Journal of Science and Technology Research 1(1) 2019 pp. 37-44

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Production of Polyvinyl Chloride-Grass Composite Using Injection Moulding Process

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ARTICLE INFORMATION

Article history:
Received 16 February 2019
Revised 07 March 2019
Accepted 11 March 2019
Available online 25 March 2019

Keywords:
Barrel temperature,
Injection moulding,
Mechanical properties,
Polyvinyl-grass composite.

ABSTRACT

This study focused on the production of polyvinyl chloride-grass composite using injection moulding process. The effects of barrel temperature on the mechanical properties of the produced composite were also investigated. The polyvinyl chloride (PVC) material and grass were mixed together to form a homogenous mixture with various percentage composition by volume. The two screw plunger injection moulding machine with maximum clamping force of 70 tons and shot capacity of 3.0oz was used to produce polyvinyl chloride-grass composite at various barrel temperature ranging from 210°C to 310°C. The produced polyvinyl chloride-grass composite was evaluated for its mechanical properties which included tensile strength, proof stress, percentage elongation and flexural strength. The maximum tensile strength, proof stress, percentage elongation and flexural strength for PVC-Grass composite were determined as 9.85N/mm^2, 5.33N/mm^2, 180% and 27.6×10^{2}N/mm^2 at barrel temperature of 270°C, 260°C, 270°C, 260°C respectively. The results obtained shows that barrel temperature of injection moulding machine contributes significantly to the production of polyvinyl chloride-grass composite.

1. Introduction

In the past twenty years, materials research and development (R&D) has shifted from monolithic to composite materials, adjusting to the global need for reduced weight, environment friendliness, low cost, high quality and high performance in structural materials [1].The demand for new materials with higher specifications led to the concept of combining different materials to form a single material called composite. Such composite materials results in high performance, and high flexibility in design that cannot be attained by the individual constituents. Moreover, it has been shown that technological development depends on the progress in the field of material sciences [2]. The research and development of new materials together with its design is the engine that drives economic progress. That is to say, today, technology depends greatly on scientific research of materials, and this contributes to economic growth of any nation. Furthermore, injection moulding is a cost-effective way to produce complex, three dimensional shapes at high volumes. Injection moulding is a very complex process and its process variable like barrel temperature, injection pressure, the material flow rate, mould temperature and flow pattern usually influence the properties of polymeric materials. A qualitative analysis of the influence of these factors, in this case barrel temperature on the mechanical properties of injection moulded parts will be helpful in gaining better insight into the presently used processing methods. Mosle et al. [1]

examined the sawdust-PET composite using the hot press compression moulding, they examined the effects of melt temperature on the tensile strength, proof stress, percentage elongation and the flexural strength, their results compared favourably with this study. Osarenmwinda and Nwachukwu [2] developed a composite from agro-waste consisting of sawdust and palm kernel shell and they determined its physical and mechanical properties. The results obtained for yield strength, ultimate tensile strength, modulus of elasticity, modulus of rupture, internal bond strength, density, thickness of swelling and water absorption were found to be satisfactory. Chunping et al. [3] carried out a study aimed to model fundamental bonding characteristics and performance of wood composite. In their work, mathematical model and a computer simulation model were developed to predict the variation of inter-element (strand) contact during mat consolidation. The mathematical predictions and the computer simulations agree well with each other. Their results showed that the relationship between the inter-element contact and the mat density was highly nonlinear and was significantly affected by the wood density and the element thickness. Harless et al. [4] in their study, examined the mechanical properties of composite panels to depend on the density variations which occur through the pan thickness. They then proposed an analytical tool to predict density profile as a function of the manufacturing processes. A multilayer description of the density and moisture gradients resulting from the felting process provided input for the mode inputs for the pressing process included plate temperature and press closing rate. The model developed simulated the physical and mechanical processes that occur in the press and mat system. Zhou and Mallick [5] examined the effect of reinforcement combination on the mechanical strength of glass reinforced plastic using compression moulding. They obtained a proof stress at a specific barrel temperature which was found to be satisfactory. Osarenmwinda and Olodu [6] also investigated the effect of barrel temperature on mechanical properties of injection moulded PVC (polyvinylchloride) plastics, from their result, optimum tensile strength, proof stress, percentage elongation and flexural strength was attained for PVC at barrel temperature ranging from 240^oC to 280^oC respectively.
This study focused on the production of polyvinyl chloride-grass composite using injection moulding process.

