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An Experimental Study of The Properties of Mild Steel Micro Particle Reinforced Epoxy Matrix Composites

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ABSTRACT

Particle-reinforced composites have demonstrated unique or excellent properties, which have made them suitable materials for application in many areas. In this study, 5-20 wt. % of mild steel microparticles were used in the reinforcement of epoxy resin matrix to produce polymer composites by stir casting technique. The microstructure of the composites was examined by employing a scanning electron microscope (SEM). In addition, their physical and mechanical properties were evaluated. The results revealed presence of pores in the samples and dispersion of ductile mild steel phase in the epoxy matrix phase. The density of the samples became higher as concentration of reinforcing mild steel particles increased, and reinforced sample E demonstrated the greatest density of 4.3 g/cm^3. The much-reinforced samples D and E, which contained 15 and 20 wt. % of mild steel particles, respectively, demonstrated the least water absorption of 9.6 %. Reinforced sample E, which contained the highest amount of mild steel particles (20 wt. %) exhibited the highest ultimate tensile strength (UTS) value of 51.3 MPa, which is almost 85 % more than unreinforced-control sample A. Furthermore, it possessed a hardness of 23.4 HV, which is 45 % more than the control sample. Sample E also exhibited an impact energy of 5.44 J, indicating a 14.3 % improvement over the control sample.

Keywords: Composites, Mild steel particle, Epoxy resin, Stir casting.

1. INTRODUCTION

Advancement in technology goes with the utilization of materials and new materials with enhanced qualities are needed to meet the demand for improvement **(Sahu and Broutman,**

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1972). Hence, there is a need to develop materials that will exhibit unique or excellent properties for potential application in many areas. There have been some limitations in the use of polymers in engineering and other fields because of their low-impact energy and stiffness. For example, epoxy resin has the disadvantages of low toughness, strength, and stiffness **(Kumar et al., 2016).**

The quest to overcome these disadvantages or limitations resulted in the production of polymer matrix composites (PMCs) obtained by reinforcing the matrix material (epoxy resin) with different particulate fillers. Epoxy resin is a thermosetting polymer matrix that has desirable properties. Epoxy resin-based composites are widely used as structural components in industries because of their high adhesion, low weight, and good chemical resistance. The mechanical properties of cured epoxy resins are influenced by their structure, curing time and temperature **(Srivastava and Verma, 2015)**.

A composite with improved properties is produced by combining two or more materials having different characteristics. The invention of composite materials is one of the most significant advances in the history of materials **(Srivastava and Verma, 2015)**. Composites are very important materials which are now used widely and continue to replace traditional materials like steel and aluminium across various industries from aerospace, automobile, civil, defence, and railway to marine **(Karle and Tungikar, 2021)**. High strength, low density, great wear resistance, and a low coefficient of thermal expansion are common characteristics of composites, which are desirable properties for potential application in many areas **(Karle and Tungikar, 2021)**.

A wide variety of micro or nanoparticulate fillers are added to process epoxy composites and modify their properties, thereby merging the benefits of both original components, i.e., the matrix and reinforcement **(Pinto et al., 2015)**. The selection of fillers depends on their ability to improve the general properties of composites. The incorporation of particulate fillers in matrices improved the chemical, thermal, electrical and mechanical properties of the epoxy composites **(Fu et al., 2008; Sidhu et al., 2014; Pawar et al., 2022)**.

Fillers have been incorporated into all types of matrices for the development of composites from the very beginning, and fillers will continue to be very important in the enhancement of the properties of composites **(Jeyapragash et al., 2020)**. Among the benefits of adding filler is the fact that it reduces cost, but now the focus has shifted to the functional properties achieved by the incorporation of particulate fillers **(DeArmitt and Rothon, 2016)**.

The development and application of particles and fibre-reinforced PMCs are gaining much attention in recent times. PMCs are valuable materials to the aerospace industry because of their stiffness and lightness. In PMCs, carbon/hydrocarbon fibres, metallic strands, filaments, or particles are bonded by resins in fibre wound or sheet form **(Nagarajan, 2017)**. The composition of PMCs could be in form of a series of short or continuous fibres or particles, which are bonded by an organic polymer matrix. In contrast to ceramic matrix composites, where reinforcements/fillers are mainly used to enhance fracture toughness, the fillers in PMCs provide high strength and stiffness. In PMCs, the fillers carry the loads to which the composites are subjected, while the matrix binds the fillers together and ensures load transfer between them **(Nagarajan, 2017)**.

