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Tensile Strength and Micro-Hardness Properties of Common Roofing Sheets in Ghana.

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ABSTRACT

Background: The request for housing in Ghana is great and as a result the selection of durable roofing sheets have become very significant as roofing plays a vital role in building construction. This study examines some mechanical properties of the most common locally-produced and imported roofing sheets in the housing industry in Ghana to inform decision-making when it comes to roofing. The roofing sheets chosen were One Star Galvanized Japan (G1*Jap), Galvanized Coated (GC), Aluzinc three star galvanized ($AlZn_3$*), One Star Galvanized Indi (G1*Ind) and Aluminium (Al) due to their popularity and wide availability on the market. Samples from these were cut into specific dimensions and placed in a Tinius hydraulic Universal Testing Machine (Model 602) for testing.
Results: The results showed that $AlZn_3$* had the highest Young's Modulus of Elasticity of 18.21MPa, Ultimate Tensile Strength (UTS) of 50.27 MPa; Aluminium (Al) recorded the highest Percentage Elongation of 28% and Breaking Energy 7956600 MJm-2 with G1*Jap recording the least UTS of 26.6 MPa and Breaking energy of 55378 MJm-2 whiles G1*Ind showed the least Young's Modulus of Elasticity of 7.6 MPa and Percentage Elongation of less than one percent (0.5%).
Conclusion: These numbers lead to the conclusion that $AlZn_3$* roofing sheet is generally the best roofing sheet. Based on this it was concluded that $AlZn_3$* is the best roofing sheet on the Ghanaian market due to its unmatched mechanical strength.

1. Introduction

Throughout history, man has used a variety of natural materials, technical processes, and methods of application to develop the ecologically safe, functional roofing that we have today. Because a roof can only be as excellent as the resources accessible, each civilization used different methods, tools, and materials to construct its roofs. The completed product, as well as the resources needed to make it, is a true representation of the level of advancement in terms of technology and creativity a civilization has. Although the majority of the expansion in the roofing sector occurred in the previous 200 years, the history of roofing dates back for further [1]. Industrial roofing at the time had little insulation but a good slope for rainwater and other debris, so dreadnought clay tiles were introduced in 1805. Concrete tile roofing was first used over a century later. While the history of roofing began to change, American roofing styles, like those around the world, were still reliant on materials available within that region [2].

Metal sheets, slate, and felt are among the most commonly used roofing materials today. It's difficult to forecast the roofing industry's future and what technologies will impact it, but one thing is certain: the history of roofing has

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developed and will continue to evolve indefinitely [3]. Metal roofing is the most prevalent roofing material in many houses, businesses, and industrial buildings [4]. Long run roofing (corrugated, trapezoidal, trough section/concealed fix), tile, shakes, and flat sheets are all examples of metal roofing. Prior to the invention of zinc/aluminum alloy coatings, galvanized steel sheet was the most often used form of profiled metal roofing. Other materials such as aluminium, stainless steel, lead, zinc, copper, etc can all be used as roofing material [5].

The characteristic of tensile strength is used to anticipate how a material will behave under loads other than uni-axial tension. The tension required to generate substantial plastic deformation or the maximum stress that the material can endure are two ways to assess a material's strength. In engineering design, these strength measurements are employed with caution [6, 9]. The tensile strength of a test specimen is an intensive attribute that is independent of its size. However, it is dependent on the specimen's preparation as well as the temperature of the surrounding environment and material [7, 10].

This study looks at the mechanical qualities of certain locally manufactured and imported roofing sheets used in Ghana's construction sector. As a consequence of the many types of roofing sheets available in the country, these tests are carried out to determine the strength of these metal sheets. Such features will determine the selection of a roofing sheet with a long-life span.

In Ghana, there is a significant need for housing, and choosing a long-lasting roofing sheet is critical because roofs are such a vital part of building. As a result of an upsurge in request for roofing sheets, local businesses such as the Tema Aluworks and others have been incapable of matching the request, necessitating imports from Asia, Europe and America.

These imported roofing supplies come in bundles and are cut into thicknesses ranging from 0.3 to 1.5 mm, widths ranging from 820 to 1000 mm, and lengths ranging from 2000 to 3000 mm before being corrugated by local businesses. Local industries then advertise the sheets as one-star galvanized coated Japan (G1*Jap), galvanized coated (GC), three-star aluzinc galvanized ($AlZn_3$*), one-star galvanized India (G1*Ind), aluminum (Al) roofing sheets, and so on for the local market.

