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# Mechanical Properties of Alloys and Thermoplastic Composites Derived from Non-Biodegradable Municipal Solid Waste

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## Abstract

*Waste management is a global environmental problem that is becoming more prominent in emerging nations. This study focused on mechanical properties of alloys and thermoplastic composites derived from non-biodegradable municipal solid waste. The materials selected from the waste site were thermoplastics and scrap metals which together make up about 80% of the non-biodegradable waste found in the dump site in Benin City, Edo State, Nigeria. The melted thermoplastics and the smelted scrap metals were evaluated for their mechanical properties. The values obtained from the mechanical properties of recycled scrap metals shows that the average tensile strength, shear modulus, Brinell hardness number, and modulus of elasticity were 45.754MPa, 49.682x10$^3$MPa, 156.15kgf, and 1.4656GPa respectively. Moreover, for the recycled thermoplastics, the average tensile strength, modulus of elasticity, Brinell hardness number, and Percentage of water absorption were 43.708MPa, 2.084GPa, 45.604kgf and 0.410% respectively. The recycled materials provide opportunities for a multitude of products which are used extensively in the construction and manufacturing industry. Concomitant with these findings, it is apparent that the infrastructure and the societal means to facilitate solid waste reduction, reuse and recycling are possible.*

***Keywords:*** *Alloy, Mechanical properties, Municipal solid waste, Non-biodegradable, Public awareness, Thermoplastic composites, Waste management strategy*

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## 1. Introduction

The production of waste has steadily increased in recent years (Babayemi and Dauda, 2009; Sha'ato, et al., 2006). This is driven by population growth, rapid urbanization, and the need for more environmentally friendly and sustainable waste management strategies (Coker et al., 2016; Olodu and Erameh, 2023). These factors have put pressure on the waste industry. A paradigm shift from "waste management" to a more "resource management" focused mentality has resulted, in line with the principles specified in Agenda 21 (International Solid Waste Association (ISWA), 2009). For instance, solid waste may be viewed as "a resource in the wrong place," according to Adewumi et al. (2005). Although the production of solid waste by anthropogenic activities is inevitable, it is still possible to restore some value by developing management techniques that focus on value as a resource rather than something that needs to be disposed of (Armijo et al., 2008; Maity, 2018).

The characterization analysis of the generated SW serves as the foundation for any effective SWM design or practice. Given that garbage generation has become an integral part of daily life and necessitates proper attention, a thorough evaluation of the many components that comprise the waste stream generated is imperative (Chadar and Chadar, 2017). Two key values are realized for the institution or municipality as a result of using the necessary reduction, prevention, or recovery approach: decreased institutional cost and extended life of the sanitary landfill (if there is one) (Okeniyi, and Anwan, 2012). Additionally, a decrease in the amount of solid trash generated in any city or institution directly reduces the negative effects on the area's environment and social values (Olodu and Erameh, 2023). However, due to the general issues plaguing most developing countries, such as the rising generation of solid waste, rapid economic development, political interference, corruption, rising population growth, insufficient expertise, poor infrastructure, and a lack of understanding of the various factors encountered at various stages of waste management, the majority of Nigerian universities have failed in this regard (Armijo et al., 2008; Ike et al., 2018). Concurrently, solid garbage is also dumped at roadside locations at a rate that exceeds the capacity of collection services (Coker et al., 2010). This issue is made worse by rising population expansion and a lack of effective waste management policies on a local and national level. According to Ogwueleka (2009), Nigeria has the highest population in Africa, with 10% of its citizens reportedly living below the poverty line. As a result, a lot of people make an effort to survive by scouring open dump sites for goods they may sell (Hazra and Goel, 2009; Uwadiae et al., 2017). This exposes them to a number of health concerns, including exposure to pathogens, bacteria, insects, and rodents (Ogwueleka, 2009). Because they offer salvageable pieces that may be sold on for reuse and, thus, are enticing to buyers because of possible cost savings, electronic wastes like computers and mobile phones are highly sought after (Messineo and Panno, 2008). A lot of dangerous metals, including lead, mercury, and cadmium, are unfortunately exposed to people involved in the collection and disassembly process (Miller, 2006). The management of waste has proven to be very difficult for the Nigerian local government (Banar et al., 2008).

Metal recycling opens the door to a wide range of items. Aluminum, copper, steel, brass, and other scrap metals are recycled to create a wide range of new products (Adewumi et al., 2022; Sales, et al., 2021). It is less wasteful and better for the environment to use scrap metal for a variety of products (Armijo et al., 2008). There are numerous innovative applications for recycled metal. For instance, scrap metals like iron and aluminum are widely employed in the construction sector for a variety of projects, including roads and bridges (Agdag, 2009; Zhang et al., 2020). Tensile strength is the most useful and widely referenced assessment of these characteristics (Olodu and Erameh, 2023), and Friends (2022) reported that reinforcement improves aluminum strength, fatigue strength, modulus, wear resistance, and creep. Yao et al. (2010) reported the study of the aluminum trimodal metal matrix and the parameters affecting its strength. Saravanan et al. (2015) found a 30% increase in stiffness and almost a doubling of tensile strength compared to the base aluminum alloy. Prabu et al. (2006) investigated the effects of mixing duration and speed on particle dispersion in SiCAMC. The deformation behavior of solid aluminum matrix cylinders in dry conditions was analyzed by Joardar et al. (2012). Venkatesh and Harish (2015) look into the connection between fracture toughness and the Charpy V-notch test. Tensile tests were used to determine the deformation behavior of the alloys under investigation. Furthermore, to measure absorbed energy under mild impact conditions, Charpy V-notch experiments were carried out; the test results are in line with previous research (Osaremwinda and Olodu, 2015).

