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Mechanical Behaviour and Microstructural Characterization of Carbon Steel Samples from Three Selected Steel Rolling Plants

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Abstract : *The research investigated the mechanical behavior of samples of steel rods obtained from three selected Steel Rolling Companies in South Western part of Nigeria. This was done by carrying out some mechanical tests such as tensile, impact and hardness as well as microstructural examination.Four sets of 16 mm steel rod samples were collected from Tiger steel industries, Phoenix steel and Oxil steel Industies, all located in South West Nigeria, The chemical composition was carried out using a Spectrometer (EDX3600B). Afterwards, different samples were prepared, cut and machined according to ASTM standards dimensions of tensile and impact tests as well as hardness test from which their Ultimate tensile Strength, Yield strength, Percentage elongation, Impact strength and Brinell hardness number were obtained and compared to three standards (ASTM A706, BS 4449 and Nst 65-Mn). Their microstructures were also examined and analyzed.The results showed that the Ultimate tensile strength for the samples from Oxil steel, Phoenix Steel and Tiger steel were 661 N/(mm)^2, 653 N/(mm)^2 and 631 N/(mm)^2 respectively while their hardness values were 150 BHN, 178 BHN, 214 BHN respectively. The sample from Tiger steel and Oxil Steel had the finest and most coarse microstructure respectively. In conclusion, it was observed that the results of the sample analysis from the three selected Steel Rolling Companies conformed to most of the standards except the sample from Tiger steel which had a high hardness value compared to the standard.*
Key words: *Microstructures, Tiger steel, Phoenix steel, Oxil steel, steel rolling, characterization*

I. Introduction

According to Smallman and Bishop (1999), determination of the structural character of a material, whether massive in form or particulate,crystalline or glassy, is a central activity of materials science. Through the last few decades a category of steels known as high strength steels have undergone constant research (Bello, 2007and Sinha, 1989). Nowadays, need of steels has soared up due to newly introduced massive construction projects in civil, mechanical, naval, aeronautical engineering and in other engineering fields. Particularly in developing countries, such as in Ethiopia, India, and china, steel materials are used extensively to develop infrastructure such as road, power, water, and telecommunication (Dawitand Kidan, 2013).

Plain carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication (Smith and Hashemi, 2006). According to Rajan *et al*. (1988), steels with carbon content varying from 0.25% and 0.65% are classified as medium carbon, while those with carbon up 0.25% C, are termed low carbon. High carbon steels usually have car-bon content ranges between 0.65% - 1.5%.

Steel had been produced in bloomery furnaces for thousands of years, steel's use expanded extensively after more efficient production methods were devised in the 17th century for blister steel and then crucible steel. With the invention of the Bessemer process in the mid-19th century, a new era of mass-produced steel began. This was followed by Siemens-Martin process and then Gilchrist-Thomas process that refined the quality of steel. With their introductions, mild steel replaced wrought iron. Further refinements in the process, suchas basic oxygen steelmaking (BOS) in which carbon-rich molten pig iron is made into steel and the Bessemer process, largely replaced earlier methods by further lowering the cost of production and increasing the quality of the metal(Kelle, 1968). Steel with low carbon content has the same properties as iron, soft but easily formed (Smith and Hashemi, 2006). As a result, it can be rolled thin into products like car body panels. It is also extensively used in building and construction works to reinforce concrete. Low carbon steel is the most common form of steel due to the fact that its material properties are acceptable for many applications (Al-Qawabah *et al*. 2012). They are extensively used in making beams and structural shapes for bridges and buildings. In such applications, accurate and precise conformance to standard is highly important as consequences of deviations from these standards and specifications often result in failure while in service. Instances of collapse of buildings in the country which often result in fatal loss of lives and properties are notable examples of this. Hence, the need to carry out this research on the mechanical behaviour and material characterization of various low carbon steels produced in certain companies within the country becomes imperative.This research covered the study of some mechanical behaviour of the carbon steel samples produced from three selected companies, case studies of Oxil and Phoenix steel, Lagos state, Nigeria and Tiger steel Industries and comparison of the test results with standards.