This research aims to investigate the tensile strength and micro-hardness qualities of these popular locally made and other imported roofing sheets on the market, since these attributes are a measure of a material's mechanical strength [8,2].

1.1 Tensile testing

Tensile tests are used to measure Ultimate Tensile Strength (UTS), Young Modulus of Elasticity, Toughness, and other properties, and the results aid in the selection of materials for engineering applications [9-12, 3-6]. Tensile characteristics are typically added as part of a material’s key features to assure how safe the material is in real life applications. It is one feature that is regularly tested when a new material is being developed in order to be able to do comparative analysis with other various materials and processes. They are frequently use tell what to expect from a material when they put under load condition other than uniaxial tension [9,13; 3, 7]. The tensile features of a material define how it reacts to tensional forces. As a result, a material’s the tensile strength is defined as the greatest quantity of stress it is capable of enduring before failure. Tensile test is therefore carried out to achieve this purpose. A tensile test is simply a mechanical test which involves a cautiously prepared sample that is burdened with a load in a meticulous manner whiles taking note of the applied load and the elongation of the sample that will take place over a distance [9]. They are generally used to assess toughness, modulus of elasticity and tensile strength, as well as elastic limit, percentage elongation, yield point, and other tensile parameters [14, 15;8, 9].

2. Methodology

2.1 Tensile strength

On the Ghanaian market, samples of G1*Jap, GC, AlZn3*, G1*Ind, and Al roofing sheets were obtained. These specimens were then cut into 2 cm × 25 cm squares for tensile testing. To prevent heating up samples owing to frictional force, sample sheets were cut very slowly to the desired form and size, as illustrated in Fig. 1 below. They were then carefully cleaned before being tested on the Tinius Olsen super "L" hydraulic Universal Testing Machine (Model 602). The gauge length was represented by L, the parallel area length was represented by P, and the specimen thickness was represented by T. The Tinius Olsen super "L" hydraulic Universal Testing Machine was used to apply pressure to each specimen and quantify tensile strength and elongation (Model 602). The minimum and maximum values were removed for accuracy, and the averages of the remaining measurements were utilized as specimen values [16,17; 10, 11].

2.2 Micro hardness tests (The vickers hardness test)

To remove stains like oil, each roofing sample was cut into 5cm x 5cm squares using shears, and cleaned. The specimen was then glued with an adhesive to a metal block of the same dimensions to produce a level surface for the diamond indenter. The specimen was indented with a diamond indenter after being subjected to a force of 5 kgf for 10 seconds in the micro hardness tester in the shape of a right pyramid with a square base and an angle of 136 degrees between opposite faces [16, 10]. From the two diameters obtained, the Vickers hardness values were determined. The impression's diameter is the mean of two different indentation values. A well-structured Vickers hardness number shows the test circumstances and should be recorded as 800 HV/5, which indicates that a Vickers hardness of 800 was attained by applying a 5kg force for 10 seconds [18, 19; 12, 13].

Figure 1. Prepared sample for tensile testing

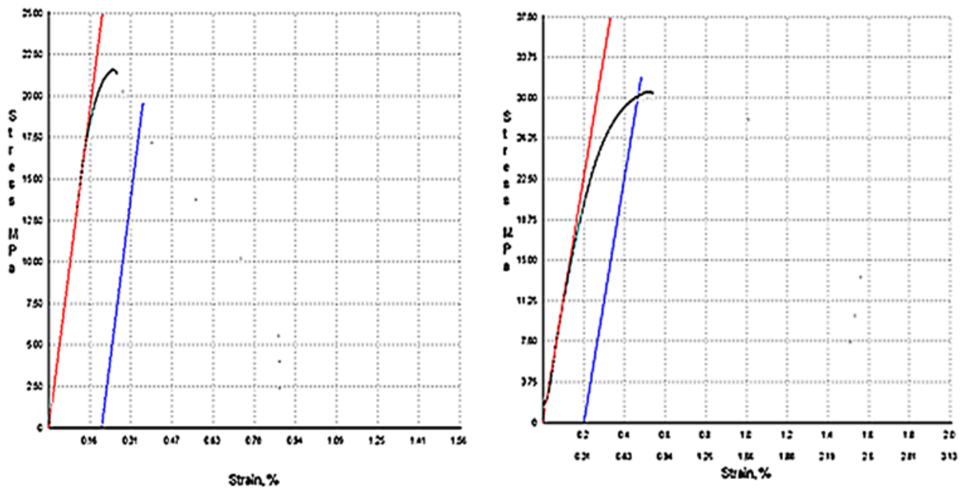
Table 1: Mechanical properties obtained for the various roofing sheets

