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## Short Communication

## Development and application of nanocomposite for sustainable rail vehicle with low environmental footprint



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## ABSTRACT

In many developing countries, society is characterized by increasing population growth, urbanization, and industrialization, which have an effect on the environment. The growing population demands improved and safe ways of transporting people, goods, and services from one point to another at a minimal impact on the environment. The high demand for energy is another concern for any developing nation, most especially for a country where rail cars are powered by electricity. The weight of the rail cars contributes to the total carbon dioxide (CO<sub>2</sub>) emission. In order to reduce the energy demand, CO<sub>2</sub> emission and increase return on investment, there is a need for improved composite materials. The current research focused on the production of composites made from polypropylene, sisal fiber and nanoparticle. The fiber was treated and the content was varied from 10, 20, 30 and 40 wt%, while the clay and the compatibilizer were kept constant at 3 and 5 wt% respectively. There was an improvement in the mechanical and thermal properties of the composites. Based on the improvement observed, the material can be used for the interior component of the rail vehicle.

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## 1. Introduction

Rail and road infrastructure development are a vital indicator of economic growth and critical asset of any nation, which can be influenced by the increasing population growth, urbanization, and industrialization [1]. Hence, the increase in the numbers of road and rail users has a direct impact on the infrastructural need. The weights of the rail cars have a direct correlation to wear rate of the rail tracks, the amount of energy required for traction and the level of vibration/noise level. The increasing demand for alternative means of movement for the South African rail

transport system and geographical regions of the world will require a lightweight material. Fig. 1 shows the discovery, development and various improvement that have been made with dates for both passenger and cargo rail cars. Among the recent development made include the use of lightweight materials. The adoption of lightweight materials could lead to many advantages including but not limited to minimal rail track maintenance, reduction in production cost, energy saving, weight reduction and maintenance of the rail cars. High-performance polymeric materials are widely used in the automotive, aerospace, packaging, construction and electronics industries for various applications due to the properties they possess.

Another important area where these composite materials are finding useful application is the rail systems. There has been a gradual increase and the trend is envisaged to continue. The main reason of choosing high-performance lightweight materials in relation to the existing materials used for the rail cars, which is

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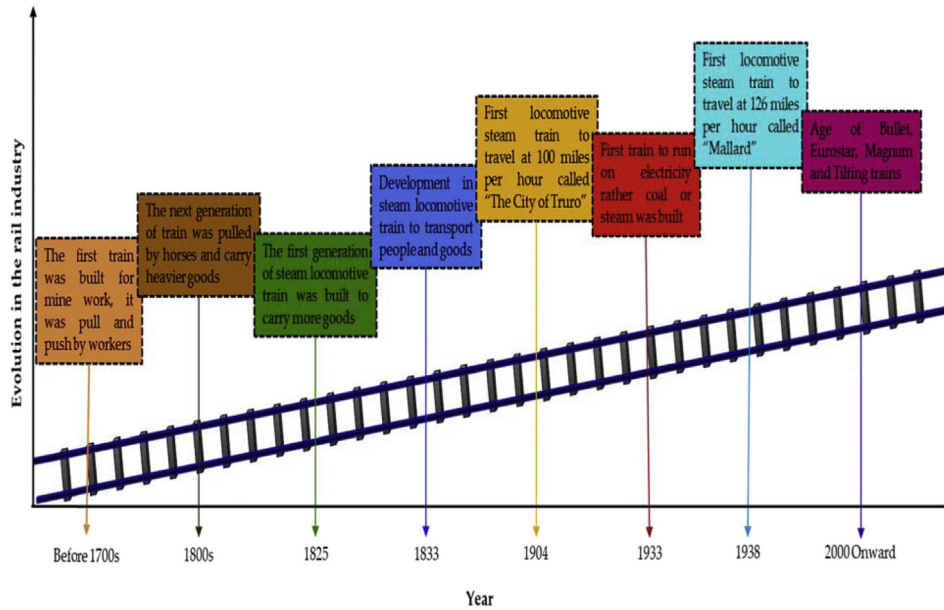


Fig. 1. Discovery, development and various improvements made with dates for both passenger and cargo rail cars.

equally applicable to the automobiles, is the ease in processing method, functionality, economic value and reduction in fuel or energy consumption. About 10% reduction in vehicle weight is estimated to result in a 5–7% reduction in energy usage [2,3]. Fig. 2 shows the areas of application of polymer composites for the interior components of passenger trains.

