Enhanced Mechanical Properties Characterization of General-Purpose Unsaturated Polyester Resin using Nano Cellulose Particles: Industrial Application

Angaw Chaklu [1]*, Araya Abera[1], Daniel Tilahun [1], Negash Getachew[2]

[1]*School of Mechanical and Industrial Engineering, College of Technology and Built Environment, Addis Ababa University, Addis Ababa, Ethiopia*
[2]*Department of Chemistry, Addis Ababa University, Addis Ababa, Ethiopia.*
[*]*Correspondence Author's E-mail address: Angawch1988@gmail.com*

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ABSTRACT

Though the unsaturated polyester resin is highly versatile with a wide range of application, its low impact strength, low elongation at break and low toughness constrain its applications. In this article, study of an unsaturated polymer resin was conducted by adding optimum amount of nanocellulose fillers extracted from sugarcane bagasse. Mechanical and microstructural properties were characterized by testing the composite with 0.5 %, 1 %, 2 %, and 3 % fiber weight fraction of the nanocellulose. Mechanical properties such as tensile, compression, impact, flexural, as well as X-ray powder diffraction, Fourier Transform Infrared Spectroscopy (FTIR), and thermo gravimetric analysis (TGA) were performed. The results indicate that 10 nm particle size and 2 % nanocellulose by weight fraction is best, which gives enhanced mechanical properties of the composite material up to 45 % tensile strength, 38 % flexural strength, 13 % compression strength and 8 % impact strength improvement. The composite material also shows improved thermal stability and bond stretching due to the incorporation of nanocellulose particles.

Keywords: Enhanced mechanical property; Polyester resin; Nanocellulose; Toughness; Tensile strength.

1. INTRODUCTION

Polyester resins were first discovered by the Swedish chemist Berzelius in 1847 [1–3]. The unsaturated Polyester (USP) in particular is a versatile and low-cost condensation resin formed generally by the reaction of polyhydric alcohols with unsaturated dibasic acids [1]. Polymer matrix composites of cellulose nanofiller are widely used in various application areas like sanitary wares, furniture, water proofing, matrix for composite materials, water tanks, pipes, gratings and high-performance components. Agro-industrial wastes are increasingly recognized as valuable and cheaper bio-resources for development of renewable high-performance materials. Residue from annual crops such as wheat, rice, cotton, sisal, jute, and so forth, potentially provides an inexhaustible source of cellulosic fibers [4–5]. The marine and transportation industry (closure, body panels, fenders, boat construction etc.), aerospace, construction, shipbuilding, automobile industry are also the prominent users of cellulose nanofiller due to its excellent and rich hydroxyl group used for surface modification [6–10], though it shows low mechanical properties. Nanocellulose filler can be extracted from agricultural residues [11] such as sugarcane bagasse, cotton linter, and rice husks. Eco-friendly and green materials development paradigm approach aims to reduce the emissions of greenhouse gases to safeguard the environment at a global level and replacement of synthetically available

materials. The naturally occurring materials offer several advantages like sustainability, low cost, better resistance toward wear, low toxicity, high modulus of elasticity, and large specific area with better mechanical and biological properties [5].Nanocellulose filler can be used as a reinforcing material for composite materials which gives very high specific stiffness and strength [6]. Elastic modulus of nanocellulose is predicted more than the Kevlar fiber [10] and the specific strength is approximately 7–8 times higher than stainless steel [11]. Due to its low toxicity, renewable nature, nano scale dimension and good biocompatibility, the future scope of nanocellulose is very wide. Nanocellulose has rich hydroxyl groups which are used for surface treatment of materials. Mechanical properties of nanocellulose such as high stiffness and strength are attractive to use as filler material for composites which gives better mechanical and thermal properties. Nanocellulose composites are used in various applications such as in biomedical for tissue repair, drug delivery and implants of some body parts, in paper and packaging industry, in electronic industry such as time- temperature integrator, gas and leak detector, in structural material, sealant, etc. [12]. Maradini et al.[13] Presented the result for effect of using 0 – 5 % concentration nanocellulose filler (NCF) on curing, thermal and mechanical properties of epoxy polymers. The morphologies were examined using scanning electron microscopy (SEM) and transmission electron microscope (TEM), and the results show that NCF has positive effect on thermal, tensile, compression, flexural and water barrier properties. The overall results dictate that NCF has the potential as green nanofiller for epoxy polymer, but they did not study the effect of particle size, cost and environment. Omran et al. [14] also investigated how the micro and nanocellulose reinforcements yield enhanced mechanical properties of composite materials but did not investigate the possibility of using small particle sizes for more enhanced mechanical properties in industrial application using polyester. Embirsh et al. [15] presented the results of a study by using sugarcane nanocellulose and aluminum silicon carbide (Al-SiC) with polyester. The characterized results for tensile, compression, flexural, impact and thermal test gave enhanced mechanical properties compared with pure polyester resin for structural and other industrial applications, but they did not study the sugarcane nanocellulose and Al-SiC hybridization effect with polyester resin and didn't consider effect of particle size. Mateo et al. [8] reviewed the importance of agricultural wastes to produce nanocellulose particles which can be used as food packaging, mechanical reinforcement and water filtration process. The paper used acid hydrolysis and mechanical treatment methods for nanocellulose extraction which is costly and not safe for the environment. Nano materials have a typical grain size of less than 100 nm, whilst micro materials are characterized by grain size of less than 500 nm up to 100 nm [1, 15, 17], but it is challenging to extract nanoparticles to the required particle size.

Unsaturated polyester resin has low mechanical properties and is not preferred in the industrial and structural [16, 18] applications due to its low toughness, low impact strength, low elongation at break and poor resistance to crack propagation [1, 19], which limits its application as weak polymer matrix material. So, there is a need to enhance its toughness and strength by reinforcing using nanocellulose fillers. Based on the literature, mechanical properties of composite materials can be modified using potential substrate materials and nanoparticles [20–21]. In general, mechanical properties enhancement of composite materials can be achieved using filler size variation, hybrid bonding of nanocellulose fillers or use of alternative potential green material as filler has not been addressed well and needs further investigation. This research focuses on use

of potential nanocellulose green material with nanocellulose filler size of 10 nm from sugar cane bagasse ash (SCBA) at Wenji Showa sugar factory. The aim is to enhance mechanical properties such as strength and toughness of unsaturated polyester resin by incorporating nanocellulose fillers for industrial applications.

