# Comparative Studies of Locally Produced and Imported Low-Carbon Steels on the Ghanaian Market

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## Abstract

*A comparative research on the mechanical properties and microstructural studies of locally produced and imported low-carbonsteels have been conducted. These low-carbon steels have played major roles in the building and fabrication industries in Ghana.Twodifferentbatches of samples (rebars) from local and foreign producers were used. The rods were obtained from the dealers on the open market. The chemical analyses werecarried out at Tema Steel Works Company Ltd.The tensile tests, hardness measurements and microstructural studies were carried on both the local and the imported steels. The results showed that, the imported rods were more ductile, with higher toughness values and percentage elongation than the locally produced samples. The locally produced rods, however, had higher ultimate tensile strength, higher hardness and were more brittle than the imported samples. The differences in the mechanical properties of the samples were attributed to the different elemental compositions and the production methods used.*

**Keywords**: Low-carbon steels, Ultimate Tensile Strength, Young's Modulus, Percentage Elongation, Optical Microscopy

## *Introduction*

Steel is the common name for a large family of iron-carbon alloys which are easily malleable after the Molten stage. Steels are commonly made from iron, coal and limestone (Higgins, 1993). Lindberg (1977) noted that carbon is an important alloying element in steels; it is aneffectivealloying agent which gives a variety of strength and hardness by varying its composition in steel. Low carbon steel is a type of metal that has an alloying element made up of a relatively low amount of carbon. Typically, steel has a carbon content that ranges between 0.05% and 0.25%. It is one of the most common types of steel used for general purposes because it is often less expensive than other types of steel. Since it has a low amount of carbon, it is more malleable than other kinds of steels.

As a result, it can be rolled thin into products of many shapes (Rolf, 2006).According to Rolf (2006) steel has been part of one of the greatest achievement in history of man's discovery. American Iron and Steel Institute (2002) stated that steel is the backbone of bridges, the skeleton of skyscrapers, the framework for automobiles, the stronger and the more durable frame in building construction etc.Kankam et al. (2002) observed that in Ghana, reinforced concrete buildings with low-carbon steel constitute about 95% ofthe building stock in the urban centres.

Kankam et al. (2002) noted again that,the reinforcing low-carbon steel bars usedin Ghana are milled from re-cycled scrap ferrous metalsby the local producers and the imported rods which are produced fromiron ores. In Ghana, steels are used for fabricating burglar proofs forwindows and doors and super structures for overhead water reservoirs.

**Tensile Test**

The tensile test is a standard test which is conducted using a tensile testing machine. In this work an Avery testing machine was used. The ten test specimens each from the local and foreign producers were prepared for test by British standard as specified in Table 2. The prepared test specimen were position in the jaw of the Avery hydraulic tensile testing machine , as the machined started to stretched the rod readings of loads against extensions were recorded. At the yield point the extensometer was removed to prevent damage. Further readings of load against extension using dividers and calipers at intervals of 0.00127 m increments were recorded.

The experiment continued until the specimen fractured and the necking diameter was recorded. From the tests, the Ultimate tensile strength, Young's Modulus, Percentage elongation, Fracture stress, Toughness and the percentage reduction in area were determined. The tensile strength was calculated using the following formulas of Olsen et al. (2007). Other properties were calculated from these fundamental parameters.

$UTS = P_{max}/A_o$

Where $P_{max}$ is the maximum load applied

$A_o$ is the Original Cross sectional area.

The percentage elongation after fracture is given as

$\% \varepsilon = (\ell_u - \ell_o) \times 100 / \ell_o$

Where $\ell_o$ is the original gauge length

$\ell_u$ is the final gauge length.

The percentage reduction in area is also given as

$\%\Delta A = (A_o - A_u) \times 100 / A_o$

Where $A_o$ is the original cross-section area

$A_u$ is the minimum cross-sectional area after fracture.

**Hardness Test**

The three most popular hardness methods are: Brinell hardness test, Rockwell hardness test and Vickers hardness test(Low et al.,2006). These hardness tests measure a metal's hardness by determining the metal's resistance to the penetration of a non-deformable ball or cone.