2. Materials and method

2.1. Materials

The extracted sisal fibers were supplied courtesy of Dr Maya John from CSIR, Port Elizabeth, South Africa. Dr Gomotsegang F.

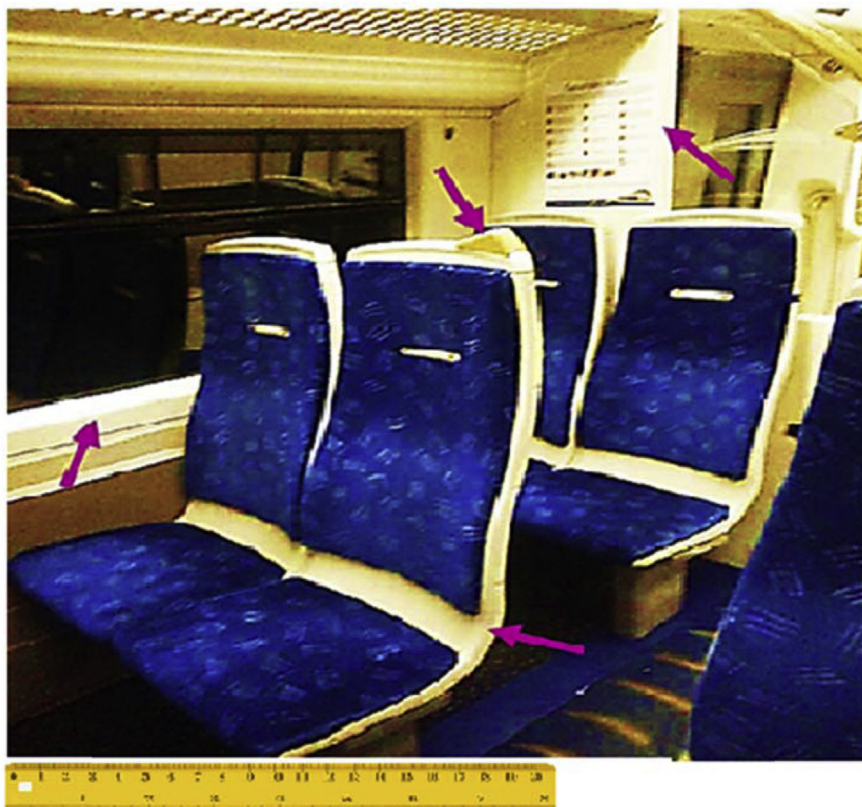


Fig. 2. Interior application of polymer composites in passenger trains as indicated by the arrows.

Molelekwa supplied the recycled polypropylene made by Transpaco Polymer Recycling. Southern Clay Products Inc., USA supplied the organically modified montmorillonites, Cloisite®30B. Maleic anhydride grafted polypropylene (MAPP, Eastman™ G-3003 Polymer) was supplied by Eastman Chemical Company 200 S. Wilcox DR. Kingsport, TN37660, United State.

## 2.2. Method

The fibers were soaked in 5% sodium hydroxide (NaOH) solution for 2 h in a vacuum oven at a constant temperature of 70 °C. The fiber was rinsed with distilled water, followed by 1% acetic acid solution and finally rinsed with distilled water. Furthermore, it was air-dried (by placing it on a polyethylene plastic surface after the water was drained completely) and lastly, oven-dried at 60 °C for 24 h. Gunti et al. [4] adopted similar treatment method, where they treated jute, sisal, and elephant grass fibers. Further details about the pre-treatment of the materials (polypropylene, nanoparticle, and MAPP) and the fiber contents were varied from 0, 10, 20, 30 and 40 wt%. Going beyond 40 wt% will lead to higher fiber-to-fiber interaction, which will weaken the composite, therefore, affect the properties [5]. The clay content and MAPP were maintained at 3 and 5 wt% respectively. The samples were premixed in HAAKE PolyLab OS Rheomixer (Thermo Electron Co., USA) and later compression molded with Carver Laboratory Press (Model –3851-0, USA) at a temperature of 200 °C and pressure of 1500 psi for 8 min.

## 3. Characterization of prepared samples

The produced samples were characterized in the following subsections according to the respective standards associated with each individual method.