Sample	Young's Modulus [Stress/Strain] (MPa)	UTS (MPa)	Percentage Elongation (%)	Toughness (MJ/m^2)
G1*Jap	13.05	26.59	3	55378
GC	11.76	43.25	5	177770
$AlZn_3^*$	18.21	50.27	1	316810
G1*Ind	7.57	32.31	0.5	92230
Al	17.99	37.52	28	7956600

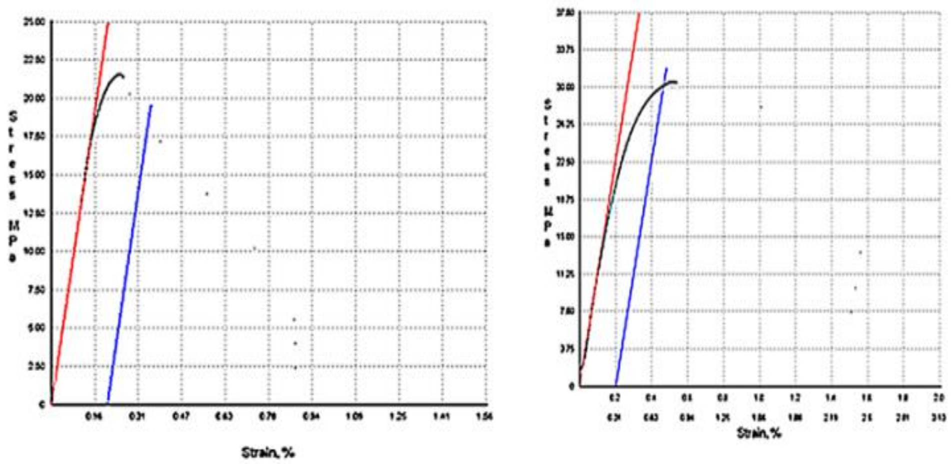
3. Results and discussion

3.1 Results

The stress-strain curves of the chosen metal roofing sheets are shown in Figures 2–4. Data for ultimate tensile strength (UTS), percentage elongation, Young's modulus, yield strength and maximum breaking energy can be determined.



(a)



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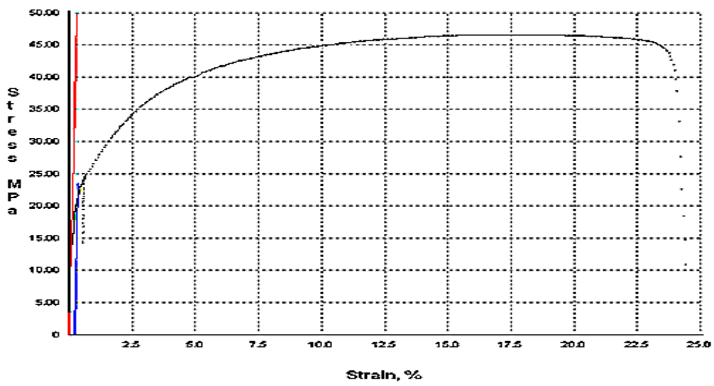

(c)

Figure 2. (a) Tensile Test graph for G1*Jap and GC (b)Tensile Test graph for $AlZn_3$* and G1*Ind (c) Tensile Test graph for Aluminium sheets

The average Young's Moduli of Elasticity for the various sampled roofing sheets were 13 MPa, 12 MPa, 18 MPa, 8 MPa, and 18 MPa, respectively, as shown in Table 1.0. The greatest Young's modulus of elasticity value was $AlZn_3$*, while the lowest was G1*Ind.

G1*Jap, GC, $AlZn_3$*, G1*Ind, and Al sheets had average ultimate tensile strengths of 27 MPa, 43 MPa, 50 MPa, 32 MPa, and 38 MPa, respectively, as shown. AlZn3* had the greatest UTS value of 50 MPa, indicating that it is extraordinarily strong, whereas G1*Jap had the lowest.

