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Measuring the Correlation between the Tensile Strength and Hardness of Steel and Aluminum as Alternative Ship Hull Construction Materials in Local Ship Yards in Nigeria

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Abstract:-**The study assessed the correlation between the tensile strength and hardness of each of steel and aluminum alternative ship hull construction materials in use in ship building in Nigeria shipyards. It also compared the hardness'sof aluminum and steel as well as their tensile strengths.Since the mode, frequency and nature of failure of ship hulls has relationship with the tensile strength and hardness of its material of construction which among other things influences the demand for ships of differing hull material types; determining the nature of relationship between the tensile strength and hardness of specific hull material types will provide knowledge on how best either of the hull material properties may be improved without compromising the other in the drive to build stronger, more reliable and durable ships in local ship yards. The experimental and case study research design methods were employed in which the hydraulic powered universal tensile test equipment was used to determine the tensile strengths of specimens of steel and aluminum ship hull materials obtained from West Atlantic Ship yard, Starz Ship Yard and the West African Ship Yard sampled from the Port-Harcourt ship building cluster in Rivers state Nigeria. The hand held hardness testing equipment and the Rockwell hardness test method were used to determine the hardness's of steel and aluminum hull material specimens collected.To limit error, each test type was carried out four times on each hull materials type from each ship yard and readings were taking from which the averages were determined for purposes of analysis and findings. The statistical correlations methods of spearman's rank correlation and Pearson's correlation were used to measure the nature of correlation between the hardness and tensile strength of each ship hull material type. The independent sample t-test was used to compare the tensile strengths and hardness's of each of steel and aluminum hull material in use in the ship yards. It was found that a perfect strong positive correlation exist between the hardness and tensile strength of both steel and aluminum ship hull material types indicating that the hardness of each material increases as the tensile strength increases. The comparison of the tensile strengths and hardness's of steel and aluminum materials in use for ship hulls in Nigeria each showed a significant difference in favour of the steel hull. Recommendations were proffered based on the findings of the study.**

Keywords: **correlation, tensile-strength, hardness, ship-hull, material.**

I. INTRODUCTION

Ship construction and use for maritime transportation is as old as man on the earth's surface; originating in antiquity following the biblical history of Noah's arch constructed with strict adherence to God's instruction, using basically wood as the hull material. The ship hull is the outmost surface of the body structure and the integrated sub-surface structures providing form, weather tight and water tight integrity to the ship and protecting the internal structures including the cargo holds, tanks, accommodations, stores, machinery and equipment rooms among others. The importance of the hull and its influence on the hydrodynamic features, stability (transverse, longitudinal and dynamic) andin ensuring the seaworthiness of the ship cannot be overemphasized. The strength of the hull too is to a great extent determined by the strength of material of its construction which will equally influence the seaworthiness and longevity of the vessel. The same can be said of the hardness of ship's hull materials. Ship hull construction materials over the years has witnessed continuous progression from the use of less durable and decay prone wood materials and rust prone iron materials to more durable rust resistant, corrosion resistant and decay free steel, Aluminum, hybrid materials (fiberglass) and alloys of metals.In Nigeria, the local shipyards over the years were involved in shipbuilding, fabrication and construction of local boats for navigation majorly within the internal/ inland waters of Nigeria. Surveys of local available shipyards reveal the predominance of the use of mostly steel, Aluminum (AL) and wood as alternative ship hull materials. This suggests the adoption of global trends in the local ship building industry in Nigeria except for the continued use of wood which has declined in use and almost phased out in the global ship building industry due to the characteristic decayon exposure to the marine environment(preben, 2015).