According to Adeniran et al. (2022), only a small portion of the University of Lagos' plastic garbage is recycled. Thermoplastics are often used to make a variety of products, including pipes, insulators, adhesives, and more. Many of these products can be recycled to generate brand new, useful ones (Ogwueleka, 2009). The fact that thermoplastics are easily heated and reshaped for new uses makes them recyclable (Agbede and Ajagbe, 2021). A significant problem has been presented by the proper and sustainable management (SWM) of solid waste (SW) produced by various countries around the world (Adewumi et al., 2022; Agbede and Ajagbe, 2021). Zhou and Mallick (2005) investigated the impact of hold pressure and melt temperature on the injection-molded, 40% talc-filled polypropylene's static tensile and fatigue behavior. Both yield strength and fatigue strength increased with increasing hold pressure for specimens in the flow direction, but they were comparatively insensitive to melt temperature for specimens normal to the flow direction, where both attributes decreased with increasing melt temperature (Osarenmwinda and Olodu., 2015). This study therefore focused on the mechanical properties of alloys and thermoplastic composites derived from non-biodegradable municipal solid waste.

## 2. Materials and methods

### 2.1 Materials

The following items were chosen from the waste dump sites: scrap metals and thermoplastics (polyethylene, polyvinyl chloride, polypropylene, and other thermoplastic materials), which together make up around 80% of the non-biodegradable waste found in the landfill in Benin City, Edo State, Nigeria.

### 2.2 Method of data collection

The materials were collected from various dumpsites within Benin metropolis. The Benin City is located in Edo state, Nigeria.

### 2.3 Classification of solid wastes

In this study, the wastes found in the dumpsites were classified as biodegradable and non-biodegradable waste. The non-biodegradable solid waste such as thermoplastics and scrap metals were of paramount importance. It should be noted that the majority of waste categories fits into a number of subclasses, as stated in Table 1.

**Table 1:** Waste generated in Benin City, Edo State Nigeria and their characteristics

| Type | Characteristics | Recyclability | Items Considered | Source/Origin | Management Strategy(s) |
|---|---|---|---|---|---|
| Paper/cardboard | Combustible when dried and biodegradable when continuously wet | Recyclable | Papers and allied packages-carbon papers, tissue papers, cement bags, cartons, wrappers and cardboards | Domestic and industrial waste and may result from lecturer quarters and hostels, lecture rooms, photocopying centers, offices and mini markets | Source separation<br>Reusable<br>Recyclable<br>Energy Generation |
| Garbage | Organic and biodegradable; and combustible when dried | Recyclable | left over from food, soups, sauces, meat and cheese, bread, cakes, uneaten sandwiches, peel and leaves from fruits and vegetable, eggs and dead animals. | Domestic and may result from lecturer quarters and hostels, bread/cake production and consumption from kitchens/refectories/restaurants, and markets. | Compost formation<br>Energy generation<br>Feed for livestock<br>Source separation |
| Plastics, polythene and packaging foils | Not biodegradable and when burnt, their residue hardly decay | Recyclable | Plastic materials-cans, caps, bags, bucket, waterproof bags, syringes beakers, pipettes and burrettes, spoilt plastic chairs, automobile tyres, tubes, cables, and ball pens | Domestic and industrial wastes and may result from market, medical center/hospital and laboratories. | Recyclable |
| Metals/Junks | Neither combustible nor biodegradable | Recyclable | Disused cars, lorries, buses, automobile junks, metal cups, cans, plates, buckets, | Majorly industrial waste and may result from quarters, hostels, guest houses, markets, and vehicles (very plenty at works department). | Recyclable<br>Reusable<br>Source separation |
| Ashes | Not combustible but biodegradable | Non-recyclable | Burnt wood, char coal, burnt leaves and paper | Quarters, hostels, guest houses, and offices. | Soil treatment and enrichment<br>Source separation |
| Rags | Combustible but not biodegradable | Recyclable | Abandoned cloths, Threads, cotton, wool and nylon | Domestic waste and may result from quarters, hostels and tailoring shops | Recyclable<br>Reusable<br>Source separation |
| E-Waste | Made up of different components that are non-biodegradable. While some parts are combustible like the rubber, plastic, etc., some are not like the | Recyclable | Electric cables, printers cartridge, phones accessories | Domestic and also industrial wastes from electrical appliances/parts and results from quarters, hostels and commercial areas | Reusable<br>Recyclable<br>Source separation |

| | | | | | |
|---|---|---|---|---|---|
| | metal parts | | | | |
| Leather | Combustible but not biodegradable | Recyclable | Shoes and bags made of leather | Mostly from the quarters and the hostels | Reusable Recyclable |
| Sanitary waste | Non-biodegradable | Non-recyclable | Pads, diapers and cotton wools | Mostly from the quarters and the hostels | Hygienic disposal |
| Miscellaneous refuse | While all are non-biodegradable, some are combustible | Either recyclable or non-recyclable depending on the waste type | Hospital waste and waste from cottages, construction and demolition rubbles, solid chemicals, | Hospital wastes are clinical wastes, while construction wastes and chemicals are industrial wastes | Strategy is dependent on waste type |

### 2.3.1 Selection of waste

In this study, the selected non-biodegradable waste materials within Benin metropolis include thermoplastic material of different types and scrap metals (iron, copper, aluminium, zinc etc). These wastes were selected due to their engineering and structural applications.