The toughness of the sampled specimens was 55378 MJm-2, 177770 MJm-2, 316810 MJm-2, 92230 MJm-2, and 7956600 MJm-2, respectively, as shown in Table 1.0

Al has a larger value, although G1*Ind and G1*Jap have fairly similar breaking energy values of 55378 and 92230 MJm-2, respectively.

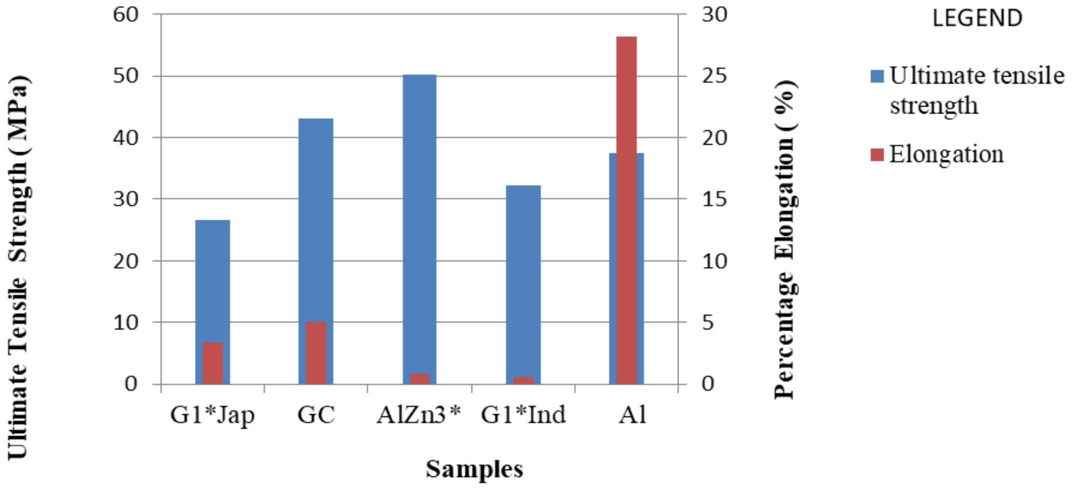

Figure 3. Graph of average UTS and Percentage Elongation of different roofing samples

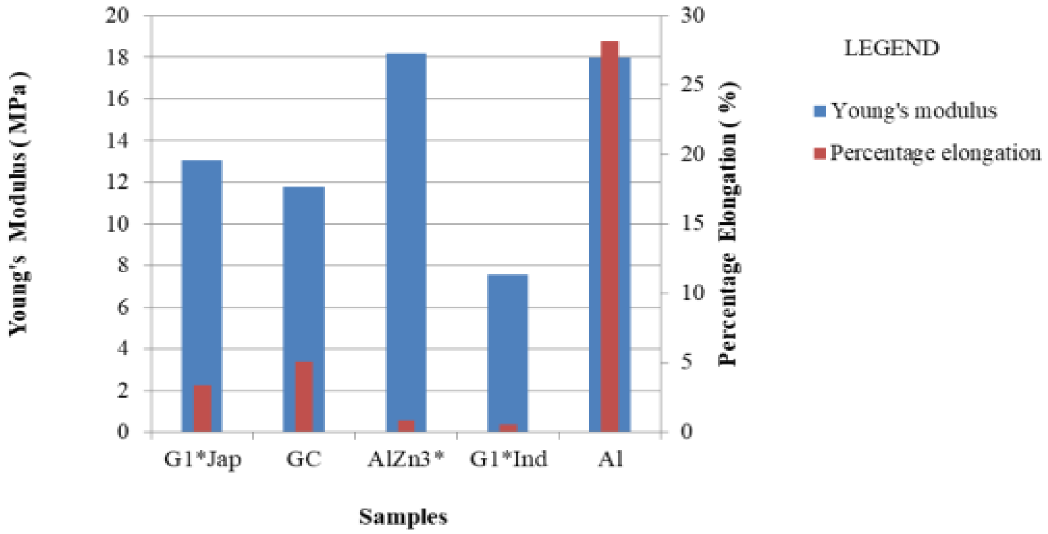

Figure 4. Graph of average Young's Modulus and Elongation of different roofing sheets

In comparison to Al roofing sheets, $AlZn_3$* sheets can withstand larger stresses before cracking (see Fig. 5). Young's Modulus, which is stress divided by strain, revealed the resistance of the atoms in the structure to plastic deformation.