2. MATERIALS AND METHODS

2.1. Matrix- Unsaturated Polyester Resin

Unsaturated polyester resin was prepared by esterification reaction of unsaturated dibasic acids with dihydric alcohols [1]. It is mostly used as polymer matrix material due to its excellent adhesion, low cure shrinkage, low cost and availability with a proportional combination of resin to hardener in the ratio of 10:1 as recommended in [22–24].

Hardeners are used as a catalyst to cure the resin properly by making a chemical reaction without changing its own composition and they facilitate solidification process of unsaturated polyester resin and filler materials from liquid to solid state. The curing agent used for this research was methyl ethyl ketone peroxide [MEKP] due to its good mechanical curing capability, availability and because it does not affect the mechanical properties of the individual composite materials [1]. The physical and mechanical properties of general purpose commercial unsaturated polyester resin used for this study were density 1.103 g/cm^3 [12], dynamic viscosity 11.789 Pa.s [12], specific gravity 1.2 g/cc [12], tensile strength 28.25–78.85 MPa [12], tensile and flexural modulus 1978.5–3000 MPa [25], flexural strength 44.50–120 MPa[25], compression strength 110.00-150 MPa [1, 12, 25], volume shrinkage 7% [25], tensile elongation 2.5% [25], fracture energy 90 J/m^2 [17, 25], impact energy at 25 ºC 3.5–6.5 Joule [17, 25], hardness 31.5–48 BHN [25], fracture toughness 0.30 MPam$^{0.5}$ [25] and Young's modulus 1±0.4 GPa [25–31].

2.2. Fiber-Nanocellulose Particle Extraction

Sugarcane bagasse was collected from Wenji Showa sugar factory and washed thoroughly with distilled water. Later, it was boiled in a vertical autoclave for one hour at 110 ºC to remove water-soluble materials. It was then sun-dried to remove the absorbed moisture. Later, the dried sugarcane bagasse was crushed and soaked in a 15 wt. % NaOH solution at room temperature to remove water insoluble materials such as lignin, pectin, natural oil, and wax that shields the surface and alkaline from the bagasse as illustrated in the Figure 1. Following that, the bagasse was exposed for drying. The alkali-treated fibers were then soaked in a 1 mol HCl solution at 70 ºC to dissolve the cell walls and detach the micro fibrils. To remove the remaining nanocellulose components, the treated bagasse was re-soaked in a 2 wt. % NaOH solution at 70 °C after the fibers had been thoroughly washed with deionized water to remove the hydrochloric acid. The fibers were cleaned and sun dried after being treated. To produce the nano cellulose from sugarcane bagasse, these fibers were finely ground at a high-speed grinder for 20 min at a revolution of 1500 rpm [4]. The importance of having fine nanocellulose particles such as 10 nm has great ability to bridging effect of polyester resin so that its strength can be enhanced well. Figures 1 and 2 summarize the nanocellulose extraction process.

2.3. Composite Material Preparation

150 mL resin was poured into a big separate bowl and nanocellulose was added to the bowl in the ratio of 0.5%, 1%, 2%, 3% by weight fraction of the total bowl volume for one-time sample preparation and the mixture was poured into the standard mold. The mixture was homogenized by stirring vigorously at 660 rpm for three minutes to have good nanocellulose dispersion as shown by SEM image in Fig.8. The hardener methyl ethyl ketone peroxide [MEKP] was added gradually, with the type

chosen depending on the mold material type and the desired properties of the final parts. Paste wax and polyethylene plastic were used as mold releasing agent to enhance the surface quality of composite and safe removal of the sample. Curing of the sample was done in open space environmental condition until the sample got good strength to remove from the mold.

(a) (b) (c) (d)

Figure 1 Nanocellulose extraction process: (a) Sugarcane bagasse, (b) Crusher, (c) Crushed bagasse, (d) Crushed cellulose

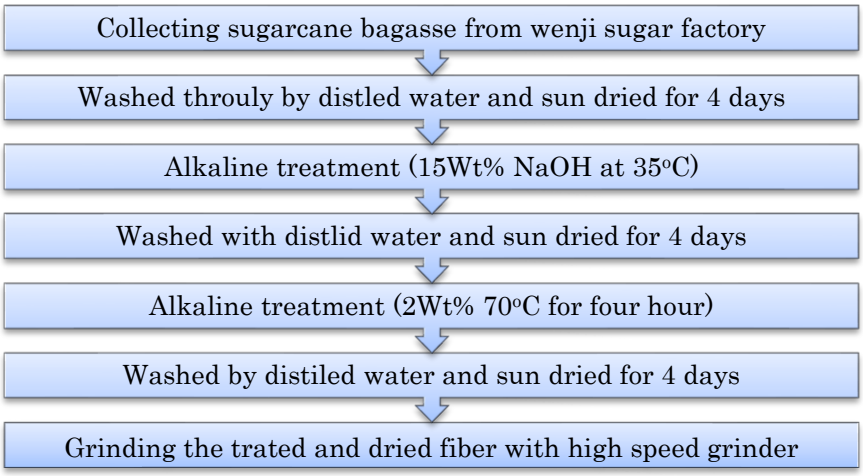


Figure 2 Nanocellulose extraction from sugarcane bagasse collection and removal process.

2.4. Characterization Setup and Apparatus for the Composite Materials

This research was carried out using experimental method via polymer composite material test standard to compare with literature value for validation. A computer-controlled small punch creep testing machine that can handle loads up to 200 kN was used during the test. The machine comes with a load cell capable of measuring up to 200 kN. The machine was used to perform a series of tests, such as assessing tensile strength according to ASTM D638-14 standards, as well as conducting compression strength and high-temperature tensile tests [21]. The miniflex 600 powder XRD machine for particle size determination, HCT_1 compressive thermal analyzer was considered for the measurement of thermal characteristics of the composite material and measuring device thermo scientific Nicolet is 50 FTIR with a range of (12000 – 50 cm^{-1}) and resolution of 0.125 cm^{-1} was used for the spectroscopy testing process.