### 2.3.2 Recycle and reuse of non-biodegradable waste

Metal recycling is a significant industrial operation with intricate networks of wrecking yards, sorting facilities, and recycling plants. This is especially true of structural steel, ships, and used manufactured items such as cars and white goods. There are many different types of metals used in the recycling of metals. Scrap steel, iron (ISS), lead, aluminum, copper, stainless steel, and zinc are the metals that are recycled most commonly. Utilizing scrap metal for a variety of goods lowers waste and promotes environmental protection for future generations. There are numerous innovative applications for recycled metal. For instance, scrap metals like iron and aluminum are widely employed in the construction sector for a variety of projects, including roads and bridges. Automobiles, aircraft, and other forms of transportation are also made from scrap metal. Scrap is made up of recyclable materials, most often metals that are left over after a product is manufactured and consumed. In contrast to waste, recovered metals in particular are worth money, and non-metallic items are also recovered for recycling. After being gathered, the materials are divided into different types; normally, metal scrap which was processed mechanically before being crushed, shredded, and sorted. Recycling scrap metals are crucial for developing a sustainable economy or a circular economy since it consumes less energy and has a far less negative impact on the environment than mining metal ore.

There are so many uses for recycled plastics in the building sector. Roofing tiles, concrete buildings, indoor insulations, structural timber, PVC windows, construction bricks, fences, floor tiles, and carpeting are a few examples of applications. The discarded plastics gathered would be mechanically recycled in this effort to create two crucial products: Interlocking blocks built of composite materials with waste plastic bottles and a. interlocking tiles made of composite materials with waste nylons. The recycled plastic-based composite concrete components will go through a variety of mechanical and physical testing.

**Fig. 1:** Sample of waste dumping site

### 2.4 Development of selected waste into usable products and test for mechanical properties

The mechanical characteristics of the thermoplastics, such as tensile strength, elasticity modulus, hardness, and shear modulus, were assessed after they had been fused together. On the other hand, all the metals scraps were melted together as well, and their mechanical properties were assessed. The tests below were carried out to investigate the material properties and to validate its adequacy as structural materials.

### 2.4.1 Brinell hardness test

Ball indentation hardness according to ISO 2039-1 was employed in this study. A consistent test force was applied as a spherical indenter with a diameter of 5 mm which was driven into the plastic and smelted scrap metals specimens. The factor that determines the hardness value is the depth of the indentation after the application of load. The indentation depth was restricted to a range of 0.15 mm to 0.35 mm by the standard's definition of a number of test loads. High test loads and a significant indentation enable measurement over a sizable test surface and, as a result, a robust average of the observed value was determined (Fig. 2).

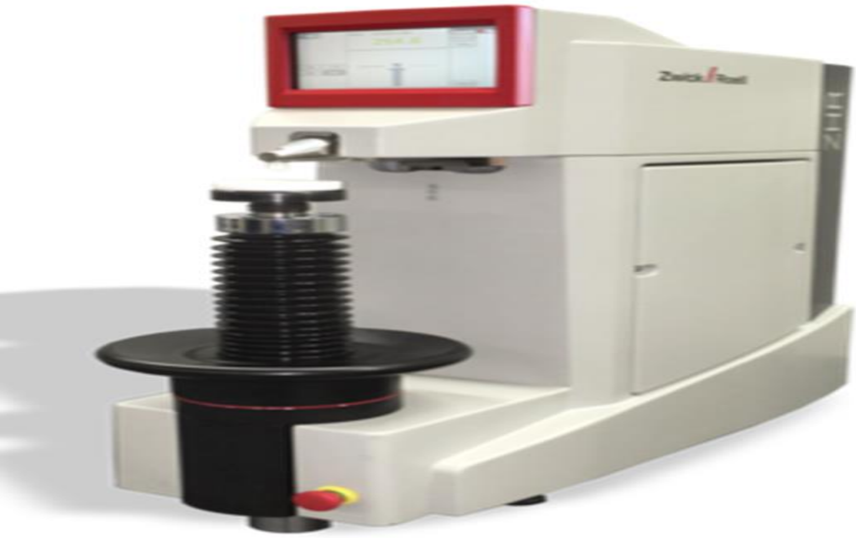

**Fig. 2:** Ball indention hardness ISO 2039-1

### 2.4.2. Tensile strength

The tensile testing equipment used in the experimental study is shown in Fig. 5. Three test pieces were removed from the stock, each measuring 9 mm in diameter and 45 mm in gauge length. The dimensions of the tensile specimens are shown in Fig. 3 and 4. The tensile test specimens were machined to the required standards using the universal lathe machine.

