

PRODUCTION OF PLASTIC MOULDS FOR MAKING INTERLOCKING TILES FROM RECYCLED LOW-DENSITY POLYETHYLENE (rLDPE) AND SAWDUST COMPOSITE

Elakhe, P.O.* and Agboola, O.F.

Nigerian Defense Academy, Department of Mechanical Engineering, Kaduna

*Corresponding email: pauloelakhe@yahoo.com

ABSTRACT

The increasing environmental concerns regarding plastic waste and the need for sustainable materials in manufacturing have highlighted the importance of utilizing recycled materials. This study addresses the challenge of repurposing waste plastics and sawdust, which are often underutilized, by developing a composite material suitable for producing durable plastic moulds. The aim of the research was to evaluate the mechanical properties of composites made from recycled Low-Density Polyethylene (rLDPE) and sawdust for potential manufacturing applications. Composites with varying proportions of rLDPE and sawdust were fabricated using a compression moulding machine. Mechanical properties, including tensile strength, elastic modulus, hardness, and compressive strength, were measured. Dynamic mechanical analysis (DMA) and thermal analysis were also conducted to assess loss modulus and thermal stability. The results showed that a composite with 15% sawdust and 85% rLDPE exhibited the best overall performance, achieving a tensile strength of 23.08 MPa, elastic modulus of 182.7 MPa, hardness of 54.03 Hv, and compressive strength of 12.61 MPa. DMA revealed a loss modulus of 27.0 MPa at a peak temperature of 94.6°C, indicating enhanced stiffness and thermal stability due to sawdust reinforcement. The study concludes that the 85/15 rLDPE/sawdust composite offers significant potential as a sustainable material for manufacturing durable plastic moulds, including applications like interlocking tiles. It is recommended that future research investigate the long-term durability and environmental impact of these composites under real-world conditions.

Keywords: Recycled Low-Density Polyethylene (rLDPE), Sawdust Composite, Mechanical Properties, Compression Moulding, Tensile Strength, Plastic Moulds

1 INTRODUCTION

Plastics, known for their durability, lightweight nature, and cost-effectiveness, are integral to numerous applications due to their ability to be easily moulded into various products. Globally, more than 100 million tons of plastics are produced annually, with around 200 billion pounds of plastic material being thermoformed, foamed, laminated, and extruded into countless packages and products [1]. However, the rising demand for resources is anticipated to increase resource consumption and waste generation, including plastics, leading to environmental degradation, climate change, and adverse effects on future generations [2]. The environmental, health, and sustainability challenges posed by waste, particularly plastic waste, are significant concerns worldwide. As a result, developing sustainable methods to manage plastic waste from communities and industries is essential. Recycling plays a crucial role in addressing this issue, as it involves recovering waste or scrap plastic and reprocessing it into functional and useful products [3]. The primary goal of plastic recycling is to reduce the high rates of plastic pollution while lessening the reliance on virgin materials for producing new plastic products. This approach not only conserves resources but also diverts plastics from landfills and unintended destinations such as oceans [4]. Plastics are categorized into seven main types: Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low-Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), and others [5]. Among these, used pure water sachets, which are made from LDPE, pose a significant environmental challenge, especially by

contributing to flooding during the rainy season due to their tendency to block drainage systems. Recycled Low-Density Polyethylene (rLDPE) is commonly utilized in producing piping, sheeting, films, and trash bags, as well as composite lumber for building and agricultural applications. rLDPE exhibits properties such as good chemical resistance, low water absorption, semi-rigidity, translucence, and corrosion resistance [6]. Similarly, agricultural waste residues, particularly lignocellulosic materials, are abundant in many African countries and often contribute to environmental issues due to their limited alternative uses. These organic fillers, which are cheap, readily available, and non-abrasive to equipment, can be effectively used to reinforce composite materials [7]. Material scientists are increasingly focusing on synthesizing new green polymeric materials and processes that enhance environmental quality. Natural fibres and fillers, due to their renewability, biodegradability, high filling effect, abrasion resistance, and other advantageous properties, are emerging as some of the best reinforcing materials for polymer-based composites [7]. Interlocking tiles, a type of flooring or paving material designed to fit together like puzzle pieces, are made from materials such as concrete, composite, and rubber. These tiles are widely used both indoors and outdoors for various applications due to their durability, resistance to wear, moisture, and impact, as well as their ease of installation and maintenance. The moulds used to produce these tiles are often made from plastics like PVC and plastic composites, which are known for their good impact strength, corrosion resistance, and low water absorption [8]. While plastics offer many beneficial mechanical properties, such as resistance to chemical attack, corrosion, and ease of processing and recycling, these properties can be compromised by factors such as stress, temperature, and environmental conditions during their service lives. This degradation has led to skepticism about the use of certain polymers in demanding applications, such as aircraft parts [9]. To overcome these limitations, fillers—both inorganic and organic—are incorporated into recycled plastics, resulting in polymer composites that offer improved reliability and performance. The recycling of plastics to create polymer composites with enhanced mechanical properties is crucial for addressing environmental challenges, improving material performance, and achieving sustainability and cost-effectiveness. With the growing demand for sustainable materials, repurposing plastic waste into value-added products presents a feasible and impactful solution. Sawdust, a common byproduct of wood processing, offers an inexpensive and eco-friendly reinforcement material for polymer composites. This research seeks to address these challenges by developing and evaluating a composite material made from recycled Low-Density Polyethylene (rLDPE) and sawdust. The aim is to produce durable plastic moulds, specifically for manufacturing interlocking tiles, thereby offering a solution that benefits both the environment and the economy.

2 LITERATURE REVIEW

Siroćić *et al.* [10] developed low-density polyethylene (LDPE) nanocomposite films specifically for packaging applications. In their research, LDPE composites with various fillers, including zeolite, TMAZ 7, nanoclay Cloisite 20A, and precipitated calcium carbonate (CaCO_3), were produced using extrusion and injection moulding techniques. The mechanical properties of the samples were evaluated using scanning electron microscopy (SEM) and tensile tests, while the thermal degradation was also studied. Their findings indicated that even a minor concentration of clay was highly effective in achieving good morphology. The presence of nanoparticles at lower content reduced the oxygen permeability of LDPE, and the results further showed that the inclusion of fillers enhanced the thermal stability of the LDPE composites compared to pure LDPE. Severino *et al.* [11] examined LDPE/recycled LDPE (rLDPE) blends with montmorillonite (MMT) as nanocomposite fillers, using different MMT contents (0.0, 1.0, and 3.0wt%). The nanocomposites were produced through hot pressing followed by die-cutting. Their results revealed that the rLDPE-based nanocomposites exhibited satisfactory mechanical, thermal, and morphological properties, with the optimal MMT concentration being 1wt%. This research confirmed the feasibility of recycling LDPE from prepreg packaging, thereby contributing to waste reduction and the application of this material in technological contexts. Sarifuddin *et al.* [12] investigated the effects of plasticized sago starch on the properties of LDPE reinforced with kenaf core fibre (KCF). The LDPE/KCF ratio was fixed at 80/20, with thermoplastic sago starch (TPSS) content varying from 10 to 40wt%. Mechanical testing of the blended samples showed a gradual decrease in tensile strength, modulus, and elongation at break with increasing TPSS content. However, the thermal stability of the composite improved significantly with TPSS addition. Mysiukiewicz *et al.* [13] explored the effects of aluminum (Al) filler content (ranging from 1 to 2wt%)