The tests determine either the width or depth of indentation the indenter makes on or into the metal, under a given load, within a specific period of time. According to the authors, comparing the methods with each other, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which accurately accounts for multiple grain structures and any irregularities in the uniformity of the material. Samuel R. (2007) also stated that the Brinell hardness test method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures; hence, its usage for this work.

First, a standard block from the manufacturer of the machine was used to check the accuracy of the machined. Ten specimens each for both the locally produced and imported samplessurfaces were machined flat to provide large surface area for the 10 mm hardened steel ball indenter. The sampleswerepositioned in the machine and the 10 mm diameter hardened steel ball indenter was used to make three different indentations for each sample when a load of 3000 kg was applied for 15 seconds. The diameter of the indentations made on the test materials were measured with a low power microscope and their average value was calculated by substituting the average diameter computed value into equation below. Hardness measurement table can also be used.

$$BHN = \frac{F}{\frac{\pi}{2} * D * (D - \sqrt{D^2 - D_1^2})}$$

Where BHN is Brinell Hardness Number, F is the Load, D is the diameter of the steel ball indenter (10 mm) and $D_1$ is the average value of the indentation computed.

**Metallography**

Metallography is the study of the structure of metals and of metal alloys through the examination of specimens with a metallurgical microscope(Brandon, 1966). The structures observed in the microscope are often recorded photographically (micrograph), and are normally calledmicrostructures.A very good analysis of a material’s microstructure depends on how the samples are prepared. Greavers et al. (1960) stated that the basic steps for proper metallographic specimen preparation include:documentation, sectioning and cutting, mounting, planar grinding, rough polishing, final polishing and etching.

The microstructure of the low-carbon steels has a significant effect on the strength ofthe materials. For iron rods with a certain composition, the microstructure can be altered through varying the processing route used. For example, different yield strength can be achieved for a fixed composition at different temperatures (Rostoker et al. 1965).Ten local and imported samples were studied along the transverse and longitudinal section of the iron rods.

## *Materials and Methods*

**Materials and Specimens Preparation**

Low-carbon steel rods of diameter 19 mm were obtained from the dealers in both local and imported low-carbon steelson the open market inGhana.

The chemical compositions of the two different types of materials are shown in Table 1.Table 1.The chemical composition in wt. % for the imported and local low-carbon steels

| | C | Mn | Si | P | S | Fe |
|---|---|---|---|---|---|---|
| Imported steel (IS1) | 0.20 | 0.78 | 0.03 | 0.021 | 0.033 | Balance |
| Imported steel (IS2) | 0.19 | 0.76 | 0.03 | 0.025 | 0.019 | Balance |
| Local Steel (LS1) | 0.21 | 0.50 | 0.15 | 0.025 | 0.031 | Balance |
| Local Steel (LS2) | 0.15 | 0.33 | 0.28 | 0.076 | 0.045 | Balance |

The mechanical properties investigated were Ultimate Tensile Strength (UTS), Young's Modulus, Percentage Elongation, Fracture Stress, Toughness and Hardness. Microstructural studies on the two types of steels were also done. A set of ten specimens were prepared for themechanical tests andthemicrostructural studies. The properties investigated and the methods used have been summarized in Table 2.

**Table 2. Methods used in determining the properties**

| **Properties** | **StandardSpecimen Type** | **Mode of Evaluation** |
|---|---|---|
| Tensile Strength | British Standard round test piece (19 mm x 400 mm) | AVERY testing machine of 600KN and gauge length (0.0508 m) |
| Hardness | British Standard round test piece (19 mm x 400 mm) | Brinell Hardness testing machine of load 30000Kg,10mm indenter steel ball for 15 seconds |
| Microstructural studies | Microscopy (LEICA) | Optical microscopy |

**Preparation of samples for Microstructural studies (Metallography)**

## Grinding and Polishing

Ten sets of samples, each of height 2.5 cm were taken from both local and imported low carbon steels. They were then sectioned longitudinally and transversely, and ground on different grits of silicon carbide papers of grades 180, 240, 400, 600 and 1000. Water was poured on the samples regularly every one to two minutes to carry away heat and to enable effective grinding as the samples were turned through an angle of $90^0$ on transfer to different grinding papers. They were placed on a rotating polishing wheel using a suspension of alumina powder; the samples were polished to mirror-finish.

