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Effects of Microstructures and Process Variables on the Mechanical Properties of Rolled Ribbed Medium Carbon Steel

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Abstract

Various factors have been responsible for differences in the mechanical properties of rolled ribbed medium carbon steel and these factors have not been studied extensively and ought not to be judging from the importance of the rolled ribbed medium carbon steel in building construction. The study investigated the effects of the section sizes which ranged from 12 mm to 25 mm diameters, chemical composition of the steel as process variables and resulting microstructures on the mechanical properties of the rolled ribbed medium carbon steel were carried out. Here the as received rolled ribbed medium carbon steel were analysed to determine the chemical composition using spectrometric analyser and they were then machined using lathe machine to tensile, impact and hardness tests and micro structural samples. These samples were used to determine the tensile, hardness, impact properties of rolled ribbed medium carbon steel. The micro structural analysed were also studied. It was found from the studies that the percentage carbon content has great influence on the mechanical properties of the materials as they all increased with increase in carbon content except impact strength which decreased with increase in carbon content. The diameters of the rods also have great effect on the mechanical properties of the materials since the rate of cooling is a function of size of the rod. The study is relevant to steel industries that produced rolled ribbed medium carbon steel and structural engineers that made use of this steel in building construction.

Keywords: mechanical properties; diameter, rolled-ribbed steel; microstructure; and medium carbon steel

INTRODUCTION

The understanding of the properties of materials is essential in both the design and applications in any engineering project if it is to prove satisfactory for its intended purpose (Neil and Ravindra, 1996). The ability of a material to adequately perform in service demonstrates several mechanical properties of the material. For instance, the network of bridges and structures, high rise buildings and road ways are illustrations of the capabilities of materials (Vernon, 1977). Demands for safer materials have made Engineers to become knowledgeable in the field of materials. Consequently, the understanding of the influence of chemistry and physics of material on its overall and mechanical properties is pre-requisite for design and applications. Engineers must be able to plan, produce and determine the required strength of their products as these products function in everyday life and in extreme environments. They must aware of microstructures of materials and their relationship to mechanical properties (Williams, 2000). Materials Engineers are concerned with producing and fabricating materials to meet service requirements as predicted by the laboratory analyses, especially in their mechanical properties. Hence, materials are frequently chosen for structural application provided they have the desirable combinations of mechanical properties (Williams, 2000). These mechanical properties of materials are of prime interest to the Engineers and the results of tests to determine these properties are used for various purposes (Pascoe, 1978). They are of concern to a variety of parties such as producers and consumers of materials, research organisations, government agencies, that have differing interests. Consequently, it is imperative that there be some consistency in the manner in which tests are conducted, and in the interpretation of result.

Large amounts of carbon steel are used for the reinforcement of concrete in buildings, bridges and marine structures. The reinforcement bars therefore constitute a competitor to structural steel plates and section (Llewellyn, 1992). Simecek and Hajduk (2007) studied prediction of mechanical properties of hot rolled steel products and Oyetunji and Adebayo (2011) also worked on the development of models for the prediction of mechanical properties of rolled ribbed medium carbon steel are some of the recent works reviewed. From this works little work have been done on this crucial area since affect our life, thus engered this and this is the rationale behind this work. Hence, the purpose of this research was to investigate the influence of some process variables (chemical composition, section sizes and microstructures) on the final mechanical properties of the material – rolled ribbed medium carbon steel, commonly used in various structural engineering designs.

MATERIALS AND EQUIPMENT

The rolled ribbed medium carbon steel rods used for the research work were obtained from Nigerian steel rolling mills. The rods used were 12 mm, 16 mm, 20 mm and 25 mm in diameters. Other materials included abrasive papers, emery cloth, and diamond paste, water as coolant, etchant, cotton wool and desiccators. This equipment include lathe machine with coolant, hacksaw, electric table grinder, grinding and polishing machine and a high magnification optical microscope with digital camera attached.

Selection of Samples

Specimens were obtained from portion of the work-piece as a representation of the samples. They were cut and taken for spark test for chemical analysis done in accordance with work of Oyetunji and Adebisi, 2011 and the result was presented in Table 1. Furthermore, the remaining samples were cut into small sizes for holding during grinding and polishing. Water as coolant was continuously applied to lubricate the specimens and prevent any alteration in the original structures.

Table 1: Chemical Compositions of the Used Rolled Ribbed Medium Carbon Steels

Rods Diameter (mm)	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Cu	%Co	%W	%Fe
12	0.359	0.72	0.171	0.016	0.015	0.78	0.08	0.221	0.038	0.157	97.443
12	0.357	0.63	0.101	0.016	0.015	0.69	0.08	0.276	0.016	0.158	97.661
12	0.355	0.74	0.18	0.016	0.014	0.72	0.07	0.249	0.024	0.158	97.474
16	0.358	0.62	0.18	0.041	0.039	0.019	0.075	0.25	0.031	0.148	98.239
16	0.359	0.60	0.19	0.039	0.038	0.021	0.074	0.27	0.028	0.147	98.234
16	0.362	0.67	0.20	0.038	0.042	0.017	0.074	0.26	0.019	0.151	98.167
20	0.389	0.68	0.16	0.042	0.031	0.015	0.026	0.251	0.016	0.121	98.269
20	0.391	0.67	0.18	0.04	0.028	0.018	0.021	0.248	0.014	0.11	98.280
20	0.390	0.61	0.17	0.041	0.031	0.011	0.072	0.253	0.022	0.119	98.281
25	0.422	0.691	0.224	0.031	0.042	0.01	0.021	0.248	0.018	0.158	98.135
25	0.415	0.685	0.219	0.030	0.041	0.01	0.02	0.248	0.017	0.156	98.158
25	0.418	0.72	0.222	0.032	0.038	0.01	0.02	0.252	0.018	0.158	98.112

