International Journal of Science, Engineering & Environmental Technology (IJOSEET), 1(6): 40-49, 2016
ISSN 0794-9650
www.repcomseet.org

Comparative Characterization Analysis of Aluminium Bars Produced from Aluminium Scraps

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Abstract- The full analysis and documentation of the physical, mechanical and microstructural analysis of four different aluminium bars produced from recycled four aluminium scraps which include: discarded aluminium gearbox casing, long span aluminium roofing sheet, aluminium cans and aluminium high-voltage cable, were presented in this study. These four items were randomly collected from different locations after which they were washed, compacted, cut, melted and cast into bars for the purpose of the analysis. The physical properties (mass, colour and density) of the selected aluminium materials were compared alongside with their mechanical properties such as microstructure, impact strength and hardness. The following results were obtained: aluminium high-voltage cable showed the highest density of 2.875 g/cm^3 while 2.5725, 2.5025 and 2.4983 g/cm^3 were obtained for cans, gear box casing and long span aluminium sheet respectively, The cans showed a bright silvery colour after casting while the gearbox showed dull silvery colour, deep yellowish silvery colour for high-voltage cable and faint yellowish silvery colour for the long span roofing sheet: high-voltage cable showed the highest impact strength and lowest hardness of 65.01 J and 137.79 BHN, respectively while 20.40 J and 382.39 BHN for gearbox, 27.20 J and 238.93 BHN for cans and 35.36 J and 159.49 BHN for long span roofing sheet, respectively. The results of this study will be useful when there is the need to select the aluminium scrap to be used for casting machine parts for different purposes. The gear box casing material will be most suitable where hardness is a priority.

Key words: Aluminium, physical properties, mechanical properties, microstructures, recycling and scraps

1. Introduction

In recent times, discarded aluminum parts have been used by industries and machinists for production and fabrication works. Making use of it has also been a way of recycling this waste into new parts, even though, it has been abandoned for sometimes and serves as both economic and industrial waste. In their discarded states, they are nuisance to the environment. Aluminum is best known for its light weight characteristics. When it is cold worked, the material strengthen becomes double. It does not oxidize quickly in air due to its microscopic oxide coating on the surface. Aluminum is the most widely used metal in the industries due to it light weight, malleability, and excellent corrosion resistance. It also exhibits a good strength-to-weight ratio for products manufactured using aluminum alloys, which have varying degree of hardness based on the alloy composition. Pure aluminum is used when corrosion resistance is more critical than strength in the end product. (All Metals and Forge Group, 2016). Aluminum is 100 percent recyclable. The metal can be melted down and reformed without losing any quality (Alupro, 2016). Accordingly, recycling 1 ton of aluminum saves 9 tons of CO_2 emissions. Making aluminum from raw materials is a complex process, however, once made the metal can be re-melted and reformed without losing any quality (IAI, 2009). The process can be repeated over and over again. Along with the energy savings, recycling aluminum saves around 95 percent of the greenhouse gas emissions compared to the "primary" production process (Alupro, 2016). Improving mechanical properties of alloys to suit different applications constitutes a major concern during fabrication. Hence, interests are growing in the use of aluminum based metal matrix with improved mechanical properties and wear resistance, especially in the transport industries where light weight and enhanced friction and wear performances are the key objectives. (kumar and Swamy, 2011)

The growing requirement of materials with high specific mechanical properties and weight savings characteristic has increased significant research activities in recent times focusing primarily on further development of aluminium based composites Alloys with distinctive properties such as high stiffness, high strength, significant toughness and low density have promoted an increasing number of applications in different areas (Asafa et.al , 2015).

2.0 General Aluminum Recycling

2.1 The Problem of Aluminium Scraps Management

Daily, very high volumes of aluminium wastes are generated through most of the numerous activities of men and these discarded materials are littered over the streets particularly in events prone areas. These discarded cans, utensils, roofing sheets, aluminium frames become breeding grounds for harmful insects and reptiles. Many have had to burn them as a means of disposal. This is economic wastage. This paper seeks to present a comparative study that reveals some characteristic qualities possessed by recycled aluminium materials from the discarded parts.

Information from these characteristic qualities becomes good source of information for material selection for certain production purposes. This study recycled four of these discarded materials and compared their physical, mechanical and microstructure compositions.

Hence, this study is both a waste-to-wealth project as well as a step towards the prevention of environmental pollution from the indiscriminate disposal of these aluminum scraps in the immediate environment.