2.4.1. Tensile test Setup and Apparatus

For the tensile test of this polyester resin with nano cellulose composite material, proportional additives of 0.5%, 1%, 2% and 3% (by weight fraction of fiber to matrix) were used. Samples were prepared and tested using polymer ASTM standard as

shown in the Figure 3 with ambient temperature of 23±2 ^{0}C and humidity value of 50±5 % as per ASTM D638-14 statement.

$$\sigma_t = \frac{P}{bh} \quad [25–30] \qquad (1)$$

Where, P= Failure load (N), B= Specimen's width (mm), H= Specimen's thickness (mm), σ_t=Tensile Strength (MPa).

Figure 3 Tensile testing machine setup

2.4.2. Flexural Characterization test Setup and Apparatus

Flexural mechanical property is also another point of interest to be enhanced using the ASTM test standards via UTM machine with capacity of 100 kN, load cell 300 kN, strain rate 5mm/min at ambient temperature of 25^{o}C with relative humidity of 62% as per ASTM D-790+17 for unsaturated polyester resin and Nano cellulose additive particles as a composite material shown in Figure 4.

$$\sigma_f = \frac{3PL}{bh^2} \quad [25–30] \qquad (2)$$

Where, P= maximum load (N), L=Specimen's Span length (mm), b= Specimen's width (mm), h= Specimen's thickness (mm), σ_f=Flexural Strength (MPa).

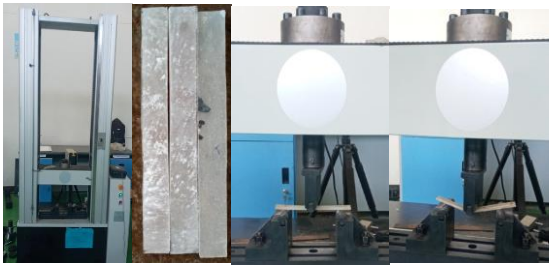


Figure 4 Three point flexural testing UTM machine setup

2.4.3. Impact Characterization Setup and Apparatus

Notched Charpy impact test using Charpy Izoid Impact testing machine shown in Figure 5 with capacity of 90J was carried out. In each type, specimens were tested in the ambient condition according to the ASTM D-256 standards with ambient temperature of 25^o C and approximate humidity value of 50±10% as per ASTM D-256. The average value was noted at the initial load deformation and tabulated as impact strength.

$$IS = \frac{A}{bxh} \quad [25–30] \qquad (3)$$

Where; IS=Impact strength, A=Energy consumed by Impact Specimen (Jm), b=width (mm) of specimen from middle of the notch, h=thickness (mm) of specimen from middle of the notch.

Figure 5 Charpy Izoid Impact testing machine setup

2.4.4. Compression Characterization test setup and Apparatus

Compression mechanical property analysis was done using the WDM-100S universal testing machine (UTM) shown in Figure 6 with loading velocity of 2mm/min as a strain rate, load cell 300 kN and test samples were done at temperature of 23±2 ^{o}C and humidity of 55±5% as per ASTM D-695-10 standards description [27].

$$\sigma_C = \frac{P}{bh} \quad [25–30] \qquad (4)$$

Where p=failure load (N), b=Specimen's width (mm)h= Specimen's thickness (mm), $\sigma_{C=}$Compression strength (MPa).

Figure 6 Compression testing machine setup

3. RESULTS AND DISCUSSION

3.1. X-Ray powder Diffraction of Nanocellulose

A miniflex 600 powder XRD, Tokyo, Japan machine was used. A micro focus X-ray tube with a Cu kα target was used as X-ray source, producing radiation (λ=1.5406A^0) at 40kV and 15 mA In the 2θ range of 10^0-70^0 with a step size of 0.01^0 on pure cellulose powder to determine crystallite size using Debye-Scherrer [1, 28, 32] equation. The raw XRD data were smoothed using origin 2018 software to obtain the full width at half maximum (FWHM) and peak positions of the particle as shown in Figure7. The figure shows the different peaks analyzed with baseline using peak analyzer features of the software and an average nanofiller crystallite size of 10 nm is obtained. FWHM (β) value is 0.945981 radians with peak position (2θ) is 58.46614^0 & λ=0.15406nm has been used.

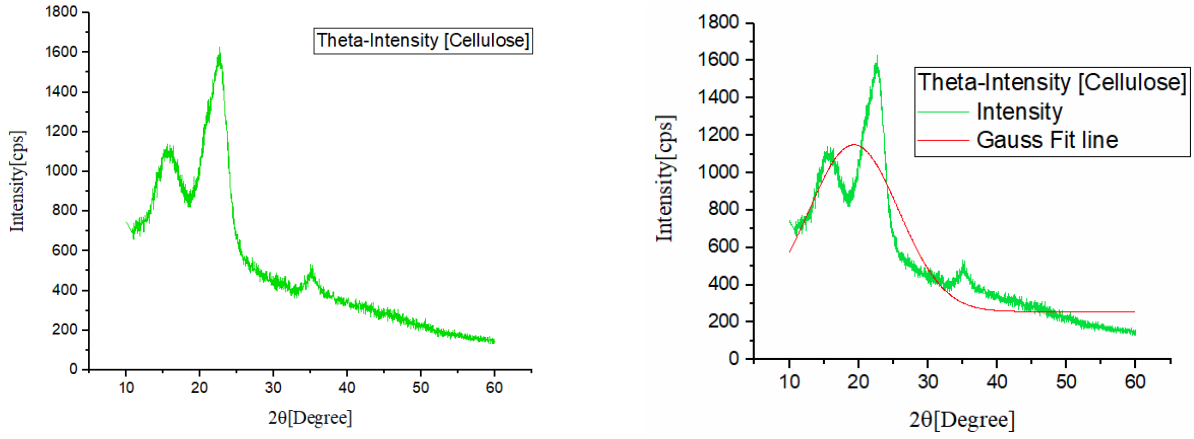
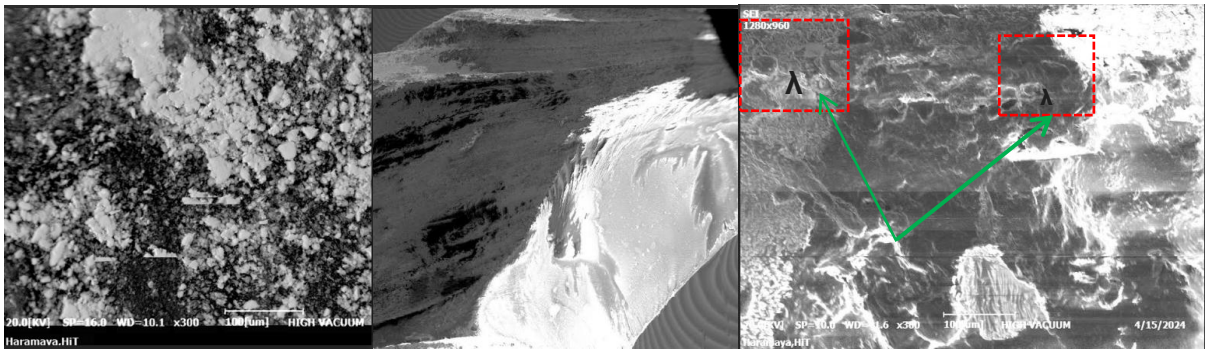