II. Methodology

The materials that were used for the project research were samples of carbon steel produced by three selected steel rolling plants which includes: Phoenix Steel Mills Limited in Ikorodu, Lagos, Tiger Steel Industries and Oxil Steel Company in Lagos. The samples were subjected to some mechanical tests which include tensile test, hardness, impact test and fatigue test as well as metallographic analysis. Furthermore, the characterization of the microstructure of the carbon steel samples was also carried out. The chemical analysis of the samples was carried out. Afterwards, the samples from the three steel rolling plants were machined according to the requirements of tensile and impact test. Two samples produced from each of the three steel rolling plants were prepared for each of tensile, impact, and hardness test as well as for the microstructural analysis through metallography. The chemical analysis revealed the chemical composition of the samples i.e. the percentage composition of each element present in the samples is as shown in Table 1.

The tensile test specimens were prepared according to the dimension specifications of the Instron tensile testing machine by machining them using a CNC lathe (CK6132). The standard tensile test samples were subjected to tensile test using the Instron tensile testing machine (Series 3369, Load Cell Capacity 50KN) and a stress-strain curve was plotted from which the percentage elongation (ductility), yield strength and ultimate tensile strength was determined.

The hardness test was carried out using a manually operated Brinell hardness tester. A small cylindrical part of the samples from each of the three steel rolling plants were cut and grinded to get a flat surface after which they were indented by a 10 mm hardened steel ball under a load of 750 kgf for a period of about 15 seconds. The samples were then removed from the Brinell hardness tester after which the diameter of the indentation was read using the Brinell microscope. The hardness value was determined by corresponding the diameter of the indentation with the corresponding hardness value from the Standard table of Brinell hardness number. In order to confirm this hardness values, they were also calculated using the equation 1 below.

$$BHN = \frac{2F}{\pi D[D - \sqrt{(D^2 - d^2)}]} \quad (1)$$

Where

F is the imposed load (in kg).

D is the diameter of the spherical indenter (in mm).

d is the diameter of the impression of the indenter (in mm).

For this project research, the Izod impact test was employed to determine the impact property.The microstructural characterization of the samples was carried out by cutting the samples using sectioning machine. The samples were mounted in Bakelite using mounting machine, the grinding of the samples were done using grinding machine with emery paper 400, 800, 1000 and 1200μm to obtain mirror like surface.. The surfaces were then polished using polishing paste on emery cloth to remove the scratches. Etching of the samples were carried out using nital after which the microstructures were examined using a metallurgical microscope.

III. Results and Discussion

The result of chemical analysis carried out revealing the percentage composition of elements in the sample is shown in Table 1.

Table 1: Table showing the result of chemical composition of the steel samples

Chemical Composition	%C	%Fe	%Mn	%S	%P	%Si	%Cu
OXIL STEEL	0.327	98.171	0.574	0.056	0.077	0.230	0.246
PHOENIX STEEL	0.391	97.975	0.542	0.059	0.086	0.225	0.284
TIGER STEEL	0.488	98.025	0.569	0.045	0.068	0.159	0.235

After the samples underwent the impact test using the Housefield balanced impact testing machine, the amount of energy absorbed by each of the samples from the three steel rolling plants were shown in Table 2.

Table 2:Table showing the result of impact test

	IMPACT STRENGTH (1 ft-lb = 1.3558179483314J)	
	In Foots-pound(ft-lb)	**In Joules(J)**
OXIL STEEL	43.50	58.98
PHOENIX STEEL	41.90	56.81
TIGER STEEL	36.95	50.10

Using the Brinell hardness tester to carry out the hardness test using a 10mm steel ball indenter with a 750 kg load, indentation was made on each sample from the three steel rolling plants. The diameter of indentation was determined using a brinell microscope. The Brinell hardness numbers were as calculated using equation 1 and results tabulated as shown in Table 3:

Sample from Oxil Steel
Diameter of indentation, d =2.5mm

$$BHN = \frac{2(10)}{\pi(10)[10 - \sqrt{(10^2 - 2.5^2)}]}$$

$$\boldsymbol{BHN = 150.36}$$

Sample from Phoenix Steel
Diameter of indentation, d = 2.3mm

$$BHN = \frac{2(10)}{\pi(10)[10 - \sqrt{(10^2 - 2.3^2)}]}$$

$$\boldsymbol{BHN = 178.10}$$

Sample from Tiger Steel
Diameter of indentation, d =2.1mm

$$BHN = \frac{2(10)}{\pi(10)[10 - \sqrt{(10^2 - 2.1^2)}]}$$

$$\boldsymbol{BHN = 214.1}$$

Table 3: Table showing the result of the hardness test

	Diameter of Indentation(mm)	**Brinell Hardness Number(BHN)**
OXIL STEEL	2.50	150.36
PHOENIX STEEL	2.30	178.10
TIGER STEEL	2.10	214.12

The tensile test samples were subjected to tensile test using the Instron tensile testing machine after which stress-strain graph were generated for the three steel rolling plants (Oxil, Phoenix and Tiger steel Industries) samples as shown in Figures 1-3. From the corresponding data generated, the Ultimate tensile strength (UTS), yield strength and percentage elongation were as determined below;

Original gauge length is 30 mm
Diameter of the tensile samples is 4 mm

Area, $\boldsymbol{A = \pi r^2}$

$\mathbf{r} = \frac{\boldsymbol{d}}{\mathbf{2}}$

Where r is the radius of the tensile sample
d is the diameter of the tensile sample.