2. Materials and Method

2.1 Equipment and Tools

(a) Two stage-screw plunger Injection machine. Fox and offord, 70 tons two stage-screw plunger
(b) A toggle clamp attached to the injection end of injection moulding machine was used.
(c) The mould was made of Silicon–killed forging quality steel AISI type H140 treated to 252-302 Brine 11. Such steel was used for moulds that require high quality parts, long production runs and is safe to use at high clamping pressures.
(d) Monsanto Tensometer, Type ‘W’ Serial No. 8991was used for tensile testing experiment.

2.2 Materials

(a) The grass used for this research work is giunea gra**ss** (*Panicum maximum*), it was obtained from Benin City, Edo State, Nigeria**;**
(b) The plastic material used for this study was polyvinyl chloride (PVC), it exist in powder form and was obtained from Adig Plastic Company Limited in Lagos State, Nigeria

2.3 Preparation of Grass

The harvested grass which was about 200kg in weight was washed and soaked with dilute sodium hydroxide (NaOH) of concentration 0.10mol/dm^3 for 6 hours to ensure effective bonding between the grass and the Polyvinyl Chloride material. The grasses were first air dried in the sun and later transferred to an oven and further dried at 105^oC. It was continuously monitored until moisture content of about $4\pm0.2\%$ was obtained [7]. The grass was ground to granules using crushing machine. The ground grass was screened to a particle size of 300μm diameters using vibrating sieve machine.

2.4 Production of Polyvinyl Chloride-Grass Composites

Polyvinyl Chloride (PVC) was mixed with ground grass in the proportion shown in Table 1 [2, 3, 6]. The polyvinyl chloride-grass mix was blended in a cylindrical container until a homogenous mixture was obtained. The homogenous mixture of the composite was fed into the hopper of the injection moulding machine and was produced at various barrel temperature ranging from 210^oC to 310^oC.

Table 1: Composition of the Produced PVC-Grass Composite [2, 3, 6]

Serial Number	Percentage by Volume of Plastic (PVC)	Percentage by Volume of Grass
1	80	20
2	70	30
3	60	40
4	50	50
5	40	60
6	30	70
7	20	80

2.5 Estimation of the Required Shot and Clamping Force Required

In order to mould the PVC-grass composite, it is necessary to determine the amount of PVC-grass composite melt required to fill the mould [8]. This amount of PCV-grass composite melt must be displaced by the screw plunger in one single stroke. This is described as a shot [9]. At the same time, it is important to estimate the required force which is required to hold the mould closed during the injection process so that the mould will not open. The force is referred to as the clamping force.

2.5.1 Estimation of the Required Shot

The required shots in terms of PVC-grass composite can be estimated as follows [6];

Volume of Tension test specimen = 4.32 cm^3
Volume of Deflection test specimen = 3.00 cm^3
Volume of sprue and runners = 2.268 cm^3
Therefore, total volume of plastic-grass composites required per shot
= (4. 32 + 3. 0 + 2.268) cm^3
= 9. 588 cm^3 / shot

The amount of material per shot required for PVC-Grass composite is shown in Table 2.

Table 2: Amount of Material Per Shot Required for PVC Grass- Composite

Material	Density (Average Values) g/cm^3	Amount of Material Per Shot	
		grams/shot	ounces /shot
PVC-grass composite	1. 34	12.86	0.45

2.5.2 Estimation of Required Clamping Force

Projected area of Tension Test specimen = 21.60 cm^2
Projected area of deflection Test Specimen = 15.00 cm^2
Projected area of sprue and runners = 6.21 cm^2
.: The projected area of moulding = 42.81 cm^2

Assuming a maximum moulding pressure of 180 kg/cm^2, then the

Clamping force required will be calculated as follows:

Clamping force > 180 x 42.81 = 7,700 kg

> 8. 5 Tons.

Using 8.5 tons as a guide and by trial, a clamping force of 12 tons was found suitable [1].