Figure 7 The XRD result after performing baseline correction & peak analysis

3.2. SEM Image of Nanocellulose



(a) (b) (c)

Figure 8 SEM image of **a)** Pure cellulose with a scale bar of 100 µm and resolution 300X, **b)** Pure rsin with a scale bar of 100 µm and resolution 300X, c) Composite cellulose(2%) and resin with a scale bar of 100 µm and resolution 300X

3.3. Mechanical Test Results of the Composite Material

3.3.1. Tensile Test

The stress – strain plots of the tensile test results are summarized in Figure 9.

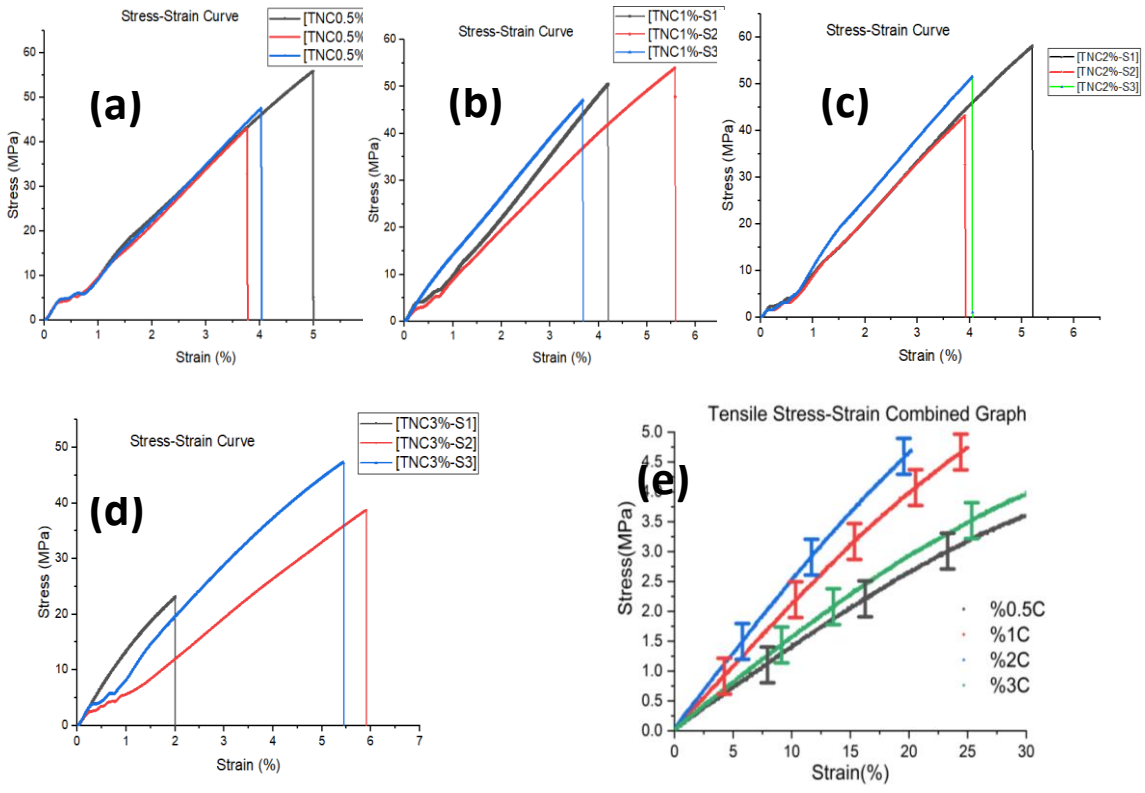


Figure 9 Plots of tensile test results: (a) 0.5 % nanocellulose and polyester resin, (b) 1 % nanocellulose and polyester resin, (c) 2 % nanocellulose and polyester resin, (d) 3 % nanocellulose and polyester resin and (e) (0,5%,1%,2% & 3 %) nanocellulose and polyester resin combined.

3.3.2. Flexural Test

The flexural test results are summarized in Figure10.