Therefore, $A = \pi(\frac{4}{2})^2$

Area of the tensile samples is **12.57mm^2**

Sample from Oxil Steel
Ultimate tensile strength, UTS =$\frac{Maximum\ load}{A}$

Maximum load (Oxil Steel) is 8301.50 N

$$UTS = \frac{8301.50}{12.57}$$

$$\mathbf{= 660.61 N/(mm)^2}$$

Ultimate tensile Strength (Oxil Steel) is approximately **661 N/(mm)^2**

$$\text{Yield Strength} = \frac{Load\ at\ yield}{A}$$

Load at yield (Oxil Steel) is 5833.09N

$$\text{Yield Strength} = \frac{5833.09}{12.57}$$

$$\mathbf{= 464.18 N/(mm)^2}$$

Yield Strength (Oxil Steel) is approximately **464 N/(mm)^2**

Percentage Elongation $= \frac{finalguagelength - Originalgaugelength}{originalgauge\ length} \times 100$

$= \frac{8.64}{30} \times 100$

$= 28.79\%$

Percentage elongation (Oxil Steel) is approximately **29%**

Sample from Phoenix Steel

Ultimate tensile strength, UTS $= \frac{Maximum\ load}{A}$

Maximum load (Phoenix Steel) is 8209.86 N

$$UTS = \frac{8209.86}{12.57}$$

$$\mathbf{= 653.32 N/(mm)^2}$$

Ultimate tensile Strength (Phoenix Steel) is approximately **653 N/(mm)^2**

$$\text{Yield Strength} = \frac{Load\ at\ yield}{A}$$

Load at yield (Phoenix Steel) is 5668.31N

$$\text{Yield Strength} = \frac{5668.31}{12.57}$$

$$\mathbf{= 451.07 N/(mm)^2}$$

Yield Strength (Phoenix Steel) is approximately **451 N/(mm)^2**

Percentage Elongation $= \frac{finalguagelength - Originalgaugelength}{originalgauge\ length} \times 100$

$= \frac{8.26}{30} \times 100$

$= 27.54\%$

Percentage elongation (Phoenix Steel) is approximately **28%**

Sample from Tiger Steel

Ultimate tensile strength, UTS $= \frac{Maximum\ load}{A}$

Maximum load (Tiger Steel) is 7935.53 N

$$UTS = \frac{7935.53}{12.57}$$

$$\mathbf{= 631.49 N/(mm)^2}$$

Ultimate tensile Strength (Tiger Steel) is approximately **631 N/(mm)^2**

$$\text{Yield Strength} = \frac{Load\ at\ yield}{A}$$

Load at yield (Tiger Steel) is 5605.24N

$$\text{Yield Strength} = \frac{5605.24}{12.57}$$

$$\mathbf{= 446.05 N/(mm)^2}$$

Yield Strength (Tiger Steel) is approximately **446 N/(mm)^2**

Percentage Elongation $= \frac{finalguagelength - Originalgaugelength}{originalgauge\ length} \times 100$