The good qualities that are demonstrated by PMCs are their lightweight, appreciable stiffness and strength along the path of reinforcement, which make them choice materials in aircraft, automobiles, and other moving structures. Furthermore, they are highly resistant to fatigue and corrosion. However, because of their low matrix-decomposition temperature, they are applied in areas where the operating temperature is not higher than 316 °C

(Nagarajan, 2017).

Generally, the mechanical characteristics of PMCs are usually enhanced by the uniform distribution of weight fraction or volume of reinforcing particles in the polymer **(Bello et al., 2015**). Hence, blending polymers with particles is vital in enhancing the mechanical characteristics of PMCs. PMCs have found application in electrical industries, aviation (civil and military), heaters, and electrodes **(Uygunoglu et al., 2015)**.

Researchers **(Imoisili et al., 2012; Boopalan et al., 2013; Ozsoy et al., 2015; Rufai et al., 2015; Oladele and Ishola 2016; Rafique et al., 2016; Muslim et al., 2018; Adeyanju et al., 2019; Manik et al., 2019; Reddy et al., 2019; Durowaye et al., 2022)** have used particles to reinforce epoxy matrix to develop PMCs, which were subjected to various physical and mechanical tests. The results indicated improved mechanical properties. Composites, which are regarded as advanced materials, have justified their application by demonstrating unique properties, and the rate of application of composites in many areas has tremendously increased. The wide and increasing areas of their application are proof of their suitability and effectiveness **(Popat and Patil, 2017)**. Improvement of the properties of polymers via blending with particles to produce particulate polymer matrix composites (PPMCs) is a welcome development. Therefore, the aim of this study is to develop mild steel micro particle-reinforced epoxy matrix composites and evaluate their physical and mechanical properties.

2. MATERIALS AND METHODS

2.1 Materials, Apparatus and Production of Samples

Epoxy resin mixed with hardener employing a ratio of 2:1 (epoxy: hardener) is the base material. Chips of mild steel were sourced from Central Workshop of the University of Lagos after a turning operation by the lathe machine. The chips were well sorted from dirt, ground using a steel ball mill and sieved to 100-μm as presented in **Fig. 1**. The Chemical composition **(Table 1)** of the mild steel was determined using a spectrometer. A wooden mould shown in **Fig. 2**, beakers, stirrers, and an electric weighing machine were used for the production of the samples by the stir casting method. Measured amounts of mild steel particles (5 – 20 wt. %), as shown in **Table 2,** were added to the resin matrix, and the blend was poured into the laminated wooden mould. The samples were ejected from the mould after curing for about 24 hrs.

(a) (b)

Figure 1. (a) Chips of mild steel, (b) Ground and sieved 100-μm mild steel particles.

Figure 2. Fabricated wooden mould.

Table 1. Composition of mild steel please emerge the two tables in one table

Element	Fe	Mn	C	Ni	Si	Cr	S	P	Cu	Mo	Pb	Zn	Vn
Wt. %	98.865	0.614	0.225	0.103	0.101	0.03	0.023	0.021	0.014	0.032	0.002	0.002	0.001

Table 2. Materials used in weight percentages (wt. %) and grammes (g)

Sample	Mild steel particles (wt. %)	Epoxy and hardener (wt. %)	Mild steel particles (g)	Epoxy resin (g)	Hardener (g)	Total (g)
A	0	100	0	133	67	200
B	5	95	10	127	63	200
C	10	90	20	120	60	200
D	15	85	30	113	57	200
E	20	80	40	107	53	200

2.2 Testing of Samples

Surface cleaning was done on the samples after which a microstructural examination was conducted on five test samples of 20 mm square-shaped dimension using an ASPEX 3020 variable pressure scanning electron microscope (SEM) with an energy dispersive X-ray (EDX) facility. Archimedes' principle was employed to determine the density of the test samples in accordance with **(ASTM D792, 2020)** standard. The mass of the samples in air was measured. Thereafter, they were separately immersed in water contained in beakers. Density was obtained by applying Eq. (1) **(Aigbodion et al., 2010; Olabisi et al., 2016)**.

$$Density\ (\rho) = \frac{m}{v} \quad (1)$$

Where:
m = mass of sample in air (g)
v = volume of water displaced in cm^3
The water absorption test was carried out by immersing the samples in water contained in beakers for 24 hrs in line with **(ASTM D570-98, 2018)** standard. This was also employed by **(Islam et al., 2013**; **Mat-Shayuti et al., 2013)** using Eq. (2).