2.5.3 Evaluation of PVC-Grass Composite for Mechanical Strength

The produced composite was evaluated for mechanical strength (tensile strength, proof stress, percentage elongation and flexural strength) using Equations 1 to 4 respectively.

$$\text{Tensile strength} = \frac{\text{Maximum Load}}{\text{Original Cross - Sectional Area}} \quad (1)$$

The original cross-sectional area of the specimen is 18.9mm^2.

$$\text{Proof stress} = \frac{\text{Force at yield}}{\text{Cross - Sectional Area}} \quad (2)$$

The cross-sectional area of specimen =18.9 mm^2

$$\text{Hence, proof stress} = \frac{\text{Force at yield}}{18.9} \text{N}/mm^2$$

$$\text{Percentage (\%) Elongation} = \frac{\text{Extension}}{\text{Gauge Length}} \text{ x } 100\% \quad (3)$$

$$\text{Flexural Strength} \quad (\text{EI}) = \frac{\mathbf{P}L^3}{\mathbf{48y}} \quad (4)$$

Where y is the deflection in mm, P= Load, L= Length of test specimen

3.Results and Discussion

Figure 1-4 shows the effects of barrel temperature on tensile strength, proof stress, percentage elongation and flexural strength for PVC-Grass composite respectively.

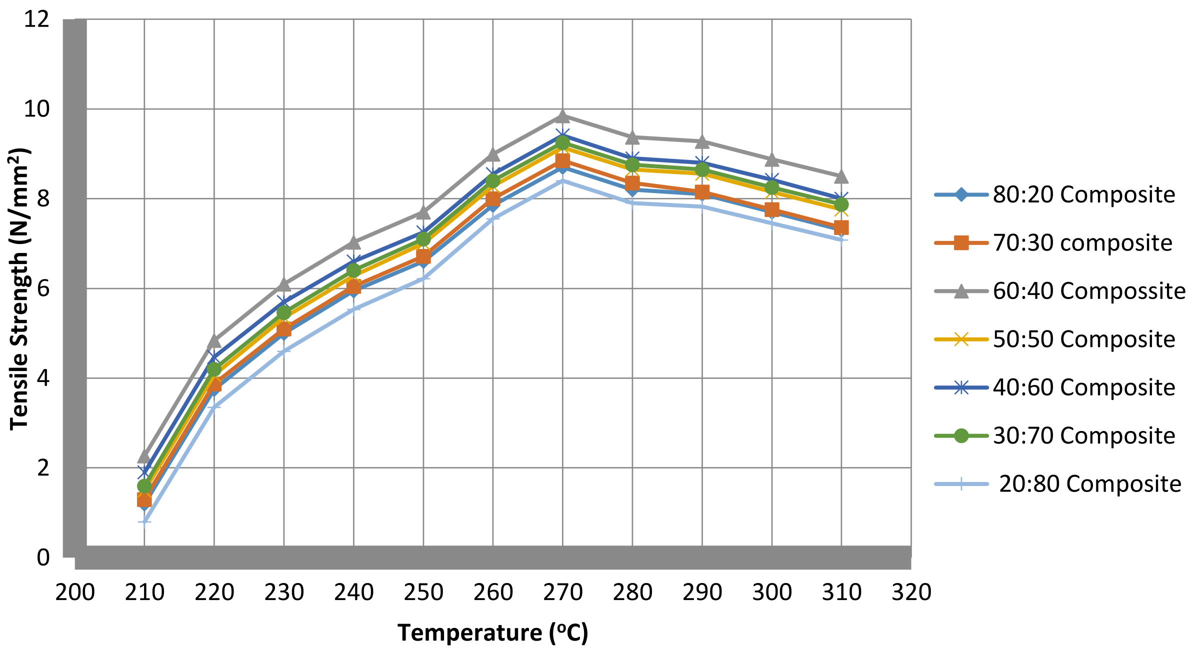

Figure 1: Effects of Barrel Temperature on Tensile Strength for PVC-Grass Composite.

