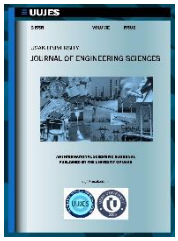

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Research article

EFFECTS OF ALUMINIUM DROSS AND IRON FILINGS PARTICULATES ON THE MECHANICAL PROPERTIES OF HYBRID THERMOPLASTIC (NYLON) MATRIX COMPOSITES

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Abstract

Utilisation of waste as filler in the production of polymer matrix composites for properties enhancement and solving the menace of environmental pollution has been explored in this study. 5 – 25 wt. % of 300 g of ground aluminium dross and iron filings with an average particles size of 50 µm were used to reinforce thermoplastic (nylon) matrix by casting at room temperature (27°C). Microstructural, water absorption, tensile strength, modulus of elasticity, hardness and impact energy tests were carried out on the developed samples. The microstructure of the samples revealed a uniform distribution of the reinforcements within the thermoplastic matrix with different morphology of the phases in the composites. The results showed that the hybrid composite exhibited the lowest water absorption of 0.23 %. It also exhibited the highest tensile strength, modulus of elasticity and Brinell hardness number (BHN) of 8.92 MPa, 17.84 MPa and 12.84 BHN respectively at 15 wt. % filler addition. The strong adhesion/bonding between the reinforcing particulates and the thermoplastic (nylon) matrix contributed to the reduction in the water absorption and enhancement of the tensile strength, modulus of elasticity and hardness of the composites. The decrease in the mechanical properties of the composites could be due to poor dispersion of the particulates in the matrix resulting to weak bonding/adhesion between the particulates and matrix. The results indicated that the hybrid composite has potential for applications in areas where low strength is required and its development will go a long way in reducing/mitigating environmental pollution.

Keywords: *Polymer composites; thermoplastic (nylon) matrix; aluminium dross; iron filings; mechanical properties.*

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1. Introduction

Polymers are compounds of long-chain molecules with each molecule consisting of repeating units connected together. There may be thousands of units in a single polymer molecule. Most polymers are carbon based and are therefore classified as organic materials. Polymers are synthesized by joining many small molecules together into very large molecules called macromolecules having a chain-like structure.

Polymers are noted for their versatility, high resistance to chemicals, outstanding adhesion to a variety of substrates, toughness, high electrical resistance, durability at high and low temperatures, low shrinkage upon curing, flexibility, and the ease with which they can be poured or cast without forming bubbles [1]. Among the polymers, thermoplastics (polyethylene, nylon, polyvinylchloride, polypropylene and polystyrene) are the most widely used. The use of thermoplastics for domestic and industrial applications is increasing rapidly due to their low cost and ease of manufacture. The increasing utilisation of thermoplastics in many forms has led to a large amount of plastic waste being generated and the accumulation creates a big challenge. Despite the suitability of thermoplastics for a wide varieties of applications, societies are faced with the growing problem of finding alternative methods of disposal of large volumes of these waste.

Disposal of plastic waste in environment is considered to be a big problem due to its very low biodegradability and presence in large quantities [2, 3]. Another challenge is the fact that polymers generally do not possess high impact energy and other mechanical properties thereby limiting their application in some areas. In particular, their strength and stiffness (modulus of elasticity) are low compared to metals and ceramics. In order to overcome these shortcomings, polymer matrix composites (PMCs) have been developed using different kinds of reinforcements. The reinforcement of polymers with particulates plays an important role in improving the mechanical properties of polymer matrix composites [4, 5].

The use of particles as reinforcement is being encouraged because they are economical, effective, and are good for modifying the properties of polymers. Many researches have been carried out using particulates to reinforce polymers with improved properties. It has been proven that the addition of wood dust to recycled polyethylene terephthalate (PET) enhanced the mechanical properties of the PET polymer matrix composites [6]. It has also been established that reinforcement of recycled high density polyethylene (HDPE) and PET polymer matrix by rice husk (RH) particles led to an improvement in the mechanical properties of the composites [7]. The addition of cow bone particles to recycled low density polyethylene (LDPE) also enhanced the mechanical properties of LDPE polymer matrix composites [8].

The conversion of polymeric (thermoplastic) waste into a useful engineering material for industrial application is a welcome development. This will lead to economic benefits and will also mitigate/reduce environmental pollution caused by the improper disposal and open burning of these waste as it is being done in many under developed and developing countries. Hence, this study aims to develop hybrid polymer matrix composites for engineering applications using non-biodegradable thermoplastic waste (nylons) and particulates of iron fillings and aluminium dross.