$$WA = \frac{W_{1-}W_0}{W_0} x\ 100 \quad (2)$$

Where:
WA = water absorption in %
W_0 = sample's weight before immersion
W_1 = sample's weight after immersion

Each of the tensile test samples having a reduced section of 12.5 mm was placed in the centre of a digital XLC universal tester with a load to break the sample according to **(ASTM D638, 2014)** standard. Microhardness of the samples was determined according to **(ASTM E384-17, 2022)** standard using a Vickers hardness tester with a load of 1.91N. Test samples of size 55 x 10 x 10 mm and a 2 mm deep V-notch at the centre were subjected to a low-speed impact test using an Izod impact-tester according to **(ASTM D256-10, 2018)** standard. The pendulum, from a height of 1.4 m with a speed of 4 m/s struck each sample, causing them to fracture.

3. RESULTS AND DISCUSSION

3.1 Microstructure of The Samples

The scanning electron micrographs (SEM) revealed the presence of pores in the samples as presented in **Figs. 3** to **6**. The microstructure of the reinforced samples revealed that the phases are not homogeneous as ductile mild steel micro particles are well dispersed in the epoxy matrix, as shown in **Figs. 4** to **6**. The energy dispersive x-ray (EDX) spectra confirmed the presence of the revealed elements and some indistinguishable ones in traces or minute amounts in the samples. It has been established in the literature that when particles are uniformly/well distributed in the matrix of composites, their mechanical properties are enhanced **(Kaewpirom and Worrarat, 2014; Balaji et al., 2019)** coupled with a strong interfacial bond between the particles and the polymer (epoxy) matrix.

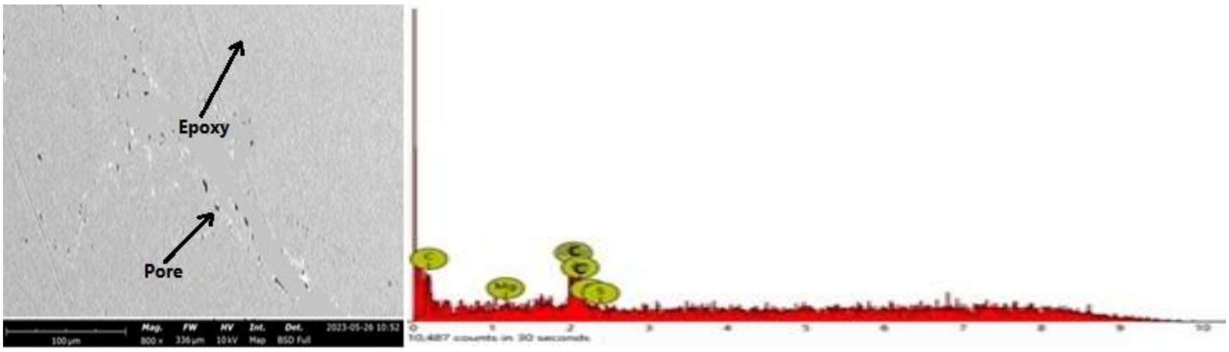

Figure 3. SEM and EDX spectrum of the control (unreinforced) sample A.

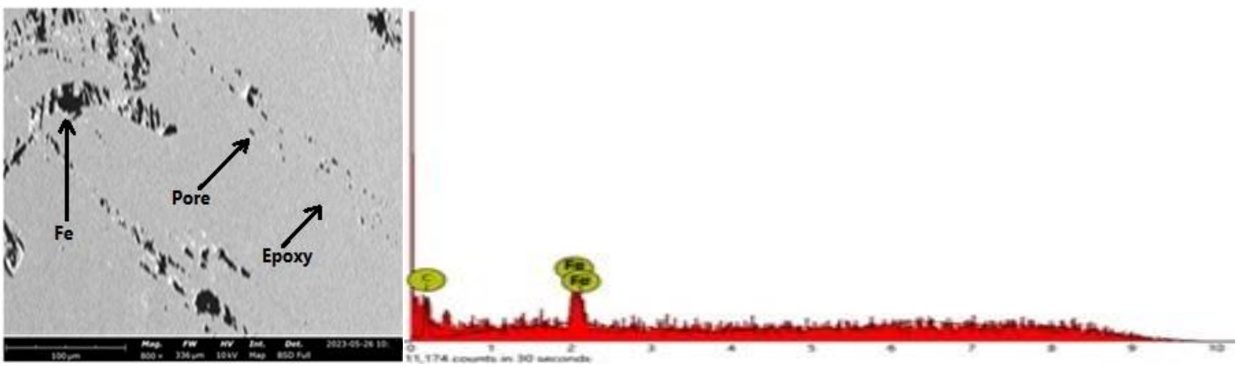

Figure 4. SEM and EDX spectrum of sample B.