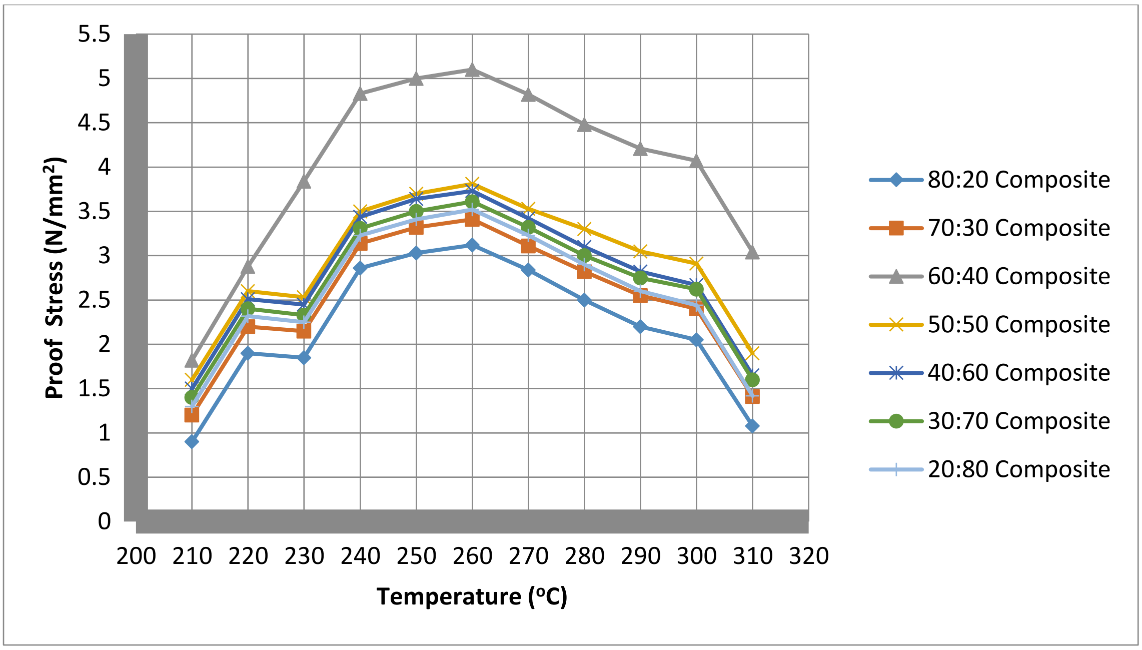

Figure 2: Effects of Barrel Temperature on Proof Stress for PVC-Grass Composite.

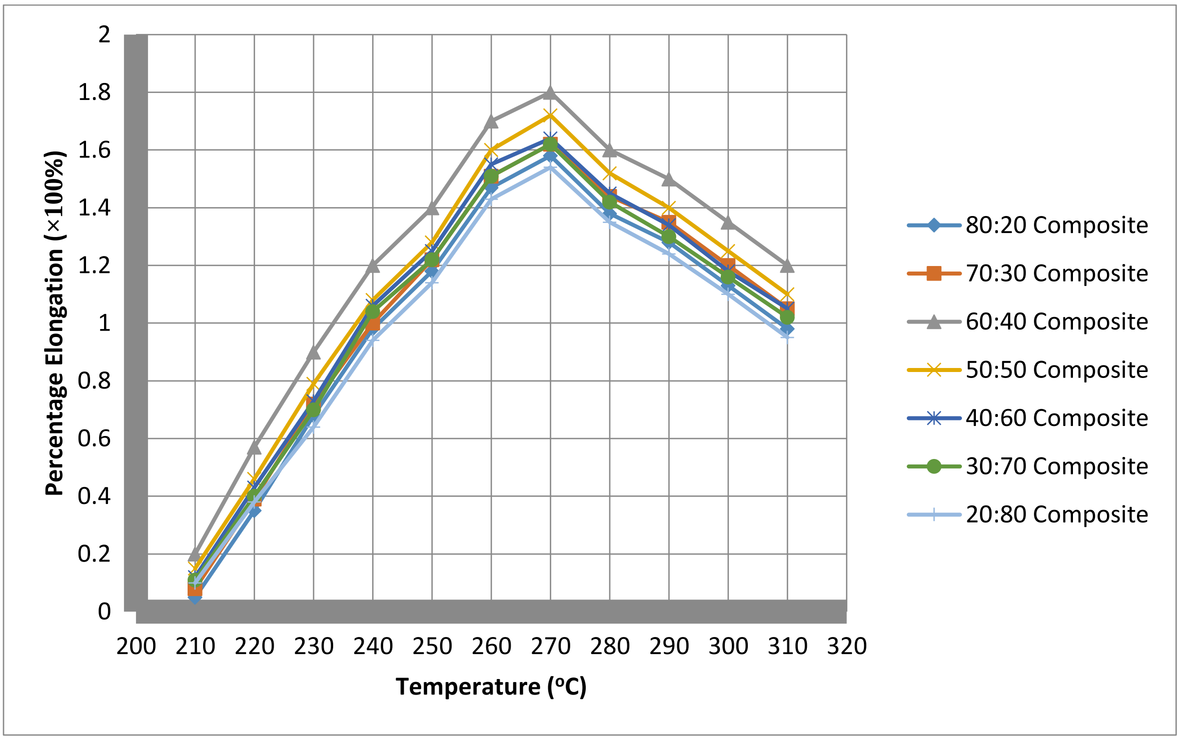

Figure 3: Effects of Barrel Temperature on Percentage Elongation for PVC-Grass Composite.

