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Flammability and Burning Behaviour of Low-Density Polyethene/Natural Rubber-Filled Coir Fibre Composites

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Abstract: *Coir is becoming more popular as a filler/reinforcement in the production of bio-composites, due to its inherent property of high lignin content coupled with non-toxicity, availability and low cost. The work aimed to study the flammability of coir fibre-filled non-vulcanized and dynamically vulcanized thermoplastic natural rubber composites. Two sets of composites, the non-vulcanized and corresponding vulcanizates were compounded using two rolls mill by melt blending of low-density polyethene/natural rubber at 90/10 ratio, respectively, filled with (0-50) per cent untreated coir fibre, and also fabricated using compression moulding techniques. The flame resistivity of the composites produced was studied using the UL-94 horizontal burning test. The ignition time and the extent of burning were found to decrease with an increase in fibre loading by up to 40%. Dynamic vulcanization was also found to improve the general stability of the composites when exposed to flames.*

Key words: Coir fibre, composites, flammability, dynamic vulcanization, thermoplastic natural rubber

INTRODUCTION

In recent years scientists and engineers have paid special attention to the way forward for the replacement of synthetic fibres such as glass and renowned carbon fibres with plant natural fibres (PNF) in the production of polymer-reinforced composites (Mahir *et al.*, 2019). Natural fibres are known to be biodegradable, cheap, have good thermal insulation and are generally eco-friendliness. Coir fibre is one of the most important PNF with the inherent properties of low density, resistance to wear, high hardness, non-toxic, resistance to fungi, and not easily flammable (Thomason and Rudeiros-Fernandez, 2018). Coir fibres are more resilient to moisture, heat, and seawater as compared to other PNF. Coir fibre from the husk of coconut fruit that grows extensively in coastal areas is normally extracted using suitable methods of extractions such as water retting, enzymes and chemical and mechanical methods. Generally, coir is economically utilized as furnishing constituents, and in the production of other domestic products such as mats, mattresses, brushes, carpets, and insulation panels. Coir fibre is lignocellulose in nature with high content of lignin up to 46 % which made it strong heat resistant. Many authors have reported on the effect of coir fibres as reinforcement on the different properties of polymer composites (Jayavani *et al.,* 2016).

The most common matrices used in the production of composites are either thermoplastics or thermo-sets. A thermoplastic elastomer is another set of materials normally developed by melt blending of rubber (elastomer) and thermoplastic (Homkhiew *et al.,* 2018), having a wide range property of elastomer such as elasticity at ambient and service/processing temperature coupled with the ability to be remoulded, recycled and reprocessed using conventional types of machinery for processing thermoplastics (Sampath *et al.*, 2016). Natural plant fibres are sometimes added to thermoplastic natural rubber to form composites with a general improvement in stiffness and other properties (Charles *et al.,* 2021). However, one of the major disadvantages of composites filled with cellulosic fillers is the less resistance to fire.

In this research, low-density polyethene and natural rubber composites were produced using melt blending at a percentage ratio of 90/10 filled with coir fibre at different loadings up to 50%. The corresponding vulcanizates were also produced using the same compositions via dynamic vulcanization. The incorporation of coir fibre, a material of high lignin content with the characteristics of char formation, would improve the flammability exhibited by most composites with high content of cellulose.

MATERIALS AND METHODS

Materials

Coir fibre (CF): The coir fibre was obtained as waste and extracted using the water retting method. The process involved the impregnation of coir husks and allowed them to remain in the water for fifteen days followed by mechanical extraction using a wooden mallet, followed by washing and drying. Natural rubber (NR) was obtained from the National Rubber Institute, Benin. Low-density polyethene (LDPE) is obtained as commercial grade.

Equipment

Two rolls mill, Model: 5183 North Bergen U.S. A. A Compression Moulding Machine, Model: 0557 and Digital analytical weighing balance.

