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Application of Digital Logic Method in the Selection of Suitable Polymeric Materials for Ceiling Tiles Production

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Abstract

Polymeric materials are widely employed in the production of ceiling tiles due to their attractive qualities such as thermal insulation, low water absorption characteristics, light weight, availability, cost effectiveness and their good surface finishing. This study focused on the production, property characterization and the optimization of five different polymer composite material which are 20SE (20 wt.% of sisal reinforced epoxy), 20JH (20 wt.% jute fiber reinforced high density polyethylene), 20BP (20 wt.% bagasse fiber reinforced polypropylene), 6CP (20 wt.% coconut shell ash reinforced Polyvinyl chloride) and 20CL (20 wt.% cotton reinforced low density polyethylene). Selected properties considered are flexural and tensile strengths, thermal conductivity, water absorption and bulk density. The values obtained after characterization were evaluated using digital logic method so as to determine the composite material with the optimum property while putting their cost effectiveness into consideration. The result showed that 20BP (20 wt.% bagasse fiber reinforced polypropylene composite) had the highest performance index and figure of merit, making it the most preferred polymeric composite for ceiling tiles application.

Keywords: Ceiling tiles, polymer composites, digital logic method, property evaluation.

1. Introduction

Diverse materials are used in the production of ceiling tiles which include, wood, asbestos, polymers and ceramics (plaster of Paris). Metallic materials are not used for this application based on their thermal conductive nature and weight. Ceiling tiles are very important part of building construction due to their aesthetic values, protection for electrical wirings and plumbing pipes. One important reason why ceiling tiles are being used is that they effectively reduce the amount of total heat dissipated into the room from the heat absorbed by the roof [1]. Materials used for this application must possess good thermal insulation property, enhanced mechanical properties, light weight, resistance to corrosion, must be durable, and affordable. Traditional polymeric material being used majorly is polyvinyl chloride which has been observed to sag over time due to lower flexural strength. This observation resulted into production of reinforced polymer composites with the view of improving flexural strength and other properties. Putting in mind the need for lightweight in ceiling tiles, light reinforcements (sisal, jute fiber, bagasse, coconut shell ash and cotton) were considered in reinforcing polymeric materials [2]. A substitute material for polyvinyl chloride (PVC) ceiling tiles is considered worthwhile in order to prevent the occurrence of sagging which eventually affects the integrity of the material, while maintaining aesthetic value. Previous studies carried out on reinforcing polymers such as PVC, epoxy, high density polyethylene and polypropylene were aimed at improving their physical, mechanical and thermal properties [3-6]. PVC is a polymeric material that possess good strength and good surface finish [7]. Roman developed PVC/corncob composite; the result of the research showed an increase in the tensile strength and hardness of the composite produced with increasing corncob content while the thermal conductivity of the PVC remained unchanged [8]. Oil palm empty fruit bunch was observed to increase the density, flexural and impact strengths of unplasticized PVC composite as the weight content of fiber increased [9]. Properties such as stiffness, modulus and impact strength of high density polyethylene (HDPE), low density polyethylene (LDPE) and polypropylene (PP) can be modified with the addition of fiber reinforcements. Authors [10], reported an increase in tensile and flexural properties of jute/PP composite up to 40 wt.% fiber addition followed by a decrease, indicating that tensile and flexural properties can be enhanced up to 40 wt. % jute fiber. An increase in mechanical properties was observed at higher percentage weight fraction of palm fiber when treated and untreated palm fibers were added to recycle HDPE [11]. This improvement was due to the good interfacial adhesion between the matrix and fibers added. Epoxy is a thermosetting polymeric material that possess good tensile and flexural properties and is being utilized in various applications such as interior parts of an aircraft, automobile interior, and motorcycle headlight casing [12-14]. Oil palm pressed fruit fiber addition to epoxy resulted into improved mechanical properties of epoxy composites at 20 wt. % fiber addition [3]. This study is aimed at developing five different polymeric composites, subjecting them to tests in order to evaluate properties such as flexural strength, tensile strength, thermal conductivity, water absorption and bulk density while employing digital logic method to select most suitable composite material for ceiling tiles production.