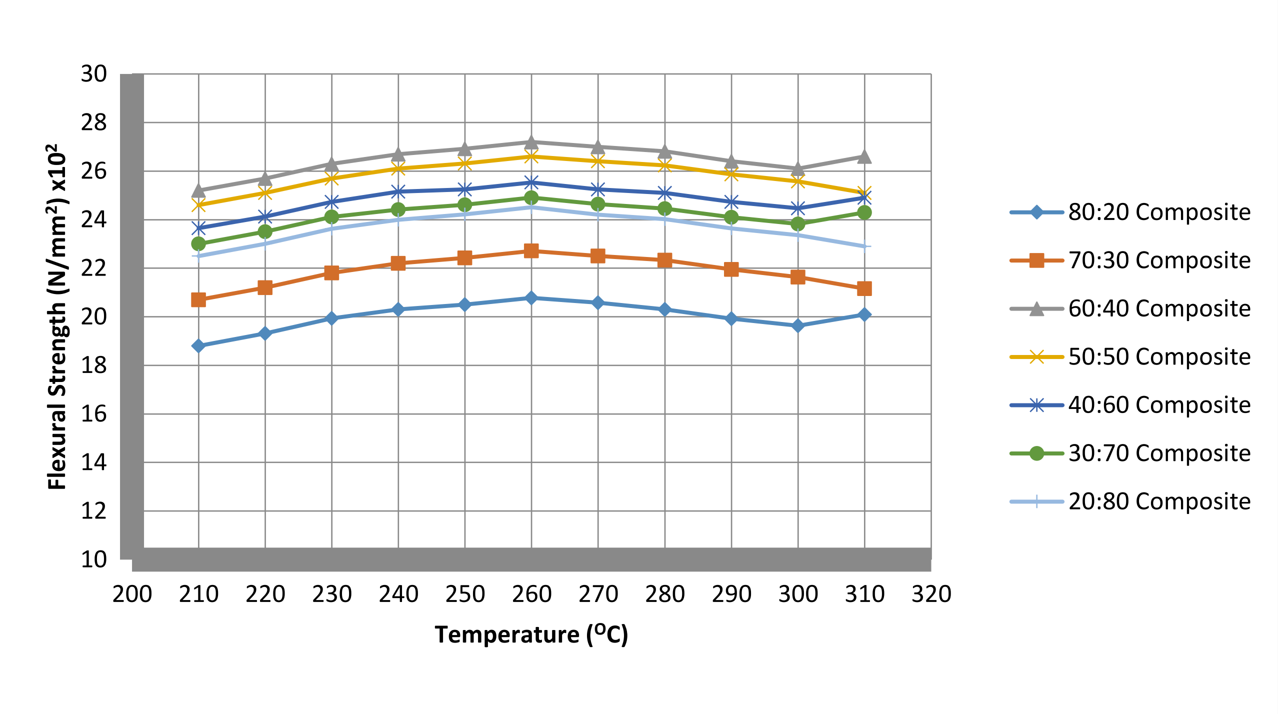

Figure 4: Effects of Barrel Temperature on Flexural Strength for PVC-Grass Composite.