Methods

Fabrication of LDPE/NR/CF Composites

The composites were compounded using two rolls mill and compression moulding technique. The blend of LDPE/NR at 90 and 10 percentage ratios ($P_{90}R_{10}$) was used as the matrix for the production of composites loaded with 0-50% coir fibre. Similarly, another set (dynamically vulcanized composites) was produced by incorporating vulcanizing agents in situ, to arrive at the corresponding vulcanizates. The formulations used for the production of both non-vulcanized and dynamically vulcanized composites are shown in Table 1. Eventually, the composites produced were subjected to a flammability (UL-94 horizontal) test for the determination of ignition time and extent of burning.

Table 1: Formulation for LDPE/NR blend and their vulcanizates

S/N	Sample code	LDPE (%)	Natural Rubber (%)	Coir fibre (%)	Vulcanizing agents (Phr)				
					ZnO	MBTS	Stearic Acid	TMQ	Sulphur
1.	$P_{90}R_{10}$	90	10	0	-	-	-	-	-
2.	$P_{90}R_{10}C_{10}$	90	10	10	-	-	-	-	-
3.	$P_{90}R_{10}C_{20}$	90	10	20	-	-	-	-	-
4.	$P_{90}R_{10}C_{30}$	90	10	30	-	-	-	-	-
5.	$P_{90}R_{10}C_{40}$	90	10	40	-	-	-	-	-
6.	$P_{90}R_{10}C_{50}$	90	10	50	-	-	-	-	-
7.	$VP_{90}R_{10}$	90	10	0	5	2	2.5	1.5	2.5
8.	$VP_{90}R_{10}C_{10}$	90	10	10	5	2	2.5	1.5	2.5
9.	$VP_{90}R_{10}C_{20}$	90	10	20	5	2	2.5	1.5	2.5
10.	$VP_{90}R_{10}C_{30}$	90	10	30	5	2	2.5	1.5	2.5
11.	$VP_{90}R_{10}C_{40}$	90	10	40	5	2	2.5	1.5	2.5
12.	$VP_{90}R_{10}C_{50}$	90	10	50	5	2	2.5	1.5	2.5

(Baba, 2022)

Fabrication of Dynamically Vulcanized LDPE/NR/CF (10 - 50%)

Similarly, LDPE/NR loaded with CF (10 - 50%) were dynamically vulcanized in situ, to obtain a corresponding set of vulcanized LDPE/NR composites loaded with 0 – 50 per cent coir fibre, as shown in Table 1.

Flammability of the composites

Flammability (burning test) on the composites was carried out to study the ignition time (s) and extent of burning (mm) of the non-vulcanized and dynamically vulcanized LDPE/NR coir fibre-filled composites following ASTM D 635-76.