2. Materials and methods

2.1. Materials and preparation

The thermoplastic waste nylons were obtained from the campus of the University of Lagos. They were washed in a detergent solution, rinsed in water, sun dried for three hours, shredded into pieces and ground using a pulverizer. The iron filings were the waste obtained during turning operation on 12 mm diameter mild steel rods using lathe machines in the engineering workshop of the University of Lagos while the aluminium dross was obtained from Tower Aluminium Nigeria Limited, Ota, Ogun State, Nigeria. The chemical composition of the mild steel sample was determined using metals analyser (model, ARL 3460, Ecuben, Switzerland). The iron filings and aluminium dross were separately ground using the pulverizer and manually sieved to 50 μm with the aid of a British standard sieve (BSS). The details of these materials and the wooden mould used for the production of the composite samples are shown in Tables 1, 2 and Fig. 1

Table 1 Composition of mild steel sample

Element	Fe	Mn	C	Ni	Si	Cr	S	P
Wt. %	98.836	0.616	0.226	0.104	0.102	0.04	0.024	0.021

Table 1 Composition of mild steel sample(continued)

Element	Cu	Mo	Pb	Zn	Vn
Wt. %	0.015	0.004	0.003	0.002	0.002

Table 2 Composition of aluminium dross particulate

Element	Al_2O_3	Al	SiO_2	CaO	Na_2O	MgO	Fe_2O_3	SO_3	K_2O
Wt. %	63.85	28.76	7.14	0.08	0.06	0.04	0.03	0.03	0.01

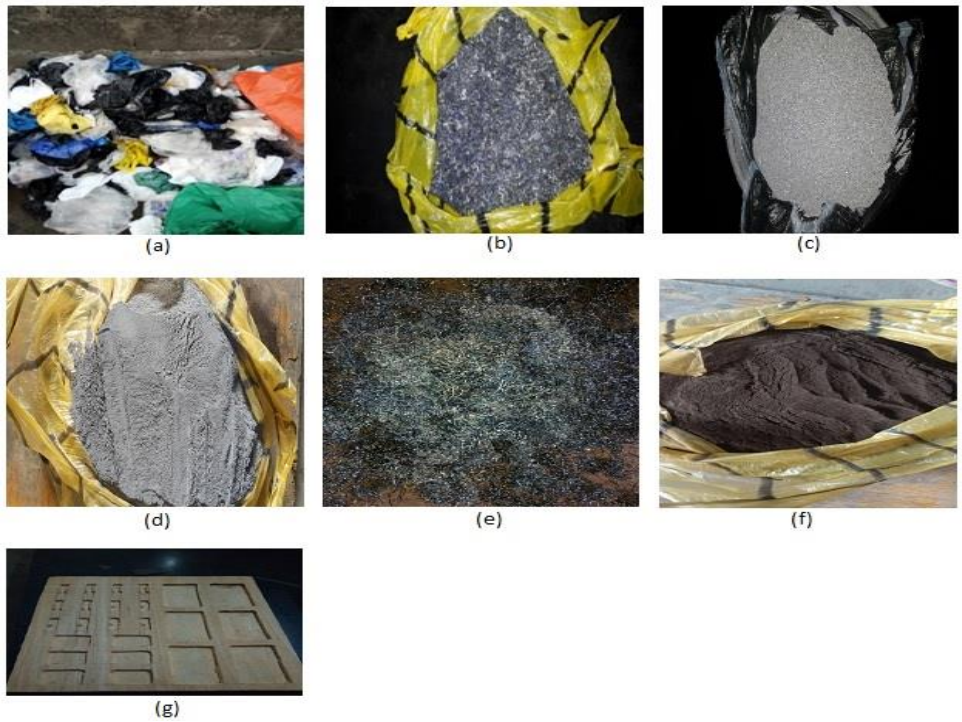

Fig. 1 Details of the materials (a) thermoplastic waste nylons (b) ground thermoplastic waste nylons (c) as-received aluminium dross (d) 50 µm aluminium dross particulates (e) as-received iron filings (f) 50 µm iron filings particulates (g) wooden mould