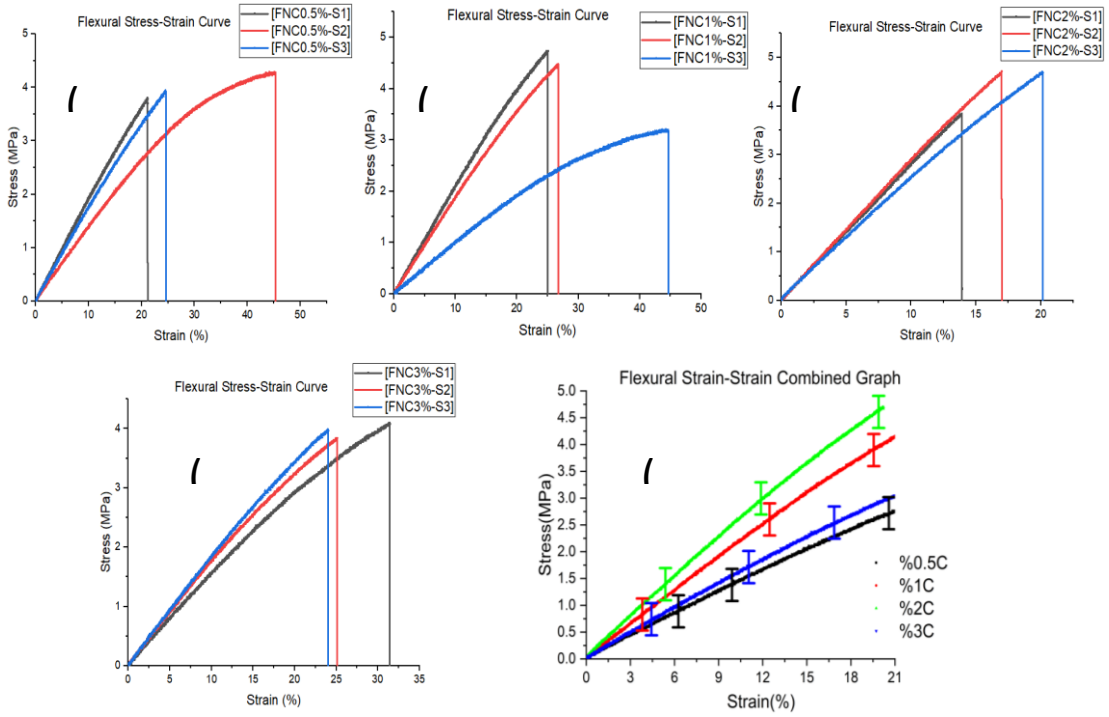


Figure 10 Plots of the flexural test result (a) 0.5 % nanocellulose and polyester resin, (b) 1 % nanocellulose and polyester resin, (c) 2 % nanocellulose and polyester resin, (d) 3 % nanocellulose and polyester resin and (e) (0,5%,1%,2% & 3 %) nanocellulose and polyester resin combined graph shown below.

Table1 Tensile and Flexural tests

Tensile test Sample code	Stress (MPa	Mean Dev.(MPa)	standard dev.(MPa)	Flexural test Sample code	Failurestress(MPa)	Mean Dev.(MPa)	Standard Dev.(MPa)
TNC0.5 %-S1	53	46.5	46.5±9.19	FNC0.5%-S1	152.40	116.20	116.20±51.1
TNC0.5 %-S2	43	41.5	41.5±2.12	FNC0.5%-S2	176.46	128.23	128.23±68.2
TNC0.5 %-S3	48	44.0	44.0±5.66	FNC0.5%-S3	160.42	120.21	120.21±56.8
TNC1 %-S4	51	45.5	45.5±7.78	FNC1%-S4	192.51	136.25	136.25±79.5
TNC1 %-S5	54	47.0	47.0±9.90	FNC1%-S5	184.48	132.24	132.24±73.8
TNC1 %-S6	47	43.5	43.5±4.95	FNC1%-S6	128.34	104.17	104.17±34.1
TNC 2 %-S7	58	49.0	49.0±12.7	FNC2%-S7	160.42	120.21	120.21±56.8
TNC 2 %-S8	43	41.5	41.5±2.12	FNC2%-S8	192.51	136.25	136.25±79.5
TNC 2 %-S9	52	46.0	46.0±8.49	FNC2%-S9	192.51	136.25	136.25±79.5
TNC 3 %-S10	23	31.5	31.5±12.0	FNC3%-S10	168.44	124.24	124.24±62.5
TNC 3 %-S11	39	39.5	39.5±0.71	FNC3%-S11	152.40	116.20	116.20±51.1
TNC 3 %-S12	47	43.5	43.5±4.95	FNC3%-S12	160.42	120.21	120.21±56.8

3.3.3 Impact Test

The mixture of unsaturated polyester resin and cellulose fillers (USP + cellulose filler) shows a slightly higher impact resistance than pure unsaturated polyester resin, according to reports in the literature [1, 3]. The increase in impact strength is 8%.

When conducting the test, the machine determines the average value for different amounts of cellulose filler [25].

3.3.4 Compression Test

In the first sample batch, the compression test results are as shown in Table 2. For CNC0.5 %-S1 (compression test of nanocellulose 0.5% for composite sample batch-1) failed under a failure load of 33.15 kN, CNC1 %-S1 failed under a maximum failure load of 22.846 kN, CNC2 %-S1 failed at a maximum failure load of 28.262 kN and finally CNC3 %-S2 failed at a maximum failure load of 26.339 kN.

