in an aluminum pan, which is then heated at a controlled rate (5-10 °C) in a nitrogen environment to eliminate oxidation. The difference of heat flow between the sample and the empty reference pan is observed and used to interpret the thermal behavior of the tested polymer.

3. Results and Discussion

3.1. Flexural Test

The results indicate that the blend of epoxy and polyester has the highest flexural strength of 57.4 MPa. This is due to the flexible nature of epoxy and polyester [16]. When reinforcing with weight fractions of 5 and 7.5% NC, the flexural strength decreases to 25.4-25.1 MPa, respectively. Flexural strength was lowered to its lowest value (16.53 MPa) when reinforced with 5% weight fraction NC and 10% volume fraction rockwool. However, it increased to 45.77 MPa when reinforced with 7.5% weight fraction NC and 10% volume fraction RW. **Fig. 3** illustrates the results.

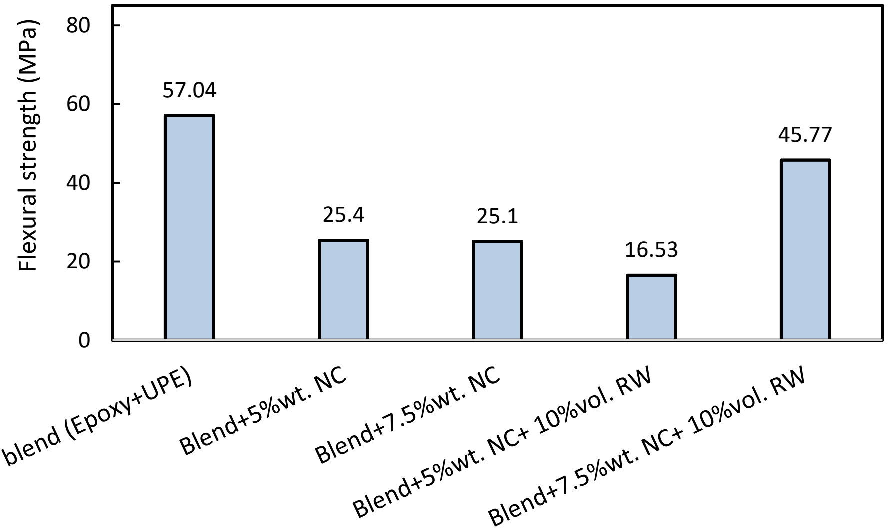

Figure 3: Flexural strengths of the specimens.

The addition of NCs in less than 1.5% may have a negative effect since they may act as stress concentrators, and at high addition percentage, the viscosity of the mixture prior to casting can increase to an extent where it becomes so difficult to remove bubbles and voids, hence mechanical properties of the cast can weaken [6][7]. This result agrees with those obtained by Reddy *et. al.*, as they concluded that the excessive addition of particulate reinforcement can has a deteriorating effect on the mechanical properties of polymeric composites. The researchers suggested that the addition of graphite to the blend matrix and cordia dichotoma fibers had improved the mechanical properties due to the enhanced miscibility and homogeneous dispersion, together with the strong interface interaction created by hybridization between the three phases (The blend matrix, the fibers, and filler), up until the addition of graphite reached a 15% wt. which showed the highest value of flexural strength, after which the addition increased and the strength began to decline [17]. In a comparative study [18] NC was added to a composite material made of epoxy reinforced with glass fibers, and various tests were carried out (Thermal and mechanical tests, in addition to various microscopic characterizations). The researchers found that the addition of more than 1.5% wt. of NC to the composite led to poor adhesion between the three phases (epoxy, glass fibers and the NC), and this eventually led to weak interface, where the cracks penetrate through the matrix, and then separates the fibers from the matrix, which supports the assumption that over-addition of fillers can lead to adverse effects on the mechanical properties of the composite. The results are in line with other works [19][20].

3.2. Water Uptake

This test determines how various liquids affect polymers by studying their hydrolysis and composition with water, acids, or alkaline solutions.

The outcome of the water absorption experiment showed that, in addition to the standard concentration, the type of material also affects water absorption, in addition to the ratios of its components. These factors affect the material's resistance to decomposition, frequently making it resistant to even small changes in the medium's standard concentration, temperature, and other parameters [21]. Hydrolysis has a variety of effects on polymers and their composites:

1. Different types of liquids propagate through the polymer, causing swelling.
2. The polymeric desorption phenomenon causes polymers to dissolve in various media when they touch it [18].