Because ship building materials like other engineering materials fail in various forms induced by exposure to working stress and environmental condition effects with failures ranging from fracture, rupture, breakage, strain, fatigue, brittle, plastic deformation, indentation, etc.; it is important that the tensile strength and hardness of such materials be predetermined for optimal strengthening, improvementand professional layering of the hull material inline to the expected work load and longevity /life span of the vessel. Oncethe tensile strength and hardness of the material is determined, the failure trend and expected operational life of the vessel under load condition which the hull material is expected to withstand without fail over time is determined too; such that required level of improvement in the strength of the hull material can empirically be carried out by the most appropriate means and methods. This will equally influence the decision on the nature of marine environment (sea water, fresh water or rivers) that a vessel of particular hull material strength and type will operate. For choice among or between alternative ship hull materials, the material that offers highest level strength and hardness is preferred over the others, particularly in rough sea areas (Da-weil and Gui-jie, 2018). This is most possible however if such material shows preferable better performance in other material properties thantensile strength and hardness; for example weight, abrasiveness, corrosion, rusting, etc., depending upon the expectations and interests of the shipyard and the specifications and requirements of the owners. Also the type of marine environment in which the vessel is to be exposed such as salt or fresh water may equally affect material performance and life span/longevity of the ship.Strength (tensile strength) and hardness however remain very important properties that all hull materialtypes are to be subjected to; since most ship hull failures have relationship with strength and hardness properties of the material of its construction.

According to Aevelina and Karim (2015) the first property that comes to mind in the decision to choose between alternative ship hull materials is the tensile strength and yield strength. The UltimateTensile Strength (UTS) is referred to as the stress/load needed to cause a hull material to break. Tensile strength refers to the ability of a material to withstand a pulling (tensile) force. Since the ship under loaded condition and when in motion faces the action of multiple forces including the frictional and retarding effects of opposing forces, the propulsive forces must be far higher to pull in the opposite direction to sustain the motion of the craft; these stresses and loads induced on the hull of the ship even when in motion induces a breaking effect on the hull material. The maximum load which over time secures the failure of the hull material by pull induced breaking is the ultimate tensile strength of the hull. Thus the higher the tensile strength, the lesser the proneness of hull materials to sudden failure by pulls induced brittle and vice versa. To limit stress induced breaking of hull materials therefore requires that the tensile strength of the material be improved or optimized to levels above the expected stress and load conditions under which the vessels will be operated when in motion. Tensile strength is customarily measured in units of force per cross-sectional area. It is important to note that the ability to withstand breaking under tensile stress is one of the most important features of ship hull materials used in marine structural applications. It is an important test particularly for materials that brittle than ductile materials. The tensile strength of a hull material is thus the maximum amount of tensile stress that it can take before failure by brittle or permanent deformation.

Tensile strength testing for metal will determine how much a particular alloy will elongate before hitting ultimate tensile strength and how much load a particular piece of metal can accommodate before it loses structural integrity. Therefore, it is very important in ship hull materials given the very dangerous nature of the marine environment to which they must be exposed during their useful life. It is also vital for construction safety and personal safety, both during and after the building is completed as it helps to predetermine and proactively limit ductile and brittle failure (ACC, 2013). The yield strength determines the ability of the hull material not to undergo plastic deformation under stress/load. It is the stress that the material of hull construction can withstand without permanent deformation. Studies have however found the existence of positive correlation between tensile strength and yield strength of most ship hull materials (Hidarisetal, 2014; Serden, 2005).