$= \frac{8.35}{30} \times 100$

$= 27.83\%$

Percentage elongation (Tiger Steel) is approximately **28%**

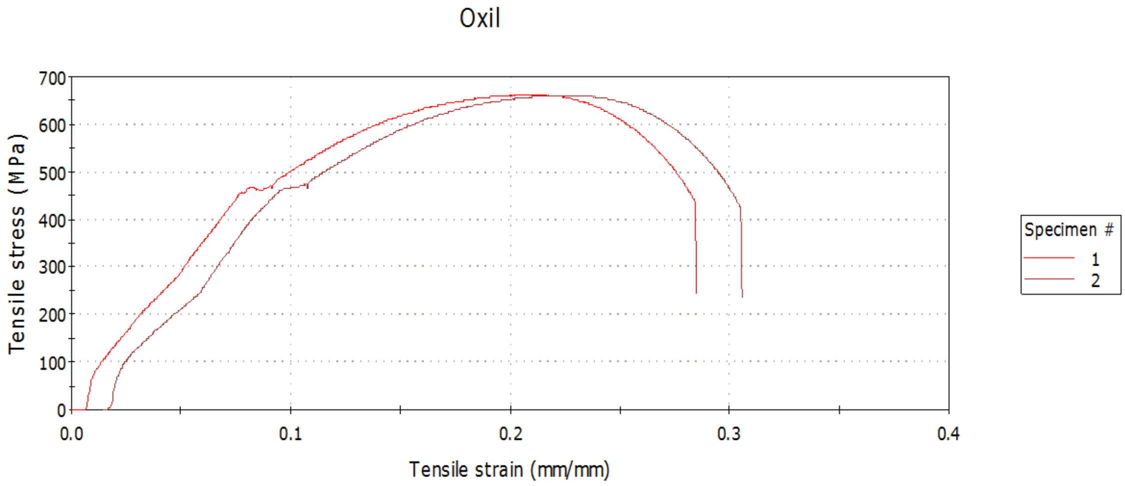


Figure 1: Stress Strain curve for samples from Oxil Steel Lagos

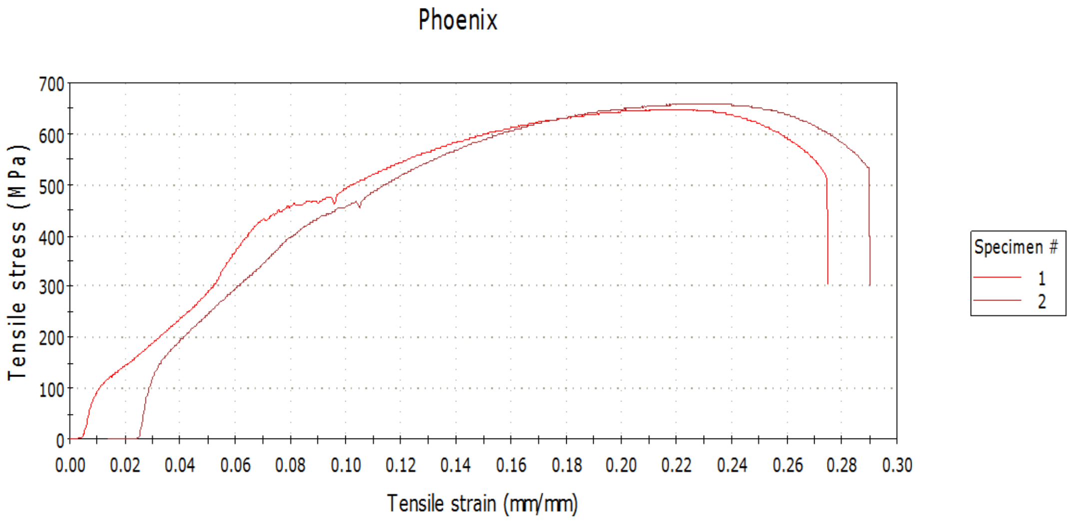


Figure 2: Stress Strain curve for samples from Phoenix steel Lagos

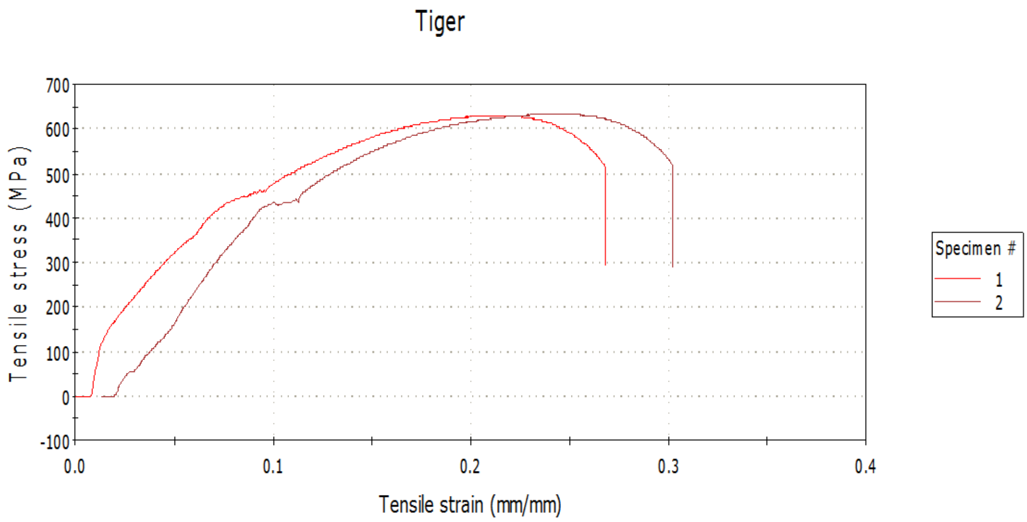
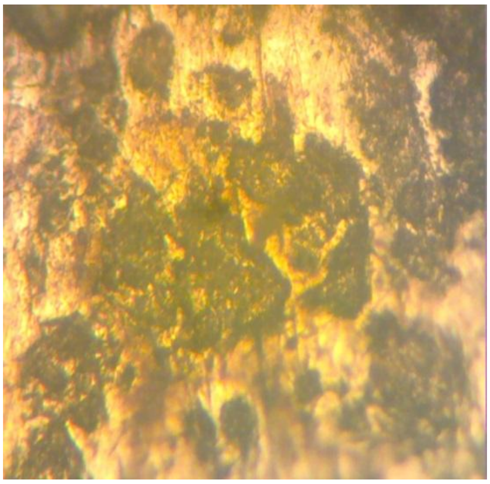
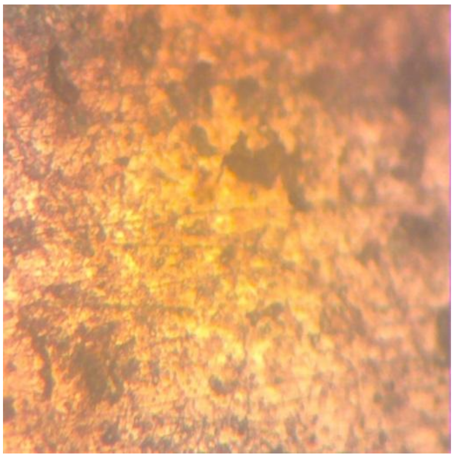


Figure 3: Stress Strain curve for samples from Tiger steel industry

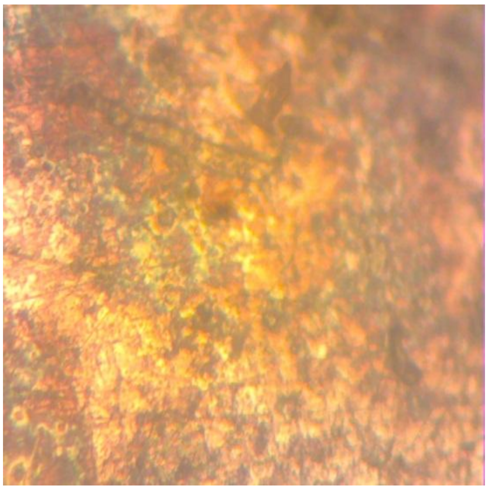
The samples from the three steel rolling plants were subjected to observation under the metallurgical microscope in the laboratory after they were grinded and polished. The results were shown in Figures 4 – 6.



Dark patches-Pearlite Grains, Light areas- Ferrite Matrix
Figure 4: Microstructure of Oxil steel sample (X600)



Dark patches-Pearlite Grains, Light areas- Ferrite Matrix
Figure 5: Microstructure of Phoenix steel sample (X600)



Dark patches-Pearlite Grains, Light areas- Ferrite Matrix
Figure 6: Microstructure of Tiger steel sample (X600)

The elemental make-up of the samples from oxil steel company, Phoenix steel limited and Tiger steels as observed from the result of the chemical analysis carried out revealed a variation in the percentage of elements in the three samples. The percentage carbon content in the sample from Oxil steel was the least (0.327%). Slightly higher was the sample from Phoenix steel (0.391%) while the highest was Tiger steel sample (0.488%).
Comparison these values with the standards used (ASTM A706, Nst 65-Mn and BS 4449 of 1997 standards) as shown in Table 4 and Figure 7 it was seen that the three samples have higher values than all the three standards except Oxil steel which conforms within ASTM A706 and Nst 65-Mn. Phoenix Steel has the highest variation from the standards as its percentage carbon was far higher than any of the standards.
Considering the Sulphur and Phosphorus content, only the sample from Tiger steel fell within any of the three standards as the samples from Oxil steel and Phoenix steel did not conform to any of the standards. Observing the silicon content, all the samples conform to the standard except Tiger steel with the least silicon content (0.159%).
Based on the percentage carbon content of the three samples from the three steel rolling plants, they were all classified as medium carbon steels (between 0.3-0.6%).