### 3.1. Tensile strength and tensile modulus

Test samples were prepared by compression molding after blending in a HAAKE PolyLab OS Rheomixer (Thermo Electron Co., USA). The tensile strength and tensile modulus were determined using an Instron 5966 tester (Instron Engineering Corporation, USA) in accordance with ASTM D638. These tests were performed at room temperature, in tension mode with a single strain rate of 5 mm/min. Fig. 3a shows the dog-bone test samples for tensile strength and tensile modulus.

### 3.2. Impact strength

An Impactometer (Ceast, Italy) as per ISO 179 was used to determine the toughness of the produced material [6]. Notched samples with a depth of 2.5 mm and a notch angle of 45° were used to evaluate the impact strength of the samples. The results represented are an average of five test samples. Fig. 3b shows the test samples for impact strength.

### 3.3. Thermal stability

The thermal stability of the samples was investigated using a thermogravimetric analyzer (Model Q500, TA Instruments, USA). Approximately 5 mg weight of the sample was used for each test. The TGA was operated in air and the heating rate was set to 10 °C/min, from 20 to 700 °C.

## 4. Results and discussion

### 4.1. Tensile strength (TS) and tensile modulus(TM)

Fig. 4 presents the tensile strength and modulus of sisal fiber reinforced polypropylene nanocomposites. A common trend is observed with the fiber content having a direct relationship with the tensile strength and modulus because as the fiber content increased, there was significant increase the TS and TM. Similar observation was reported for TS and TM by Zhao et al. [7] and Haque et al. [8] respectively. The incorporation of MAPP and clay nanoparticle contributed to the improvement in the tensile strength and modulus of the nanocomposites. The improvement is a result of good interfacial adhesion that exists between the contributing components (fibers, nanoclay, compatibilizer and the matrix) that made up the composites. This result confirms the observation made by Ibrahim et al. [9], where bamboo fiber was used instead of sisal fiber. The MAPP created an enhanced interfacial adhesion between the fiber and the polymer matrix, leading to a better interaction among the various components.

### 4.2. Impact strength

The impact strength of fiber/polypropylene nanocomposites at various fiber contents and fixed MAPP and clay content are shown in Table 1. From the table, it was observed that as the fiber content increased, there was an increase in the impact resistance of the

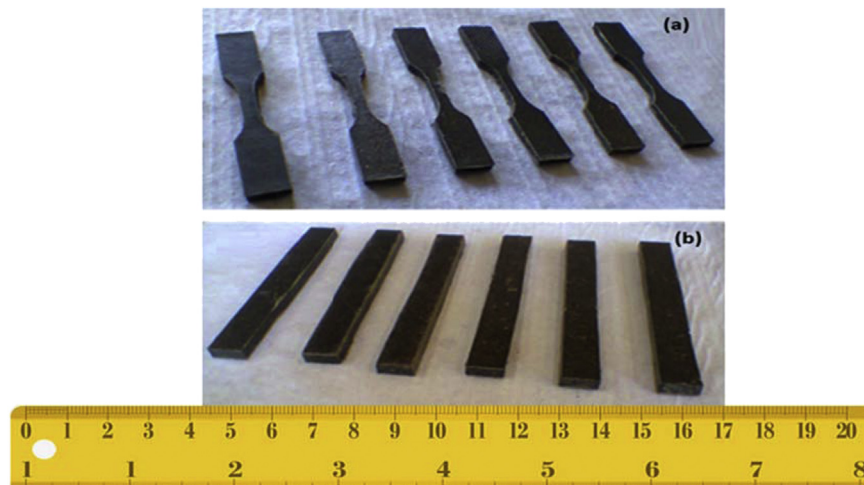


Fig. 3. Test samples for (a) tensile strength and tensile modulus and (b) impact strength.



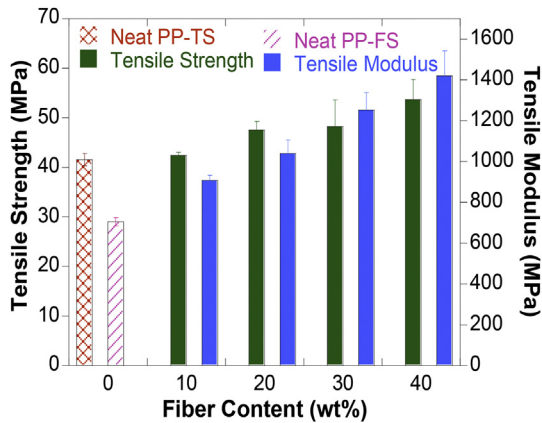


Fig. 4. Tensile strength and tensile modulus of fiber reinforced nanocomposites.