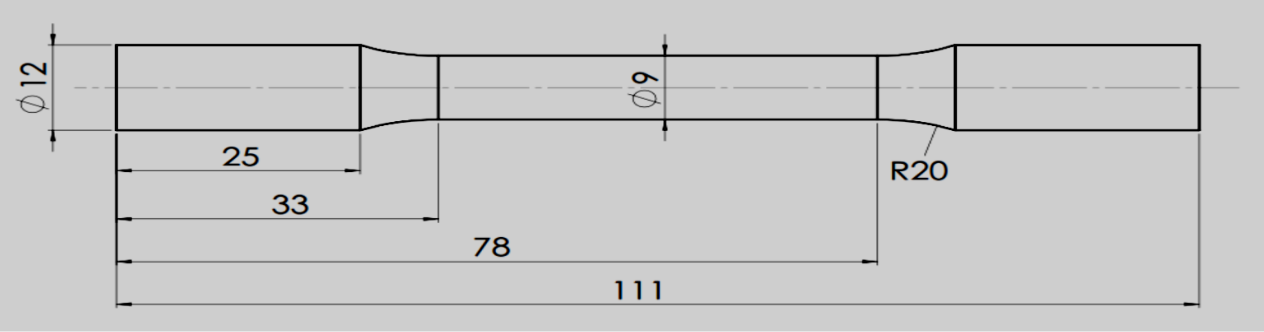

**Fig. 3:** The dimensions of the tensile testing specimen in relation to ASTM E8-09 [1].

**Fig. 4:** The tensile test specimen

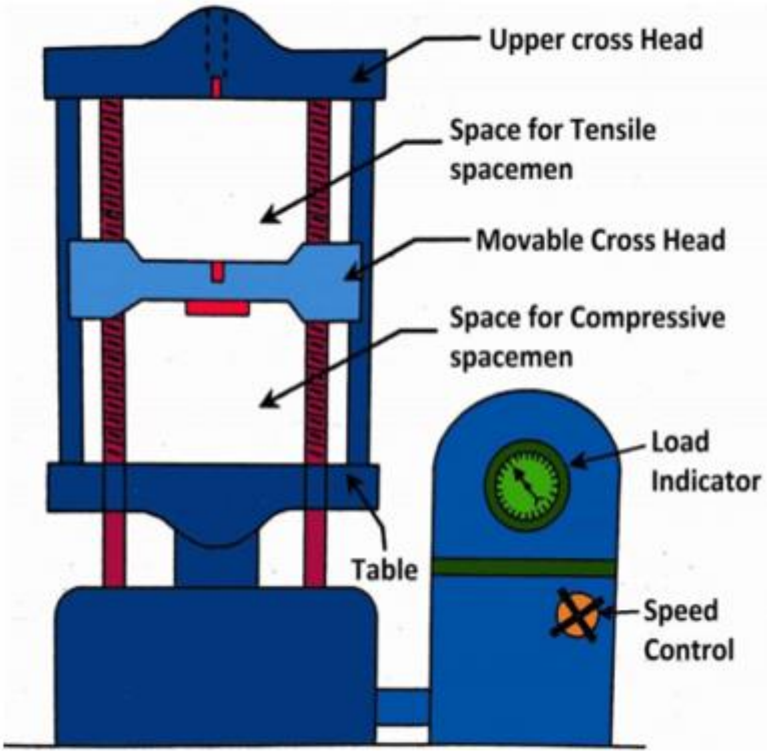

**Fig. 5:** Universal testing machine

### 2.4.3 Evaluation for tensile strength

The samples developed from thermoplastics and scrap metals were evaluated for their mechanical strength (tensile strength) according to Equation (1).

$$Tensile\ Strength = \frac{\text{Maximum Load}}{\text{Original Cross−Sectional Area}} \quad (1)$$

### 2.4.4. Shear modulus

This referred to the ratio of shear stress-to-shear strain. This was used to determine how resistant the developed thermoplastic and scrap metal material is as regards to shearing deformation. It was observed that the higher the stiffness of the developed materials, the higher the shear modulus, In other words, the deformation only occured when a strong force was applied. The shear modulus was calculated using Equation (2).

$$\text{shear modulus} = \frac{\text{shear stress}}{\text{shear strain}} \quad (2)$$

$$\text{shear modulus, G} = \frac{\frac{F}{A}}{\frac{\Delta x}{l}}$$

where G is the shear modulus or modulus of rigidity, $\tau_{xy}$ is the shear stress, $\gamma_{xy}$ is the shear strain, A is the area over which the force acts, Δx is the transverse displacement, l is the initial length

### 2.4.5 Modulus of elasticity

The elastic modulus of a substance is a gauge of stiffness. In this test, force was applied to the material, and the outcomes are recorded. Equation (3) was used to compute the modulus of elasticity.

$$\text{Modulus of Elasticity} = \frac{\text{stress applied}}{\text{elastic strain}} \quad (3)$$

### 2.4.6 Percentage of water absorption

The specimens were dried in an oven for a predetermined amount of time and temperature before being put in a desiccator to cool. A Meter balance was used for the water absorption test. The specimens are weighed as soon as they have cooled. The substance is subsequently submerged in water at the predetermined temperature, typically 23 °C, for 24 hours or until equilibrium. After being taken out, specimens are weighed after being dried with a lint-free cloth. To calculate the percentage of water absorption (PWA), Equation (4) was utilized.

$$\mathrm{PWA} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} X 100\% \qquad (4)$$

## 3. Results

Tables 2 to 5 show the measured values of tensile strength, shear modulus, hardness, and modulus of elasticity of smelted metals, while Table 6 shows average mechanical properties of recycled metals. Figure 6 shows the average mechanical properties of recycled metals.