2.2. Production of the samples

300 g of the ground thermoplastic waste nylons were placed in 5 crucibles and heated in a muffle furnace to 115°C to attain molten form. Measured proportions (5 – 25 wt. %) of aluminium dross particulates were added to the molten polymer matrix and stirred thoroughly for 10 mins using a long stainless steel tong to avoid clustering and to achieve faster distribution of the particles in the matrix. The composite slurry was steadily poured into the wooden mould to which an aluminium foil had been placed to avoid sticking. The composite samples were allowed to reach a semi-solid stage by cooling after which they were pressed at 0.33 MPa for 5 mins using a presser and finally removed from the mould. This was recorded as 1st batch. The same procedure was used for samples reinforced with iron fillings and recorded as 2nd batch. The 3rd batch were the hybrid samples which were thermoplastic waste nylons reinforced with equal mixture of aluminium dross and iron fillings particulates. The 4th batch (control samples) were the unreinforced molten thermoplastic waste nylons which were cooled to semi-solid form, pressed and removed from the mould. The materials formulation is presented in Table 3.

Table 3 Materials formulation

Matrix (wt. %)	Reinforcement (wt. %)			
Nylon	**50 µm ADP**	**50 µm IFP**	**50 µm hybrid (ADP + IFP)**	**Total (wt. %)**
100 (control)	-	-	-	100
		1st Batch		
95	5	-	-	100
90	10	-	-	100
85	15	-	-	100
80	20	-	-	100
75	25	-	-	100
		2nd Batch		
95	-	5	-	100
90	-	10	-	100
85	-	15	-	100
80	-	20	-	100
75	-	25	-	100
		3rd Batch		
95	-	-	2.5 ADP + 2.5 IFP	100
90	-	-	5 ADP+ 5 IFP	100
85	-	-	7.5 ADP + 7.5 IFP	100
80	-	-	10 ADP + 10 IFP	100
75	-	-	12.5 ADP + 12.5 IFP	100

ADP = Aluminium Dross Particulates
IFP = Iron Filings Particulates

2.3. Physical and mechanical properties determination

The samples were excavated according to ASTM E407-99 by using Keller's reagent (95 ml water, 2.5 ml HNO_3, 1.5 ml HCl, 1.0 ml HF) by swabbing manually for 15 secs at room temperature. Thereafter, a scanning electron microscope (SEM) JOEL JSM – 6480LV was used to examine their microstructure. For the determination of the water absorption (W_A), initially weighed (W_1) dried samples were placed in a beaker with water and reweighed (W_2) at an interval of 24 hours for six days (144 hours). The water absorption of the composite was determined in accordance with ISO 175:1999 (E) standard using Equation 1 which was earlier used by Islam et al. [9] and Mat-Shayuti et al. [10].

$$W_A(\%) = \frac{W_2 - W_1}{W_1} \text{ x } 100 \quad (1)$$

The tensile strength of the samples was determined according to ASTM D3039 standard while the modulus of elasticity was determined according to ASTM D638 standard. The hardness of the samples was carried out by using Brinell hardness tester according to ASTM D2240 standard. Impact energy testing was also carried out using an Izod impact tester according to ASTM D256 standard.

3. Results and discussion

3.1. Microstructure

Nylon is one of the thermoplastics with many relatively long branches of molecular chains [11]. The scanning electron micrographs (SEM) of Figs. 2 – 5 reveal the morphological differences in the microstructure of the samples with dendritic (tree like) and oval shapes. The presence of carbon in the micrographs confirms the fact that thermoplastics are carbon based organic materials. The micrographs (Figs. 3 – 5) show inhomogeneity in the microstructure of the reinforced samples. In Figs. 3 and 4, the micrographs show the presence of reinforcement particles of aluminium dross (Al) and iron filings (Fe) in white and dark patches respectively which are fairly distributed within the thermoplastic matrix. In Fig. 5, the SEM micrograph shows a uniform distribution of the reinforcement particles in the microstructure of the hybrid composite. The energy dispersive X-ray spectrographs (EDS) of the reinforced samples is a confirmation of inhomogeneity in the microstructure of the reinforced samples by the presence of C, Al, Fe, Mg, P, Si, Ca, K, Ti, etc in the EDS spectra.