on various properties of composites based on a high-density polyethylene (HDPE) matrix. Their study covered crystalline structure, rheological behavior (melt flow index and oscillatory rheometry), thermal properties (differential scanning calorimetry), and both static and dynamic mechanical properties. The results indicated that introducing 1-2wt% of aluminum filler led to slight enhancements in mechanical properties, while higher filler loadings (5-10wt%) yielded similar performance to neat HDPE. These outcomes were supported by the observed consistency in the composites' rheological behavior, suggesting that significant aluminum filler content could be integrated into the HDPE matrix without additional pre-treatment, maintaining composite performance. Usman *et al.* [14] examined the impact of groundnut shell powder (GSP) on the mechanical properties and biodegradability of recycled polyethylene composites. Both alkaline-treated and untreated GSP with particle sizes of 0-300 μ m and 300-600 μ m were used at varying proportions (5%, 10%, 15%, 20%, 25%, and 30% wt). The tensile and hardness tests showed improved mechanical properties for the treated fibre composites. Additionally, water absorption tests revealed lower rates of water uptake in treated GSP-recycled polyethylene composites compared to untreated ones. Fourier transform infrared spectroscopy (FTIR) showed the disappearance of characteristic peaks for hemicellulose and lignin. Evidence of biodegradability was observed through fungal growth on the fibre-reinforced composites. SEM micrographs displayed uniform distribution of treated fibres within the polymer matrix, correlating with the observed enhancements in mechanical properties. Goll *et al.* [15] studied the mechanical properties of polymer composites made from solid bleached sulfate (SBS) paperboard shavings coated with polyethylene terephthalate (PET) and recycled LDPE. Tensile properties, flexural strength, impact resistance, and water absorption was evaluated according to ASTM standards. The composites with the highest LDPE concentration demonstrated greater resistance to water and humidity absorption. Density measurements showed a 19.5% increase for the 30% cellulosic fibre-reinforced composite relative to pure LDPE. However, while the tensile strength of these samples was approximately 55% higher than those produced by pressing, the overall mechanical properties (tensile, flexural, and impact strength) were lower than expected due to the non-uniform distribution of SBS paperboard shavings. Salmah *et al.* [16] investigated the properties of LDPE composites reinforced with palm kernel shell (PKS), using polyethylene co-acrylic acid (PEAA) as a compatibilizer. Tensile properties, thermal analysis, water absorption, and morphology of the LDPE/PKS composites were analyzed. The study found that increasing PKS content decreased tensile strength and elongation at break but increased the Young's modulus and water absorption. The addition of PEAA improved filler-matrix interaction and adhesion, as shown by SEM studies, leading to higher tensile properties and reduced water absorption. PEAA also increased the crystallinity of the composites. Atuanya *et al.* [17] investigated the potential use of recycled LDPE in wood composite boards. The boards were produced through compressive moulding, with LDPE content increased from 30% to 50%wt at intervals of 10%wt. The microstructure and mechanical properties, including modulus of rupture (MOR), modulus of elasticity (MOE), tensile strength, and impact strength, were determined. The results showed that the boards produced at 140°C with 60/40wt% wood particles to LDPE content achieved a high MOR of 20.31N/mm and an MOE of 1363N/mm, meeting the minimum requirements of European standards for general-purpose boards. The tensile strength of these boards was also within acceptable limits, suggesting that recycled LDPE can be used for general-purpose board production. Burkar *et al.* [18] developed and evaluated the mechanical properties of coconut fibre-reinforced LDPE composite material. The effects of fibre loading on the tensile, flexural, and impact properties of the composite material were investigated by varying fibre content by weight at 0%, 10%, 20%, and 30%. Fractured surface morphology analysis indicated a homogeneous mixture of coir fibre and the LDPE matrix, although weak interfacial bonding between the coir fibre and LDPE matrix was also observed. Water absorptivity tests showed that the composite materials exhibited low water absorptivity at low fibre loading, but this property increased significantly at higher fibre loadings. Ekwedigwe *et al.* [19] evaluated the effects of bean pod ash particles on the properties of recycled LDPE composites. The composites were produced using compounding and compressive moulding techniques, with factorial design of experiments and ANOVA employed for optimization. Mechanical properties and microstructure of the composites were determined, with results showing optimal flexural strength at 140°C, 12 minutes, 40wt% bean pod ash particles, and 6MPa. The addition of bean pod ash particles improved hardness values, tensile strength, and bending strength, with compressive properties reaching 18.25N/mm². The fairly uniform distribution of bean pod ash particles within the composite microstructure was identified as the key

factor behind the improvements in mechanical properties, indicating that bean pod waste could serve as a biodegradable and eco-friendly reinforcement. Onyedika *et al.* [20] modeled the mechanical properties of clay powder-filled recycled LDPE composites. The clay powder was prepared by sun-drying, grinding, and sieving, with two particle sizes ($-90\mu\text{m}$ and $-425\mu\text{m}$) used at different clay powder contents (5%, 10%, 15%, and 20% wt). These were thoroughly mixed with recycled LDPE in an injection moulding machine at 173°C . The study revealed that tensile strength, tensile modulus, hardness, flexural strength, fatigue strength, and hardness increased with clay powder content, while strain-at-breakage and shear strength decreased. Smaller particle sizes were found to enhance mechanical properties, with model equations predicting composite properties at predetermined clay contents. The standard deviations indicated that the models generally exhibited lower scatter compared to the $-90\mu\text{m}$ and $-425\mu\text{m}$ particle sizes. Olumuyiwa *et al.* [21] examined the effects of palm kernel shell on the microstructure and mechanical properties of recycled LDPE composites. The composites were produced using compounding and compressive moulding techniques, varying palm kernel shell particle content from 5% to 25% vol% with particle sizes of 150, 300, and $400\mu\text{m}$. The study found that the hardness of the composite increased with palm kernel shell content, while tensile strength reached an optimum at 5% vol. SEM images revealed fairly good interfacial interaction between palm kernel shell particles and the recycled LDPE matrix. Composites produced with $150\mu\text{m}$ particle size exhibited the best properties, making them suitable for interior applications such as car seats, dashboards, and other automotive interiors where high strength is not critical. Tom *et al.* [22] investigated the impact of incorporating coffee-derived fibres into LLDPE composites on their thermal and mechanical properties. Their study found that the addition of these fibres enhanced the thermostability of the composites. Chemical treatment of the fibres led to a 58.3% reduction in water absorption and an increase in elongation and tensile strength by approximately 48% and 17%, respectively. The use of maleated polyethylene (MAPE) further improved fibre-matrix interaction, resulting in better adhesion, wetting, and dispersion. This treatment also ensured more uniform fibre distribution within the matrix, minimizing voids and gaps. Consequently, composites with treated fibres demonstrated superior properties compared to those with untreated fibres, and higher fibre contents (up to 30% wt) were used effectively while maintaining acceptable mechanical properties.