Table 2 Compression and Impact test

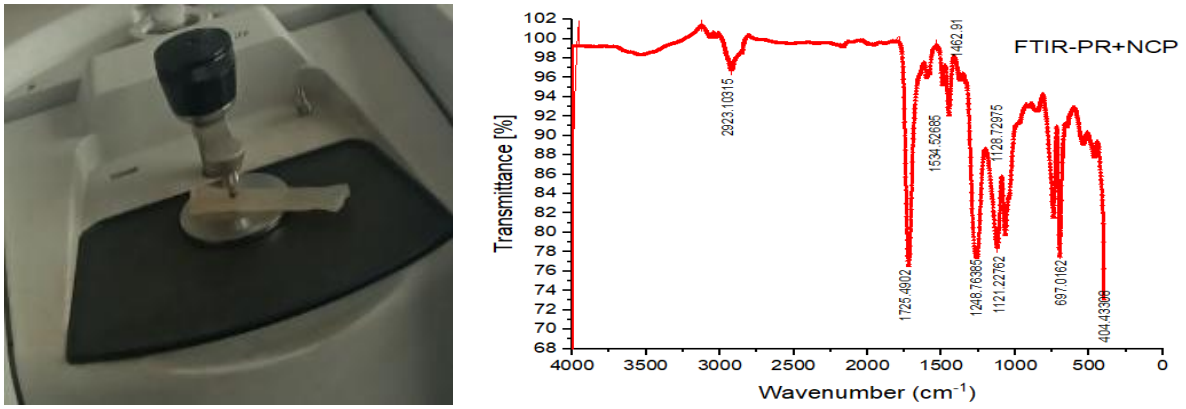
Compression test Sample code	Compression Stress (MPa)	Mean Deviation (MPa)	standard deviation (MPa)	Impact test Sample code	Failure Energy (J)	Mean Dev. (MPa)	Standard deviation (MPa)
CNC0.5 %-S1	114.72	112.36	112.36±3.34	INC0.5%-S1	4.4	4.4	4.45±0.14
CNC0.5 %-S2	132.60	121.30	121.30±15.9	INC0.5%-S2	4.5	4.5	4.50±0.00
CNC0.5 %-S3	84.60	97.30	97.30±17.96	INC0.5%-S3	4.3	4.4	4.40±0.28
CNC1 %-S4	91.40	100.70	100.7±13.15	INC1%-S4	4.4	4.45	4.45±0.14
CNC1 %-S5	67.08	88.540	88.54±30.35	INC1%-S5	4.3	4.4	4.40±0.28
CNC2%-S6	113.04	111.52	111.52±2.15	INC1%-S6	4.2	4.35	4.35±0.42
CNC2%-S7	118.40	110.70	110.7±0.99	INC2%-S7	4.6	4.55	4.55±0.14
CNC2%-S8	123.00	112.00	112.0±2.83	INC2%-S8	4.4	4.45	4.45±0.14
CNC3%-S9	107.20	105.60	105.6±6.22	INC2%-S9	4.5	4.5	4.50±0.00
CNC3%-S10	105.36	107.68	107.68±3.28	INC3%-S10	4.2	4.35	4.35±0.42
CNC3%-S11	78.20	94.10	94.10±22.48	INC3%-S11	4.5	4.5	4.50±0.00

3.3.5. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Thermo Nicolet iS50 Fourier Transform Infrared Spectroscopy (FTIR) Thermo Fisher Scientific, Waltham spectroscopy was used for the study. Samples were placed on sample holder after a carful cleaning with acetone solution. The machine can use either solid, liquid or powder sample types. Thermo Nicolet iS50 instrument uses the range of 400–4500 cm^{-1} to analyze stretching frequency of nanocellulose composite.

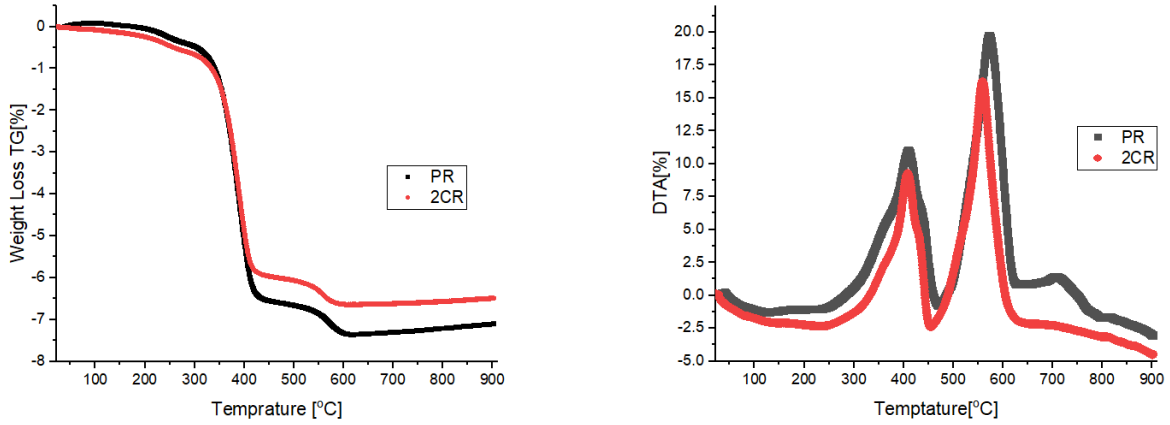
3.3.6 Thermo-Gravimetric Analysis of Nanocellulose with Resin

TSA 409 PC Luxx simultaneous thermal analyzer was used to determine nanocellulose composites' thermal stability. First, powder form of the composite was prepared, then 12 mg of powder was loaded into TGA crucible and heated at 10 ^{0}C/min in nitrogen atmosphere, in the temperature range of 25^{0}C to 900^{0}C as shown in Figure 12. TGA analysis of the composite material and pure polyester resin material were done and compared at maximum weight loss (Tdmax), which is more effective than five percent weight loss (Td5%) and ten percent weight loss (Td10%) thermal stability parameters.



(a) (b)

Figure 11 FTIR results, a) FTIR testing machine; b) spectra result of 2 % cellulose Nanoparticles particles (NCP) with pure resin (PR) composite material



(a) (b)

Figure12 TGA results (a) pure resin (PR) and 2 % cellulose resin (CR) composite vs temperature and (b) pure resin (PR) and 2 % cellulose resin (CR) vs Temperature differential thermal analysis (DTA)