**Table 2:** Measured values of tensile strength of smelted/ recycled metals

| **Experiment No.** | **Tensile Strength (MPa)** | | | | |
|---|---|---|---|---|---|
| | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | 45.5 | 46.7 | 47.0 | 46.0 | 45.8 |
| 2 | 44.4 | 45.8 | 46.3 | 46.3 | 45.8 |
| 3 | 45.8 | 45.3 | 46.0 | 46.0 | 45.3 |
| 4 | 45.3 | 44.9 | 45.9 | 45.9 | 44.9 |
| 5 | 44.9 | 46.3 | 46.5 | 46.5 | 45.8 |
| 6 | 45.7 | 46.0 | 46.8 | 45.8 | 45.5 |
| 7 | 44.6 | 45.9 | 46.3 | 45.3 | 44.4 |
| 8 | 44.8 | 46.5 | 46.0 | 44.9 | 45.8 |
| 9 | 45.2 | 46.8 | 46.3 | 45.8 | 45.3 |
| 10 | 45.5 | 45.5 | 46.3 | 46.3 | 45.5 |
| Mean | 45.17 | 45.97 | 46.34 | 45.88 | 45.41 |

**Table 3:** Measured values of shear modulus of smelted/ recycled metals from five selected dump site

| **Experiment No.** | **Shear Modulus of Smelted Metals (1x10$^{3}$MPa)** | | | | |
|---|---|---|---|---|---|
| | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | *50.0* | 50.2 | 51.0 | 50.7 | 50.2 |
| 2 | 49.4 | 49.5 | 51.5 | 48.8 | 49.5 |
| 3 | 49.8 | 48.8 | 50.8 | 50.2 | 48.8 |
| 4 | 48.9 | 49.6 | 50.9 | 49.5 | 50.8 |
| 5 | 50.2 | 50.8 | 50.9 | 48.8 | 50.9 |
| 6 | 49.5 | 50.2 | 48.8 | 49.6 | 50.9 |
| 7 | 48.8 | 50.2 | 49.6 | 50.8 | 49.4 |
| 8 | 49.6 | 49.5 | 50.8 | 48.8 | 49.8 |
| 9 | 50.8 | 48.8 | 50.2 | 49.6 | 48.9 |
| 10 | 49.3 | 48.8 | 48.8 | 50.8 | 49.4 |
| Mean | 49.63 | 49.64 | 50.33 | 49.75 | 49.06 |

**Table 4:** Measured values of Brinell hardness number of recycled metals

| **Experiment No.** | **Brinell Hardness Number (kgf)** | | | | |
|---|---|---|---|---|---|
| | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | 154.5 | 171.0 | 160.0 | 158.0 | 157.0 |
| 2 | 153.5 | 165.0 | 162.0 | 159.0 | 155.5 |
| 3 | 152.4 | 163.0 | 164.0 | 156.0 | 157.8 |
| 4 | 153.5 | 164.0 | 160.0 | 157.0 | 157.5 |
| 5 | 155.5 | 170.0 | 163.0 | 155.5 | 153.5 |
| 6 | 151.5 | 168.0 | 162.0 | 157.8 | 152.4 |
| 7 | 152.5 | 169.0 | 164.0 | 157.5 | 157.5 |
| 8 | 151.6 | 167.0 | 164.0 | 154.3 | 155.5 |
| 9 | 153.5 | 164.0 | 160.0 | 156.1 | 154.3 |
| 10 | 152.5 | 169.0 | 164.0 | 154.3 | 157.5 |
| Mean | 153.1 | 167.0 | 162.3 | 156.55 | 141.85 |

**Table 5:** Measured values of modulus of elasticity of recycled metals

| | **Modulus of Elasticity (GPa)** | | | | |
|---|---|---|---|---|---|
| **Experiment No.** | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | 1.43 | 1.50 | 1.32 | 1.47 | 1.60 |
| 2 | 1.32 | 1.60 | 1.38 | 1.44 | 1.55 |
| 3 | 1.38 | 1.55 | 1.44 | 1.47 | 1.50 |
| 4 | 1.44 | 1.50 | 1.47 | 1.32 | 1.32 |
| 5 | 1.47 | 1.45 | 1.44 | 1.38 | 1.38 |
| 6 | 1.44 | 1.40 | 1.60 | 1.44 | 1.44 |
| 7 | 1.47 | 1.48 | 1.55 | 1.55 | 1.47 |
| 8 | 1.46 | 1.52 | 1.50 | 1.50 | 1.46 |
| 9 | 1.52 | 1.53 | 1.45 | 1.45 | 1.52 |
| 10 | 1.48 | 1.52 | 1.49 | 1.44 | 1.48 |
| Mean | 1.441 | 1.505 | 1.464 | 1.446 | 1.472 |