## Etching

The etchant was prepared from 2% (2 vols.) of Nitric acid and98% (98 vols.) of ethanol. The polished samples were agitated in the etchant for 40 seconds and quickly washed in water to stop the etchant from attacking more of the phases. The sample surfaces were then rinsed in ethanol and then dried byblowing with hot air.

## Microstructural Examination

The etched samples were mounted on a plasticine placed on a glass slide. The desirable magnification was chosen by selecting one of the objective pieces (x 500). The focusing was adjusted until a good focus was found by looking into the eye piece. The image of the microstructure was captured by a digital camera connected to a computer.

## *Results and Discussions*

### Chemical Composition and method of production

The chemical compositions of the local low-carbon steels obtained from the Ghanaian market was compared with the approved compositions of the Ghana Standard Authority (GSA).Table 3 below showsthattheManganese content of the local low-carbon steels even thoughwithin the acceptable range given by GSA, it was not enough to make the rods ductile; since the main function of the Mnwas to increase the ductility and toughness of the rods (Tema Steel Works company Ltd, 2009).In the local low-carbon steels the Manganese content was reduced in orderto lower the cost of production.

To compensate forMn reduction, the Thermo Metallurgical Treatment (TMT) method of production was applied, which involved the rapid cooling of the molten metal to a temperature range of $600^0$Cto $650^0$C – this resulted in a non-homogenous solid solution. Ahardandbrittleproduct at a lower cost was rather produced, compared to the more ductile imported samples (TemaSteel Works Company Ltd, 2009). According to Degarmo(2003), Phosphorus and Sulphur are unwanted elements in steels, because they eventually form phosphides and sulphides which do not contribute to the toughness of steel.

Phosphorus particularly induces fast cooling rate which makes the local rods non-homogenous in solute distribution.These‘harmful’ elements exceeded the approved range of GSA for both local and imported samples especially local sample two (SL2) which contributed to its having the highest ultimate tensile strength value of 550±11 MPaas shown in table 4. The local producers do not remove all the slag with the impurities and this brings about the hard and brittle products at a lower cost. The chemical composition of the imported samples are fine-tuned closer to the approved composition by GSA, hence, a more ductile and tougher products were produced.

**Table. 3 Approved selectable composition of low-carbon steel by GSA.**

| Elements | C | Mn | Si | P | S |
|---|---|---|---|---|---|
| (wt %) | ≤ 0.25 | ≤ 1.65 | ≤ 0.60 | ≤ 0.05 | ≤ 0.05 |

### Mechanical Properties

**Table. 4 Showing some Mechanical Properties of the local low-carbon steels (LS1, LS2) and those of the imported steels (IS1, IS2)**

| **Samples** | **Ultimate Tensile strength (MPa)** | **Young’s Modulus (GPa)** | **Percentage Elongation** | **Fracture Stress (MPa)** | **Toughness ($MJm^3$)** | **Brinell Hardness (BHN)** |
|---|---|---|---|---|---|---|
| IS1 | 456±12 | 110.1± 0.6 | 30.0±0.1 | 317±28 | 102±3 | 169±1 |
| IS2 | 453±33 | 108.3±0.5 | 30.0±0.4 | 286±10 | 100±3 | 183±2 |
| Average of IS | 454.5±22.5 | 109.2±0.6 | 30.0±0.3 | 301.5±19 | 101±3 | 176±2 |
| LS1 | 520±14 | 157.5±0.4 | 25.0±1.7 | 338±7 | 89±5 | 224±7 |
| LS2 | 550±11 | 168.2±0.3 | 22.8±0.5 | 374±5 | 86±3 | 258±1 |
| Average of LS | 535±12.5 | 162.4±0.4 | 23.9±1.1 | 356±6 | 87.5±4 | 241±4 |

From Table. 4 above and Fig.1below it can be seen that the local samples has Ultimate Tensile Strengthand Young's Moduli average values of 535±12.5MPa, 162.4±0.4GPa respectively,which were higher than those of the imported steelswith corresponding average values of 454.5±22.5MPa and 109.2±0.6GPa respectively, which meant that the local samples could bear more loads before fracture. The local samples were also harder as compared to the imported samples with average hardness value of 241±4BHN. This was due to the differences in elemental compositions and the modes of production which were evident in the microstructures shown in Fig.2 below.