Hardness of a ship hull material is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasionobject (Wrenderberg, Fredrick and Larson (2009). There are therefore, different measurements of hardness for hull materials since these materials are generally exposed to routine mechanical indentation forces; optimizing the ability of the materials to withstand these over its life require an initial measure of its hardness for acceptability decisions. Hardness is dependent on properties such as ductility, elastic stiffness, plasticity, strain, toughness, viscoelasticity, and viscosity. Hardness as a hull material property exists in various forms such Scratch hardness which is a measure of how resistant a hull material sample is to fracture or permanent plastic deformation due to friction from a sharp object (Wrenderberg, Fredrick and Larson (2009). Scratch hardness refers to the force necessary to cut through the film to the material (Allen, 2006).Indentation hardness measures the resistance of a hull material sample to deformation due to a constant compression load from a sharp object; this is most commonly used in ship building and metallurgy fields.Rebound hardness, also known as dynamic hardness, measures the height of the "bounce" of a diamond-tipped hammer dropped from a fixed height onto a hull material or object; it is related to elasticity (Allen, 2009).It is important to note that hardness as a property of ship hull materials is a feature that enables it to resist deformation, bending, scratching, abrasion, and/or cutting. It is a crucial test in the hull material testing processes for ship building since collision risks impact on the hull structure; for example; the hardness of the hull material will determine the magnitude of damage and effects of collision and impact forces on the hull. For most hull materials, hardness tests are performed by use of devices that measure depth of an indentation left by a point of a specific shape, with a specific force, and for a specific amount of time (Hito and Philip, 2013).Hito and Philip (2013) notes that the most common hardness tests that measure the relationship between hardness and the size of the impression left by the test are the Rockwell, Brinell, and Vickers hardness tests (Hito and Philip 2013). Since the carriage of loads on the hull structure of ship particularly deck cargo, cargoes carried in holds and containerized cargo induce bending forces/loads on the hull; hardness of the hull material becomes an inevitable property of importance that must be ascertained and ensured relative to the magnitude of the loads to be expected handled or carried on the structure and the expected bending forces such loads may induce on the ship's hull. It is obvious that improving the hardness of a ship hull material will limit the level influence of impact forces as well ascollision induced forces while preventing and/or lowering frequencies of failure by bending, abrasion, cutting, scratching and indentation.

The central questions of the study therefore include: what nature of relationship exists between the tensile strength and hardness of specific specimens' of ship hull building materials? Does optimizing the tensile strength of a sample of ship hull materials such as steel and aluminum equally optimize the hardness of such materials? Does lowering the hardness of steel and aluminum ship hull materials improve the tensile strength of such materials? The challenges posed by the questions can be resolved by determining the nature of correlation between the tensile strength and hardness of the identified alternative ship hull materials(Greenetal, 2017; Abdul and Khalid, 2012). The knowledge will in turn enable ship yards to device appropriate methods of improving to required levels the hardness's and tensile strengths of ship hull materials of various types by having an empirical knowledge of the nature of relationship between them since both properties are very important hull material properties that influences hull failures modes and frequency. This is will help in developing strategies for optimizing the tensile strength and hardness of local ship hull materials so that locally made boats can have improved longevity and fail less unexpectedly (Iqualetal, 2015; Allen, 2006).

II. OBJECTIVES OF THE STUDY

The main aim of the study is to Measure the correlation between the hardness and strength of Steel and Aluminum as alternative ship hull construction materials in local ship yards in Nigeria. This is with a view to determining strategies for optimizing the tensile strength and hardness of local ship hull materials so that locally made boats can have improved longevity and fail less unexpectedly. Other specific objectives of the study include:

1) To measure the correlation between the tensile strength and hardness of steel hull material in use in Nigeria ship yards.
2) To determine the nature of correlation between the tensile strength and hardness of Aluminum hull material in use in Nigeria ship yards.
3) To compare the tensile strengths of Aluminum (AL) and Steel as alternative ship hull materials in use in Nigeria shipyards.
4) To compare the hardness of steel and Al as alternative ship hull materials in use in Nigeria shipyards.

III. MATERIALS AND METHODS

The research combined experimental research design with case study approach. The experimental design approach was used to conduct tensile strength and hardness tests on samples of steel and aluminum ship hull materials used in the local ship yards in Nigeria. The ship yards used as case studies in the are the West African ship yard (WAS), Starz ship Yard and West Atlantic ship yard all randomly sampled from the ship building clusters in Port-Harcourt, Rivers state south - south Nigeria.Samples of aluminum and steel hull materials (plates) from each selected ship yard in the Rivers ship building clusters were obtained and used to conduct tensile and hardness tests to determine the average tensile strength and hardness of each hull material type in use in Nigeria ship yards.Primary data on tensile strength of each hull material type were thusobtained from experiments conducted on each hull material types from the yards using the hydraulic powered universal tensile test equipment while primary data on the hardness of each hull material type from the ship yards were obtained from tests conducted by the use of hand held hardness testing equipment. Readings of hardness and tensile strength of each hull material collected from each ship yard were measured and taking four times and the average readings were adopted for use in data analysis employing correlation analysis statistical tool.