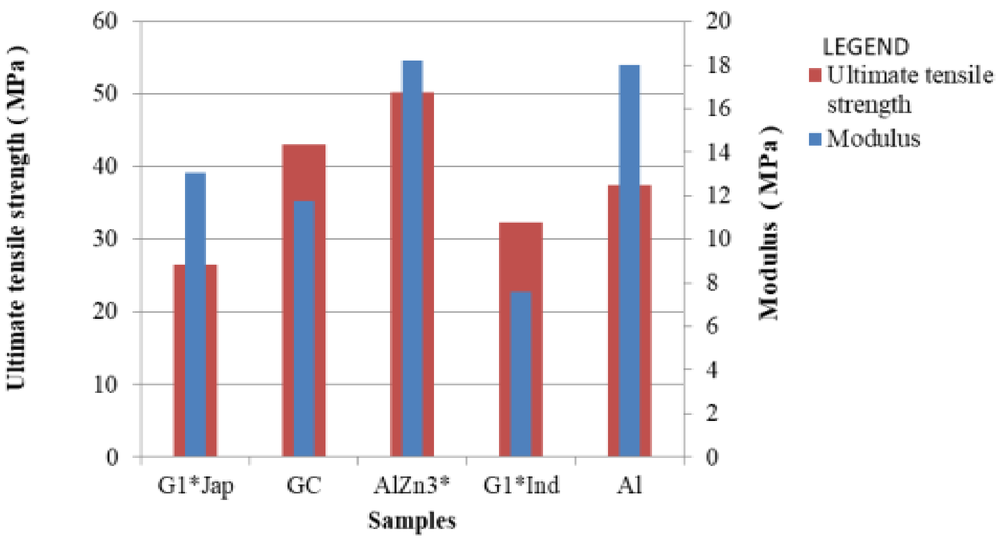

Figure 5. Graph of the UTS and Toughness of the different roofing sheets

3.1.1 Micro-Hardness

G1*Jap, GC, $AlZn_3$*, G1* Ind, and Al had average hardness values of 797.0 Nm-2, 377.0 Nm-2, 3875.4 Nm-2, 195.5 Nm-2, and 67.3 Nm-2, respectively, according to the hardness test findings in Table 2.

$AlZn_3$* had the highest value, followed by G1*Jap, with Al having the lowest value. This is due to Al's higher ductility, which allows it to tolerate both plastic and elastic deformations.

Table 2: Average Micro-Hardness for all samples

Sample	Micro Hardness/Nm^{-2}
G1*Jap	797.0
GC	377.0
$AlZn^{3*}$	3875.4
G1*Ind	195.5
Al	67.3

3.2 Discussions

The tensile strength graphs of all the samples show a proportional/elastic region as seen (Figure 2 (a) and (b)) before deformation. The proportional or elastic limit is seen in the initial linear region of the curves. Hooke's rule is followed within the elastic limit because the strain material is proportionate to the applied stress. The reason for this is because of the disruptions in the strained metal roofing sheet and the inter-atomic interactions of the carbon atoms [17, 11]. The presence of distinct phases in the microstructure explains the mechanical behaviour. As a result, before the roofing sheet breaks, it undergoes plastic deformation due to sluggish crack propagation [20, 14].

Generally, all the metal roofing sheets used produced a minimum 'waist' or 'neck' that formed cavities after thinning homogenously throughout its span during the plastic stage. Internal cavities then may emerge later in the plastic strain when stress concentration occurs in places with a significant number of interlocking dislocations. [21, 15]

As shown in Fig. 3, $AlZn_3$* had the greatest Young's modulus of elasticity, indicating that it had a better capacity to recuperate under a given load or stress than the others [22, 16]. AlZn3* was tougher and more brittle than Al and the other roofing sheets because of its internal stress and an increase in movable dislocation density. As a result of the greater Young's Modulus value, $AlZn_3$* bears more load than the others.

The toughness or ultimate tensile strength of the roofing sheets was determined by their yield points (UTS). $AlZn_3$* may best be defined as very strong, as evidenced by the greater elastic limit, and the capacity to withstand higher weight before cracking than the other chosen roofing sheets (see Fig. 3). Due to the load put on it by workers, this feature makes $AlZn_3$* excellent for installation.

