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PERFORMANCE COMPARISON OF RIBBED STEEL BARS PRODUCED FROM RECYCLED SCRAP AND IRON ORE

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Abstract: Solid wastes which are often regarded as the third pollutant after air and water are wastes which arise from various human activities and are normally discarded as useless or unwanted. Recycling of these wastes, especially metals, which are non-biodegradable becomes necessary. In an attempt to control environmental pollution and produce raw materials for further use, metallic scraps, which can be found virtually everywhere is considered for recycling in this work. The study carried out a comparative analysis of the mechanical properties of ribbed bars made from recycled steel material and iron ore. Metal scraps were collected, melted and formed into ribbed bars. Ribbed bar made from steel produced from the ore was used as a control experiment to serve as basis for comparison. The results showed that the rib bars produced recycled steel have a tensile strength, hardness and impact strength of 604.4 N/mm^2, 174 Hz and 30.4 ft/pounds respectively; while the one produced from the ore has a tensile strength, hardness and impact strength of 728.3 N/mm^2, 189 Hz and 33.0 ft/pounds respectively. This shows that the recycled steel has appreciable mechanical properties when compared to the steel produced from the ore, which qualifies it for use in many engineering applications.

Keywords: metal, waste, ribbed bars, mechanical properties, recycle steel

INTRODUCTION

Steel, certainly an indispensable material of the modern technology driven society (Javaid et al., 2022; Janke et al, 2000) is a significant component of municipal solid waste after failing from service (Raphela et al., 2024; Zhang et al., 2024; Adedara et al., 2023; Abiola, 2023). Average of 70% of the tonnage of steel end products will turn waste, 20 years after the manufacturing (Conejo et al., 2020; Schoeman et al., 2021; Kanyilmaz et al., 2023). These materials are removed from their respective engine component as a part or assembly, which is then dumped as a waste or scrap (Diener and Tillman, 2016; Ogbimi, 2007).

Managing solid wastes has been a major challenge in Nigeria. Solid wastes are frequently disposed along the streets, gutters, drainage channels, rivers and abandoned plots of land (Ebikapade and Baird, 2016). Mainwhile, poor waste disposal has been linked to blockage of gutters and other drainage channels causing flood, poor aesthetics, release of foul odour and greenhouse gases, obstruction of traffic flow and pollution of surface and ground water (Simon-Oke and Fadoju, 2025; Ohimain, 2013). Steel which has the widest industrial application can be awfully toxic to the surrounding environment. Exposed metal waste, breaks down over time, forming metal salts which can affect water quality and aquatic organisms (Singh et al., 2024; Oladimeji et al., 2024; Aziz et al., 2023; Sharma et al., 2022; Sridhar and Hammed, 2014).

Recycling is key, given that it reduces the need for resource extraction, typically requires far less energy consumption than when processing steel produced from the ore, and results in lower emissions and other environmental impacts (Harvey, 2021; Bowyer et al., 2015; Ko et al., 2015). Recycling on the other hand, is considered an effective way of waste management with its expanded benefit of resources conservation, avoidance of fresh raw material exploitation and in reducing undesired influence on the environment (Christopher, 2011). It has significant savings in greenhouse gas emissions as opposed to the mining and processing of raw materials and conserve space in land filling sites (Edet and Maduabuchi, 2019; Ohimain, 2013). Thankfully, it is ideal for recovery and recycling due to their chemical makeup and high market value (Damuth, 2010; Wernick and Themelis 1998).

While scrap metal can be considered as a renewable resource, the mineral resources they are produced from are non-renewable as their supply is finite. Consequently, the paper seeks to produce ribbed bars from recycled steel and then compare with ribbed bar made from iron ore. This was with a view to controlling the impact of scrap metals on the environmental pollution and produce raw materials for further use.

EXPERIMENTAL SETUP

▦ Materials and sources

Ferrous steel metal scraps, scavenged from the surrounding were used for the experiment. Finished ribbed bars were sourced from the Universal Steel Limited located at Universal Steel Crescent, off

Surulere Industrial Road, *Ogba*-scheme Lagos. The company is a manufacturer of reinforcement bars such as ribbed bars, round bars and angle bars with different specifications.