RESULTS AND DISCUSSION

Ignition time

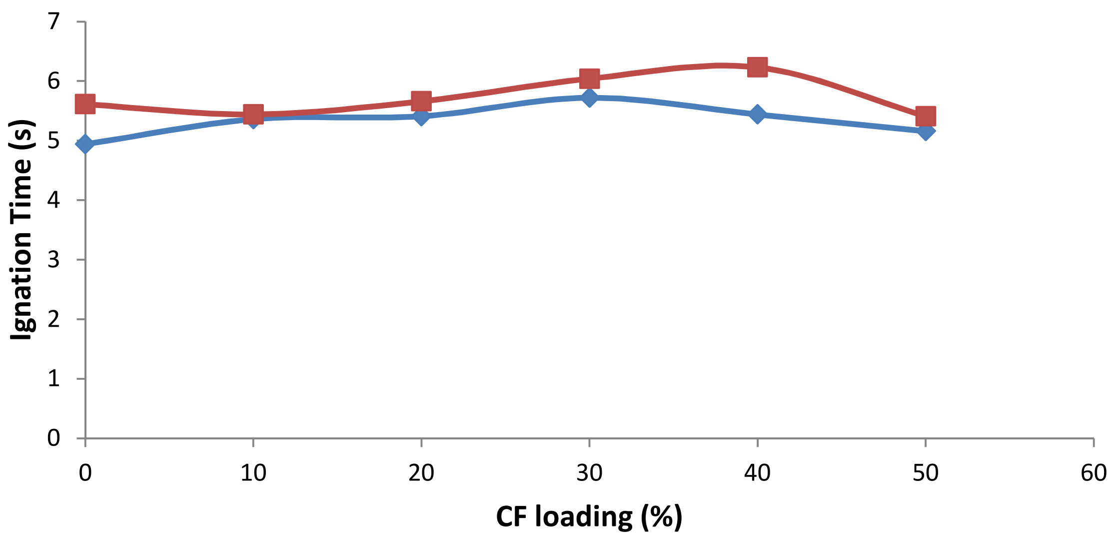

Figure 1: Effect of fibre loading and dynamic vulcanization on time of ignition of LDPE/NR filled coir fibre composites

Figure 1 showed the time taken for the non-vulcanized and dynamically vulcanized LDPE/NR-filled coir fibre to be ignited. The non-vulcanized composites loaded with 10%, 20%, 30%, 40% and 50% have recorded ignition times of 5.36s, 5.41s, 5.72s, 5.44s and 5.16 respectively. While the vulcanized samples with similar fibre loadings recorded 5.44s, 5.66s, 6.04s, 6.23s and 5.41s, respectively. The general increase in the time of ignition with CF loading could be due to high lignin and high moisture contents associated with coir fibre which could lead to a lowering of the rate of pyrolysis (Siva, 2019). It was generally indicated that non-vulcanized composites ignited faster as compared to their corresponding vulcanizates. Dynamic vulcanization made the composites to be more compacted and stable due to a high cross-linkage formed with sulphur.

Extent of burning

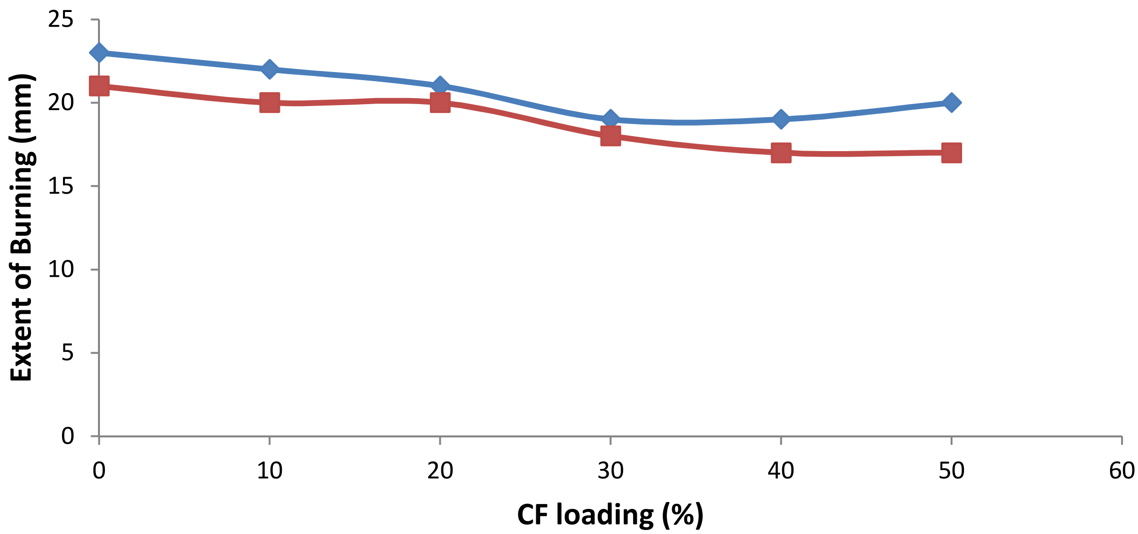

Figure 2: Effect of fibre loading and dynamic vulcanization on the extent of burning of LDPE/NR filled coir fibre composites

Figure 2 shows the effect of fibre loading and dynamic vulcanization on the extent of the burning of the coir fibre-filled LDPE/NR composites and the vulcanizates. From the result obtained the composites with higher CF content experienced a low extent of burning, this could be attributed to the high content of lignin (41-45%) from the untreated fibre embedded in the thermoplastic natural rubber matrix, as lignin immensely contributes to char formation than cellulose or hemicelluloses, thus resulted into lower flammability. Besides, the orientation of fibres and also fibre and matrix interaction contribute to the flammability of the composites.