Again, as can be shown in Fig. 4 and Table 1, Al had a greater toughness rating than the others. This indicated that Al could withstand greater weights before breaking than the other roofing sheets. When the load is increased beyond the yield point, Al progressively stretches until the cross-sectional area can no longer handle the extra strain. The maximum stress supplied data on the maximum stress that the roofing sheet could endure, that is, the greatest load that the roofing sheet could carry prior to it fracturing.

As shown in Fig. 3, G1*Jap, GC, and $AlZn_3$* yielded fast to achieve their extreme stress, but had a shorter total extension before fracture. As a result of the thermal metallurgical treatment (TMT) used during their manufacture, G1*Jap, GC, and $AlZn_3$* were hard and brittle [16-19]

Under less applied weight, Al roofing sheets underwent more stretching when compared with the other roofing sheets. The stress-strain curves in Fig. 2 show this, with the stress steadily decreasing until the roofing sheet cracked.

Fig. 2 indicates that a metal with high UTS is not always ductile or plastically deformable. This is due to the fact that, while $AlZn_3$* could withstand higher weights, it could not stretch further than Al before breaking. It suggests that Al roofing sheets were more ductile than $AlZn_3$* roofing sheets.

Fig. 5 illustrates that just because a metal sheet is robust doesn't mean it has a high UTS. Toughness relates to a material's capacity to absorb energy rather than the amount of load it can take; therefore, a material may not be tough yet may withstand a lot of force before breaking. Al sheets were more ductile than $AlZn_3$* sheets, but G1*Ind sheets were less ductile. The UTS and Modulus of Elasticity of the $AlZn_3$* sheet was both high.

3.2.1 Micro-Hardness

Fröhlich et al [27, 21] describe micro-hardness as a body's capacity to resist certain persistent deformation [28, 29; 22, 23]. Due to the fact that, it is more ductile and can bear both plastic and elastic deformations, AlZn3* had the greatest value in Table 2, whereas Al had the lowest value.

It's also a sign that AlZn3* with a greater Yield Strength has a higher hardness (is more brittle), and that the hardness of AlZn3* with significant strain-hardening capacity is influenced not just by fracture strength but also by Yield Strength. As a result, AlZn3*'s capacity to resist lasting distortion is greater, causing higher hardness.

This could be an explanation as to why $AlZn_3$*'s hardness rises when the atomic bonding characteristics of various composites in the materials improve.

The decrease in area in tension and percentage elongation are commonly employed as experimental metrics of ductility. The ductile character of Al is due to the fact that atomic bonding qualities improve as atomic bonding increases.

4. Conclusions

The goal of the research was to measure the mechanical strength of roofing sheets in Ghana by tensile and micro-hardness testing on a variety of standard roofing sheets [30-33; 24-26]. Using a Tinius Olsen super "L" hydraulic Universal Testing Machine, the sheets were sliced into various dimensions and put through a series of tests (Model 602). The data obtained was analysed and interpreted in confirmation to what is already established in various literatures. According to the data obtained, $AlZn_3$* has the greatest Young's Modulus of Elasticity and UTS; G1*Jap had the lowest UTS and Breaking Energy, whereas G1*Ind had the lowest Young's Modulus of Elasticity and Percentage Elongation.

From the research the following conclusions could be drawn:

(i) $AlZn_3$* roofing sheets were extremely rigid, implying that they had a high deformation resistance. The high Young's Modulus of 18 MPa, which was the largest recorded, clearly confirmed this. The minimum value recorded was for G1* Ind roofing sheets with a value of 8 MPa.

(ii) Among the selected sheets, $AlZn_3$* sheets exhibited the greatest average

UTS of 50 MPa. G1*Jap has the lowest pressure of 27 MPa.

(iii) Al had the highest average toughness (Breaking Energy), with a value of 7,956,600 MJm-2, whiles G1*Jap had the lowest value of 55378 MJm-2, indicating that Al roofing sheets could withstand a greater load before cracking at a lower strain than other roofing sheets.

(iv) G1*Ind had the lowest average percentage elongation (0.58 %), while Al roofing sheets had the highest average percentage elongation of 28%.

(v) $AlZn_3$* roofing sheets were found to be extremely brittle and hard. The sheet's hardness allowed it to withstand more load, but due to its brittleness, it fractured quickly just after the yield strength.

Based on these, it was concluded that $AlZn_3$* is the best roofing sheet on the Ghanaian market due to its unmatched mechanical strength.

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