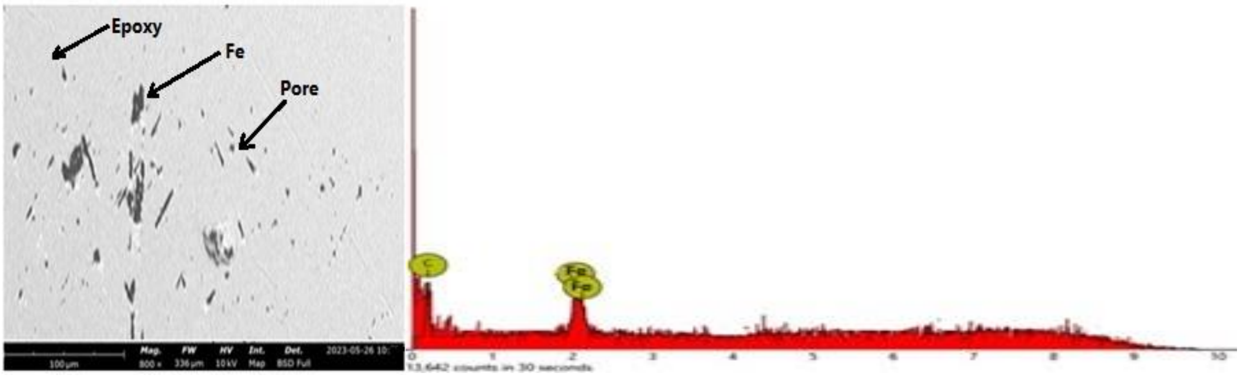

Figure 5. SEM and EDX spectrum of sample C.

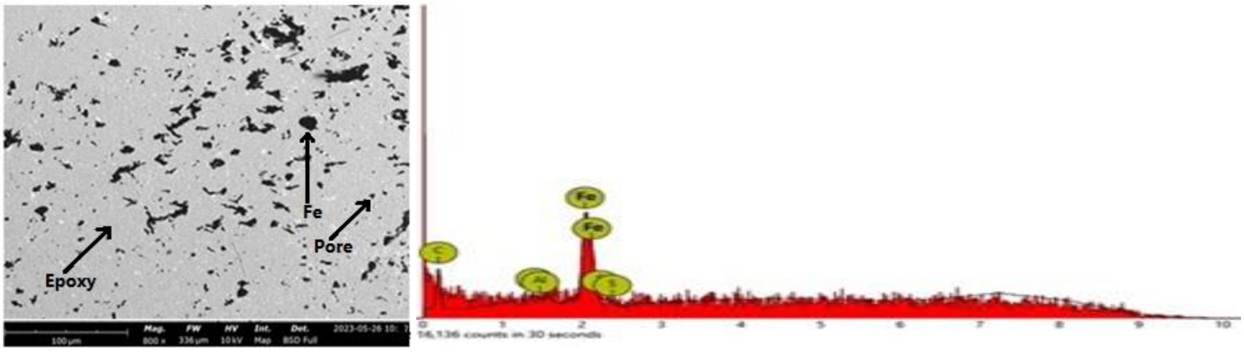

Figure 6. SEM and EDX spectrum of sample E.

3.2 Density

The density of the samples got higher with increasing concentration of reinforcing mild steel particles as presented in **Fig. 7**. The unreinforced polymer sample A demonstrated a density of 3.4 g/cm^3 while reinforced sample E containing 20 wt. % of mild steel particles demonstrated the highest density of 4.3 g/cm^3. This supports the report that iron-based materials demonstrate high-density characteristics **(Asif et al., 2011)**.