3 MATERIALS AND METHOD

3.1 Materials

The following materials were used in this research work: Recycled Low-Density Polyethylene rLDPE, Hardwood Powder (sawdust), Sodium Hydroxide (NaOH) Solution, Distilled Water (H_2O). The list of equipment used in this research work and their specifications are shown in Table 1 below;

Table 1. List of Equipment and their Specifications

Equipment	Model	Brand	Capacity
Plastic Film Shredder	S600	MID TECH	2000kg
Pelletizing Extruder	ATE65	ACERETECH	4000kg/hr
Ball Milling Machine	1500*3000		8tph
Roll Mills	5183	North Bergen USA	140kg
Compression Moulding Machine	0557	Samtech Exim	150t
Compression Strength Testing Machine	5851-0	Carver inc.	3000grams
Izod Impact Tester	6757	Pianezz-terino Italy	25.02Joules
Vickers Hardness Test Machine	MV1-PC	Bluestar	1gf – 2kgf
Tensiometer	W6466	Hounds Field Tensiometer	0 – 3000grams
Measuring Cylinder	-	-	-
Weighing Balance	-	-	-

3.2 Methods

3.2.1 Sourcing of Used Pure Water Sachets (LDPE) and Sawdust

Used pure water sachets (LDPE) were collected from various restaurants within Zaria Metropolis. These sachets were gathered into a sack and transported to the plastic recycling workshop at the Department of Polymer Technology, Nigerian Institute of Leather and Science Technology

(NILEST), Samaru-Zaria, Kaduna State. Hardwood sawdust (Mahogany) was obtained from Danbale Sawmill in Samaru-Zaria, Kaduna State.

3.2.2 Sorting, Washing and Drying of Used Pure Water Sachets

The procedures for sorting, washing, and drying used pure water sachets (LDPE) followed general best practices in polymer recycling as outlined in ASTM D6288 – Standard Practice for Separation and Washing of Recycled Plastics Prior to Testing. Sorting: Contaminants were manually removed based on visual inspection, as described in ASTM D6288. Washing: Sachets were immersed in a soap solution, which is analogous to ASTM D6288’s recommendation for aqueous cleaning agents to remove surface contaminants. Drying: The sachets were sun-dried until a constant weight was achieved. While this step aligns with common practices, it does not directly adhere to a specific ASTM standard, as solar drying is more context-specific.

3.2.3 Recycling Using a Pelletizing Film Extruder

The recycling process for the LDPE sachets adhered to standard extrusion practices. The following standards and recommendations were considered: Extrusion Process: The general methodology aligns with ASTM D4703 – Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques, or Sheets, which includes protocols for melting and extrusion of thermoplastics. Though specific to compression moulding, the temperature settings and material handling are analogous. Melting Temperature: The chosen temperature of 120°C aligns with standard processing conditions for LDPE, as detailed in polymer processing guidelines by material manufacturers (e.g., LDPE melt processing temperatures typically range between 110–140°C). Pelletizing: While no explicit standard for pelletizing LDPE exists, the use of the extruder and cold-water cooling aligns with ASTM D3418 (melting temperature determination) in maintaining material integrity during thermal processing. Where no explicit standards exist (e.g., solar drying), best practices were followed based on local conditions and equipment availability. The described methods ensure minimal contamination and optimal material quality for recycling.

3.2.4 Preparation of Sawdust Powder for Mixing with rLDPE

The sawdust powder was prepared through drying, ball milling, sieving, and treatment with NaOH solution. Initially, the collected sawdust was weighed and dried under the sun until a constant weight was achieved. The dried sawdust was then ground into a fine powder using a ball milling machine. The sawdust was placed in a ball mill ceramic cylinder with ceramic balls and milled. The milled sawdust was sieved through an ASTM 150µm sieve [23] for 30minutes, and the sieved particles were collected for use in the research. The sieved sawdust was treated with a 2% w/v NaOH solution, prepared by dissolving 2g of Sodium Hydroxide (NaOH) pellets in 100ml of distilled water. The sawdust was immersed in the NaOH solution and allowed to stand for 2hours at room temperature [24]. After treatment, the sawdust was rinsed several times with distilled water until the rinse water was neutral on pH paper. The treated sawdust was then dried in a hot air oven, with weight checks performed every 30minutes until a constant weight was achieved, which took 5hours. Plate 1 shows sawdust powder and pelletized rLDPE, while Table 2 shows the Formulation of the Varying Proportion of rLDPE and Sawdust Composite.

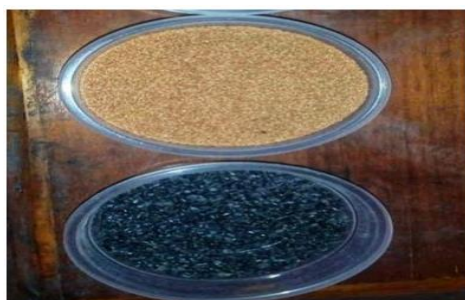


Plate 1. Sawdust Powder and Pelletized rLDPE

Table 2. Formulation of the Varying Proportion of rLDPE and Sawdust Composite

Samples	Temperature(°C)	Time (Minutes)	Pressure (N/m ²)	rLDPE (g)	Sawdust (g)
rLDPE	140	10	40	100	-
RS ₁	140	10	40	95	5
RS ₂	140	10	40	90	10
RS ₃	140	10	40	85	15
RS ₄	140	10	40	80	20
RS ₅	140	10	40	75	25
RS ₆	140	10	40	70	30
RS ₇	140	10	40	65	35
RS ₈	140	10	40	60	40
RS ₉	140	10	40	55	45
RS ₁₀	140	10	40	50	50
RS ₁₁	140	10	40	45	55

3.2.5 *Mixing of rLDPE and Sawdust Using a Two-Roll Mill Machine*

Composite samples with varying proportions were prepared by mixing rLDPE and sawdust using a two-roll mill machine. During the mixing process, the rolls of the machine were set in counterclockwise motion. As a band and bank of rLDPE formed on the front roll, the treated sawdust was gradually introduced into the bank. The mixture was cross-mixed and allowed to blend for 10minutes under a pressure of 140N/m². After mixing, the composite was sheeted out and labeled accordingly [25].