2.2 Recycling

Recycling is an act of processing used materials (waste) into new, useful products and it is done to reduce the use of raw materials that would have been used. Recycling also aid the control of air, water and land pollution as it involves less energy use (Eschool, 2015). Using aluminium as the material to be recycled is more effective in order to control the environmental pollution because it is one of most discarded material in the environment and according to Alupro, (2016), it is 100 percent recyclable with no downgrading of its qualities: Re-melting of aluminium requires little energy: only about 5 percent of the energy required to produce the primary metal initially is needed in the recycling process.

2.3 Aluminium

According to Rusal, (2015), aluminium is a silvery-white metal, the 13 element in the periodic table. One surprising fact about aluminium is that it's the most widespread metal on Earth, making up more than 8% of the Earth's core mass. It's also the third most common chemical element on our planet after oxygen and silicon. (Rusal, 2015). Asafa et.al (2015) used snail shell to reinforce discarded aluminium materials. Several other authors like Barekar et.al (2009), PE (2010), and Arjunraj et.al (2015), have carried out varied studies on aluminium composite productions from aluminium scraps or ingots. Owoeye et.al (2012) studied a comparative analysis on aluminium plates in different concentrations of lime solution. Ibrahim et.al (2011) carried out their comparative analysis on aluminium welded joints, using SEM analysis. None of the above studies carried out the type of comparative study which this research work focused on.

2.3.1 Physical Properties of Aluminium

The major advantages of using aluminium are tied directly to its' remarkable properties. Some of these properties are outlined below:

1) Strength to weight ratio Aluminium has a density around one third that of steel and is used advantageously in applications where high strength and low weight are required. This includes vehicles where low mass results in greater load capacity and reduced fuel consumption (Aalco, 2016).
2) Corrosion resistance: A protective oxide coating is formed almost instantaneously when the surface of aluminium metal is exposed to air. This oxide layer is corrosion resistant and can be further enhanced with surface treatments such as anodizing (Aalco, 2016).
3) Electrical and thermal conductivity: Aluminium is an excellent conductor of both heat and electricity. The great advantage of aluminium is that by weight, the conductivity of aluminium is around twice that of copper. This means that aluminium is now the most commonly used material in large power transmission lines. The best alternatives to copper are aluminium alloys in the 1000 or 6000 series. These can be used for all electrical conduction applications including domestic wiring (Aalco, 2016).
4) Conductivity: Twice as good a conductor of heat and electricity as copper (based on weight), aluminium is now playing a major role in power transmission lines. (Constellium, 2016).
5) Reflectivity: As a reflector of heat and light, aluminium is suitable for such applications as solar technology and rescue blankets. (Constellium, 2016)
6) Recyclability: Aluminium is 100% and infinitely recyclable with no deterioration in quality (Constellium, 2016). Less energy is required for production of aluminium bars from recycled scraps than to produce the same volume of aluminium materials from raw materials.

2.3.2 Physical Metallurgy of Aluminium

Table 1 below illustrates some of the physical metallurgical properties of aluminium:

Table 1: Physical metallurgy of aluminium (Source: Tapany Udomphol, 2007)

Description	Specification
Density / specific gravity (g.cm^{-3} at 20^{o}C)	2.70
Melting point (^{o}C)	660
Specific heat at 100 ^{o}C, cal.g^{-1}k^{-1} (Jkg^{-1}k^{-1})	0.2241 (938)
Latent heat of fusion, cal.g^{-1} (kj.kg^{-1})	94.7 (397.0)
Electrical conductivity at 20^{o}C (% of international annealed copper standard)	64.94
Thermal conductivity (cal.sec^{-1}cm^{-1}k^{-1})	0.5
Thermal emissivity at 100 ^{o}F (%)	3.0
Reflectivity for light, tungsten filament (%)	90.0

2.4 Samples used in the study.

2.4.1 Aluminum cans

Aluminium cans are viewed as the most sustainable beverage package on virtually every measure. Aluminium cans have a higher recycling rate and more recycled content than competing package types. They are lightweight, stackable and strong, allowing brands to package and transport more beverages using less material. The types of aluminium cans used in this project are Maltina cans.