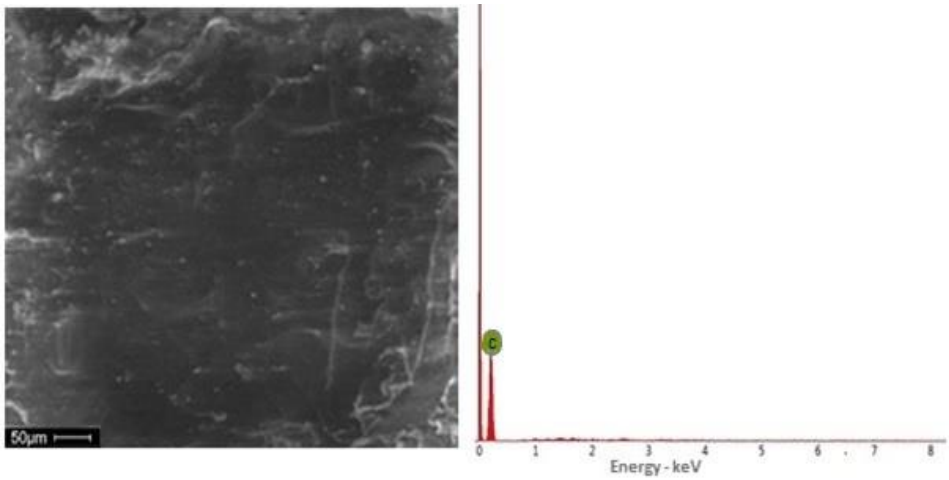

Fig. 2 The SEM and EDS microstructure of the unreinforced thermoplastic (nylon) sample

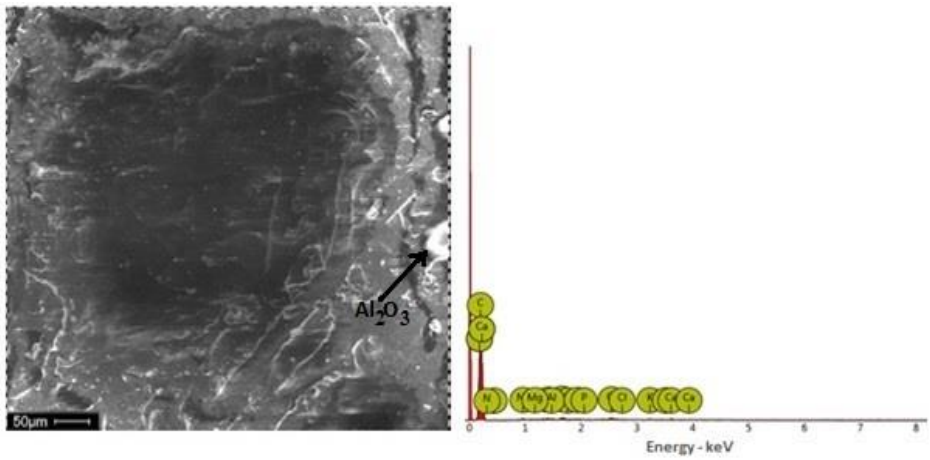

Fig. 3 The SEM and EDS microstructure of the 15 wt. % aluminium dross particles reinforced thermoplastic (nylon) composite

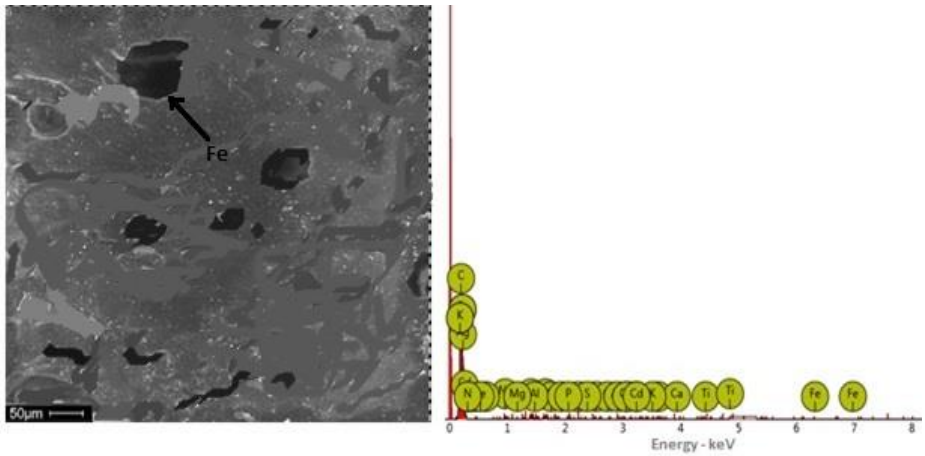

Fig. 4 The SEM and EDS microstructure of the 15 wt. % iron filings particles reinforced thermoplastic (nylon) composite