3.2.6 *Hot Pressing of Composite Using a Compression Moulding Machine*

The composite samples obtained from the mixing process were placed into a metal mold with dimensions of 120mm x 100mm x 3.2mm. The mold was then positioned in a hydraulic hot press (compression moulding machine) for shaping. The pressing was carried out at a temperature of 140°C and a pressure of 2.5MPa for 10minutes. After pressing, the composite was allowed to cool and was labeled accordingly [22]. The produced composite samples are depicted in Plates 2 and 3.

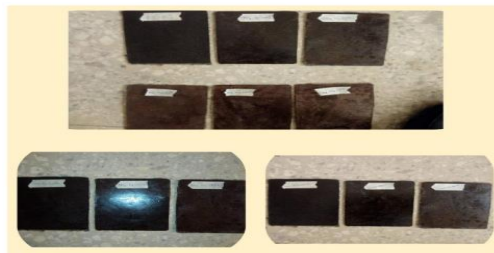


Plate 2. Produced Composite Samples



Plate 3. Composite Mould of rLDPE and Sawdust (different views)

3.2.7 *Production of the Plastic Mould for Interlocking Tiles*

A metal mould, constructed from steel and measuring 200mm x 100mm x 50mm, was first created through welding. Following this, the plastic mould was produced (see Plate 3) using compression moulding. The melted composite of LDPE and sawdust was poured into the metal mould and then placed into the compression moulding machine. After the compression process, the mould was allowed to cool. Subsequently, the plastic mould was carefully separated from the metal mould.

3.3 Characterization of the Composite

3.3.1 Tensile Strength

The tensile strength was carried out in accordance with ASTM D-638 [26]. A dumbbell shaped samples was subjected to a tensile force and tensile toughness, tensile modulus, percentage elongation at break for each sample were calculated and recorded automatically by the machine and the results were recorded.

$$\text{Tensile strength} = \frac{\text{breaking load (N)}}{\text{area (mm}^2\text{)}} \quad (1)$$

$$\text{Modulus of elasticity, } E = \frac{PL^3}{4bd^3\tau} \quad (2)$$

$$\text{Strain} = \frac{\Delta L}{L} \quad (3)$$

$$\% \text{ Elongation} = \frac{\Delta L}{L} \times 100 \quad (4)$$

$$\text{Young's Modulus} = \frac{\text{stress}}{\text{strain}} \quad (5)$$

Where F = load or force (N), b = width, d = thickness (mm), L= gauge length (mm) and τ = deflection (mm).

3.3.2 Impact Toughness

The impact test was carried out according to the standard specified in ASTM D-256 [27]. The specimens were cut to dimensions of 64 mm x 12.7 mm x 3.2 mm and 45° notched was inserted at the middle of the test specimens from all the produced composite samples. The impact energy test was carried out using Izod Impact Tester. The specimens were clamped vertically on the jaw of the machine and hammer of weight 1500 N was released from an inclined angle 150°. The impact energy for corresponding tested specimen was taken and recorded. Impact toughness was calculated and recorded accordingly using equation 6 and 7.

$$\text{Average Impact Energy} = \frac{1st+2nd+3rd}{3} \quad (J) \quad (6)$$

$$\text{Impact Strength} = \frac{\text{Average Impact Energy}}{\text{Sample Thickness}} \quad (J/mm) \quad (7)$$

3.3.3 Hardness

The hardness test was carried out in accordance with ASTM D2240 on a Mico-Vicker Harness Tester [92]. The test was carried out at different positions on each sample and average hardness was calculated using equation 8.

$$\text{Average Hardness} = \frac{1st+2nd+3rd}{3} \quad (Hv) \quad (8)$$

3.3.4 Water Absorption

The water absorption was carried out in accordance with ASTM - D570 [29]. Specimens were prepared with dimension 50mm x 50mm x 3.2mm. Water absorption test was carried out by the total immersion of specimens in distilled water at room temperature for 7 days. The water absorbed was determined by weighing the samples at regular intervals of 24 hours, with the aid of digital weighing balance. The percentage water absorption of the composite samples was calculated using equation 9.

$$\% \text{ Water Absorbed} = \frac{W_f - W_i}{W_i} \times 100 \quad (9)$$

Where W_f is weight after immersion and W_i is weight before immersion in grams.

3.3.5 Compressive Strength

The compression strength test was carried out according to ASTM D-695 [30]. The specimen was cut to specimen dimension 25mm x 25mm x 10mm and was placed at the middle of the specimen holder below the machine crosshead plunger. The crosshead was adjusted until the plunger made contact

with the specimen. The specimen was compressed steadily until failure and the load at rupture was recorded. The compression strength was calculated using equation 10. Cross Sectional Area of Sample = width x thickness.

$$\text{Compression Strength} = \frac{\text{Load at rupture}}{\text{Cross sectional area}} \text{ MPa} \tag{10}$$

3.3.6 Dynamic Mechanical Analysis

The dynamic mechanical analysis of the produced polymer composites was carried out in accordance with ASTM D4440 [31]. The samples were tested under sinusoidal load at frequencies of 2Hz, 5Hz and 10Hz and amplitude of 50µm using the temperature sweep mode from 25°C to 100°C. During the test, the temperature was increased at the rate of 3°C/min and the viscoelastic spectrum (storage modulus [E’], lost modulus [E’'], and tangent loss factor [E’/E’'']) was recorded as function of temperature over time. The storage modulus measures elasticity of material (i.e. the ability of the material to store energy). Above the glass transition temperature of a material at increase temperature, the material became soft and flexible and a drastic decrease in modulus occurred.

4 RESULTS AND DISCUSSION

4.1 Tensile Strength Test

The result of tensile strength test for rLDPE and sawdust composites is presented in Table 3.

Table 3. Results of Tensile Strength Test of rLDPE and Sawdust Composites

% Ratio of rLDPE & sawdust	Sample code	Tensile Strength (MPa)	Elastic Modulus (MPa)	Elongation at Breaking Point (%)
rLDPE	sawdust			
100	0	rLDPE	17.03	27.79
95	5	RS1	18.07	18.66
90	10	RS2	22.95	15.63
85	15	RS3	23.08	14.32
80	20	RS4	17.93	11.63
75	25	RS5	14.03	11.53
70	30	RS6	12.67	10.46
65	35	RS7	11.45	9.89
60	40	RS8	9.07	9.67
55	45	RS9	8.34	8.23
50	50	RS10	4.79	7.97
45	55	RS11	2.09	7.01

4.2 The Impact Toughness Test

The result of impact toughness test of rLDPE and sawdust composites is presented in Table 4.