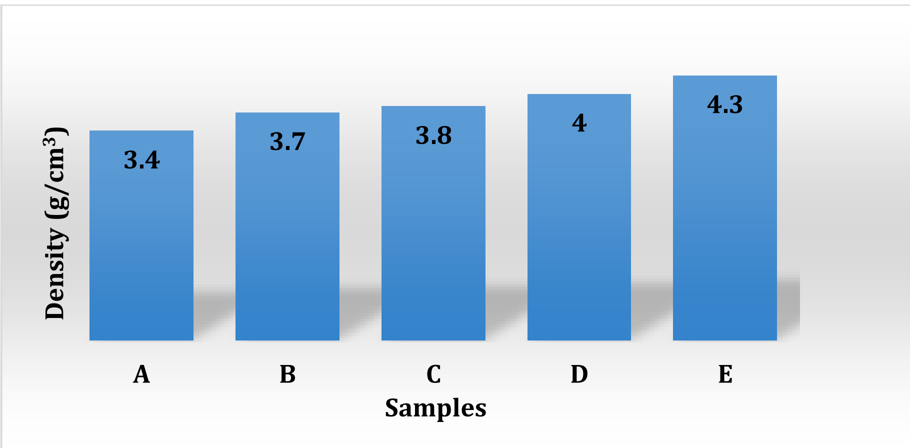

Figure 7. Density of the samples.

3.3 Water Absorption

As illustrated in **Fig. 8**, reinforced samples D and E, which contained a content of mild steel particles, demonstrated the lowest level of water absorption of 9.6 % compared to others. Water absorption increment is an indication of the availability of pores in the samples, which could have a negative effect on the mechanical properties **(Durowaye et al., 2022)**. However, a strong bond of the mild steel particles to the epoxy matrix decreased pores formation and is responsible for the low water absorption (9.6 %) of samples D and E, which contained 15 and 20 wt.% of mild steel micro particles respectively. It has been established that a strong bond of filler to the matrix improves the properties of composites **(Kaewpirom and Worrarat, 2014; Balaji et al., 2019; Durowaye et al., 2022; Kuforiji et al., 2023)**.

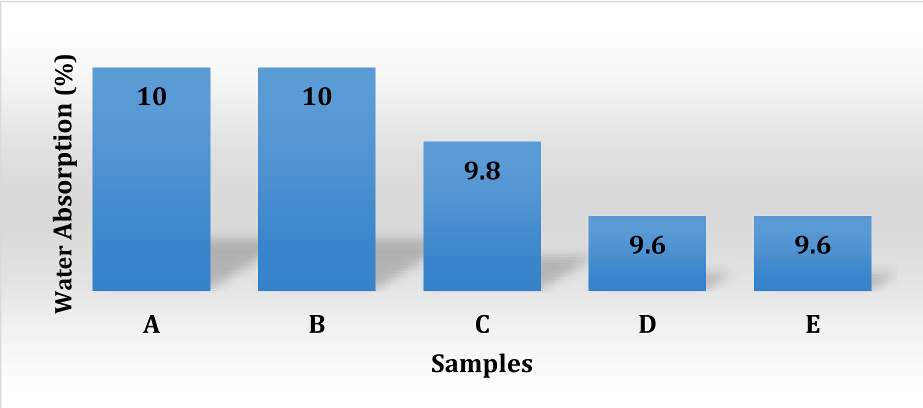

Figure 8. Water absorption of the samples.

3.4 Ultimate Tensile Strength

Generally, reinforced samples (B, C, D, and E) demonstrated higher ultimate tensile strength (UTS) values than control sample A, as shown in **Fig. 9**. The UTS demonstrated by the control sample is 27.74 MPa, while sample E, containing 20 wt. % of mild steel particles demonstrated the highest UTS of 51.3 MPa, which is 84.97 % higher. Furthermore, the UTS value improved as ductile mild steel particles increased in the composites. The increment in UTS could be because of a strong interfacial bond of the steel particles and epoxy resin **(Kuforiji et al., 2023)**. It could also be because of the ductile nature of reinforcement particles.