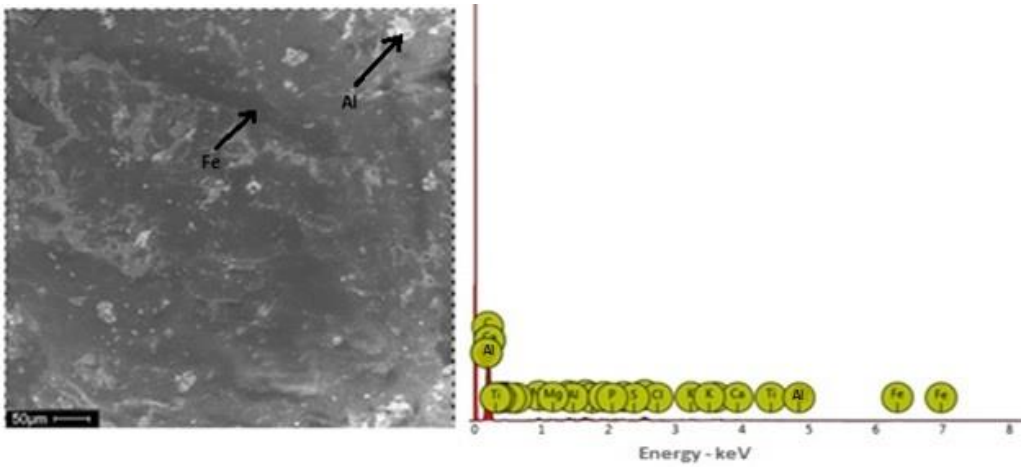

Fig. 5 The SEM and EDS microstructure of the 15 wt. % hybrid thermoplastic (nylon) composite

3.2. Water absorption

Some polymers swell and soften in water such as nylon and polyvinyl alcohol [10]. In the case of swelling and softening, molecular mobility is increased through the absorption of water. By the crowding of solvent molecules, polymer structure will open up and swell leading to increase in spacing between the polymer molecules. This will reduce the bonding and will cause a reduction in resistance to applied stress from the decrease in intermolecular friction [10].

As shown in Fig, 6, the water absorption of the composites increased with time but remained constant from 96 to 144 hrs for each sample. The water absorbed by the samples was due to the presence of pores or voids in their microstructure. This is similar to the earlier report of Tewari et al. [12]. The penetration of water through the surface layers and diffusing deep into the microstructure of the samples can cause both plasticization and wedging effects [13]. The hybrid composite sample exhibited lower water absorption than unreinforced and mono-reinforced samples. This was due to the fairly strong interfacial bonding of the reinforcing particles with the thermoplastic matrix indicating reduced pores in the microstructure. Water absorption could be detrimental to the mechanical, physical, chemical and dimensional properties of polymers [10, 14].