2.4.2 Aluminium roofing sheets

Aluminium sheets are available in a wide variety of alloys and they are roughly ⅓ the weight of mild steel, it is non-corrosive and can be formed easily. Sheets can be used for a wide range of applications from truck bodies in the transport industry to cladding and insulation in the building industry (Euro steel, 2001). Common widths of Aluminium sheets are 1000 mm, 1250 mm and 1500 mm. Common lengths are 2000 mm, 2500 mm and 3000 mm respectively (Euro steel, 2001).

The type of aluminium roofing sheet used is Tower span 150 type with the following specifications:

1) Curve crest
2) First smooth surface
3) Embossed surface
4) Six number of pitch
5) Single lap is 900mm
6) Double lap is 750 mm
7) Pitch of profile is 150 mm
8) Depth of profile is 32 mm (Tower, 2014).

2.4.3. Aluminium gear box casing

The transmission box which is also known as the gear box is the second element of the power train in an automobiles. It is used to change the speed and torque of the vehicle according to variety of road and load condition. The gearbox used is a Ford product.

2.4.4 Aluminium high voltage cable

High voltage cables are the backbones of electrical energy transmission and distribution. Technically, sophisticated high voltage cable solution is needed for both megacities and expansion of the power cable. (Siemens, 2015).

3.0 Materials and Methods

Sample materials used in this research include: Aluminium cans, Aluminium roofing sheets, Aluminium gear box casing, Aluminium high voltage cable.

3.1. Adopted procedures

The following procedures were adopted: collection, sorting, washing, drying, compacting, cutting, melting and casting.

3.1.1 Collection and Sorting

Out of seven different discarded aluminium materials gathered, the four above were selected based on their disparity and availability in our immediate environment. Sorting was carried out to remove unwanted metallic materials and dirt clinging to the selected materials samples.

3.1.2 Washing, Drying, Cutting and Compacting

Washing with water and soap solution to remove sand, dirt and oil stains on the samples were done manually, after which they were sun-dried. The maltina cans, and long span roofing sheets were compacted in a 2ton hydraulic press to ensure the lot fits into the crucible for melting, while the gear box casing and the high-voltage cable were cut and hammered into smaller bits fit for the crucible.

3.1.3 Melting and Casting

The melting was carried out in a pit furnace fired with used engine oil, atomised using a 2000 rpm blower. Heating rate were determined using the measured temperature variations and time. The temperatures were measured using a Pyrometer (range 100-1500^oC), the rectangular sample bars were designed to be 150x20x20mm. Four pieces of bars from each sample were produced and machined

The physical characteristics studied include: Mass, Colour and Density. Some of the tests carried out include: microstructural test, hardness test and impact test.

3.1.4 Mechanical Analysis of the Aluminum Bars

A portion of each bar was tested mechanically to find their various mechanical characteristics which include:

1) Microstructure test procedures:
    - Cutting and sectioning of the samples
    - Grinding (240, 320, 400 and 600 gut paper)
    - Polishing (Initial polishing using emery cloth + silicon Carbide powder (SiC) solution 1µm and final polishing using emery cloth + silicon Carbide powder (SiC) solution 0.5 µm)
    - Etching with 2% sodium hydroxide (NaOH)
    - Photography.

2) Hardness test procedures:

In Brinell tests, as in Rockwell measurements, a hard, spherical indenter is forced into the surface of the aluminum bars to be tested. The diameter of the hardened steel (or tungsten carbide) indenter is 10.00 mm (0.394 in). Standard loads range between 500 and 3000kg in 500-kg increments; during the test, the loads is maintained constant for a specified time (between 10 and 30s). The Brinell hardness number, BHN, is a function of both the magnitude of the load and the diameter of the resulting indentation this diameter is measured with a special low-power microscope, utilizing a scale that is etched on the eyepiece. The measured diameter is then converted to the appropriate BHN using a chart; only one scale is employed with this technique. Semiautomatic techniques for measuring BHN are available. These employ optical scanning systems consisting of a digital camera mounted on a flexible probe, which allows positioning of the camera over the indentation. Data from the camera are transferred to a computer that analyzes the indentation, determines its size, and then calculates the BHN. For this technique, surface finish requirements are normally more stringent than for manual measurements.

3) Impact test procedures:

The test is named after the English engineer EDWIN GIDERTIZOD [1876-1946] who described it in his 1903 address to the British association. Impact is a very important phenomenon in governing the life of a structure. An arm held at a specific height and a constant potential energy is released. The arm hit this sample and breaks it from the energy absorbed by the sample its impact strength is determined. (Azo, 2010).