Table 4. Results of Impact Toughness Test of rLDPE and Sawdust Composites

% Ratio of rLDPE & sawdust	Sample code	Impact Energy (J)			Average Impact Energy (J)	Impact Toughness (J/mm)	
		1 st	2 nd	3 rd			
rLDPE	sawdust						
100	0	rLDPE	0.687	0.687	0.685	0.686	0.214
95	5	RS1	0.642	0.640	0.628	0.637	0.199
90	10	RS2	0.610	0.618	0.606	0.611	0.191
85	15	RS3	0.505	0.498	0.509	0.504	0.158
80	20	RS4	0.500	0.505	0.498	0.501	0.157
75	25	RS5	0.492	0.488	0.496	0.492	0.154
70	30	RS6	0.454	0.432	0.411	0.432	0.135
65	35	RS7	0.421	0.411	0.401	0.411	0.128
60	40	RS8	0.367	0.379	0.374	0.373	0.116
55	45	RS9	0.363	0.354	0.362	0.360	0.112
50	50	RS10	0.311	0.321	0.346	0.331	0.107
45	55	RS11	0.307	0.314	0.299	0.307	0.101

4.3 Result of Hardness Test

The result of hardness test of rLDPE and sawdust composites is presented in Table 5.

Table 5. Results of Hardness Test for rLDPE and sawdust composites

% Ratio of rLDPE & sawdust		Sample code	Hardness (Hv)			Average Hardness (Hv)
rLDPE	sawdust		1 st	2 nd	3 rd	
100	0	rLDPE	46.70	44.80	45.40	45.63
95	5	RS1	46.80	46.50	46.70	46.67
90	10	RS2	51.40	51.80	52.60	51.93
85	15	RS3	55.00	54.70	54.50	54.86
80	20	RS4	54.80	55.20	54.60	54.73
75	25	RS5	50.40	48.80	48.60	49.29
70	30	RS6	48.90	47.70	47.60	48.06
65	35	RS7	47.80	47.10	46.80	47.23
60	40	RS8	46.50	46.80	45.70	46.33
55	45	RS9	45.30	45.50	44.90	45.40
50	50	RS10	44.80	44.90	44.20	44.60
45	55	RS11	43.70	44.20	43.60	43.83

4.4 Water Absorption Test

The result of water absorption test for rLDPE and sawdust composites is presented in Table 6.

Table 6. Results of Water Absorption Test for rLDPE and sawdust composites

% Ratio of rLDPE & sawdust		Sample code	Initial Weight 'W _i ' (g)	Final Weight 'W _f ' (g)	Change in weight [W _f - W _i] (g)	Water Absorbed (%)
rLDPE	sawdust					
100	0	rLDPE	5.812	5.819	0.007	0.12
95	5	RS1	5.762	5.788	0.026	0.45
90	10	RS2	5.863	5.893	0.030	0.52
85	15	RS3	5.812	5.874	0.062	1.07
80	20	RS4	5.725	5.798	0.073	1.28
75	25	RS5	5.764	5.842	0.078	1.35
70	30	RS6	5.756	5.842	0.086	1.49
65	35	RS7	5.808	5.897	0.089	1.53
60	40	RS8	5.789	5.883	0.094	1.62
55	45	RS9	5.776	5.881	0.105	1.82
50	50	RS10	5.811	5.919	0.108	1.86
45	55	RS11	5.791	5.904	0.113	1.95

4.5 Result of Compressive Strength Test

The result of compressive strength test for rLDPE and sawdust composites is presented in Table 7

Table 7. Result of Compressive Strength Test for rLDPE and Sawdust Composites

% Ratio of rLDPE & sawdust		Sample code	Load at Rupture (N)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
a	b				
rLDPE	sawdust	C	d	e	f
100	0	rLDPE	1	2379.50	9.59
			2	2662.10	
			3	2150.00	
95	5	RS1	1	2422.50	10.22
			2	2687.50	
			3	2552.50	
90	10	RS2	1	2702.50	11.49
			2	2942.00	
			3	2971.00	
85	15	RS3	1	2856.40	
			2	3182.00	

			3	3406.60	13.66	12.61
80	20	RS4	1	3108.40	12.43	
			2	2810.00	11.24	
			3	2947.50	11.79	11.82
75	25	RS5	1	2525.80	10.15	
			2	2865.50	11.42	
			3	3180.10	12.51	11.36
70	30	RS6	1	2697.30	10.79	
			2	2755.00	11.02	10.76
			3	2615.00	10.46	
A	B	C	d	E	f	g
65	35	RS7	1	2585.00	10.34	
			2	2572.30	10.29	
			3	2472.50	9.89	10.17
60	40	RS8	1	2472.40	9.89	
			2	2507.50	10.03	
			3	2368.00	9.47	9.80
55	45	RS9	1	2393.00	9.57	
			2	2245.00	8.98	
			3	2480.00	9.92	9.49
50	50	RS10	1	2307.50	9.23	
			2	2362.00	9.45	
			3	2255.00	9.02	9.23
45	55	RS 11	1	2238.00	8.95	
			2	2265.00	9.06	
			3	2110.00	8.44	8.82

4.6 Tensile Strength Result Analysis of the Composite

Figure 1 illustrates the tensile strength results for the produced rLDPE/sawdust composite. The graph indicates a steady increase in tensile strength as the sawdust loading rises, peaking at 23.08MPa with a 15% sawdust loading in sample RS₃. Beyond this point, a gradual decline in tensile strength was observed with further increases in sawdust loading. The observed increase in tensile strength from 5% to 15% sawdust loading is expected, as higher particulate volume typically enhances composite strength. Improved interfacial adhesion between the sawdust (filler) and rLDPE (matrix) likely contributed to better stress transfer within the composite, aiding in stress distribution during tensile testing. However, the decrease in tensile strength observed from 20% to 55% sawdust loading may result from an excessive filler-to-matrix ratio, which can lead to weaker bonding strength between the filler and matrix or cause filler agglomeration. This reduced adhesion can impair stress transfer and lower the tensile strength of the composite [32]. Comparatively, plastic molds are often made from Polyvinyl Chloride (PVC), with tensile strength values ranging from 6.9 to 25MPa [29]. The maximum tensile strength recorded for the composite was 23.08MPa, placing it within the acceptable range [33].