2. Experimental Methods

2.1 Materials used and their production process

Materials used are PVC, HDPE, PP, LDPE pellets, epoxy resin, hardener, jute, sisal, bagasse, cotton fibers, coconut shell ash, sodium hydroxide (NaOH). 20SE was produced by adding 20 wt.% of sisal fiber to epoxy resin matrix and the composite was produced by hand layup technique. Hardener was mixed with epoxy resin by manual stirring for homogenous mixture followed by addition of sisal fiber (cut to 3 mm) at 26 ˚C. Produced samples were allowed to cure for 6 hours before been removed from the mould. 20JH samples were prepared by the addition of 20 wt.% jute to HDPE matrix. The fibers were treated using of 1M NaOH solution followed by cutting into 3 mm length before been incorporated into HDPE matrix. Compounding machine was used for the even distribution of the fibers in the matrix, after which the mixture was moulded using compression moulding machine at 130 ˚C, with 0.2 kPa applied pressure for 13 minutes. 20BP was prepared by adding 20 wt.% of bagasse fiber into PP matrix; bagasse fiber was treated using 5% aqueous solution of NaOH at 30˚C for 3hours. The fiber used was cut to a length of 2mm. Samples were produced by compression moulding machine operated at 138 ˚C for 10 minutes at applied pressure of 0.2KPa and the resulting composite was air-cooled. 6CP composite sample was produced by blending of 6 wt.% coconut shell ash to PVC; proper mixing was carried out to ensure even dispersion of the particulate reinforcement in the matrix. Compression was carried out at 165 ˚C with an applied pressure of 0.2KPa and maintained for 12 minutes. 20CL was formed by incorporation of 20 wt.% sisal fiber into LDPE matrix; the reinforcement was washed with detergent, rinsed in water and sundried for 7 days. Aluminum (tensile, flexural and wear) moulds were used for the composites production at 125 ˚C and a pressure of 0.2 kPa was applied for 10 minutes using compression moulding machine.

2.2 Test Method

Flexural and tensile strengths, thermal conductivity, water absorption and bulk density of samples produced were measured in line with existing standard procedures as stated in [15-19].

3. Results and discussion

The material selection process entails evaluation of required property for such application, consideration of properties of candidate materials, analysis of performance index and selection of most suitable material and determination of performance index and cost.

3.1 Material and their property values

The values for the material property of each sample designation is as presented in Table 1.

Table 1: Variation of Properties with Materials

Sample Designation	Flexural Strength (FS) MPa	Tensile Strength (TS) MPa	Thermal Conductivity (TC) W/mK	Water Absorption (WA) %	Bulk Density (BD) g/cm^3
20SE	58.90	63.40	0.42	2.78	1.15
20JH	40.27	25.49	0.40	3.75	0.91
20BP	21.75	18.95	0.20	2.47	0.87
6CP	87.40	45.10	0.25	2.97	1.27
20CL	17.70	23.20	0.27	3.21	0.83

3.2 Decision number and weighing factor

The decision was derived by comparing two properties with one another, and the preferred property between the compared properties was assigned 1, while the other property was assigned 0 as represented in Table 2. Weighing factor as shown in Table 3 was determined by dividing the decision number of each property with the sum of the decision numbers of all the properties under consideration.

Table 2: Decision number for each property

	Decision Number										Total
FS	1	0	1	0							2
TS	0				0	0	0				0
TC		1			1			1	1		4
WA			0			1		0		0	1
BD				1			1		0	1	3

Table 3: Value of decision number and weighing factor

Property	**FS**	**TS**	**TC**	**WA**	**BD**	**Total**
Decision Number	2	0	4	1	3	10
Weighing Factor	0.2	0	0.4	0.1	0.3	1.0

3.3 Scale property index (SC)

The scale property index as revealed in Table 4 was derived by allotting 1 to the property with the highest value while the other values of the same property were evaluated using Equation 1 (for properties where higher values are desired). For properties where lower values are desired, the material with lowest value is assigned 1 and the other material values are obtained using Equation (2).

$$\text{When higher value is desired SC} = \frac{VM}{HV} \quad (1)$$

$$\text{When lower value is desires SC} = \frac{LV}{VM} \quad (2)$$

Where
SC is scaled property index,
VM is the value of material,
HV is the maximum value of property on the list and
LV is the lowest value of property on the list.

Table 4: Scale Properties of the Selected Material

	FS	TS	TC	WA	BD
20SE	0.67	1	0.48	0.89	0.72
20JH	0.46	0.40	0.50	0.66	0.91
6BP	0.25	0.30	1	1	0.95
20CP	1	0.71	0.80	0.83	0.65
20CL	0.20	0.37	0.74	0.77	1

3.4 Performance index

Weight factor index (WI) as highlighted in Table 5 was derived by multiplying the weighing factor (WF) by scale properties index (SC) for each property as expressed in Equation (3), after which performance index was obtained by adding up weight index of the materials.

$$\text{WI} = WF \times \text{SC} \quad (3)$$

Table 5: Performance Index of selected materials

	FS	TS	TC	WA	BD	PERFORMANCE INDEX (PI)
20SE	0.13	0	0.19	0.09	0.22	0.63
20JH	0.09	0	0.20	0.07	0.27	0.63
20BP	0.05	0	0.4	0.10	0.29	0.84
6CP	0.20	0	0.32	0.08	0.20	0.80

20CL	0.04	0	0.30	0.08	0.30	0.72

3.5 Figure of Merit

The figure of merit for each material as revealed in Table 6 was evaluated using equation 4. The figure of merit was determined as a function of cost and density.

$$\text{FOM} = \frac{PI}{RC \times D} \qquad (4)$$

Where
FOM is the figure of merit,
RC is the relative cost and
D is the density.