4.0 Results and Discussions

4.1 Results of Physical Characteristics of Aluminium Bars

Heating rate analysis results: Temperature-time graph for each sample were plotted and compared as shown in Figures 1 to 4: The aluminium gear box casing, Maltina can and high-voltage cable showed better heating rate than that of the roofing sheet material. This could be as a result of impurities like paint on the sheets. It could also be due to compositional characteristics which will be revealed through further studies.

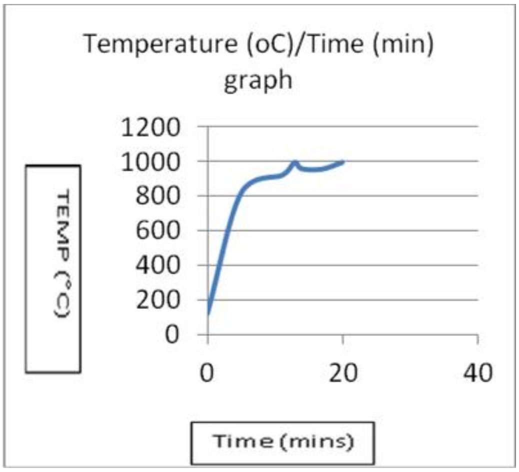


Fig.1: Melting temperature of Gearbox

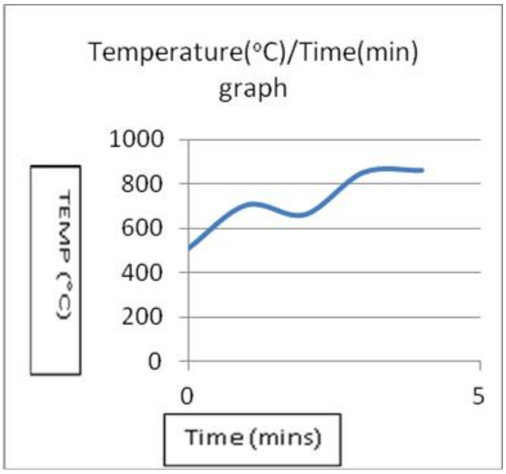


Fig. 2: Melting temperature of maltina can

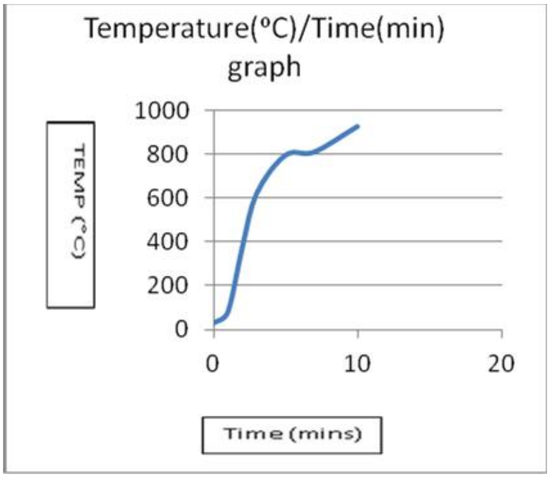


Fig..3: Melting temp of Al high-voltage cable

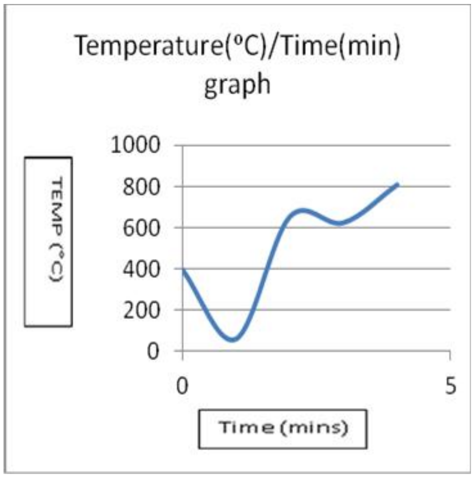


Fig. 4: Melting temp of Al roofing sheet

4.2 Colour Comparison

The resulted colour of the aluminium bars after casting were different from each other and are shown in the table 2 bellow: It was noticed that all the materials changes it colour to a pure silvery colour after machining, the Aluminium high voltage cable has a deep yellowish silvery colour on some area of it bars while the Aluminium roofing sheet has a faint yellowish colour on the entire surface of the bars.