The weight of the specimens rises as the immersion duration increases, as seen in **Fig. 4**. This may be attributed to the low molecular weight liquids like water coming into direct contact with the resin, they quickly pass through the polymer phase and start to fill the microcavities and the gaps between the structural elements. This process involves the movement of polymer chains one after another. After about 28 days, a drop in the sample weight was noticed, the swelling polymer could have brought that on, and it could have resulted in the development of enough pressure to rupture the chemical bonds, separating the atoms in the polymer chain, and causing the polymer chain to degrade to a low molecular weight as a result of the phenomena known as polymeric desorption. In the case of the composite material (NC + RW), a breakdown of the matrix material was noticed, which eventually led to breakage of the fiber-matrix interfaces, creating points for water penetration within the composite material. As a result, water absorption in composites is typically more complex than in unreinforced materials. In a similar study [22], the water absorption was directly proportional with the NC content, and this might be interpreted by the inherent capability of NC to absorb water.

Rockwool has contributed to the increase of water absorption due to its porosity, which entraps water molecules within, until a state of saturation is reached, marked by the peak in the curves in **Fig. 4** below. The results are consistent with those obtained by Mohammed *et. al.* [23], and Al-Dabbagh *et. al.* [24]. This may have resulted from leaching of residues, additives, solvents or unreacted monomers into the water, which causes weight loss, in addition to erosion and degradation caused by immersion in water [25].

However, the incorporation of RW fibers at approximately 10% enhances mechanical strength; however, it may also create voids that can retain water. That might interpret the increased water uptake when both reinforcements are added to the blend matrix. The hydrophilic nature of RW also contributed to the rapid weight gain of the RW-reinforced specimens at the beginning of immersion, compared with the other specimens. The water absorption of the polymer composites influences their experimental use and long-term durability and stability against different weather elements. The interaction between polymers and water may change their structure, as the water can penetrate the polymeric network, especially hydrophilic polymers, leading to swelling. The phenomenon can eventually weaken the mechanical properties of the material, due to the mobility of the polymer chains [26]. On the other hand, hydrophobic polymers can resist water penetration, nevertheless, water at their surface can still penetrate into their structure, resulting in partial absorption, which might affect adhesion and morphology [27]. In addition to the effect of water, temperature, and ultraviolet radiation may increase the degradation and weathering effects on the polymers.

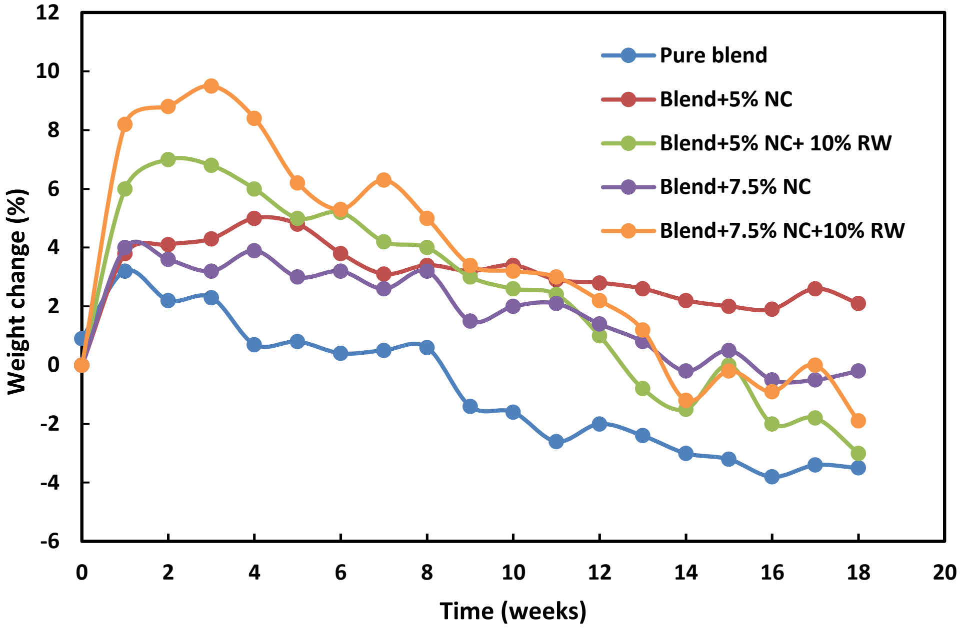

Figure 4: Water uptake of the specimens.