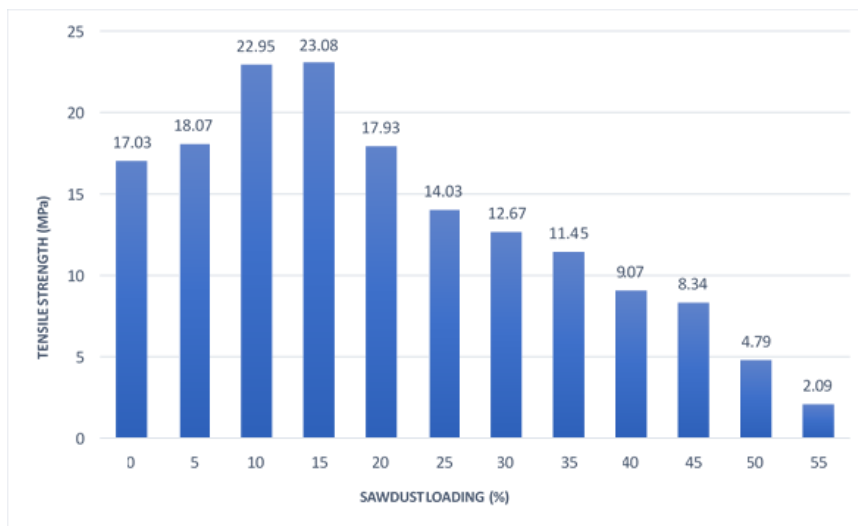


Figure 1. Graph of Tensile Strength against Sawdust Loading (%)

4.7 Young Modulus (Stiffness) Result Analysis of the Composite

Figure 2 depicts the impact of sawdust loading on the Young's Modulus of the produced composites. Young's Modulus, a measure of material stiffness, shows a trend similar to that of tensile strength. The maximum Young's Modulus of 182.70MPa was observed at 15% sawdust loading. Beyond this point, increasing sawdust loading resulted in a gradual decline in Young's Modulus. The initial increase in stiffness with rising sawdust loading can be attributed to improved interaction between the sawdust (filler) and the rLDPE (matrix). This enhanced interaction likely stiffened the composite, increasing its resistance to deformation under stress. However, the subsequent decrease in stiffness at higher sawdust loadings may be due to diminished bonding between the filler and the polymer matrix, especially when the filler content exceeds 15%. As the sawdust saturates the rLDPE matrix, the reduced bonding leads to a less cohesive composite, resulting in decreased stiffness and overall strength.

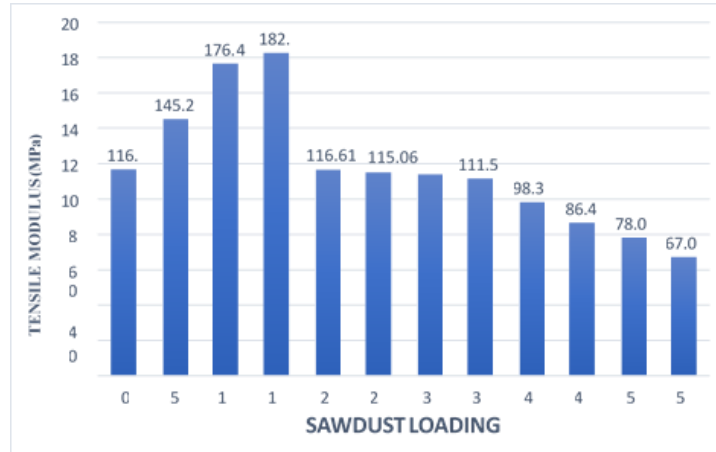


Figure 2. Graph of young modulus (stiffness) against sawdust loading (%)

4.8 Percentage Elongation at breaking Point Result Analysis of the Composite

Percentage elongation measures how much a solid material can stretch under tension before it ruptures. It is expressed as the ratio of the increase in length to the original length. Figure 3 illustrates a consistent decline in percentage elongation as sawdust loading increases. This suggests that the addition of sawdust to the recycled Low-Density Polyethylene (rLDPE) matrix stiffens the matrix core, which restricts the mobility of polymer chains and, consequently, reduces the material's ability to extend.

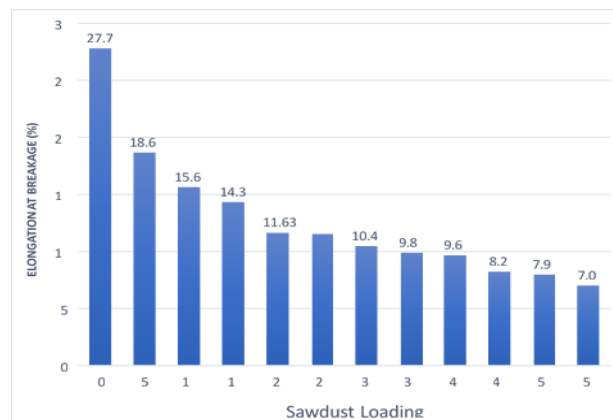


Figure 3. Graph of Sawdust Loading and the Percentage Elongation at Break of rLDPE

4.9 Impact Toughness Result Analysis of the Composite

Impact toughness measures the amount of energy a material can absorb under sudden shock before fracturing (Figure 4). Low-Density Polyethylene (LDPE) typically exhibits considerable impact strength due to its flexibility and ductility. However, the data shows a consistent decrease in impact strength as sawdust loading increases. This reduction in impact strength can likely be attributed to the

particulate nature of the sawdust, which may create voids within the composite system due to agglomeration [34].

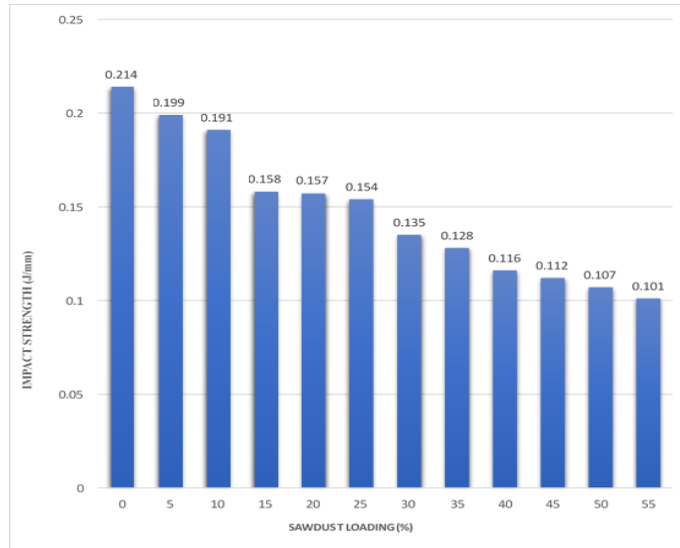


Figure 4. Graph of Sawdust Loading and Impact Toughness of rLDPE

4.10 Hardness Result Analysis of the Composite

Hardness measures a material's resistance to deformation caused by mechanical indentation or abrasion (Figure 5). The study found a gradual increase in the hardness of the composites as sawdust loading increased, reaching a peak value of 54.86 Hv at 15% sawdust loading (RS3). Beyond this point, a decline in hardness was observed starting from 20% sawdust loading. This trend is anticipated since the sawdust used as filler comes from hardwood, which naturally imparts its inherent hardness to the composite. However, the reduction in hardness at higher sawdust loadings could be attributed to the filler's bulkiness, which may have created voids within the composite. For comparison, the hardness value (Hv) of PVC molds ranges from 110 to 120, which is significantly higher than the maximum value of 54.86 obtained for the composite. This indicates that while PVC molds possess greater hardness, the composite material remains suitable for applications where lower hardness is required [35].