4.3 Mass and Density Comparison

The Aluminium high-voltage cable is the densest while the aluminium roofing sheet is the least dense. The relationship between the mass and density of the materials are shown in the Table .1 below:

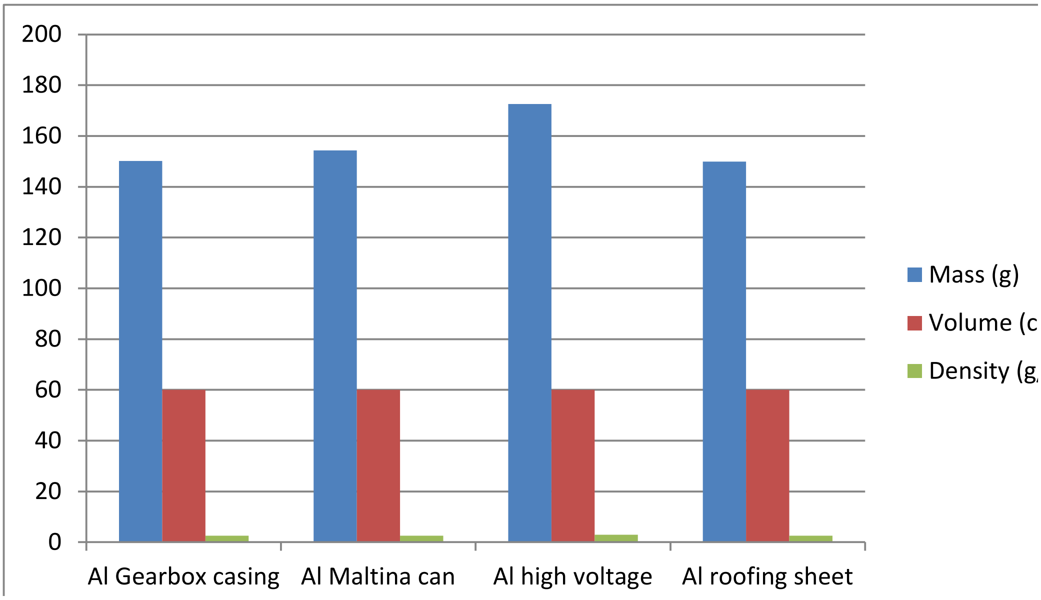
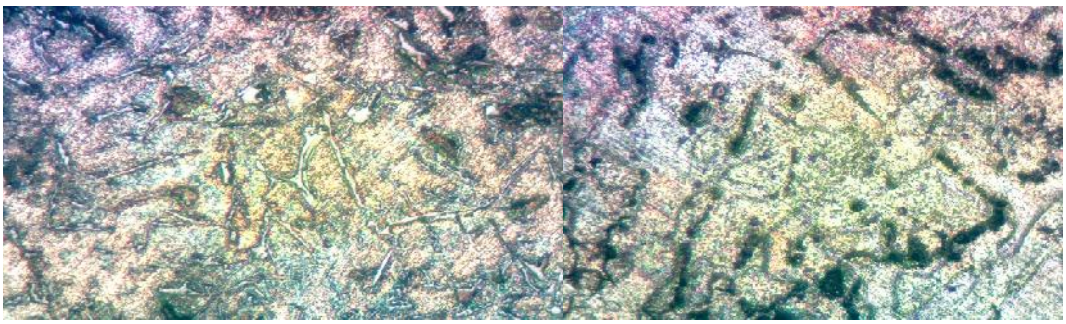


Fig 5: Chart of the mass, volume and density of the aluminium bars

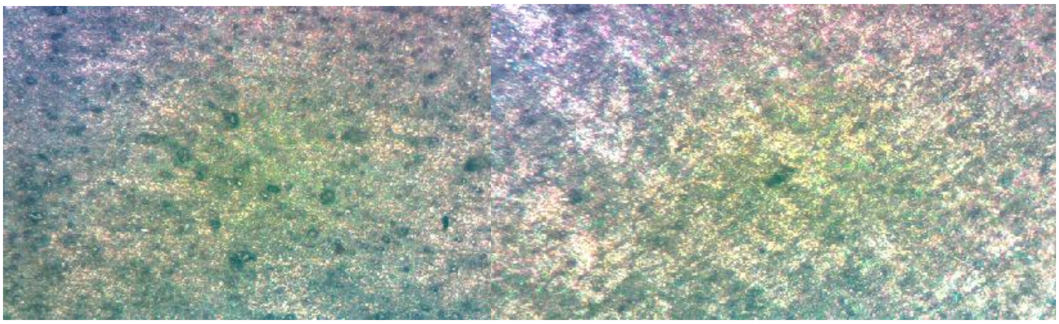
4.4 Microstructure (Optical) Characteristics