These effects, whether alone or combined, can speed up the degradation of the polymers, especially in the presence of water or humidity, leading to plasticization, and eventually damage the material over time. For instance, water absorption and UV radiation can lead to oxidation and chain scission, which results in weakening and brittleness. The design of polymers to be used in outdoor applications must consider the exposure to weather elements, so as to manufacture a durable material that can withstand these effects [28]. Some specimens showed further weight loss after immersion, in which the specimen began to lose its original weight before immersion, especially the pure blend, followed by other specimens.

This phenomenon was observed at around the 8-9th weeks of immersion. The specimens showed further loss even for the reinforced blends. This can be attributed to the hydrolytic degradation of the constituents, like oligomers, unreacted monomers, plasticizers, or impurities, from the specimens to the water. This can also be explained by the surface or the partial degradation that occurs within the polymer matrix, which causes weight loss due to the formation of debris that separates from the main composite material, causing further weight loss [29]. Another reason may be the presence of NC, which is hydrophilic, leading to higher water absorption, which eventually leads to a higher percentage of polymer hydrolysis, and formation of more debris, which diffuse into the water [30].

3.3. DSC and TGA Analysis

Fig. 5 illustrates the thermal analysis of the unreinforced blend of epoxy and polyester. The blend's behavior during thermal decomposition is depicted by the lowest point, which indicates the highest temperature at which the blend degrades thermally. This provides insight into how the material would be able to retain its properties at high temperatures before thermal collapse. Around 150 to 110°C is when the mass shift first starts, and the first stage lasts as the temperature rises until a sudden drop occurs at 286°C, signaling the second and most important stage of thermal disintegration. The first drop (from 105 to 270 °C) marks the loss of volatile component associated within the sample, and these could be impurities, humidity, lubricants, plasticizers, etc..) that are increased with the polymers during manufacturing processes, constituting about 16% of the total weight of the sample, which are lost in the heating course of the sample.