**Table 6:** Average mechanical properties of recycled metals

| Serial Number | Mechanical Properties Metal | Batch A | Batch B | Batch C | Batch D | Batch E |
|---|---|---|---|---|---|---|
| 1 | Mean Tensile Strength (MPa) | 45.17 | 45.97 | 46.34 | 45.88 | 45.41 |
| 2 | Mean Shear Modulus (MPa) | 49.63 | 49.64 | 50.33 | 49.75 | 49.06 |
| 3 | Mean Brinell Hardness Number (Kgf) | 153.1 | 167.0 | 162.3 | 156.55 | 141.85 |
| 4 | Mean Modulus of Elasticity (GPa) | 1.441 | 1.505 | 1.464 | 1.446 | 1.472 |

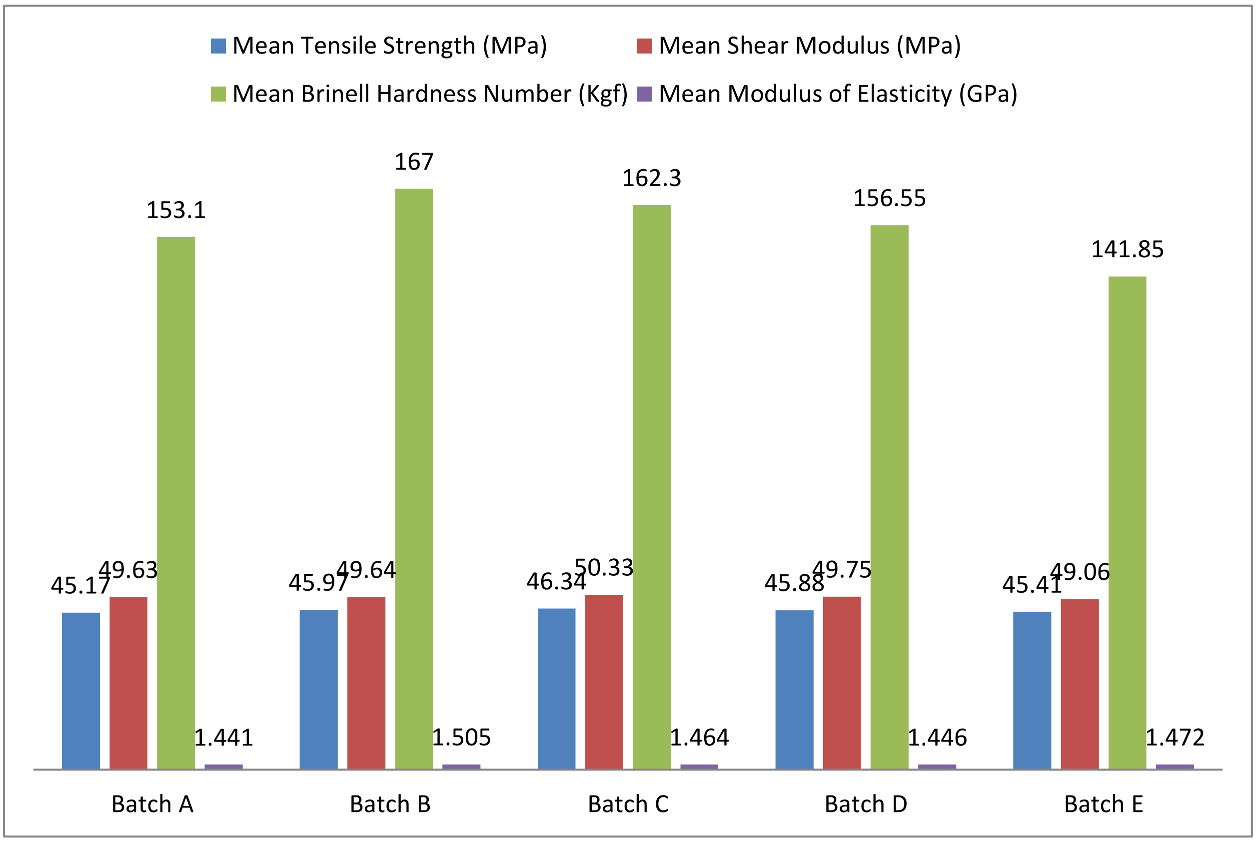

**Fig. 6:** Average mechanical properties of recycled metals

Tables 7 to 10 show the measured values of tensile strength, hardness, modulus of elasticity and percentage of water absorption of developed thermoplastics from waste, while Table 11 shows average mechanical properties of recycled thermoplastics. Figure 6 shows the average mechanical properties of recycled thermoplastics

**Table 7:** Measured values of tensile strength of the recycled thermoplastics

| **Experiment No.** | **Tensile Strength (MPa)** | | | | |
|---|---|---|---|---|---|
| | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | 42.0 | 45.6 | 43.4 | 45.7 | 42.9 |
| 2 | 42.6 | 46.3 | 43.8 | 45.3 | 42.8 |
| 3 | 43.8 | 44.7 | 43.9 | 45.9 | 42.3 |
| 4 | 39.9 | 45.8 | 42.9 | 45.1 | 42.6 |
| 5 | 41.8 | 46.0 | 43.7 | 45.8 | 42.7 |
| 6 | 41.5 | 44.9 | 43.0 | 45.6 | 41.9 |
| 7 | 42.5 | 44.6 | 43.5 | 45.3 | 42.4 |
| 8 | 43.0 | 45.2 | 43.1 | 44.9 | 42.6 |
| 9 | 40.8 | 45.8 | 43.6 | 44.7 | 42.5 |
| 10 | 40.9 | 44.6 | 43.5 | 45.3 | 42.4 |
| Mean | 41.88 | 45.35 | 43.44 | 45.36 | 42.51 |