Even though the carbon content in the local sample (LS2) was the least as compare to the rest, its phosphorus and sulphur contents were very high which made it the most brittle and the hardest; hence, the highest fracture stress value of 374±5 MPa. The imported samples are the toughest having average toughness value of 101±3MJm$^{3}$ with high percentage elongation value of 30.0±0.3 %as compared to the local samples in Table 4.This made the imported samples very ductile and preferable for high-rise buildings like towers and skyscrapers because of their ability to undergo larger plastic deformation before fracture.

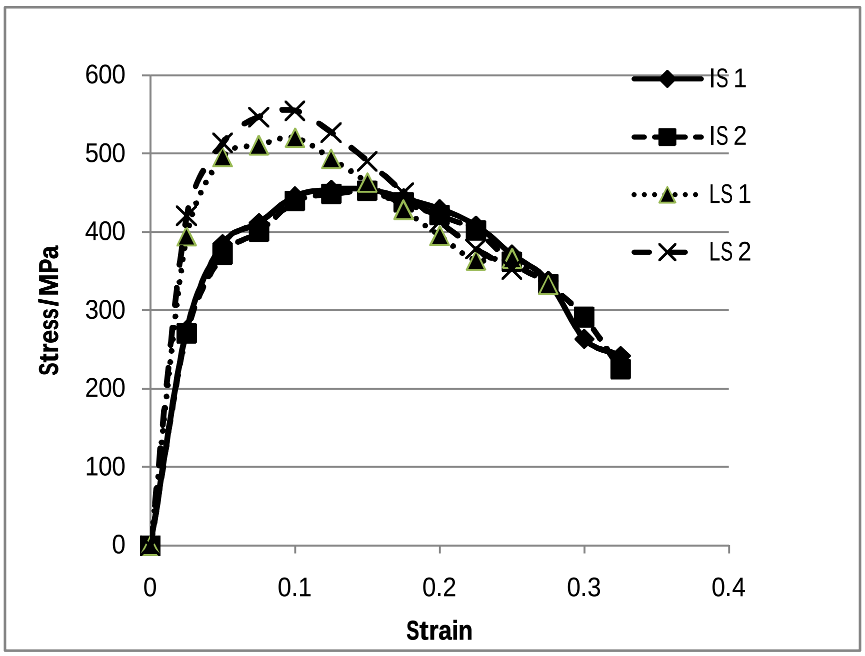


**Fig. 1 Average Stress-Strain curve for imported (IS1, IS2) and locallyproduced (LS1, LS2) low-carbon steel rebars.**

### Optical Metallography

The microstructures of the locally produced samples did not have any distinct grain boundaries as indicated in Fig.2a and Fig.2b because of the mode of production. The ferrites are the white patches and the fine pearlites (ferrites and cementites) are the dark patches. The imported samples had distinct grain boundaries because of the mode of productionas can be seen in Fig.2c and Fig.2d, which resulted in ductile and tougher products because the Ferro-alloying elements were allowed to settle evenly in the lattice structure (Wart, 1970).