3.4. Discussion

Tensile test in Figure 9 indicates maximum tensile stress for 2%C compared to 0.5%C, 1%C, and 3%C and this is in good agreement with previous literature [1, 4, 11]. Non-uniform dispersion of the nanocellulose particle may lead to particle agglomeration which can reduce material tensile strength. This is avoided during composite manufacturing phase by considering proper filler homogenization and more sample preparation to substitute premature failure. The composite material enhances its tensile strength about 45% upon the addition of nanocellulose filler in comparison with pure polyester resin tensile strength of 40MPa obtained from preliminary testing of pure polyester resin as well as comparing with literature value [1, 9]. Mean deviation is a measure of dispersion of tensile test data deviation from preliminary as well as literature value implying in good agreement with this study as shown in Table 1 and Fig.9. Flexural test in Figure 10, indicates maximum bending strength is obtained at 2%C compared with 0.5%C, 1%C, and 3%C nanocellulose by weight composition [2,9] implying that addition of nanocellulose filler provides additional strength to the composite material. Flexural strength of the composite is enhanced about 38% up on the addition of nanocellulose filler compared with polyester resin preliminary and literature

based flexural strength of 80MPa [4, 9]. Compressive test in results provided in Table 2 indicates improved value at 2%C compared with 0.5%C, 1%C and 3%C values. The composite material develops enhanced compressive strength about 13% compared with pure polyester resin preliminary accepted compressive strength of 110MPa [1, 9]. Its deviation is under the expected error range and in good agreement with literature [1]. As the amount of cellulose particle is more added, the composite brittleness increases which leads to catastrophic failure. Higher percentage cellulose filler contents show diminished mechanical properties of the composite material due to void formation, inability to fill gap between molecules, made the polyester highly viscose which imply formation of agglomeration and hinders uniform dispersion. For impact test as shown in Table 2, an eight (8%) enhancement has been achieved compared with polyester resin preliminary value of 4.5J [9] with smooth standard deviation. As the percentage of the nanocellulose increase, ability to absorb energy enhanced for this characterization but with slow percentage.

Generally, incorporating nanocellulose into polyester resin enhances interfacial bonding implying mechanical property improvement of the composite at 2%C by weight [1] for tensile, flexural, compression and impact test.

SEM image in Figure 8 indicates individual particle size and homogenously dispersed composite material structure resulting increased interfacial adhesion due to uniform dispersion of nanocellulose within the matrix which enhances effective interaction between nanocellulose and resin fillers that imply improved tensile strength. Some porosity sign of the composite material is observed which imply careful homogenization is needed during sample preparation and this may lead to failure of composite material [1, 27].

The chemical constitutes of nanocellulose composite and pure nanocellulose was evaluated as shown in Figure 11. The peak shift due to presence of various functional groups between 6000 cm^{-1} and 500 cm^{-1} has been observed. The peak observed for composite material at 1716.71 cm^{-1} corresponds to stretching of the C-O vibration group. The peak observed at 2923.1 cm^{-1} is attributed to O-H stretching vibration group of hydroxyl functional group of the composite material [1, 3]. The observed peak at 1644.47 cm^{-1} confirmed the presence of C-O bonds in polysaccharide aromatic rings of cellulose providing valuable information about the resin's unsaturation level and potential for cross-linking and the peak at 2923.1 cm^{-1} indicated the presence of single C-H bond in cellulose with C-H bending group [1, 9]. In contrast with pure cellulose particle, composite cellulose material with resin has higher peak value and new peak value has been created implying the presence of increased hydrogen bonds due to homogenized mixing of unsaturated polyester resin identified via tensile testing [1,4]. Figure 12a shows that initially, both composite materials lost some weight due to evaporation of moisture but its rate of degradation increased between 200^0C to 300^0C. However, increasing the temperature between 35^0C and 400^0C drastically increased weight loss of the composites. Particularly unsaturated polyester resin weight loss increased compared to nanocellulose composite. This is due to limited thermal conductivity of polyester resin [1, 4]. However, the addition of nanocellulose particle to the resin enhances thermal stability by making uniform distribution of heat through the composite which is enabled by uniform dispersion of nanocellulose particles than localized regions which cause high thermal weight degradation [4]. Uniform particle dispersion allows for efficient heat transfer within the composite by reducing localized hot spot and thermal stability of the composite is improved.

4. CONCLUSIONS

This research reports the experimental investigation to enhance mechanical properties of the composite unsaturated polyester resin material. The study has shown that the tensile strength, flexural strength, compression strength and impact strength have improved up on the addition of 2 % by weight of nanocellulose filler. The enhanced composite material can be used for water tank construction, water proofing work, matrix for composite materials and gratings.

Future research direction can rely on expanding the polyester resin material for structural application using hybrid bonding of nanofiller with cellulose, silica and rubber for more enhanced mechanical properties with wider scope of application. Furthermore, continuation of this study can include thermal stability at different levels of weight loss, dynamic mechanical thermal analysis (DMTA). Addressing the practical transition from laboratory scale to commercial mass production in order to achieve final materials which will be introduced in the market especially optimization of the whole process and development of new methods to produce Nano cellulose-based materials as well as reducing high production cost can be considered in the future.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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REFERENCES

[1]. E. Gashawtena, A. Kidane, and B. Sirahbizu, (2024). “The effect of nanocellulose and silica filler on the mechanical properties of natural fiber polymer matrix composites.” *Results in Engineering*, *24*, 102898.

[2]. B. Mekonen, and T. Bogale. "Experimental investigation of tensile, flexural and hardness properties of polyester resin echinatus fiber reinforced composite material." *ESM.* 2023, *11(2):* 151-162.

[3]. M. Y. Khalid, A. Al Rashid, Z. U. Arif, et al. “Recent advances in nano cellulose-based different biomaterials: types, properties, and emerging applications.” *J Mater Res Technol.* 2021, *14*, 2601-2623.

[4]. Eticha, Andinet Kumella, et al. "Biodegradable Biconstituent Melt-Blown Nonwovens for Air Filtration: Fabrication and Characterization." *Fibers and Polymers* 25.8 (2024): 2855-2873.

[5]. Tarekegn, Abrham Gebre. "Deformational Behavior of Fiber Reinforced Cement Based Materials Under Repeated Loading." *Zede Journal* 42.1 (2024): 93-104.

[6]. A. A. Betelie, A. N. Sinclair, M. et. al., “Mechanical properties of sisal-epoxy composites as functions of fiber-to-epoxy ratio.” *AIMS Mater Sci* 2019, *6(6):*985–996.

[7]. V. Thakur, A. Guleria, S. Kumar, et al., “Recent advances in nano cellulose processing, functionalization and applications: A review.” *Mater Adv* 2021, *2(6),* 1872-1895.