**Table 8:** Measured values of young modulus of the recycled thermoplastics

| **Experiment No.** | **Young Modulus (GPa)** | | | | |
|---|---|---|---|---|---|
| | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | 2.0 | 2.2 | 2.4 | 2.0 | 2.4 |
| 2 | 2.2 | 2.1 | 2.1 | 1.8 | 2.0 |
| 3 | 2.4 | 2.0 | 1.9 | 1.7 | 2.4 |
| 4 | 2.0 | 2.4 | 2.2 | 2.2 | 2.1 |
| 5 | 1.8 | 2.1 | 2.0 | 2.4 | 1.9 |
| 6 | 1.7 | 1.9 | 1.8 | 2.4 | 2.2 |
| 7 | 1.9 | 2.2 | 1.7 | 2.0 | 2.0 |
| 8 | 2.5 | 2.3 | 2.2 | 1.8 | 1.8 |
| 9 | 2.1 | 2.1 | 2.4 | 2.2 | 1.7 |
| 10 | 2.2 | 2.4 | 1.9 | 2.1 | 2.0 |
| Mean | 2.08 | 2.17 | 2.06 | 2.06 | 2.05 |

**Table 9:** Measured values of Brinell hardness number of the recycled thermoplastics

| **Experiment No.** | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
|---|---|---|---|---|---|
| 1 | 45.6 | 46.1 | 46.1 | 45.8 | 46.0 |
| 2 | 45.2 | 46.2 | 46.2 | 45.7 | 46.2 |
| 3 | 45.3 | 45.8 | 45.8 | 46.0 | 45.5 |
| 4 | 45.8 | 45.7 | 45.7 | 44.9 | 44.8 |
| 5 | 45.7 | 45.1 | 45.1 | 45.0 | 45.4 |
| 6 | 46.0 | 46.0 | 46.0 | 45.1 | 46.0 |
| 7 | 44.9 | 46.2 | 46.1 | 45.8 | 46.2 |
| 8 | 45.0 | 45.5 | 46.2 | 45.7 | 45.5 |
| 9 | 45.1 | 44.8 | 45.8 | 46.0 | 44.8 |
| 10 | 45.4 | 45.4 | 45.7 | 44.9 | 45.4 |
| Mean | 45.4 | 45.68 | 45.87 | 45.49 | 45.58 |

**Table 10:** Measured values of percentage of water absorption in plastics of the recycled thermoplastics (% weight)

| Experiment No. | **Percentage of Water Absorption (%)** | | | | |
|---|---|---|---|---|---|
| | **Batch A (Site 1)** | **Batch B (Site 2)** | **Batch C (Site 3)** | **Batch D (Site 4)** | **Batch E (Site 5)** |
| 1 | 0.24 | 0.45 | 0.30 | 0.52 | 0.45 |
| 2 | 0.20 | 0.46 | 0.32 | 0.50 | 0.46 |
| 3 | 0.35 | 0.48 | 0.33 | 0,51 | 0.46 |
| 4 | 0.23 | 0.47 | 0.30 | 0.48 | 0.47 |
| 5 | 0.25 | 0.50 | 0.35 | 0.49 | 0.49 |
| 6 | 0.40 | 0.39 | 0.36 | 0.47 | 0.48 |
| 7 | 0.36 | 0.45 | 0.34 | 0.49 | 0.47 |
| 8 | 0.38 | 0.46 | 0.33 | 0,43 | 0.50 |
| 9 | 0.39 | 0.46 | 0.37 | 0.44 | 0.49 |
| 10 | 0.36 | 0.41 | 0.38 | 0.42 | 0.43 |
| **Mean** | **0.316** | **0.453** | **0.338** | **0.475** | **0.47** |

**Table 11:** Average mechanical properties of recycled thermoplastics

| **Serial Number** | **Mechanical Properties Metal** | **Batch A** | **Batch B** | **Batch C** | **Batch D** | **Batch E** |
|---|---|---|---|---|---|---|
| 1 | Mean Tensile Strength (MPa) | 41.88 | 45.35 | 43.44 | 45.36 | 42.51 |
| 2 | Mean Modulus of Elasticity (MPa) | 2.08 | 2.17 | 2.06 | 2.06 | 2.05 |
| 3 | Mean Brinell Hardness Number (Kgf) | 45.4 | 45.68 | 45.87 | 45.49 | 45.58 |
| 4 | Percentage of Water Absorption (%) | 0.316 | 0.453 | 0.338 | 0.475 | 0.47 |