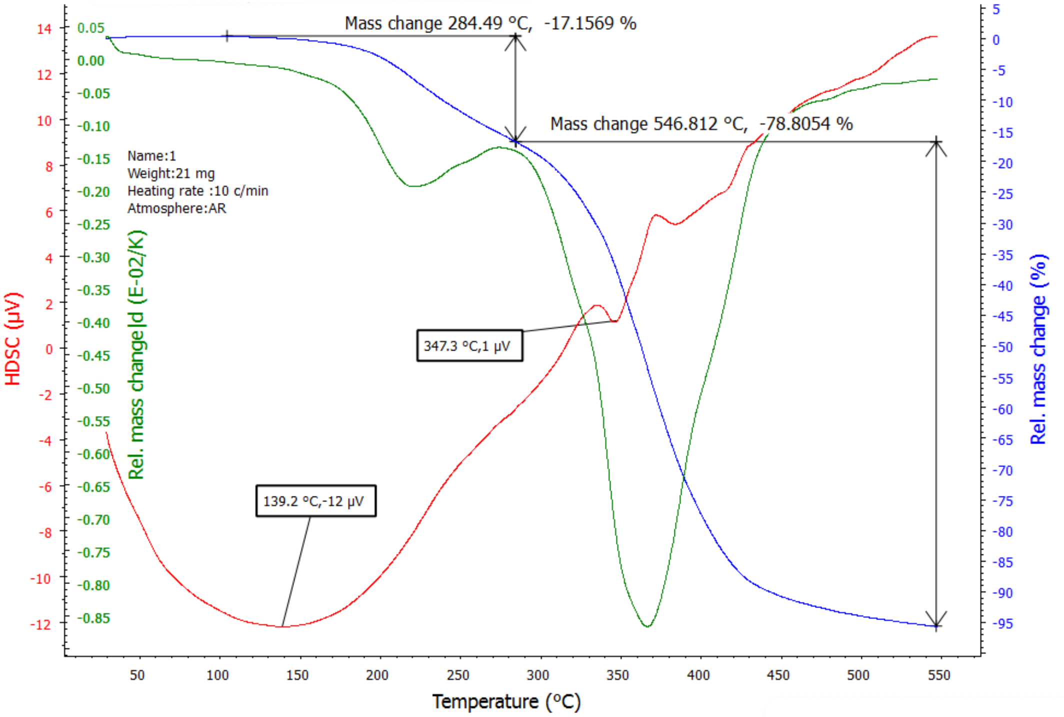

Figure 5: DSC & TGA curves for epoxy/polyester blend.

The second stage begins at about 270 °C, thermal decomposition begins, and the blend starts to thermally degrade, and pure polymer content is decomposed, and as it is noticed in **Fig. 3**, the pure polymer content constitutes 78.8 (about 79%) of the sample weight. This represents the two constituents together (epoxy and polyester). Similar results have been documented by other researchers in other works [31].

Fig. 6 shows the thermal characterization of the same blend, reinforced with 5% NC, the TGA curve (the blue line) showed a shift towards a bit higher temperature, and the onset of the initial stage of mass loss starts at (100-96) °C, instead of ~110 °C for the unreinforced blend, and as the heating proceeds, the main stage of thermal decomposition starts at 546.18 °C, with an increase of 48.95 °C higher than the unreinforced blend. The initial mass change becomes 15.88%, suggesting less volatiles than the unreinforced specimens. The second stage, which shows the thermal decomposition of the main constituent in the polymer blend, finalizes at 595.76 °C, compared with 546.8 °C for the unreinforced blend, giving a mass change percentage of 76.9% compared with 78.8% for the unreinforced specimen. The results suggest that 5 wt. %.

NC has given rise to thermal stability and delayed decomposition of the blend to about 50 °C. The DSC curve, however, hasn't largely changed compared with the unreinforced blend, and by interpolating the adjacent lines for the curve, the value of T_g for the reinforced blend remains almost the same as it is for the unreinforced one.

Fig. 7 shows the thermal behaviour of the same blend reinforced with 7.5 wt. %. NC. The main decomposition occurs at around 276 °C with a weight loss of volatiles of about 75%, indicating thermal breakdown of the blend matrix. An endothermic peak is noticed between 500 and 600 °C which suggests the final stages of degradation. The presence of NC in a 7.5 wt. %. may improve thermal stability since it presents a barrier effect, which might delay matrix degradation [31].