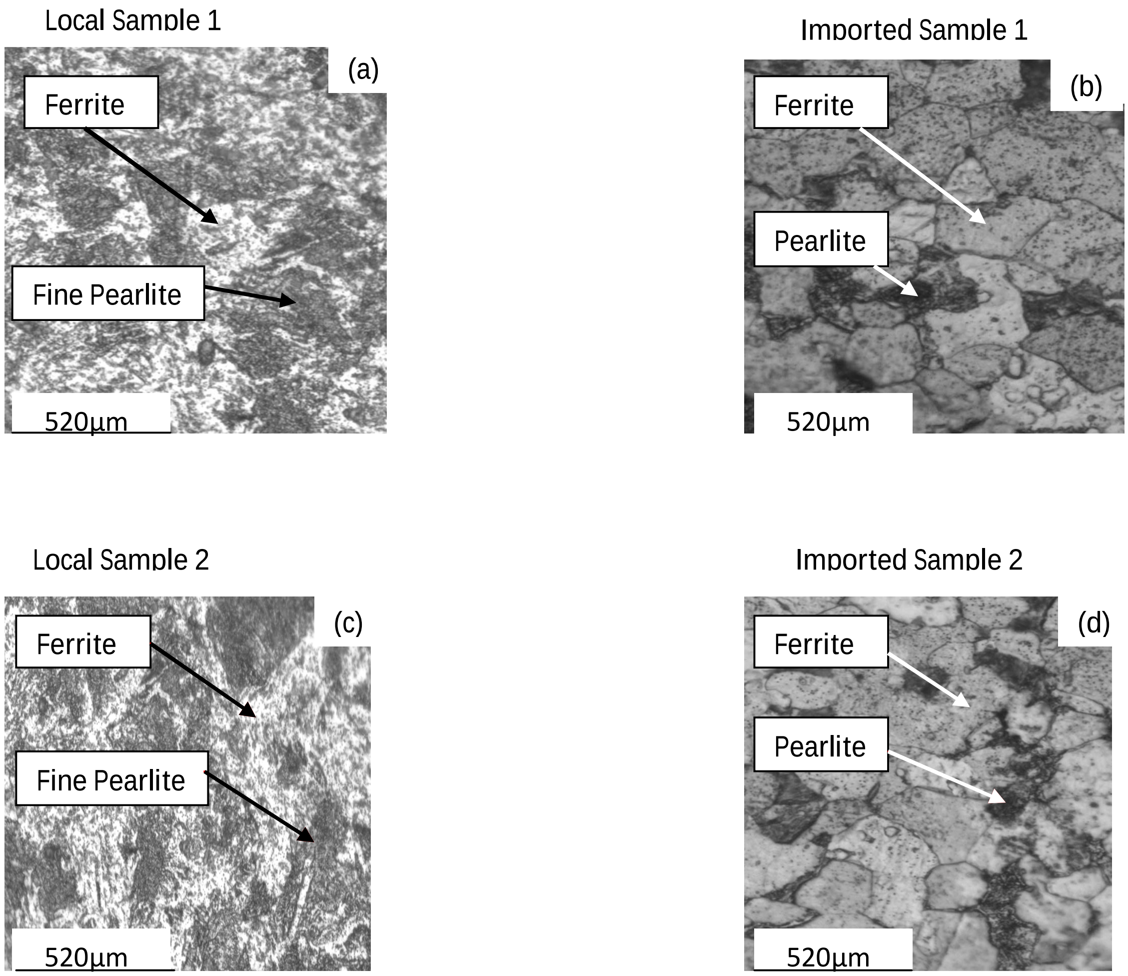


**Fig. 2. The micrographs of the local steel samples (a and c) and importedsteel samples (b and d), showing ferrites (white regions) and pearlites (dark regions).**

## *Conclusions*

Based on the studies presented in this paper, the following conclusions are presented:

1. The chemical composition of the imported samples agreed more withthe figures provided by Ghana Standard Authority (GSA), whereas the composition of the local samplesdid not completely agreed with the recommended figures.
2. The local producers based their production method mainly on affordability of the product on the market.
3. The imported low-carbon steels would be more preferable because in case of earthquakes or earth tremor they are in good position to absorb a lot of energy before fracture because of their high percentage elongation and ductility; while the local steels rods could fail catastrophically because of their brittle nature.
4. The high ultimate tensile strength and Young's moduli for the local samples indicated that they could bear more loads before fracture, but could experience poor ductility.

5. The locally produced low-carbon steels are very stiff, that is, they had a high resistance to deformation. This was clearly demonstrated by the higher Young's Moduli values and a less percentage elongation as compared to the imported rods with a higher percentage elongation and a smaller Young's Moduli.
6. The strength and toughness of a material are two opposite variable. Thus an increase in the strength of a material leads to a decrease in the ductility or toughness. The locally produced iron rods were relatively of higher strength (UTS), but were less tough than the imported iron rods.
7. Ghana Standard Board should make sure, acceptable value ranges given by them are strictly observed by all the local producers.
8. Ghana Standard Board should give more specific values of the mechanical propertiessuch as the Tensile Strength, Modulus of Elasticity, Percentage Elongation etcfor each kind of constructional work and make sure all their prescriptions for production of low-carbon steels are observed by both local manufacturers and importers of low-carbon steels.

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