3.1 Rockwell Hardness Test for Alternative Ship Hull Materials

The study adopted the Rockwell hardness test method in testing the hardness of ship hull material used in Nigerian ship yards. Though there exists other hardness test method such as

Moh's hardness test, Brinell hardness test and Vickers hardness test, the Rockwell hardness test was adopted because of its simplicity and availability of experimental equipment. The Rockwell scale is a hardness scale based on indentation hardness of a material (wikipeia.com). The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload (Pavlina and Van,2008).

3.2 Testing the Tensile Strengths of Ship's Hull materials.

Tensile strength of a hull material is the ability of the hull material to withstand a pulling (tensile) force. It is the maximum stress sustained by a material under pull or tension. If this stress is surpassed, necking begins to form and subsequently deformation occurs. Ultimate Tensile Strength is the maximum strength that a hull material can withstand. Beyond it the material fails (Wikipedia.com). Tensile strength testing also referred to as tension testing is a material testing method in which a sample is subjected to a controlled tension until failure. The tensile test was carried on each ship hull material type using a universal tensile strength testing machine. The test samples are steel and aluminum specimens hull materials of 6mm thickness and 8cm lengths each and of cross-sectional area o.5cm^3. The specimens were each properly fastened to the universal tensile test equipment as show below and forces applied until the material necks and breaks.

A universal tensile strength test equipment.

A hydraulically powered universaltensile strength testing machine was used to run the test. The test samples were each placed in the testing machine one at a time and then slowly extending it until it fractures (Wikipedia.com). The extension measurement was used to calculate the strain;ε. The parameters include:

ΔL; = the change in gauge length,

$L_{0 =}$ the initial gauge length, and

L= the final length; were all read from the machine and recorded.

The stress, σ is thus calculated from theforce measurement. The tensile strength of each hull material type was thus determined using the test method described above. The hull material type samples collected from each ship yard were tested using the same method and readings were taken. The average tensile strength of the respective steel and aluminum materialswere determined for use in data analysis.

3.3 Methods of Data Analysis

The study used the statistical method of correlation analysis to measure the correlation between hardnessof each hull material type as well as the tensile strength of each steel material and aluminum materials data determined from the experiments as explained above. The averagehardness and tensile strength of each hull material type where equally using independent sample t-test**.** The method of correlation analysis used includes both spearman's and Pearson's correlation tests. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and -1. A value of ± 1 indicates a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. The direction of the relationship is indicated by the sign of the coefficient; a + sign indicates a positive relationship and a – sign indicates a negative relationship.

The following formula is used to calculate the Pearson *r* correlation:

$$r = \frac{N\sum xy - \sum (x)(y)}{\sqrt{[N\sum x^2 - \sum (x^2)][N\sum y^2 - \sum (y^2)]}}$$

r = Pearson r correlation coefficient

N = number of observations

∑xy = sum of the products of paired scores of tensile strength and hardness of ship steel and aluminum hull materials.

∑x = sum of x scores hardness of each of steel and aluminum hull material.

$\sum y$ = sum of y scores of tensile strength each of steel and aluminum hull material.

$\sum x^2$= sum of squared x scores

$\sum y^2$= sum of squared y scores

Where a monotonic relationship exists, the spearman's correlation is used the formula for the Spearman rank correlation coefficient:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

Where P = spearman's correlation coefficient

$\sum d$= sum of difference in ranks

n = number of observations.

IV. DATA PRESENTATION, RESULTS AND DISCUSSION OF FINDINGS

Table1: Experimental Results Showing the average tensile strength and hardness of Steel and Aluminumhull materials in use in ship yards in Nigeria.