Steel preparation

Non-ferrous metal scraps were sorted from the ferrous metal scraps using magnetic separation method to ensure homogeneity and ascertain the quality of ribbed bars made from recycle steel. The non-ferrous steel scrap was charged into the charging pit and fired at a temperature of about 1600°C in the presence of oxygen; ferrosilicon, which prevent loss of carbon from molten steel; ferromanganese, which is use as low carbon ladle additive; pulverized coke, which act as auxiliary reducing agent and limestone, which act as slag formers. The molten steel was delivered into the continuous casting machine (CCM) to avoid splashing and give smoother flow, through the turn-dish with the aid of cooling water, which resulted in production of billets and was allowed to solidify.

Spectrochemical analysis

Spectrochemical analysis of the recycled metal was investigated to identify the elemental constituents of ribbed bars produced from the scrap. A scoop of molten scrap metal was poured into a mould and allowed to solidify. The surfaces of the solidified sample were grinded to a fine surface finish on a grinding machine (metallic lustre). After then, it was placed in a Spectrochemical Metal Analyzer, which is powered by argon gas and operates at a temperature of about 30°C. The grinded surface was allowed to fill the cavity of the machine and the machine was then switched on. The individual elemental concentration was displayed on the monitor connected to the machine, and the reading was printed. The procedure was repeated for the billets made from ore and the result compared with the result of recycled metal.

Materials and mechanical properties test

Three replicates of different materials and mechanical property tests such as stress, strain, Young's modulus, yield stress, tensile strength, percentage elongation, hardness and impact test were carried out on specimen made from both ore and recycled steel. The test pieces were machined into recommended test sample and dimension as shown in Figure 1. The ribbed bar made from ore was designated sample A and the one made from recycled material was marked sample B. The machining was carried out on a Lathe machine to standard test samples dimension using different machining operation such as facing and turning.

Material property test

The material property tests such as tensile stress, strain, Young's modulus, yield stress, tensile strength and percentage of elongation were carried out on samples A, produced from iron ore and B, produced from recycled steel; using Hounds Field Tensometer (HFT). On the HFT, the test samples were clamped one after the other at their edges and a known mass of 2000kg was attached to the pulling rod and with a graph sheet attached to the drum of the autographic recorder and the mercury was set to zero.

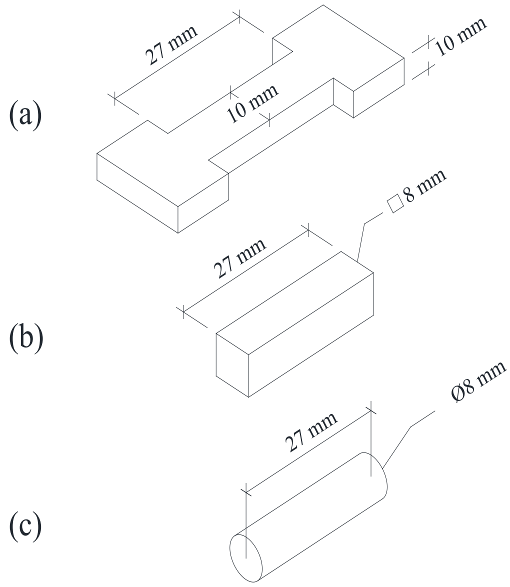

Figure 1. (a) Tensile test piece (b) Hardness test piece (c) Impact test piece

The machine was switched on and the specimen was pulled until fracture occurred. The final gauge length and cross-sectional diameter were measured with the aid of a Vernier calliper and various material property tests were calculated using Eqs 1 to 6.

$$\sigma = \frac{F}{A} \tag{1}$$

$$\varepsilon = \frac{l_f - l_o}{l_o} \tag{2}$$

$$E = \frac{\sigma}{\varepsilon} \tag{3}$$

$$\sigma_y = \frac{F_y}{A} \tag{4}$$

$$TS = \frac{F_f}{A} \tag{5}$$

$$E\% = \frac{l_f - l_o}{l_o} \times 100\% \tag{6}$$

where σ is the tensile stress, in kN/mm^2; ε is the strain; E is the young modulus, in kN/mm^2; σ_y is the yield stress, in N/mm^2; *TS* is the tensile strength, in N/mm^2 and *E*is the percentage elongation; *F* is the maximum load applied, in Newton; F_y is the yield load, in N; F_f is the load at fracture, in N; l_f is the final length, in mm; l_o is the original length, in mm and *A* is the cross sectional area, in mm^2 (U.S. Naval. Academy, 2025).