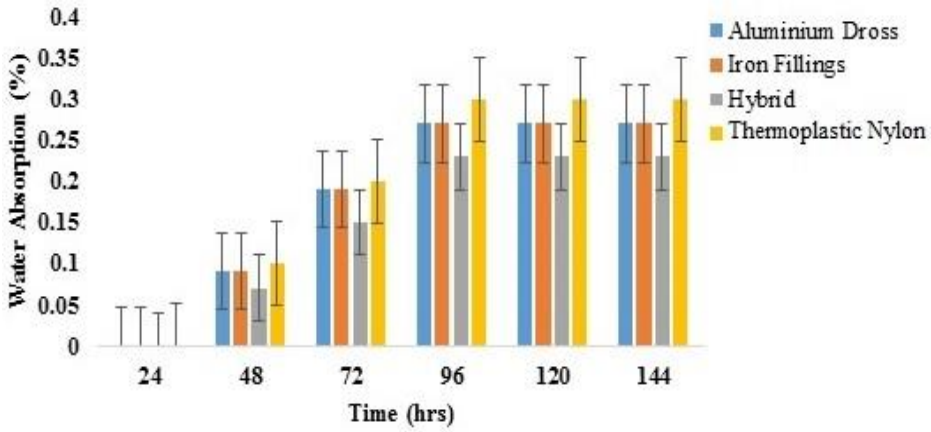

Fig. 6 Graph of water absorption against time of the composites

3.3. Tensile strength

The tensile strength gives information about the behaviour of a material when subjected to stretching or pulling force before failure. The mechanical properties of polymer composites depend on some factors such as stress-strain behaviour of fillers (particulates) and matrix phases, concentration, orientation and distribution of fillers. The curves of the tensile stress against strain of the samples are shown in Fig. 7. The reinforced composite samples exhibited higher ultimate tensile strength than unreinforced thermoplastic sample as shown in Fig. 8. The increase could be due to strong interfacial adhesion or bonding between the reinforcement and the thermoplastic nylon matrix which agrees with the report of Renner et al. [15]. The decrease in the tensile strength beyond 15 wt. % reinforcement may be due to decrease in the average inter-particle distance or spacing which increased the amount of inter-particle stress concentration overlap. This led to a higher level of debonding when tensile stress was applied and ultimately impaired or reduced the tensile strength of the composites. The decrease in tensile strength could also be due to poor dispersion of particulates in the polymer matrix. This led to weak adhesion between the particulates and matrix which adversely affected load distribution. This is similar to the earlier report of Agunsoye et al. [8] and Durowaye et al. [16].

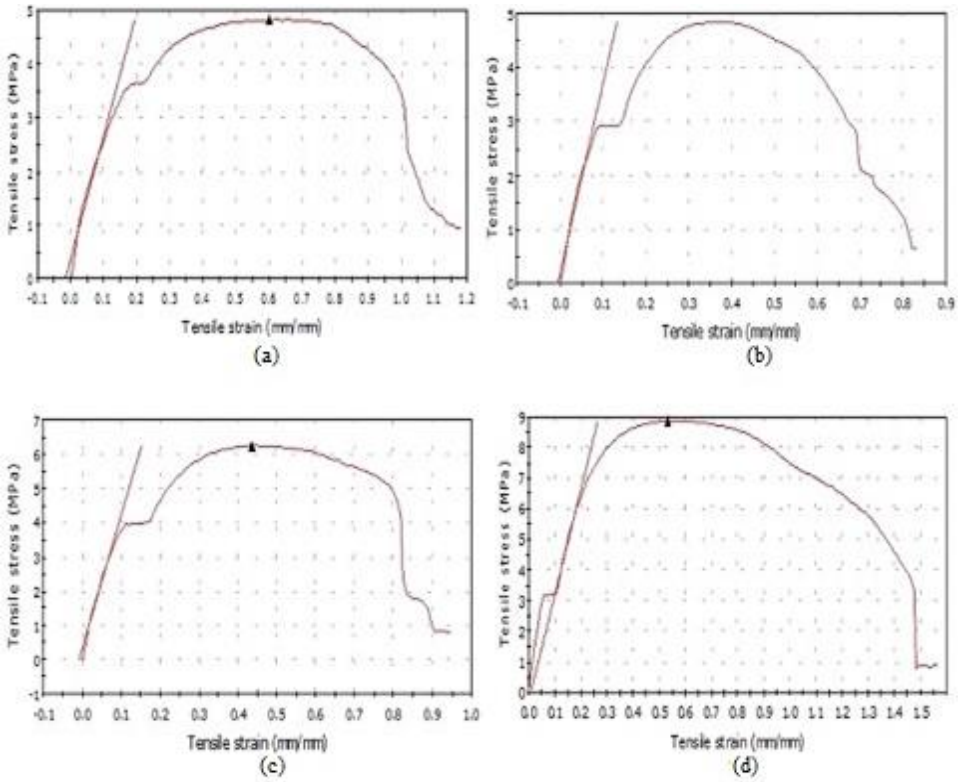

Fig. 7 Variation of tensile stress with tensile strain of the samples (a) unreinforced thermoplastic (nylon) matrix, (b) 15 wt. % aluminium dross reinforced, (c) 15 wt. % iron filings reinforced (d) hybrid