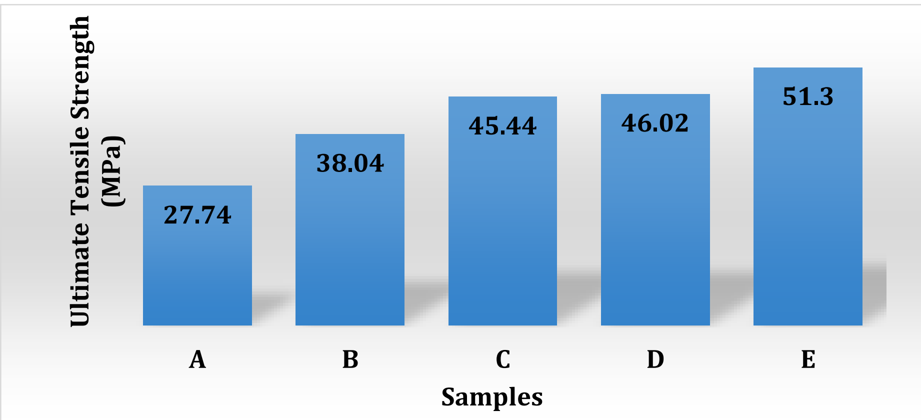

Figure 9. Ultimate tensile strength of the samples.

3.5 Hardness

The hardness demonstrated by the control sample is 16.1 HV, as illustrated in **Fig. 10**. However, reinforced samples demonstrated improved hardness when compared with the control sample A. Specifically, sample E, which contained the highest amount of reinforcing mild steel particles (20 wt. %), demonstrated the greatest hardness of 23.4 HV, which is 45 % more than the control sample. The increment could be because of strong bond of particles and the epoxy matrix, which restricted the movement of dislocation. In addition, it may be because of the increased surface area of reinforcing particles in the epoxy matrix **(Satheeskumar, 2018; Seshappa et al., 2018)**.

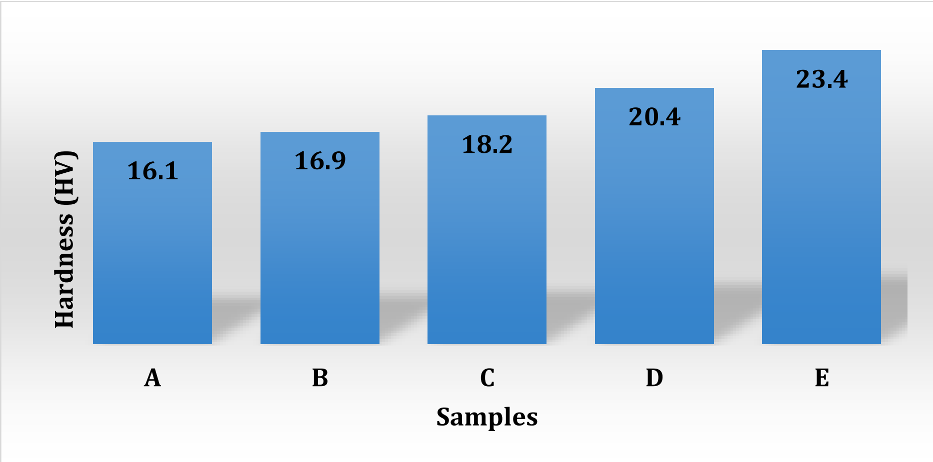

Figure 10. The hardness of the samples.

3.6 Low-Velocity Impact Energy

As presented in **Fig. 11**, the samples revealed an improvement in impact energy as wt. % of mild steel particles increased when subjected to low-velocity (4 m/s) impact loading. The control sample A showed an impact energy of 4.76 J, while that of the reinforced sample E, which contained 20 wt. % of mild steel particles increased to 5.44 J. This is 14.3 % more than control sample. The increment in impact energy is because the presence of much ductile-reinforcing mild steel particles in the composites gave the composites enough plasticity to absorb energy **(Aigbodion et al., 2010)**.

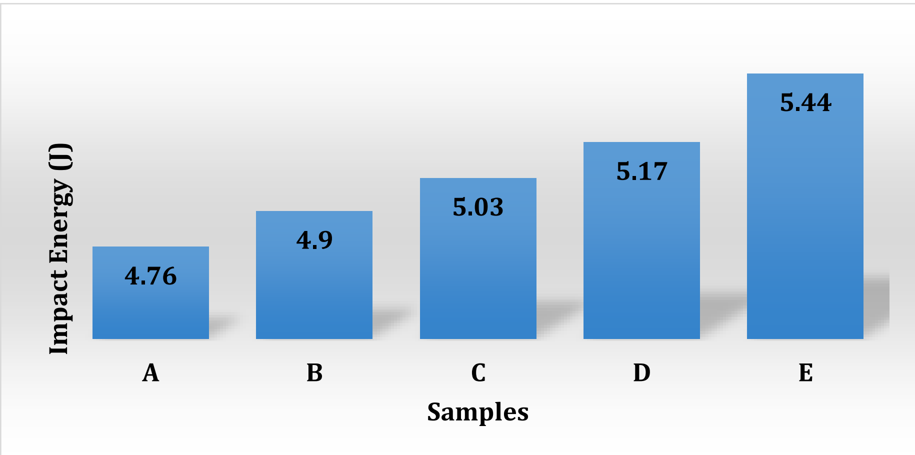

Figure 11. Impact energy of the samples.