S/no	Average tensile strength	Average tensile strength	Average hardness	Average hardness
Sample	Aluminum(kg /cm^2)	Steel(kg/cm^2)	Aluminum(hrb)	Steel (hrb)
1	2680	4500	28.10	30.30
2	2680	4520	28.10	31.00
3	2670	4510	27.90	30.20
4	2660	4500	28.00	30.20

Source: Authors presentation of test Results

The table1 above shows the results of the hardness test and tensile strength test conducted as explained in the methodology section above to determine the average tensile strengths and harnesses' of samples of steel and aluminum alternative ship hull materials in use in Nigeria ship yards. Each property of the Aluminum and steel samples were tested four times and readings taken in order to eliminate errors likely to be encountered if the tests were conducted only once. The average scores were determined and presented above in table1.

Table2: Measuring Correlation between Strength and Hardness of Steel Hull material in use in Local Ship Yards.

Correlations

		Steeltensilestrength	Steehardness
Steeltensilestrenght	Pearson Correlation	1	.818
	Sig. (2-tailed)		.182
	N	4	4
Steehardness	Pearson Correlation	.818	1
	Sig. (2-tailed)	.182	
	N	4	4

Correlations

			Steelstrenght	steelhardness
Spearman's rho	Steelstrenght	Correlation Coefficient	1.000	.500
		Sig. (2-tailed)	.	.500
		N	4	4
	steelhardness	Correlation Coefficient	.500	1.000
		Sig. (2-tailed)	.500	.
		N	4	4

Source: Authors Calculation

The result of the analysis indicates that the Pearson's coefficient of correlation between the strength and hardness of steel hull materials in use in Nigeria ships yards is 0.82. This indicates the existence of a perfect correlation between the tensile strength and hardness of steel hull material in use in Nigeria shipyards. It shows a positive perfect correlation of about 82% between the tensile strength and hardness of steel hull materials used in Shipyards in Nigeria; implying that increasing the tensile strength of steel material will equally lead to increase in the hardness of the material for ship hull construction in Nigeria. A direct positive relationship thus exists between the hardness and tensile strength of steel hull material suggesting that any bid to improve the tensile strength of steel hull materials by ship yards equally leads to increase/improvement in the steel materials hardness and vice versa. The spearman's correlation coefficient is 0.50. This also shows a strong positive correlation between the hardness and tensile strength of Steel hull materials in use in Nigeria shipyards.

Table3: Measuring the Correlation between Tensile Strength and Hardness of Aluminum Hull material in use in Nigeria Shipyards.

Correlations

		ALtensilestrength	Alhardness
ALtensilestrenght	Pearson Correlation	1	.310
	Sig. (2-tailed)		.690
	N	4	4
Alhardness	Pearson Correlation	.310	1
	Sig. (2-tailed)	.690	
	N	4	4

Correlations

			Alstrenght	Alhardness
Spearman's rho	Alstrenght	Correlation Coefficient	1.000	.778
		Sig. (2-tailed)	.	.222
		N	4	4
	Alhardness	Correlation Coefficient	.778	1.000
		Sig. (2-tailed)	.222	.
		N	4	4

Source: Authors calculation.

Similarly, the Pearson's correlation coefficient between the tensile strength and hardness of Aluminum material in use for ship hull construction in Nigeria is 0.69. Thus a perfect correlation exists between the tensile strength and hardness of Aluminum products in use for ship hulls in Nigeria. It indicates a very strong association of about 70% between the tensile strength and hardness of aluminum hull material in use in local ship yards in Nigeria. The positive correlation also implies that increasing the tensile strength of Aluminum hull materials in use in Nigeria shipyards will increase the hardness of the Aluminum materials and limit the hulls from quick failure by indentation and brittleness. Similarly, the spearman's rank correlation coefficient of 0.77 supports the result of the Pearson's test indicating that a perfect positive correlation exists between the tensile strength and hardness of Aluminum ship hull material used in Nigeria shipyards.