Table 6: Figure of Merit and Ranking of the Selected Materials

Materials	Relative cost	Figure of merit	Ranking
20SE	7.84	0.07	5
20JH	1.22	0.57	4
20BP	1.0	0.97	1
6CP	0.94	0.67	3
20CL	1.17	0.74	2

4. Conclusions

This study was carried out on five polymer composites via digital logic method and the following observations were drawn

- Thermal conductivity had the highest weighing factor of all properties indicating that thermal conductivity is the most important parameter when considering materials for ceiling tiles production. This property was followed by bulk density while tensile strength is the least.
- 20BP (20 wt.% bagasse fiber reinforced polypropylene) had the best ranking with the highest value in both performance index and figure of merit, therefore this material is recommended for ceiling production and can serve as an alternative to conventional PVC ceiling tiles currently in use.

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Reference

[1] Etuk, S. E., Akpabio, L. E. & Akpabio, K. E. (2007). Determiniation of the Thermal Properties of Cocos Nucifera Trunk for predicting Temperature Variation with its Thickness. The Arabian Journal for Science and Engineering, 30 (A1), 121-126.

[2] Ohijeagbon I. (2012). Retrofitting Composite ceiling tiles with sawdust introduction, 1-7, 10.13140/2.1.4847.8727.
[3] Mwaikambo, L. Y., Martuscelli, E. & Avella, M. (2000). Kapok/cotton fabric–polypropylene composites, Polymer Testing, 19, 905–918.
[4] Obasi, H. C., Iheaturu, N. C., Onuoha, F. N., Chike-Onyegbula, C. O., Akanbi, M. N. & Ezeh, V. O. (2014). Influence of Alkali Treatment and Fibre Content on the Properties of Oil Palm Press Fibre Reinforced Epoxy Biocomposites, American Journal of Engineering Research (AJER), 3 (2), 117-123.
[5] Daramola, O. O., Oladele, I. O., Adewuyi, B. O., Sadiku, R. & Agwuncha, S.C. (2015). Influence of Submicron Agro Waste Silica Particles and Vinyl Acetate on Mechanical Properties of High-Density Polyethylene Matrix Composites, The West Indian Journal of Engineering, 38 (1), 96-107.
[6] Oyekunle, J. A. O., Dirisu, J. O., Okokpujie, I. P. & Asere, A. A. (2018). Determination of Heat Transfer Properties of Various PVC and Non-PVC Ceiling Materials Available in Nigerian Markets, International Journal of Mechanical Engineering and Technology, 9 (8), 963–973.
[7] Wan, Y., Wu, H., Huang, L., Zhang, J., Tan, S. & Cai, X. (2017). Preparation and characterization of corn cob/polypropylene composite reinforced by wood ash, Polymer Bulletin.
[8] Roman, K. (2018.) Measurements of PVC Composite with Corn Cob Flour Additive, International Journal of Engineering Research & Science (IJOER), 4(3), 6-10.
[9] Abu Bakar, A., Hassan, A. & Mohd Yusof, A. F. (2005). Mechanical and Thermal Properties of Oil Palm Empty Fruit Bunch-Filled Unplasticized Poly (Vinyl Chloride) Composites, Polymers & Polymer Composites,13(6), 607-617.
[10] Berhanu, T., Kumar, P. & Singh, I. (2014) Mechanical Behaviour of Jute Fibre Reinforced Polypropylene Composites, 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014,IIT Guwahati Assam, India.
[11] Aldousiri, B., Alajmi, M. & Shalwan, A. (2013). Mechanical Properties of Palm Fibre Reinforced Recycled HDPE, Advances In Material Science And Engineering, 1-7.
[12] Mazumdar, S. K. (2002), Composite Manufacturing, CRC Press.
[13] Brostow, W., Kovacevic, V., Vrsaljko, D. & Whitworth, J. (2010), Tribology of Polymers and Polymer-Based Composites, Journal of Materials Education, 32 (5-6), 273 - 290.
[14] Toldy, A., Szolnoki, B. & Marosi, G. (2011). Flame Retardancy of fibre-Reinforced Epoxy Resin Composites for Aerospace Application. Polymer Degradation and Stability, 96, 371-376.
[15] American Standard of Testing and Materials, (2017). D 790. Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and electrical Insulating Materials. ASTM International. West Conshohocken, PA.
[16] American Standard of Testing and Materials, (2014). D 638. Standard Test Method for Tensile Properties of Plastics. ASTM International. West Conshohocken, PA.
[17] American Standard of Testing and Materials, (2019). C177. Standard Test Method for Measuring Thermal Conductivity of a Material by Means of Guarded Hot Plate. ASTM International. West Conshohocken, PA.

[18] American Standard of Testing and Materials, (2018). D 570-98. Standard Test Method for Water Absorption of Plastics. ASTM International. West Conshohocken, PA
[19] American Standard of Testing and Materials, (2017). D 1895. Standard Test Method for Apparent Porosity, Bulk Factor, Pourability of Plastic Materials. ASTM International. West Conshohocken, PA.