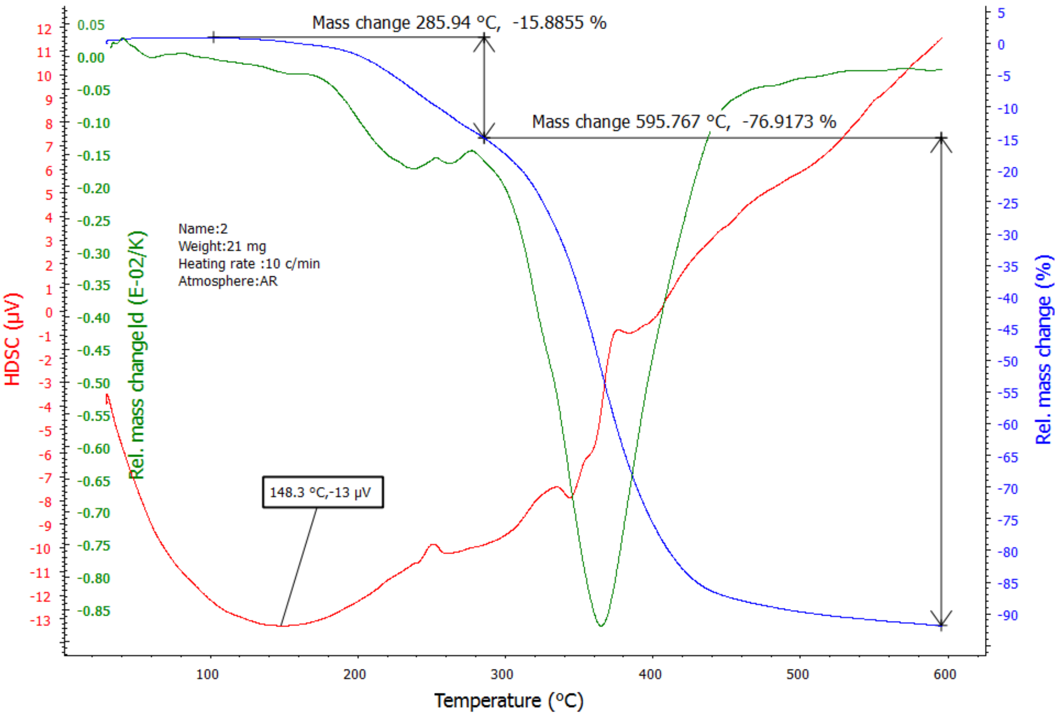

Figure 6: DSC & TGA for blend reinforced with 5% wt. nanoclay.

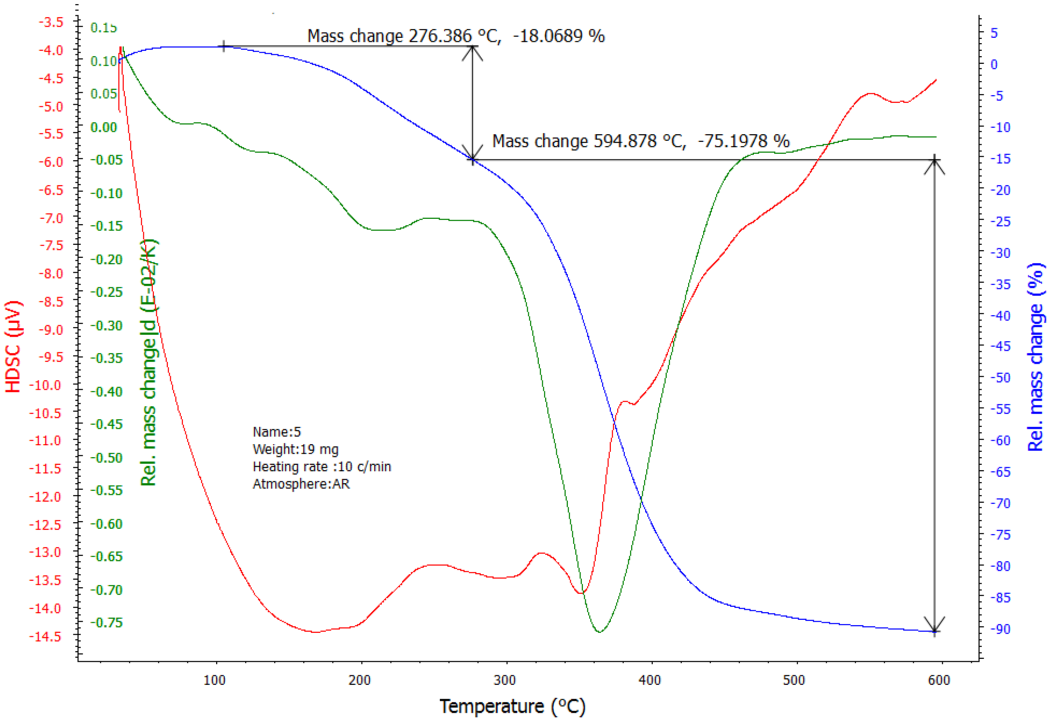

Figure 7: DSC& TGA for blend reinforced with 7.5% wt. nanoclay

Fig. 8 shows the thermal analysis for the blend reinforced with 5% wt. NC and 10% vol. rockwool. The DSC curve reveals a higher temperature of the bottom peak than the previous two samples, as the curve is a bit shifted towards a higher temperature when adding RW in weight fraction 10%. Rockwool addition caused this relatively small increase, which could have resulted from the binder associated with Rockwool during the manufacturing or packing stage [32]. TGA curve in the same figure shows similar behavior to the two previously explained samples, such that the initial stage of volatile materials decomposition starts at around 100 °C, until 285 °C, decreasing the weight by about 15.8%, then the main constituents thermally decompose at about 595.814°C, almost the same temperature as the specimen reinforced with 5% wt. NC, suggesting that the rockwool addition did not affect the thermal behavior of the composite, and the weight loss in this stage was about 76.5%, a value close to the result obtained with the second sample.