- **Hardness test**

This test was carried out using Brinell hardness test method. The specimen was polished after it was machined as shown in Figure 1(b)and placed in the assembled HFT, which consist of one compression die and Brinell ball bolster. The mercury was adjusted to zero and polished surface was placed against the Brinell ball. The handle was turned until the mercury reached 750kg and this was maintained for 15 seconds to ensure the desired mark was impressed. The sample was then removed and with impression made on the surface. The diameter of the impression was measured with the aid of a Brinell reading microscope and the value of the readings was translated on the corresponding Brinell hardness number.

- **Impact strength test**

Impact test was carried out on test samples shown in Figure 1(c) using the Izod test method. The sample was placed on the impact-testing machine in a vertical position as a cantilever. The striker of the pendulum was then set into motion to hit the specimen with a kinetic energy of 162.72J and at a velocity of 3.8m/s. The Izod values, expressed in Foot - pounds were then measured.

RESULTS AND DISCUSSION

The result presented in Table 1 show that the carbon which is the primary hardening element in steel (Kassim et al., 2021) is nearly identical in both samples, 0.3494% and 0.3461% for ribbed bars produced from iron ore and recycled steel respectively. Such similarity suggests comparable baseline strength and hardness between the two samples. As suggested by Bruhis and McDermid (2014), higher carbon content in sample A is likely responsible for the increased tensile strength as reflected in Table 2, but may reduce ductility. The comparable carbon content suggests that differences in mechanical properties between the samples shown in Table 3 are likely due to other alloying elements.

Table 1. Elemental composition of the samples.

Elements	Iron ore (Samples A) (wt.%)	Recycled steel (Samples B) (wt.%)
Carbon (C)	0.3494	0.3461
Silicon (Si)	0.1740	0.2197
Sulfur (S)	0.0141	0.0374
Phosphorus (P)	0.0065	0.0516
Manganese (Mn)	0.6933	0.7466
Nickel (Ni)	0.0919	0.1376
Chromium (Cr)	0.0514	0.1233
Molybdenum (Mo)	0.0143	0.0263
Copper (Cu)	0.2182	0.1592
Tin (Sn)	0.2388	0.0161
Colbalt (Co)	0.0085	0.0114
Aluminum (Al)	0.0100	0.0024
Calcium (Ca)	0.0003	0.0001
Zinc (Zn)	0.0024	0.0028
Iron (Fe)	98.1223	98.1136

Table 2. Material properties

Tests	Samples A	Samples B
Tensile stress, σ(kN/mm^2)	1.02	1.02
Strain, ε	0.190	0.203
Young modulus, E(kN/mm^2)	5.37	5.03
Yield stress, σ_y(N/mm^2)	712.83	590.63
Tensile strength, TS(N/mm^2)	743.38	612.18
Percentage Elongation, $E\%$ (%)	19.0	20.4

Table 3. Mechanical properties

Tests	Samples A	Samples B
Impression	21.9mm	22.8 mm
Hardness	189 Hz	174 Hz
impact strength	33 ft-pound	30.4 ft-pound

Silicon which acts as a deoxidizer and strength enhancer is 0.1740% in Sample A and 0.2197% in Sample B as shown in Table 1. Higher silicon content in Sample B may lead to improved strength and corrosion resistance, albeit with a potential reduction in ductility as explained by Guo et al. (2022). The increased silicon in Sample B may contribute to its slightly higher elongation percentage (20.4% vs. 19.0%) in Table 2 by promoting a more uniform distribution of carbon, thereby enhancing ductility.

Sulfur and phosphorus are prevalent in ribbed bars produced from recycled steel (0.0374% and 0.0516%) compared to those from iron ore (0.0141% and 0.0065%) respectively. While Sulfur and Phosphorus can enhance machinability, they are generally considered impurities that can adversely affect toughness and ductility (Huseynov et al., 2025). Elevated sulfur and phosphorus levels are known to cause embrittlement and reduce impact strength, particularly at low temperatures (Dong et al., 2022; Xiao et al., 2011). High sulfur content can cause hot shortness, leading to cracks during hot working, while phosphorus can increase strength but at the expense of ductility and toughness (Huseynov et al., 2025). The elevated levels in Sample B may contribute to its lower yield stress (590.63 N/mm^2) and tensile strength (612.18 N/mm^2) compared to Sample A as shown in Table 2.