Table4: Comparing the Tensile Strength of Steel and Aluminum Ship hull materials used in Nigeria Shipyards.

Independent Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
1	Steeltensilestrenght	4497.5000	4	9.57427	4.78714
	ALtensilestrenght	2637.5000	4	26.29956	13.14978

independent Samples Test

		Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference
					Lower
1	Steeltensilestrenght - ALtensilestrenght	1860.00000	21.60247	10.80123	1825.62565

independent Samples Test

		Differences	t	df	Sig. (2-tailed)
		95% Confidence Interval of the Difference			
		Upper			
1	Steeltensilestrenght - ALtensilestrenght	1894.37435	172.203	3	.000

Source: Authors calculation

The comparison of the tensile strength of steel and Aluminum hull materials used in Nigeria shipyards show the mean tensile strength of steel material in use in ship hull in Nigeria to be 4497.5000kg/cm^2 with a standard deviation of 9.57kg/cm^2 . The mean tensile strength of Aluminum hull material used in Nigeria shipyards is 2637.500kg/cm^{2}with a standard deviation of 26.299kg/cm^2. The difference of means between the tensile strength of steel and Aluminum materials used in Nigeria shipyards is 1860.00kg/cm^{2}with a standard deviation of 21.60kg/cm^2. This difference is in favour of steel material which has higher tensile strength than Aluminum hull materials.. A t-score of 172.2 greater than 2.35 t-tables and p-value of 0.00 at 0.05 level of significance shows that there is significant difference between the tensile strengths of steel and aluminum hull materials in use in Nigeria ship yards. Steel hulls have higher tensile strength and as such fail less suddenly by tension induced deformation than aluminum hull materials.

Table5: Comparing the hardness of steel and aluminum hull materials in use in Nigeria shipyards.

independent Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
1	Steehardness	30.2250	4	.09574	.04787
	Alhardness	27.8000	4	.16330	.08165

independent Samples Test

		Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference
					Lower
1	Steehardness - Alhardness	2.42500	.09574	.04787	2.27265

independent Samples Test

		Differences	t	df	Sig. (2-tailed)
		95% Confidence Interval of the Difference			
		Upper			
1	Steehardness - Alhardness	2.57735	50.657	3	.000

Source: Authors calculation

The analysis shows that the average hardness of steel and aluminum hull materials used in Nigeria ship yards are 30.23HRB and 27.80HRB respectively with respective standard deviations of 0.09574HRB and 0.16330HRB. The difference of means is 2.425HRB with a standard deviation of 0.09574HRB in favour of steel. This equally indicates that steel has higher hardness than aluminum for use in ship hull. This supports the earlier findings that increasing tensile strength leads to increasing hardness of ship hull materials. A t-score of 50.65greater than 2.35 t-table and p-value of 0.00 at 0.05 level of significance shows that there is significant difference between the hardness's of steel and aluminum hull materials in use in Nigeria ship yards. Steel hulls have higher level of hardness and as such fail less suddenly by brittleness and indentation.

V. CONCLUSION

The existences of a perfect positive correlation between the harnesses' and tensile strengths steel and aluminumalternative ship hull materialsin use in local ship yards implies that the hardness of each material type increases as its tensile strength increases and similarly for the tensile strength. The comparison of the tensile strengths and hardness's of steel and aluminum materials in use for ship hulls in Nigeria each shows a significantly highertensile strength and hardness for the steel hull materials than aluminum; thus steel hulls are deemed stronger and may fail less suddenly by indentation and plastic deformation when under load than aluminum hulls.

VI. RECOMMENDATION

Technologies that increase the tensile strengths of steel and aluminum ship hull materials will equally induce its hardness's to improve/increase. Ship yards are recommended to adopt such technologies in improving the tensile strength and hardness of aluminum ship hull materials in Nigeria ship yards in order to limit the rate of aluminum hull failures and increase the demand for aluminum hull ships in Nigeria.

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