In the presence of a flame, the burning of composites takes place in form of heating, decomposition, ignition, combustion and propagation in sequential order. In the burning of lignocelluloses, there are two forms of products that are obtained; these include high cellulose content and high lignin content. High cellulose provides the chance of higher flammability while the higher value of lignin showed a greater chance of char formation.

Behaviour of burning

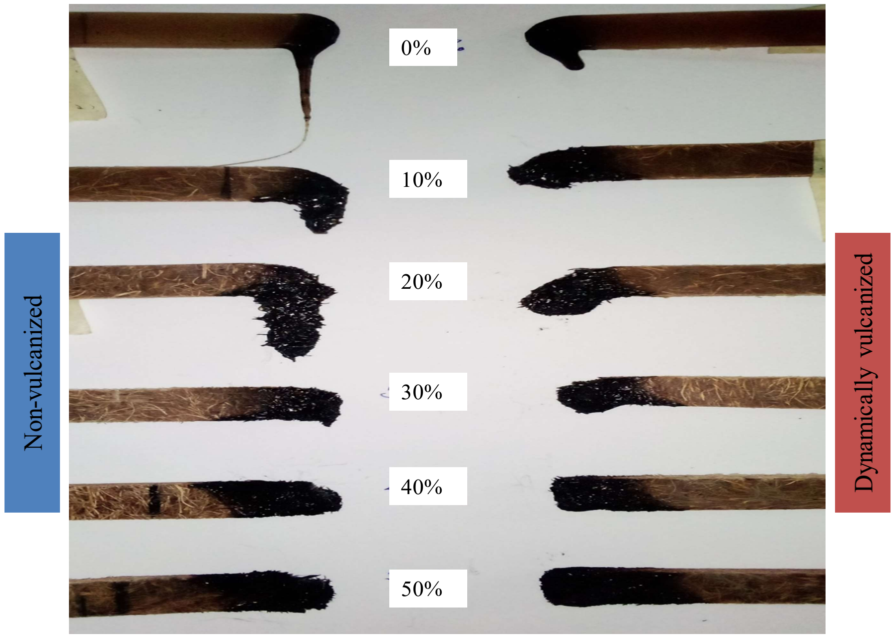

Figure 3: Burning behaviour of non-vulcanized and dynamically vulcanized LDPE/NR CF filled composites (0-50)%

Figure 3 shows the behaviour and nature of burning of the non-vulcanized LDPE/NR and dynamically vulcanized LDPE/NR composites filled with coir fibre. The unfilled non-vulcanized LDPE/NR blend and the corresponding vulcanizates burnt with flame and high dripping, although the non-vulcanized blend exhibited higher drips. The burning behaviour of LDPE/NR with drippings was reduced with the incorporation of coir fibres up to 30%. At 40% and 50% filled CF composite a char was formed with traces of white ashes, which could be attributed to the higher content of lignin with increasing coir fibre loading that supported char formation.

The general flammability characteristics were decreased with dynamic vulcanization, which was attributed to the cross-linkages that occurred during melt blending with sulphur that led to higher fibre orientation and better interaction with the matrix. Furthermore, zinc oxide as one of the additives/auxiliaries that was added during the vulcanizing process also contributed and supported the formation of char when exposed the material to a naked flame. It was reported that metal oxides, metal sulphites and metal phosphates acted as char-forming agents, and the most promising transitional metal used as flame retardant is zinc. Wu *et al.,* 2010 have shown that the addition of zinc oxide in PP composites contributed to a decrease in HRR, Total Heat Released and Smoke Production Rate of the polymer under the flammability test.

CONCLUSION

The dynamically vulcanized LDPE/NR blend burnt with less dripping as compared with the corresponding non-vulcanizates. Similarly, composites with higher CF content experienced a low time of ignition and extent of burning with char formation; which could be attributed to the high lignin content of CF.

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