**Table 1**  
Impact strength of fiber-reinforced nanocomposites.

Fiber Content (wt%)	Impact Strength (kJ/m <sup>2</sup> )	Standard Deviation
0	2.42	0.36
10 <sup>a</sup>	2.76	0.23
20 <sup>a</sup>	5.49	1.00
30 <sup>a</sup>	5.61	0.64
40 <sup>a</sup>	8.51	0.68

<sup>a</sup> Composites contained polypropylene, MAPP, clay nanoparticle and fiber.

composites [10]. Another observable fact from this research is that all reinforced samples displayed better impact strength than the unreinforced sample. This could be attributed to good stress transfer from the matrix to the reinforcement [11] and the prevention of void formation in the composite by the clay

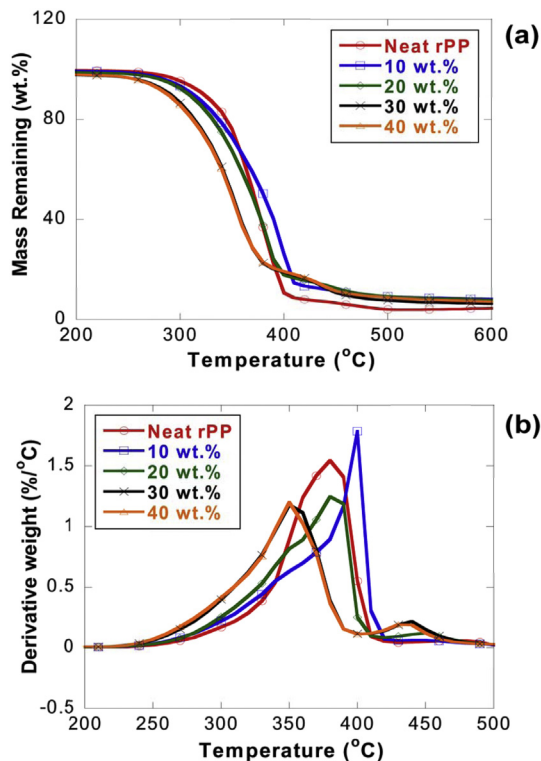


Fig. 5. TGA (a) weight loss and (b) derivative weight loss of nanocomposites with various fiber contents.

nanoparticle. Similar observation was made by Munde et al. [12], where they reported that increasing fiber content and coupling agent led to increase in impact strength. It was equally reported by Mohanty et al. [13] that impact strength of sisal fiber reinforced PP and 1% MAPP addition respectively were ~123% and ~195% more than neat PP of 23.25 Jm<sup>-1</sup> at 21% fiber ratio.

#### 4.3. Thermal property

The thermal stability of the composite materials was studied by thermogravimetric analysis as shown in Fig. 5. The developed nanocomposites performed well even at an elevated temperature of 250 °C. The increase in fiber content above 20 wt% was observed to cause a decrease in thermal stability as shown in Fig. 5b. The reason for the decrease is due to degradation because most natural fibers start to degrade at a temperature above 200 °C [14]. Hart and Summerscales [15] reported a similar observation. All composites with fibers at a temperature of approximately 350 °C produced more char residual than the unreinforced composite. The clay content, fiber treatment and incorporation of compatibilizer contributed to the improvement that was observed.

## 5. Conclusions

The current study highlighted various materials that have been used for the exterior part of the rail cars and the effect they have on the environment (CO<sub>2</sub> emission). These materials include mild steel, stainless steel, and wood. The increasing demand due to population growth, urbanization, and industrialization in the rail transport system require alternative materials that are lightweight, environmentally friendly and cost-effective. In the current study, new materials made from polymer, fibers, and nanoparticles are being considered. Based on the tensile strength, tensile modulus, impact strength and the thermal properties, the nanocomposites developed could be utilized for the interior components of the rail cars. Utilization of such materials will lead to lower energy consumption, increase speed due to lightweight, reduction in CO<sub>2</sub> emission and cost-saving.

## Conflicts of interest

The authors declare that there is no conflicts of interest.

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