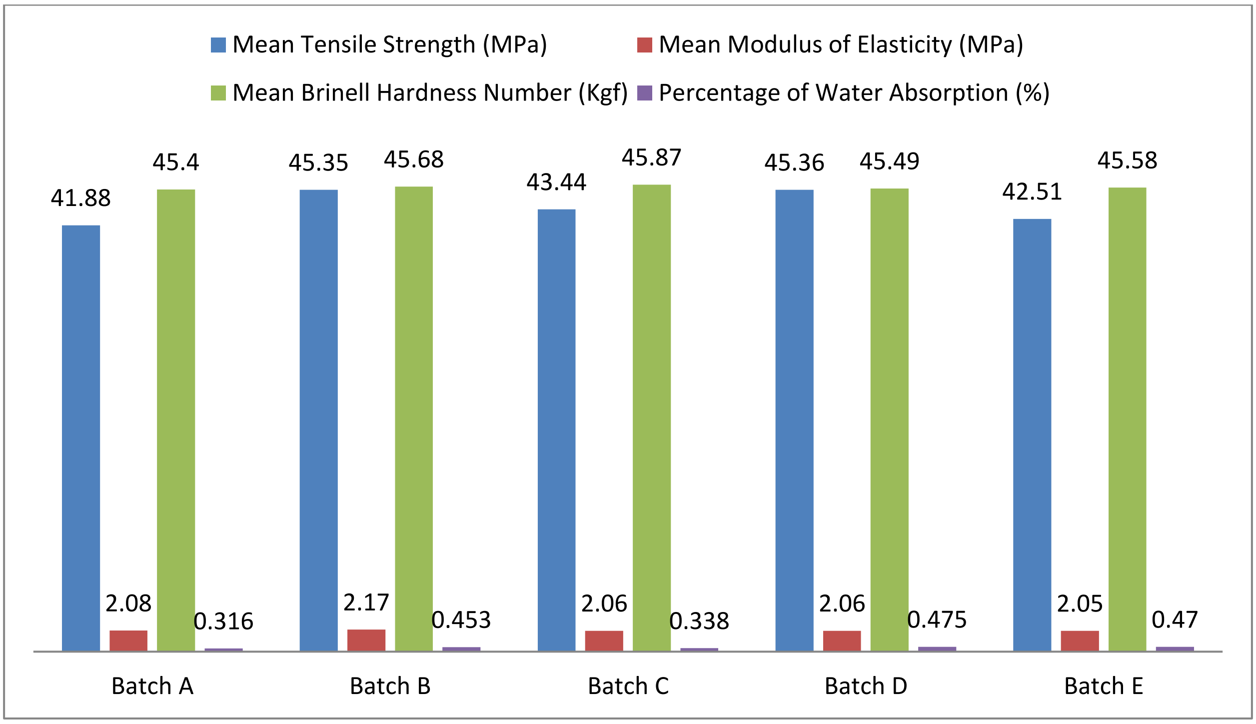

**Fig. 7:** Average mechanical properties of recycled thermoplastics

## 4. Discussion

In this study, reduction of waste was made possible through waste management approach whereby non-biodegradable solid waste was sorted out as scrap metals and thermoplastics. Among the recyclable resources in the Benin metropolitan region are metals and plastics. The waste was gathered and transferred to a manufacturing facility where it was processed and made into a new product in order to be recycled. These materials were evaluated for mechanical properties such as tensile strength, shear modulus, hardness and modulus of elasticity for smelted metals. Also, the melted thermoplastics were evaluated for mechanical properties such as tensile strength, hardness, modulus of elasticity and percentage of water absorption. After evaluation of mechanical properties of samples from melted thermoplastics and smelted scrap metals, products were developed from these non-biodegradable solid wastes. Some of the applications of developed thermoplastics include roofing tiles, concrete structures, indoor insulations, structural lumbers, PVC windows, building Bricks, fences, floor tiles, and Carpeting. The values obtained from Tables 2 to 6 show that average tensile strength, shear modulus, Brinell hardness number, and modulus of elasticity were 45.754MPa, 49.682x$10^3$MPa, 156.15kgf, 1.4656GPa respectively for smelted/recycled scrap metals. Furthermore, the values obtained from Tables 7 to 10 show that average tensile strength, modulus of elasticity, Brinell hardness number, and percentage of water absorption were 43.708MPa, 2.084GPa, 45.604kgf and 0.410% respectively for recycled thermoplastics. The values obtained in this study were slightly different from the standard values obtained from pure metals and thermoplastics (Osaremwinda and Olodu, 2015; Olodu and Erameh, 2023). This was due to the combination of different metals in the developed metal from scrap metals and different thermoplastics in the produced plastic. In this study, it was observed that the Benin Metropolitan Area's present waste management methods are still focused on the idea of collection and disposal. In close proximity to the City borders, unsorted wastes were dumped in an unregulated landfill. Raising public awareness of the value of fostering a healthy environment, as well as introducing mechanisms to control the generation of solid waste and provide alternative means of disposal are important first steps toward an effective solid waste management policy. According to Babayemi and Dauda (2009) noted that reducing trash at the source is the easiest strategy to solve the waste management issue, they were able to suggest the way waste can be reduced, hence they produced a recycled thermoplastics with tensile strength of 38.50MPa. This value obtained is in agreement with the result obtained in this study.

## 5. Conclusion

The study on the mechanical properties of alloys and thermoplastic composites derived from non-biodegradable municipal solid waste has been achieved. The battle against non-biodegradable garbage is never-ending, as its challenges grow daily. Only by educating people and influencing their attitudes about non-biodegradable garbage will this be possible or through recycling approach. The mechanical characteristics of the goods produced from waste thermoplastics and waste metals were consistent in terms of strength and quality. The recycled materials provide opportunities for a multitude of products which are used extensively in the construction and manufacturing industry and hence finds application in infrastructure development.

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