3.1 Effects of Barrel Temperature on Tensile Strength

The tensile strength increased as the barrel temperature increased for each composition, while excessive increase in barrel temperature results to decrease in tensile strength (Figure 1). From the result, a maximum tensile strength of 9.85N/mm^2 was attained for PVC-grass composite at barrel temperature of 270^{o}C after which the tensile strength began to decrease to a value of 9.37N/mm^2 at barrel temperature of 280^{o}C (Figure 1). This is due to chain scissioning (molecular breakdown), reduction in molecular weight and melt viscosity, hence decrease in crystallization and orientation occurring with processing temperatures above 270^{o}C for PVC-Gass composite. The value obtained in this research was slightly higher from the result obtained by Osarenmwinda and Olodu, Njoku and Obikwelu [6, 10] which a tensile strength of 6.10N/mm^2 was obtained at barrel temperature of 270^{o}C for PVC. It may have been slightly higher due to addition of grass to PVC in the produced composite. In the work of Mosle, et al. [1] on sawdust-PET composite using the hot press compression moulding, the tensile strength was 38.32N/mm^2 at melt temperature of 210^{o}C and was found to compare favourably with this research work.

3.2 Effects of Barrel Temperature on Proof Stress

It was observed that the proof stress increased as the barrel temperature increased for each composition while excessive increase in barrel temperature results to decrease in proof stress (Figure 2). From the result, a maximum proof stress of 5.33N/mm^2 was attained for PVC-Grass composite at barrel temperature of 260^{o}C before decreasing (Figure 2). These values were found to compare favourably with value of 29.52N/mm^2 at a barrel temperature of 232^{o}C obtained by Zhou and Mallick [5] for Talc-filled polypropylene random copolymer. The value obtained in this study was slightly higher with a percentage difference of 35.5% from the result obtained by Osarenmwinda and Olodu [6] which a proof stress of 3.44N/mm^2 was obtained at barrel temperature of 240^{o}C for PVC. It may have been slightly higher due to addition of grass to PVC in the produced composite. In the work of Mosle et al. [1] on sawdust-PET composite using the hot press compression moulding, the proof stress was 34.22N/mm^2 at melt temperature of 210^{o}C and was found to compare favourably with this study.

3.3 Effects of Barrel Temperature on Percentage Elongation

It was observed that the percentage elongation increased as the barrel temperature increased until a maximum percentage elongation of 180% was attained for PVC-grass composite at barrel temperature of 270^{o}C (Figure 3) after which the percentage elongation began to decrease. The sudden fall in percentage elongation is due to molecular breakdown as thermal degradation began to set in above 270^{o}C. The value obtained in this research was slightly lower from the results obtained by Osarenmwinda and Olodu [6] which a percentage elongation of 285% was obtained at barrel temperature of 260^{o}C for PVC. It may have been slightly lower due to addition of grass to PVC in the produced composite. In the work of Mosle et al. [1] on sawdust-PET composite using the hot press compression moulding, the percentage elongation obtained was 182% at melt temperature of 210^{o}C and was found to compare favourably with this research work.

3.4 Effects of Barrel Temperature on Flexural Strength

The maximum flexural strength for PVC-grass composite was 27.6×10^{2}N/mm^2 at barrel temperature of 260^{o}C (Figure 4). This is slightly lower than the value of 32.25×10^{2}N/mm^2 obtained by Ranjusha, et al. [11] at barrel temperature of 190^{o}C for polypropylene/ high density polypropylene/clay/glass fibre composite probably due to the presence of clay and glass fibre in the polypropylene material. The value obtained in this research was slightly higher from the result obtained by Osarenmwinda and Olodu [6] which a maximum flexural strength of 19.56×10^{2}N/mm^2 was obtained at barrel temperature of 240^{o}C for PVC. It may have been slightly higher due to addition of grass to PVC in the produced composite. In the work of Mosle et al. [1] on sawdust-PET composite using the hot press compression moulding, the flexural strength was 40.22×10^{2}N/mm^2 at melt temperature of 170^{o}C and was found to compare favourably with this research work.

4. Conclusion

The results obtained shows that the maximum tensile strength, proof stress, percentage elongation and flexural strength for PVC-Grass composite were 9.85N/mm^2, 5.33N/mm^2, 180% and 27.6×10^{2}N/mm^2 at barrel temperature of 270^{o}C, 260^{o}C, 270^{o}C and 260^{o}C respectively. It is hopeful that the development of this new material of PVC-grass composite will lead to economic growth of the country and will find application both for industrial and domestic use. The results from the developed composite will also be useful to researchers, industrialists and small scale manufacturers to ease the production of plastic-grass composite in polymeric industries.

5. Acknowledgement

The authors wish to acknowledge the assistance and contributions of the Staff of Department of Production Engineering, University of Benin, Benin City toward the success of this research.

6. Conflict of Interest

There is no conflict of interest associated with this work.

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