4. CONCLUSIONS

The production of mild steel particle-reinforced polymer (epoxy) matrix composites by stir casting technique was undertaken in this study. In addition, their microstructure was examined likewise the physical and mechanical properties determination. Based on the experimental findings, the following conclusions were drawn:

- The scanning electron micrographs (SEM) revealed the presence of pores in the samples.
- The energy dispersive x-ray (EDX) spectra confirmed presence of revealed elements and some indistinguishable ones in traces or minute amount in the samples.
- The SEM micrographs of the reinforced samples showed that the ductile mild steel particles were well distributed in the epoxy resin matrix, which improved their mechanical properties as weight percentage of reinforcement increased, which is well supported by literature.
- Composite-sample E containing 20 wt. % of reinforcing mild steel particles demonstrated the highest density of 4.3 g/cm^3.
- The much-reinforced samples D and E possessed the least water absorption of 9.6 %.
- Reinforced sample E exhibited the highest ultimate tensile strength (UTS) of 51.3 MPa, which is almost 85 % more than control sample A.
- Reinforced sample E demonstrated a hardness of 23.4 HV, which is more than the hardness of other samples. It is 45 % more than the hardness of the control sample. It also demonstrated an improved impact energy value of 5.44 J, which is 14.3 % more than the control sample.

Credit Authorship Contribution Statement

Stephen Durowaye: Supervision, Investigation, Methodology, Formal analysis, Writing – original draft, Writing review & editing. Kolawole Alonge: Investigation, Methodology, Formal analysis, Writing – original draft, Writing review & editing. Itunuoluwa Adebisi: Investigation, Methodology, Formal analysis, Writing – original draft, Writing review & editing. Abdulsalam Joki-Lasisi: Investigation, Methodology, Formal analysis, Writing – original draft. Emmanuel Omotuyi: Investigation, Methodology, Formal analysis, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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دراسة تجريبية لخصائص المواد المركبة ذات مصفوفة الإيبوكسي المعززة بجسيمات الصلب الطري الدقيقة

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الخلاصة

أظهرت المواد المركبة المعززة بالجسيمات خصائص فريدة أو ممتازة جعلتها مواد مناسبة للتطبيق في العديد من المجالات. في هذه الدراسة، تم استخدام 5-20% من الوزن من جسيمات الصلب الطري الدقيقة لتعزيز مصفوفة راتنج الإيبوكسي بهدف تطوير مركبات البوليمر باستخدام تقنية الصب بالتحريك. تم فحص البنية المجهرية للمواد المركبة باستخدام المجهر الإلكتروني الماسح (SEM). علاوة على ذلك، تم تقييم الخصائص الفيزيائية والميكانيكية. أظهرت النتائج وجود مسامات في العينات وتوزيع طور الصلب الطري المطيل داخل طور مصفوفة الإيبوكسي. زادت كثافة العينات مع زيادة تركيز جسيمات الصلب الطري المعززة، حيث أظهرت العينة E أعلى كثافة بلغت 4.3 جم/سم³. أظهرت العينات D وE، التي احتوت على 15% و20% من الوزن من جسيمات الصلب الطري على التوالي، أقل امتصاص للماء بنسبة 9.6%. كما أظهرت العينة E، التي احتوت على أكبر نسبة من جسيمات الصلب الطري (20% من الوزن)، أعلى قيمة لقوة الشد القصوى (UTS) بلغت 51.3 ميجا باسكال، وهو ما يزيد بنسبة 85% مقارنة بعينة التحكم غير المعززة A. بالإضافة إلى ذلك، امتلكت العينة E صلادة بلغت 23.4 HV، وهي أعلى بنسبة 45% من عينة التحكم، كما أظهرت طاقة صدم 5.44 جول، مما يشير إلى تحسن بنسبة 14.3% مقارنة بعينة التحكم.

الكلمات المفتاحية: المواد المركبة، جسيمات الصلب الطري، راتنج الإيبوكسي، الصب بالتحريك.