Table 4: Table showing comparison of the chemical composition of samples with standards

	%C	%Fe	%Mn	%S	%P	%Si	%Cu
BS 4449, 1997	0.25	Not Available	Not Available	0.05	0.05	Not Available	Not Available
ASTM A706	0.3	Not Available	1.5	0.045	0.035	0.5	Not Available
Nst 65-Mn	0.35	Not Available	1.6	0.04	0.04	0.3	0.025
OXIL STEEL	**0.327**	**98.171**	**0.574**	**0.056**	**0.077**	**0.230**	**0.246**
PHOENIX STEEL	**0.391**	**97.975**	**0.542**	**0.059**	**0.086**	**0.225**	**0.284**
TIGER STEEL	**0.488**	**98.025**	**0.569**	**0.045**	**0.068**	**0.159**	**0.235**

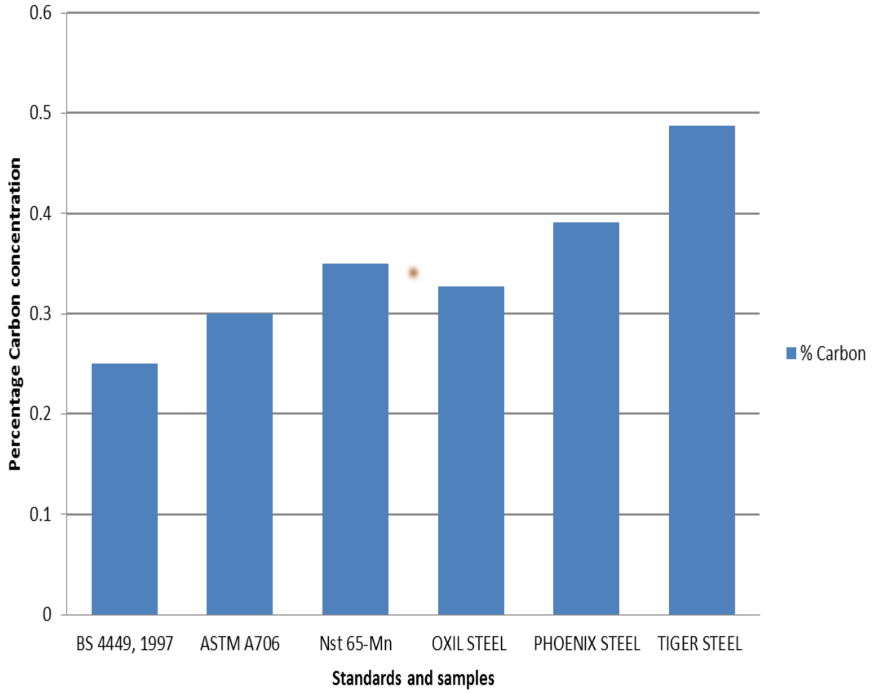


Figure 7: Chart showing the percentage carbon content of standards and samples from oxil steel, Phoenix steel and Tiger steel industries

From the results of the impact test, it was seen that the sample from Oxil steel has impact strength of 58.98J; sample from Phoenix steel has impact strength of 56.81J while the sample from Tiger steel has impact strength of 50.10J. Based on these results, the sample from Tiger steel has the least impact energy followed by the sample from Phoenix steel while the sample with the highest impact energy was the sample from Oxil steel. This meant that the sample from Oxil steel would absorb energy during fracture (could withstand more shock load) compared to the other two samples.

The result of the hardness test reveals that the sample from Oxil steel has 150 BHN, sample from Phoenix steel has 178 BHN while the sample from Tiger steel has 214 BHN. Therefore, the sample from Tiger steel has the highest hardness value while the sample from Oxil steel has the least hardness value. These results were buttressed by the percentage carbon content of the samples; the higher the carbon content the harder the material.Comparing the results to the standards(as shown in Figure 8), the sample from Oxilsteel and Phoenix steel conformed to two of the standards(ASTM A706 and Nst 65-Mn) but the sample from Phoenix steel did not conform to any of the standards as its hardness value was far higher than the standard values.