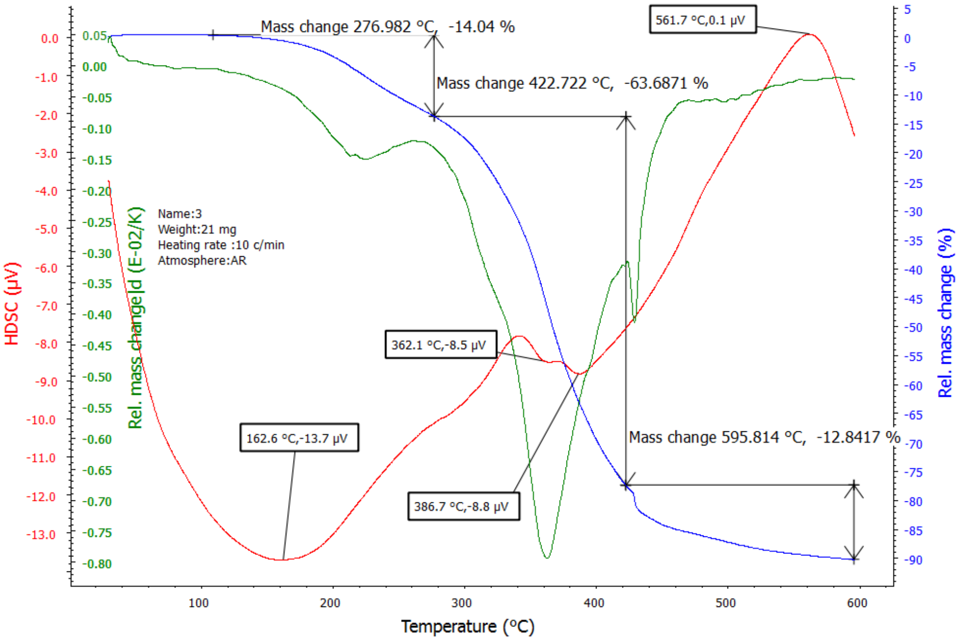

Figure 8: DSC& TGA for blend reinforced with 5% wt. NC and 10% vol. rockwool.

Fig. 9 showed the thermal behavior of the blend reinforced with (7.5% wt. NC and 10% vol. rockwool). The Tg does not change much, since the addition of reinforcement is physical and no chemical reaction took place. As for the Tg curves, the behavior also did not change too much and only small differences were observed in the onset of thermal decomposition temperature, which ends at around (595- 596) °C.