Table 1 show that manganese is slightly higher in Sample B (0.7466%) when compare to Sample A (0.6933%). Manganese improves hardenability and tensile strength and counteracts the adverse effects of sulfur by forming manganese sulfides, which are less harmful than iron sulfides (Jacob et al., 2020). The higher manganese content in Sample B may help mitigate the negative impacts of its higher sulfur content, contributing to its acceptable elongation percentage.

Nickel and chromium are both higher in Sample B (0.1376% and 0.1233%) compared to Sample A (0.0919% Ni and 0.0514% Cr) as shown in Table 1. These elements enhance toughness, corrosion resistance, and high-temperature strength (Ibrahim et al., 2025). The increased nickel and chromium in Sample B contributes to improved ductility and corrosion resistance (Gupta et al., 2023); which may be responsible for the higher elongation percentage in Table 2 and impact strength (30.4 ft-pound) in Table 3, despite its lower tensile strength (Ibrahim et al., 2025; Xiao et al., 2011).

Table 1 show that molybdenum is present at 0.0263% in Sample B and 0.0143% in Sample A. Molybdenum enhances strength, hardenability, and resistance to corrosion, particularly at high temperatures (Ibrahim et al., 2025). As described by Hu et al. (2009) the presence of molybdenum in Sample B may contribute to the material's overall toughness and resistance to deformation under stress as depicted in Table 2. Meanwhile Table 1 revealed that Copper is higher in Sample A (0.2182%) than in Sample B (0.1592%). Copper can improve corrosion resistance and strength. As explained by Abbasi et al. (2017) the higher copper content in Sample A may contribute to its superior tensile strength (743.38 N/mm²) and yield stress (712.83 N/mm²) as shown Table 2.

As shown in Table 1, Tin is significantly higher in Sample A 0.2388% when compare to Sample B. While tin can enhance corrosion resistance, excessive amounts may lead to embrittlement (Lin et al., 2025). The high tin content in Sample A may contribute to its increased hardness (189 Hz) and impact strength (33 ft-pound) as shown in Table 3, but it could also make the material more brittle (Wang et al., 2024).

Cobalt (Co), Aluminum (Al), Calcium (Ca), and Zinc (Zn) are present in trace amounts in both samples as shown in Table 1, with slight variations that are unlikely to have a significant impact on the overall properties of the steels as described by Sun et al. (2025). Cobalt can improve strength at high temperatures, aluminum acts as a deoxidizer, calcium can improve hot workability, and zinc is generally considered an impurity. Their low concentrations suggest minimal impact on the overall mechanical properties of the samples. Iron (Fe) constitutes the majority of both samples, with 98.1223% in Sample A and 98.1136% in Sample B, indicating that both are primarily composed of iron with alloying elements added to achieve desired properties (Zhang et al., 2025; Dong et al., 2022; Kassim et al., 2021; Boulifa and Ali, 2021).

The elemental differences between Samples A and B correlate with their mechanical properties. Sample A's higher copper and tin contents contribute to its superior tensile strength, yield stress, hardness, and impact strength (Reyes et al., 2023). However, these elements may also reduce ductility, as evidenced by its lower elongation percentage. Conversely, Sample B's higher silicon, nickel, chromium, and molybdenum contents enhance its ductility and corrosion resistance, reflected in its higher elongation percentage and acceptable impact strength, despite its lower tensile strength and yield stress (Song et al., 2025).

CONCLUSIONS

The elemental composition of steel significantly influences its mechanical and material properties. Ribbed bar produced from iron ore, with higher copper and tin contents, exhibits superior strength and hardness but reduced ductility. Meanwhile, ribbed bar produced from recycled steel are enriched with silicon, nickel, chromium, and molybdenum, demonstrates enhanced ductility and corrosion resistance, albeit with lower strength and hardness. These observations are crucial for selecting appropriate materials for specific engineering applications, balancing strength, ductility, and corrosion resistance requirements.

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