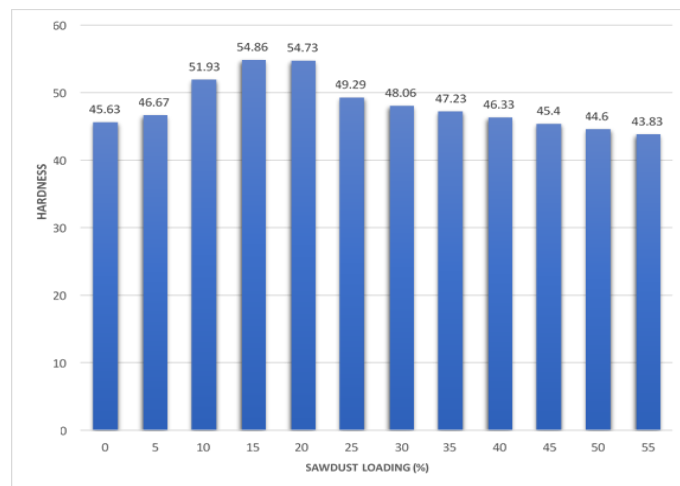


Figure 5. Graph of sawdust loading and hardness of rLDPE

4.11 Water Absorption Result Analysis of the Composite

The water absorption of the composite (Figure 6) increased steadily from 0.12% to 1.95% as the sawdust loading increased. This trend can be attributed to the hydrophilic nature of the sawdust filler, which inherently absorbs moisture [36].

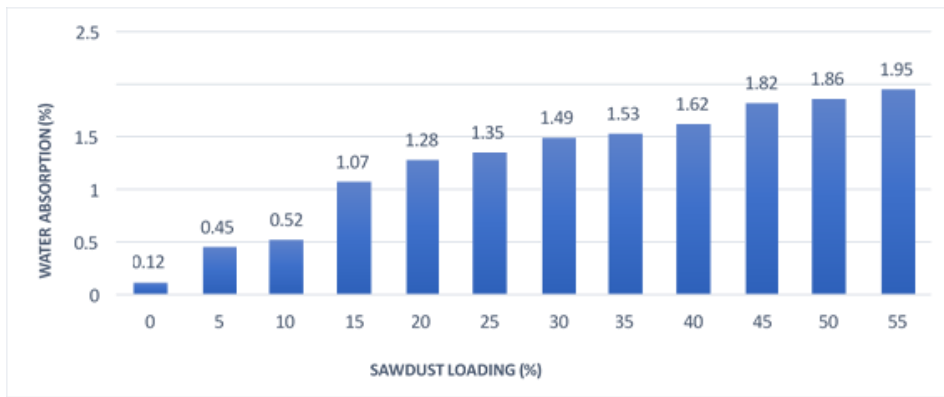


Figure 6. Graph of Sawdust Loading and Percentage Water Absorption of rLDPE

4.12 Compressive Strength Result Analysis of the Composite

Compressive strength measures the ability of a composite to withstand forces that reduce its size under pressure. As illustrated in Figure 7, the compressive strength of the composite increases with sawdust content up to 15% loading. This improvement can be attributed to the reinforcement provided by the sawdust, which enhances stress transfer from the matrix to the sawdust, better compatibility between wood sawdust and polyethylene, a more compact composite structure, and improved interfacial bonding between the sawdust and the matrix. The increased compressive strength up to 15% sawdust content likely results from the strengthened bonding between the recycled low-density polyethylene (rLDPE) matrix and the sawdust. However, beyond 15% sawdust content, the compressive strength declines. This reduction may be due to weaker interfacial bonding between the sawdust and the matrix or the increased presence of sawdust particles, which could lead to crack formation due to poor dispersion within the matrix. Comparing the composite’s highest compressive strength of 12.61MPa to the literature value for PVC molds, which is 66MPa, it is evident that PVC can endure significantly higher compressive loads than the composite [35, 37].

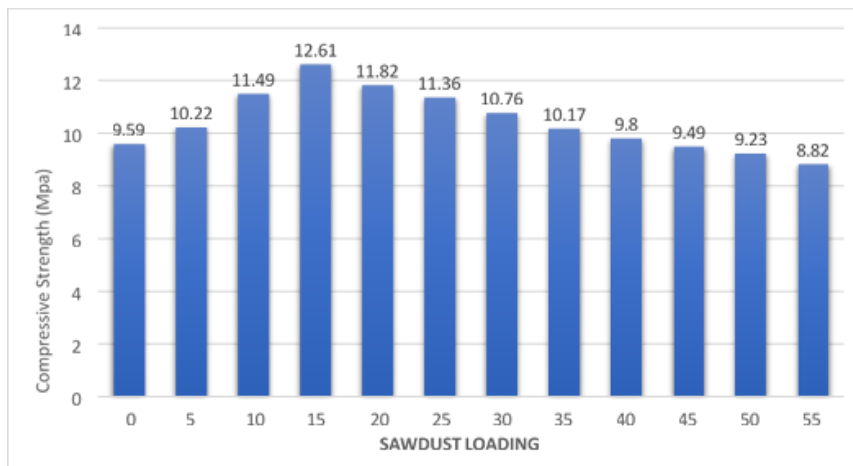


Figure 7. Graph of Sawdust Loading and Compressive Strength of rLDPE

4.13 Dynamic Mechanical Analysis (DMA) Result for Sample RS₃ (85/15%)

Dynamic Mechanical Analysis (DMA) is employed to characterize composites in terms of temperature, time, frequency, and stress (Figure 8). This technique allows for the assessment of changes in stiffness and damping as the material undergoes a temperature profile, revealing the effects of temperature on the material. DMA serves as a complement to other mechanical testing methods. The dynamic mechanical and thermal analysis of the produced polymer matrix composite was conducted following ASTM D4440 standards. The RS₃ sample was prepared with dimensions of 40mm x 10mm x 3.2mm and subjected to sinusoidal loading at frequencies of 2Hz, 5Hz, and 10Hz with an amplitude of 50µm, using the temperature sweep mode from 25°C to 120°C. During testing, the temperature was increased at a rate of 3°C/min, and the viscoelastic properties, including the storage modulus [E’], loss

modulus [E''], and loss tangent [E'/E''], were recorded as functions of temperature over time. The storage modulus represents the material's elasticity, while the loss modulus indicates its ability to dissipate energy. Above the material's glass transition temperature, as the temperature increases, the material becomes softer and more flexible, leading to a significant decrease in modulus. Figure 8 presents the DMA test results for sample RS₃ (85/15% sawdust/rLDPE). The results show a steady decrease in the storage modulus from 180MPa to 27MPa at the highest frequency of 10Hz as the temperature rises from 28.8°C to 94.6°C. Onset deformation was observed at 36.6°C, with inflection occurring at 38.2°C. The onset of deformation at 36.6°C indicates that the composite sample will be prone to mechanical failure at this temperature, likely due to the presence of wood particles (sawdust) in the recycled plastic matrix, given wood's naturally low thermal stability. A loss modulus of 27MPa was recorded at the peak temperature of 94.6°C, suggesting that sawdust improved the hardness and stiffness of the RS₃ sample. Additionally, the damping factor increased from 0.125 to 0.218 as the sample's temperature rose. However, compared to a 100% rLDPE sample, the damping factor was lower, indicating that the incorporation of sawdust into recycled polyethylene reduces its capacity to absorb stress [38].