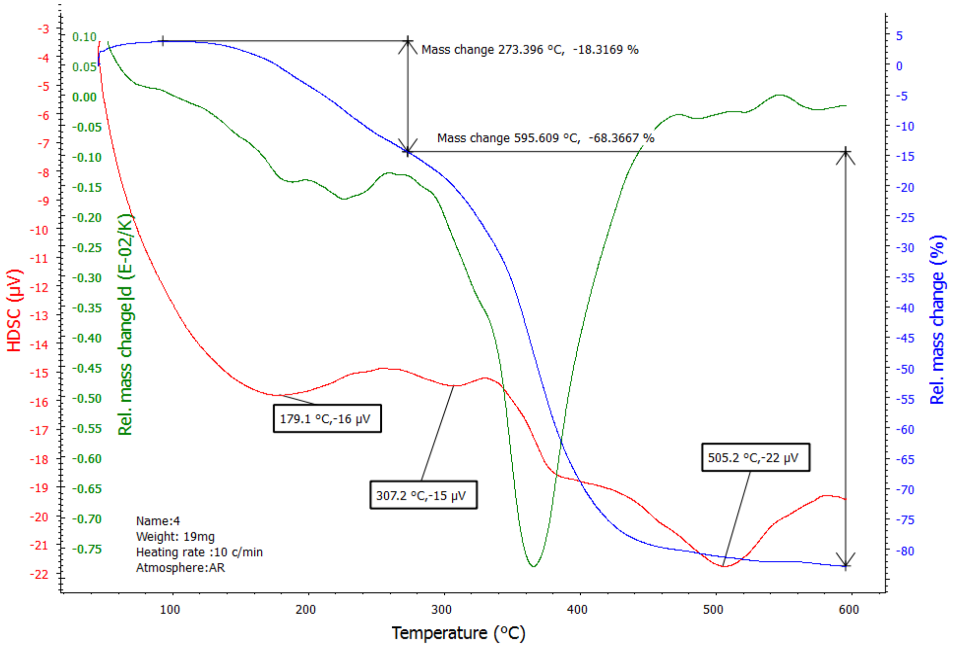

Figure 9: DSC& TGA for blend reinforced with 7.5%wt. NC and 10% vol. rockwool.

In general, thermal analysis of the fire samples indicates that the two components (epoxy and polyester) have formed a miscible blend, a fact that is proven through the single curve of glass transition temperature, and this agrees with other works [33][34]. The other point is that the blend, whether reinforced or not, can withstand temperatures up to 110 °C (before softening) and resist thermal degradation for more than 500 °C.

3.4. Comparison of TGA for the Prepared Materials

The values of thermal degradation temperatures are listed in **Table 7** below.

Table 7: Thermal degradation temperatures of the specimens.

Parameter	Value
Pure blend	270
Blend + 5% wt. NC.	546.18
Blend +5% wt. NC+ 10% vol. RW	595.814
Blend +7.5% wt. NC.	594.87
Blend +7.5% wt. NC+ 10% vol. RW	595.609

It is already established in the literature that the addition of NC enhances thermal properties and stability of the material. The current work follows the same trend, with some distinct observations that agree with the broad lines of the existing literature. Ramesh *et.al*. (2018) studied the thermal properties of NC-reinforced epoxy and concluded that the temperature of onset of thermal decomposition increased with increasing NC content, up to 5% wt., after which the behavior stayed almost stable or slightly decreased [35]. In the same context, a study carried out by Gupta *et.al*. reported that NC affected the thermal behavior of epoxy by acting as a barrier that delays degradation by minimizing the volatile product decomposition [36]. The current work agrees with those works as it is believed that NC contributes to forming a char layer that decreases thermal decomposition.

A study performed by Liu and Wang in 2021 found that the NC dispersion in the polymer matrix plays a major role in thermal stability, thus the optimum dispersion of NC activates a barrier effect, while clustering and agglomeration creates degradation within the matrix [37].

In general, the DSC results in the present study confirm that NC addition improves thermal stability, and the small variations in the degradation could result from other parameters, like dispersion.

3.5. Comparison with Industrial Findings

The results of this study are relevant to the industrial field, especially in the polymeric composites industry. Flexural strength and water uptake results are part of a bigger project to study the insulation properties of polymeric composites, which can be developed to be used in construction or automotive applications. Degradation is also considered when these materials are placed outdoors, to assess their performance at elevated temperatures or humid conditions [38]. The results also show that the properties can affect each other, and they are related, and the performance of the material is affected by their relationship. The thermal analysis of the material, together with water absorption and flexural strength, provides a glimpse of how the material would perform if exposed to weather effects, especially in construction and insulation industries. Even in the packaging material industry, these properties must be considered, like when the packaging is exposed to weather effects when stored outdoors under the sun, and how its barrier properties would be affected by the UV radiation and humidity [39].

4. Conclusions

This work concerned with the study of (water uptake, flexural strength, and thermal analysis) tests for (epoxy/polyester) blend, which was reinforced with NC and rockwool in different weight and volume ratios. The results showed that the water uptake has the highest values with the specimen reinforced with 7.5% wt. NC and 10% vol. rockwool. The flexural strength showed that the pure (unreinforced) blend was the highest value, followed by other reinforced blends, with the specimen reinforced by 10% vol. rockwool standing out as the specimen with the second-highest value of flexural strength due to the mechanical properties gained by the addition of rockwool. Thermal analysis of the specimens revealed high thermal stability of the composites due to the presence of high thermally stable NC and rockwool, in addition to the noticeable miscibility between epoxy and polyester, which is noticed through a single glass transition temperature. The prepared material can be used in industrial and construction applications that involve thermal and acoustic insulation.

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Conflict of Interest

The authors have no conflict of interest.

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