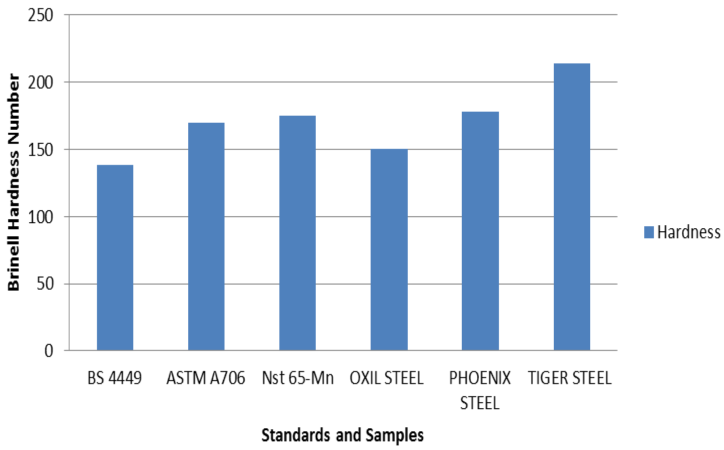


Figure 8: Chart showing the BrinellHardness Number of the samples from Oxil Steel, Phoenix Steel and Tiger steel industries compared with Standards

From the microstructures of the samples shown in Figures 4 - 6, it was observed that the microstructure of the sample from Oxil steel has coarse pearlite grains in the ferrite matrix, the microstructure of the sample from Phoenix steel has a fine (small) pearlite grains while the microstructure of the sample from Tiger steel revealed finer (smaller) pearlite grains embedded in the ferrite matrix. The coarse pearlite grains found in the microstructure of the sample from Oxil steel was confirmed by the fact that it has the least percentage carbon content thus making it the least hard of the three steel samples. The coarse grains were formed due to slow cooling which allows for considerably much time for growth of grains into large sizes. In the contrary, the fine pearlite grains in the microstructure of the sample from Tiger steel was confirmed by the fact that it has the highest percentage carbon content thus making it the hardest of the three steel samples. The fine particles are formed due to more rapid cooling which allowed for less time for the growth of grains into larger sizes.

From the results generated from the tensile test of the samples from Oxil steel, Phoenix steel and Tiger steel, the Ultimate tensile strength (UTS), Yield strength and the percentage elongation were obtained. The UTS for the sample from Oxil steel was 661 $N/(mm)^2$, the UTS for the sample from Phoenix steel was 653 $N/(mm)^2$ while the UTS for the sample from Tiger steel was 631 $N/(mm)^2$. Comparing the UTS of the samples with the standards as shown in Figure 9, it could be deduced that the samples all fall within the standards, none of the samples fall below the standards. Considering the yield strength of the samples, the results showed that the yield strength of sample from Oxil steel was 464 $N/(mm)^2$, the yield strength of the sample from Phoenix steel was 451 $N/(mm)^2$ while the yield strength of the sample from Tiger steel was 446 $N/(mm)^2$. Comparing these values with the standards, all the sample fall within the standards except the BS 4449, 1997 standards of which all the samples fall below its standards value. From the results, it could be deduced that all the sample have high values of ultimate tensile strength (UTS) and yield strength thus implying high ductility and strength.

Considering the percentage elongation of the samples the results showed that the percentage elongation of sample from Oxil steel was 29%, the percentage elongation of the sample from Phoenix steel was 28% while the percentage elongation of the sample from Tiger steel was 28%. Comparing these values to the standards as shown in Figure 10, it was seen that the percentage elongation of the samples were far higher than the standards. The high values of the percentage elongation of the samples showed that there was a high extent to which the steel samples could be elongated before they eventually fracture thus, they were ductile. This was confirmed by their high values of Ultimate tensile strength and yield strength. Table 5 compared the mechanical test results of the samples.