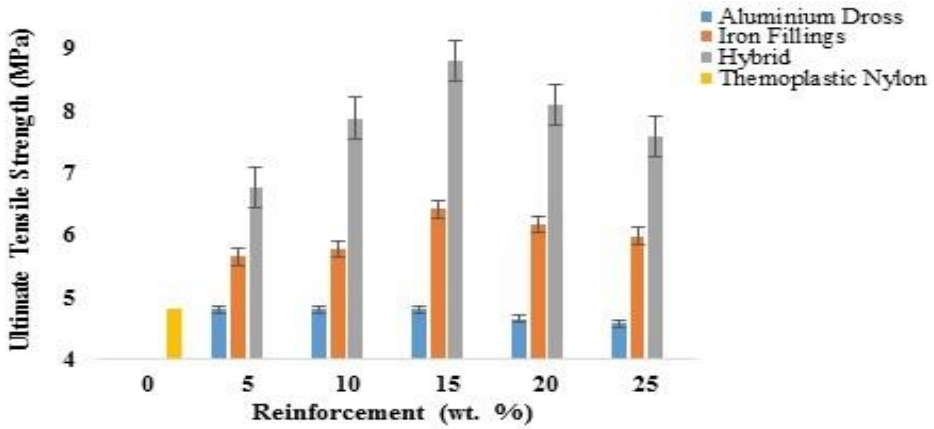

Fig. 8 Tensile strength of thermoplastic matrix composites with different aluminium dross and iron filings content

3.4. Modulus of elasticity

As illustrated in Fig. 9, the composite reinforced with iron filings demonstrated a progressive increase in modulus of elasticity as reinforcement increased up to 15 wt. %. The increase could be due to the better increased surface area of the filler in the polymer matrix. The strong interfacial bonding between the iron filings particulates and the matrix could also contribute to the enhancement of the modulus of elasticity. The strain energy stored in the thermoplastic matrix during the application of tensile stress could be equal to the adhesion or bonding of the particulates with the matrix. This caused the particle-matrix interface to debond thereby reducing the modulus of elasticity of the composites. This agrees with the earlier report of Rutz [17]. The decrease could also be due to agglomeration of the particulates in the matrix which also agrees with the report of Mechtali et al. [18], Rufai et al. [19] and Durowaye et al. [20].

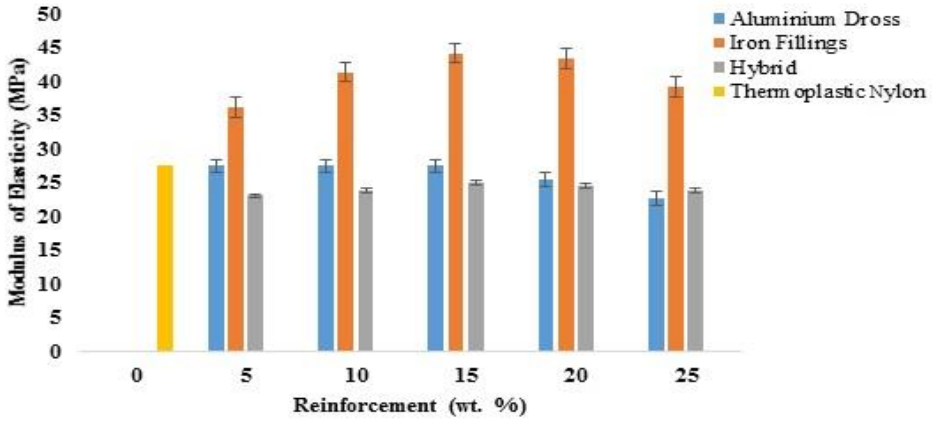

Fig. 9 Modulus of elasticity of thermoplastic matrix composites with different aluminium dross and iron filings content

3.5. Hardness

Hardness of a material implies resistance to indentation, permanent or plastic deformation. Generally, polymers are characterised by low hardness [21]. As shown in Fig. 10, the hardness of the reinforced samples is higher than the unreinforced thermoplastic sample and increased with increasing reinforcement up to 15 wt. The hybrid composite exhibited the highest hardness value of 12.84 BHN at 15 wt. % reinforcement. This is an indication of the ability of the blend of particulates of aluminium dross and iron fillings to enhance the hardness of the composites.

The uniform dispersion of the particulates in the matrix and the strong bonding **or** adhesion of the hybrid particulates with the thermoplastic matrix were the factors responsible for the increase in hardness. Beyond 15 wt.% reinforcement, there was a decrease in the hardness values which could be due to poor dispersion of the particulates in the matrix resulting to weak bonding or adhesion between the particulates and thermoplastic matrix. This agrees with the earlier report of Agunsoye et al. [8].