When the liquid metal is poured into the mould, solidification process begins with the formation of crystalline nuclei, each nuclei grows and obstruct each other, causing their regular shape to be impaired because further growth of the faces ceases at places where they interfere. Also molten metal flows into paths which is still accessible to. The structure is also affected by the cooling rate, amount of impurities, etc. Therefore the grain structure of each aluminium bar under microscope for the determination of size, structure, and orientation of the metal crystals are shown figures 6 and 7 below. The microstructure of the aluminium roofing sheets sample (figure 7b) showed the presence of pores whose sizes could not be determined at this stage, but must be responsible for its lesser density when compared with microstructures of high-voltage aluminium cable (figure 7a).



(a) Aluminium Gear box casing (b) Aluminium Maltina Can

Figure 6: Micro structure of the aluminium gear box casing and Maltina Can



(a) Aluminium high voltage cable (b) Aluminium Roofing Sheet

Figure 7: Microstructure of the aluminium high voltage cable and Aluminium Roofing Sheet

4.5 Impact Strength Results

Impact strength is the amounts of energy a material can withstand before failure occur. After testing the aluminium bars under Izod impact machine, it was the aluminium cable that absorbed the highest energy before failure and aluminium gearbox is the one that absorbed the lowest energy before failure. Therefore, the aluminium high-voltage cable has the highest impact strength (65.01J), followed by aluminium roofing sheets, aluminium maltina cans and aluminium gearbox casing respectively (see Table 2).

Summarily, the physical and mechanical characteristics of the aluminium bars analysis are tabulated below:

Table 2: Characteristics of the aluminium bars

Physical characteristics	Aluminium gear box casing	Aluminium maltina can	Aluminium high-voltage cable	Aluminium roofing sheets
Melting point(^{O}C)	818.6	661	374.7	654
Colour	Dull silvery colour	Bright silvery colour	Deep yellowish silvery colour	Faint yellowish silvery colour
Mass (g)	150.150	154.350	172.500	149.900
Density (g/cm^3)	2.5025	2.5725	2.8750	2.4983
Mechanical Characteristics				
Impact test (J)	20.40	27.20	65.01	35.36
Hardness test (BHN)	382.39	238.93	137.79	159.49

4.6 Hardness Test Results

The gearbox casing is the hardest material of all the materials tested followed by the maltina can, aluminium roofing sheet next and the aluminium high voltage cable being the last. The higher the impact strength the lower the hardness of the materials because it was the material with the highest impact strength that has the lowest hardness test value and vice versa. The Figure 8 and Table 2 below show the impact strength and hardness test results of the materials.

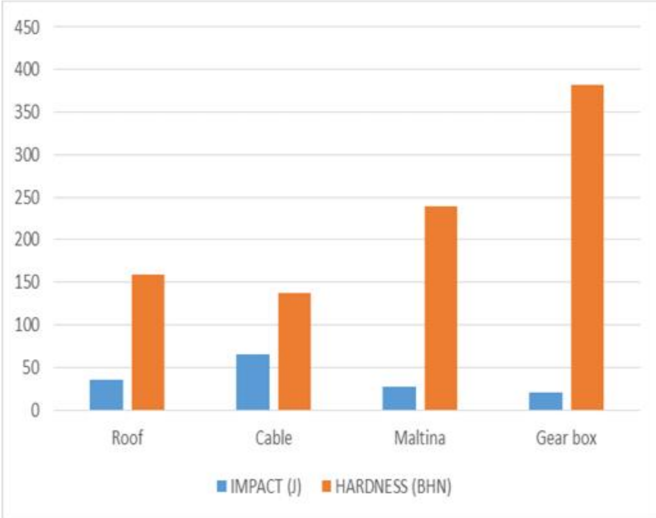


Fig.8: Results of impact and hardness of the materials

5.0 Conclusion

The aluminium gearbox casing had the highest hardness with the lowest impact strength among the four discarded aluminium materials analyzed in this research work. The variation in the properties of the different waste material show possibly the effects of alloy components on the base aluminium material. Analysis of the compositional constituents of the different materials were not covered in this report. This compositions will reveal the reasons behind characteristic variations observed in this research. However, this recycling work leads to material recovery and the achievement of waste-to-wealth policy.

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