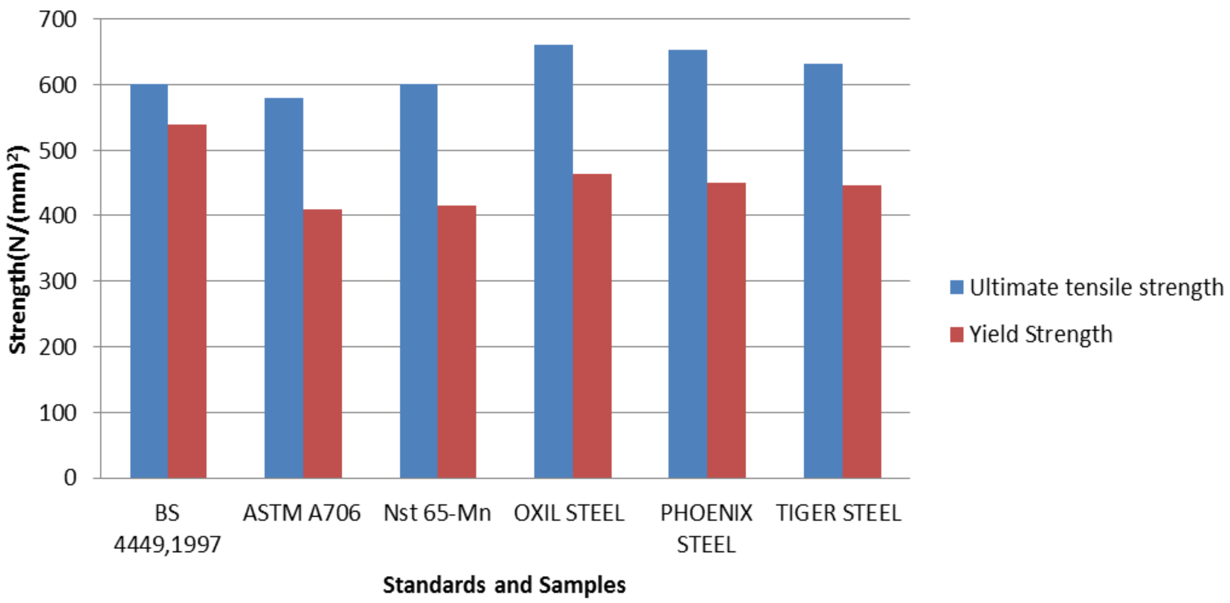


Figure 9: Chart showing the Ultimate tensile strength and Yield strength of the Standards and samples from Oxil steel, Phoenix steel and Tiger steel industries

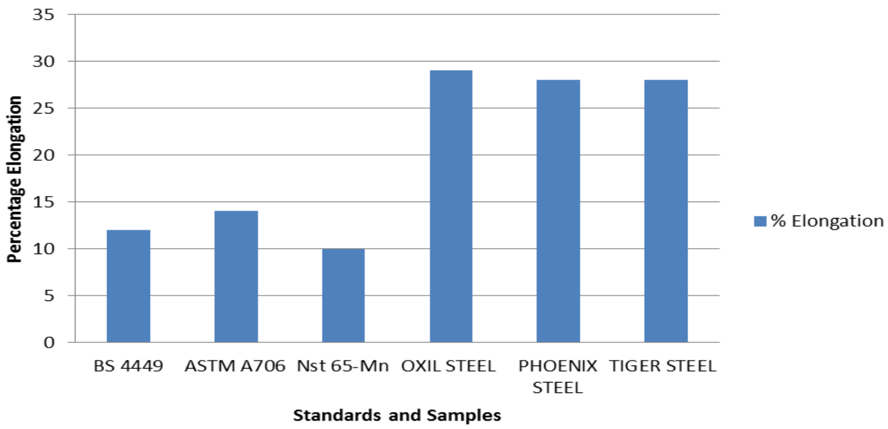


Figure 4.10: Chart showing the percentage elongation of samples of Oxil steel, Phoenix steel and Tiger steel industries compared with Standards

Table 5: Comparison of the Mechanical test results

	Ultimate Tensile Stress (UTS) (N/(mm)²)	**Yield Strength (N/(mm)²)**	**Percentage Elongation**	**Hardness (BHN)**	**Impact Strength**
ASTM A706	580	410	14	170	Not Available
BS 4449, 1997	600	540	12	138	Not Available
Nst 65-Mn	600	415	10	175	Not Available
OXIL STEEL	**661**	**464**	**29**	**150**	**58.98**
PHOENIX STEEL	**653**	**451**	**28**	**178**	**56.81**
TIGER STEEL	**631**	**446**	**28**	**214**	**50.10**

IV. Conclusion

From the results of the mechanical tests carried out it could be deduced that all of the samples from the steel industries considered conform to most of the standards except the sample from Tiger steel industry which due to its high percentage carbon content (0.488%) has a very high hardness value compared to the standards. Considering the Ultimate tensile strength, Yield strength and Percentage elongation which are very essential properties in engineering application, all the samples are suitable and meet up with the standards.

The properties of the steel produced from these industries could be maximized depending on the type of application.For an application which requires a high hardness value, Tiger steel will be the most suitable while Oxil steel will be the most suitable for an application that requires high ductility and load bearing ability such as in beams and columns in buildings.

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