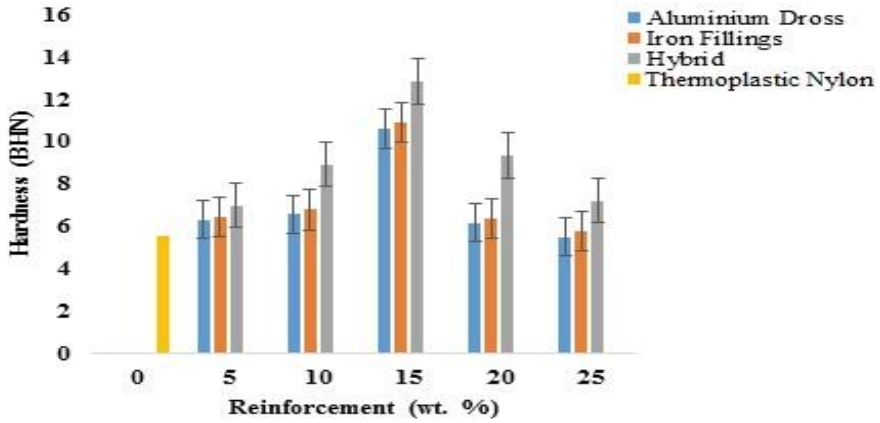

Fig. 10 Hardness of thermoplastic matrix composites with different aluminium dross and iron filings content

3.6. Impact energy

The impact energy (IE) is a measure of the energy absorbed during fracture of a material when subjected to impact loading. It gives an indication of the toughness of the material. As illustrated in Fig. 11, there was a progressive decrease in the IE of the samples as reinforcement increased. The unreinforced thermoplastic sample exhibited the highest IE of 5J. The decrease in IE may be attributable to the hardness of reinforcing particles which impacted brittleness to the polymer matrix.

During impact loading, there may be formation and propagation of cracks and micro-voids within the composite which led to a reduction in the impact energy. Increase in reinforcement also led to an increase in the surface area available for filler – matrix interaction. As the surface area available for filler – matrix interaction increased, the mobility of the matrix molecules increased thereby weakening the interfacial bonding between the matrix and the particulates which eventually caused a decrease in the impact energy. This agrees with the earlier report of Agunsoye et al. [8].

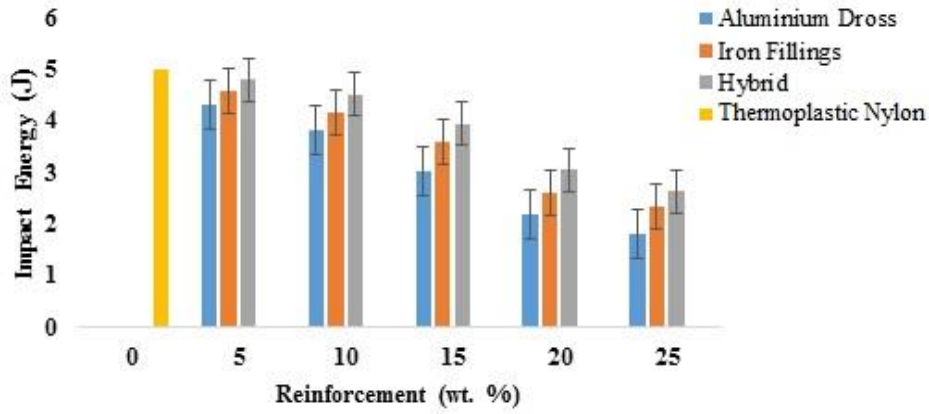

Fig. 11 Impact energy of thermoplastic matrix composites with different aluminium dross and iron filings content

4. Conclusions

In this study, hybrid polymer matrix composites have been developed and characterised using particulates of aluminium dross, iron filings and thermoplastic (nylon) as input materials. The samples produced were subjected to physical and mechanical characterisations. From the results of investigation and discussion of this study, the following inferences can be made:

- The hybrid composites exhibited the lowest water absorption of 0.23 % after 144 hours.
- The hybrid polymer matrix composite exhibited the highest tensile strength, modulus of elasticity and Brinell hardness number (BHN) of 8.92 MPa, 17.84 MPa and 12.84 BHN respectively at 15 wt. % filler addition.
- The strong adhesion or bonding between the reinforcement and the thermoplastic (nylon) matrix contributed to the reduction of water absorption and enhancement of the tensile strength, modulus of elasticity and hardness of the composites.
- The decrease in mechanical properties of the composites could be due to poor dispersion of the particulates in the matrix resulting to weak bonding or adhesion between the particulates and the matrix.
- The results indicated that the hybrid polymer matrix composite has potential for applications where low strength is required and its development will go a long way in reducing or mitigating environmental pollution.

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