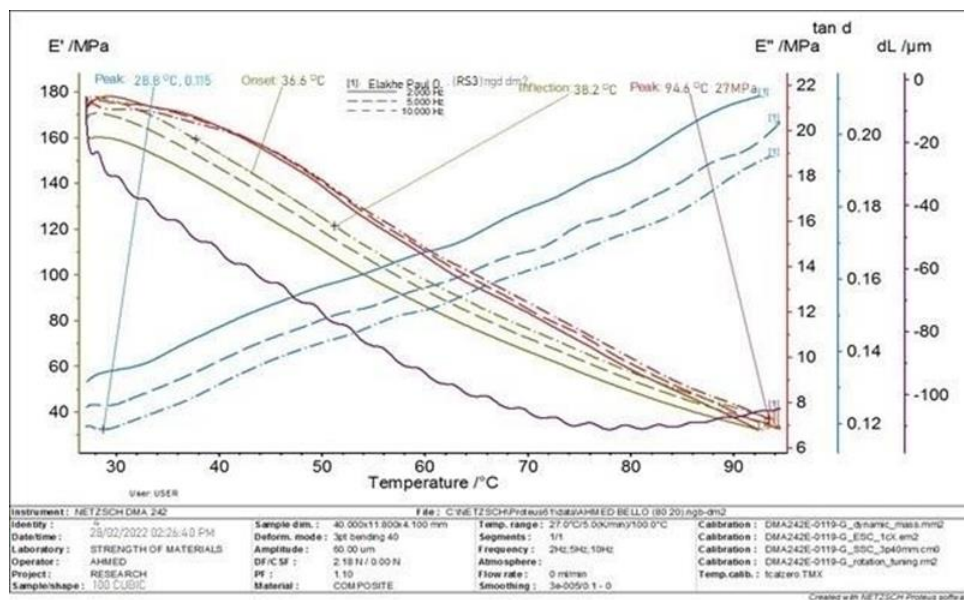


Figure 8. Dynamic Mechanical and Thermal Analysis (DMTA) for Sample RS₃ (85/15 % of rLDPE/sawdust reinforcement)

4.14 Dynamic Mechanical Analysis (DMA) Result for Sample rLDPE (100/0%) Control Sample

The result from Figure 9 indicates a steady decrease in the storage modulus from 590MPa to 20MPa at the highest frequency of 10Hz, as the temperature rises from 27.8°C to 93.5°C. Deformation onset was observed at 40.8°C, with an inflection point occurring at 44.1°C. The early onset of deformation at lower temperatures is associated with the flexible nature of LDPE, which is prone to mechanical failure at lower temperatures. The loss modulus represents the viscous behavior of a viscoelastic material, quantifying the energy dissipated as heat during cyclic loading. This loss modulus typically occurs at intermediate temperatures, reflecting molecular processes and marking the temperature at which segmental motion begins. In this sample, a minimum loss modulus of 20MPa was recorded at the peak temperature of 93.5°C. Additionally, the damping factor increased from 0.149 to 0.242 as the sample temperature increased. This increase is likely due to the transition of the plastic from a glassy to a rubbery phase as temperature rises, enhancing its ability to absorb stress[39].

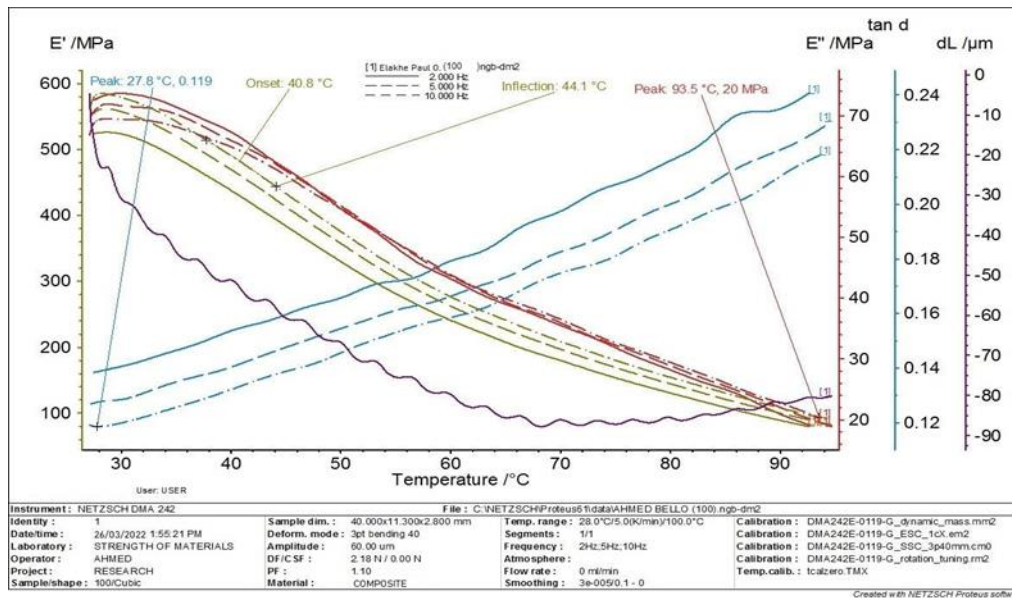


Figure 9. Dynamic Mechanical and Thermal Analysis (DMTA) for Control Sample rLDPE (100/0 % of rLDPE/sawdust reinforcement)

5 CONCLUSIONS

This research successfully demonstrated the production of polymer matrix composites using recycled Low-Density Polyethylene (rLDPE) and sawdust for creating plastic molds for interlocking tiles through compression molding. The study utilized recycled materials, including pure water sachets and acacia wood sawdust, which were processed and combined to produce various composite samples. Mechanical testing revealed that incorporating 15% sawdust into the rLDPE matrix significantly improved tensile strength, modulus, compressive strength, and hardness, although it reduced elongation, impact strength, and water absorption. The most promising sample had a tensile strength of 23.08 MPa, comparable to that of PVC plastic molds, confirming its suitability for practical use. This work underscores the potential of these composites as sustainable, economically viable alternatives in construction, particularly for producing molds for interlocking tiles.

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