[8]. S. Mateo, S. Peinado, F. Morillas-Gutiérrez, et. al., “Nanocellulose from agricultural wastes: Products and applications—A review.” *Processes* 2021, *9(9),* 1594.

[9]. Angaw Chaklu, Araya Abera and Daniel Tilahun. "Extraction and characterization of Nanosilica particles to enhance mechanical properties of general-purpose unsaturated polyester resin" *SECM.* 2024, *vol. 31*, *no. 1*, pp. 20240001.

[10]. Pandurangan, Mohan Turup, and Krishnan Kanny. "Study of curing characteristics of cellulose nanofiber-filled epoxy nanocomposites." *Catalysts* 2020, *10 (8)*: 831.

[11]. T. Ramakrishnan, M. D. Mohan Gift, S. Chitradevi, et al., "Study of numerous resins used in polymer matrix composite materials." *Jhon Wiley & Sons* 2022, *2022(1),* 1088926.

[12]. A. Engidaw, A. Betelie, and D. Redda. "Experimental determination of strain in thin aluminum plate with central hole subjected to far-field tensile loading using digital image correlation (DIC)." *Engineering Solid Mechanics* 2024, *12(4)*: 423-436.

[13]. G. D. S. Maradini, M. P. Oliveira, G. M. D. S. Guanaes, et al., «Characterization of polyester nanocomposites reinforced with conifer fiber cellulose nanocrystals." *Polymers* 2020, *12(12),* 2838.

[14]. A. A. B. Omran, A. A. Mohammed, S. M. Sapuan, et al., "Micro-and nanocellulose in polymer composite materials: A rview." *Polymers* 2021, *13(2),* 231.

[15]. H. S. A. Embirsh, I. Stajčić, J. Gržetić, et al., "Synthesis, characterization and application of biobased unsaturated polyester resin reinforced with unmodified/modified biosilica nanoparticles." *Polymers* 2023, *15(18),* 3756.

[16]. H. Mohit, G. H. Kumar, M. R. Sanjay, et al., "Hybrid nanocomposites based on cellulose Nano crystals/nanofibrils: From preparation to applications." *Publ Ser Biomater* 2021, 223-245.

[17]. P. Thomas, T. Duolikun, N. P. Rumjit, et al., "Comprehensive review on Nano cellulose: Recent developments, challenges and future prospects." *J Mech Behav Biomed Mater 2020*, (*110)* :103884.

[18]. Cho, Mi-Jung, and Byung-Dae Park. "Tensile and thermal properties of Nano cellulose-reinforced poly (vinyl alcohol) Nano composites." *J Ind Eng Chem* 2011, *17(1)*: 36-40.

[19]. Abdullah, Nur Athirah, et al., "Nanocellulose from agricultural waste as an emerging nanotechnology material for nanotechnology applications–an overview." *Polimery* 66.3 (2021): 157-168.

[20]. Hailu, Hailemariam Nigus, and Daniel Tilahun Redda. "Prediction of Mechanical and Toughness Properties of Ni-Modified Cr-Mo Alloy Steels for Transmission Gear." *International Journal of Engineering Research in Africa* 56 (2021): 1-15.

[21]. Stepanova, Mariia, and Evgenia Korzhikova-Vlakh. "Modification of cellulose micro-and nanomaterials to improve properties of aliphatic polyesters/cellulose composites: A review." *Polymers* 2022, *14 (7)*: 1477.

[22]. M. Davallo, H. Pasdar, and M. Mohseni. "Mechanical properties of unsaturated polyester resin." *Int J Chemtech Res* 2010, *2(4)*: 2113-2117.

[23]. D. Trache, A. F. Tarchoun, M. Derradji, et al., "Nano cellulose: from fundamentals to advanced applications." *Front Chem 2020*, (*8*): 392.

[24]. Sudarman, Susilo, and Muhammad Taufik. "Synthesis and application of nano-silicon prepared from rice husk with the hydrothermal method and its use for anode lithium-ion batteries."

Mater. Sci. Energy Technol 2024, (*7*): 1-8.

[25]. Islam, Mohammad Tajul, Mohammad Mahbubul Alam, and Marina Zoccola. "Review on modification of Nano cellulose for application in composites." *Int. J. Innov. Res. Sci. Eng. Technol*. 2013, *2*(*10*) 5444-5451.

[26]. A. G. N. Sofiah, J. Pasupuleti M. Samykano, et al., « Harnessing Nature's Ingenuity: A Comprehensive Exploration of Nanocellulose from Production to Cutting-Edge Applications in Engineering and Sciences." Polymers, 2023, *15(14):* 3044.

[27]. R. R. Manikumar and T. Nageswara. "Comparative FTIR analysis of liquid and cured forms of ortho-unsaturated polyester resin and flame-retardant resin: Investigating chemical structure transformations." *Research Institute of Petroleum Processing* 2024, *24* (*1*): 91-116.

[28]. A. Zhadyra, B. Oral, I.Aziza and K. Aigul. "Modification of polymers to synthesize thermo-salt-resistant stabilizers of drilling fluids" *Open Engineering*, vol. 15, no. 1, 2025, pp. 20240097.

[29]. M. Kanda, S. Puggal, N. Dhall, & A. Sharma, "Recent developments in the fabrication, characterization, and properties enhancement of polymer Nano composites: a critical review." *Mater Today Proc* 2018, *5 (14)*: 28243-28252.

[30]. A. Mohammed, J. Hassan, S. Maan, and A-Q. Hussein. "Synergistic effect of nano-silica, steel slag, and waste glass on the microstructure, electrical resistivity, and strength of ultra-high-performance concrete" *Open Engineering*, vol. 15, no. 1, 2025, pp. 20240105.

[31]. A. A. Hibatallah, L. S. Rasheed, and W. A. Alaraji, "Experimental study on behavior of hybrid columns by using SIFCON under eccentric load" *Open Engineering*, vol. 15, no. 1, 2025, pp. 20240023.

[32]. M. Zenebe, E. Woldesenbet, and E. G. Koricho, "An experimental investigation on synthesizing and characterizing of modified bagasse reinforced natural rubber composite." *Journal of Composite Materials* 56.29 (2022): 4501-4514.