Mechanical Tests

The following mechanical tests were carried out using the machined tests samples to determine the following properties. The tensile tests were tested using prepared samples. The tensile samples were tested with Universal tensile testing machine (UTM) 600KN (Avery Tenson) Model, This test was used to determine tensile strength at maximum load, tensile strength at break and yield strength (Oyetunji and Alaneme, 2005). Impact testing with Avery 300KNm capacity Model was used to determine the impact toughness of this material. It was done in accordance with work of Oyetunji (2010). While Rockwell hardness tester Scale B (Avery model) of (Rb 0 - Rb100) was used to test the hardness of the rolled ribbed medium carbon steel. This test determined both the transverse and longitudinal Rockwell hardness values A. These tests were carried out in accordance with works of Oyetunji and Omole (2011).

METALLOGRAPHIC EXAMINATION

Grinding: Each of the specimens was ground on an electric table grinder with an abrasive wheel to obtain an averagely flat surface. After this, the specimens were washed off with running water to remove any loose grit. The specimens were thereafter ground on series of silicon carbide papers of increasing fineness beginning from 200-grit, 300-grit, 400-grit and finally 600-grit papers. The usual standardized procedure of rotating through 90^0 when changing from one grade of paper to the next was observed. Water was continuously added during the operations. Excessive deformation of the surface was however prevented during the grinding by applying only light pressure on the specimen. After successful grinding, removal of all forms of scratches of the previous paper marks and the specimens were washed under running water in readiness for the next stage (Oyetunji and Omole, 2011).

Polishing: This was carried out with the aid of emery cloth attached to a rotating disc machine to remove all the remaining scratches. A diamond paste as polishing agent was applied and polishing was continued until a mirror-finish appearance was obtained. The specimens were then covered with cotton wool and put in desicator to prevent corrosion by the environmental air before etching. Care was taken to ensure very clean cloths and environment to avoid contamination during the process (Ayoola, et al., 2012).

Etching: This was to assist in revealing the structures at the surface layer of the specimens. Swabbing was done for 3 seconds after which the surface was rinsed under running water, then methylated spirit to remove water stain from the surface and finally dried in warm air. The etching was done with the aid of cotton wool using Nital (2% of nitric acid and 98% ethanol) (Oyetunji and Omole, 2011).

MICROSTRUCTURE EXAMINATION

The specimens were viewed with the aid of a metallurgical microscope of model AX10 (ZEIZZ) of 400 x magnifications with digital camera and computer system attached to determine the phases present. The snapped pictures of microstructures of the observed microscopes after etching which were taken and downloaded into the computer attached, and printed. They were prepared in accordance with the works of (Oyetunji and Alaneme, 2005) and (Oyetunji and Omole, 2011)

RESULTS AND DISCUSSION

The results were presented in Table 1 and Figures 1 to 12. The results were used to discuss as follows:

Effect of Sample Sizes on Mechanical Properties

The mechanical properties of plain carbon steel are usually dictated by the combined effects of composition and grain size. It is often difficult to quantify the individual contributions to the strength. Critical observation of all the Plates 1 - 4 revealed that the samples micro-structures consist of pro-eutectoid ferrite and pearlite, with Plates 2 and 3 having largest proportion of pearlite. The pearlite is the grey colour while the ferrite appeared as white.

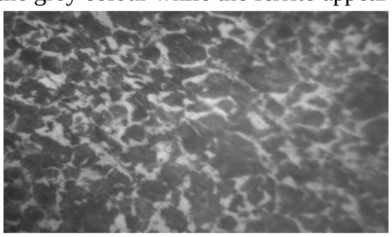

Plate 1: Microstructure of 25 mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) Etching time: 3 seconds and Etchant: 2% Nital

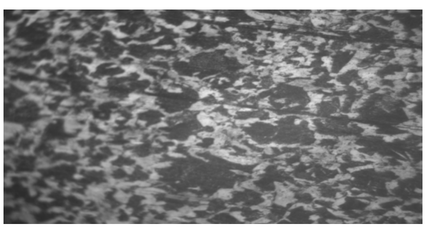

Plate 2: Microstructure of 20 mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) Etching time: 3 seconds and Etchant: 2% Nital

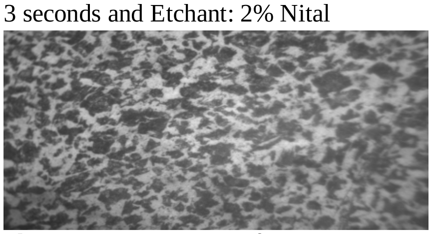

Plate 3: Microstructure of 16 mm Diameter of Rolled Ribbed Medium Carbon Steel. (X400) Etching time: 3 seconds and Etchant: 2% Nital

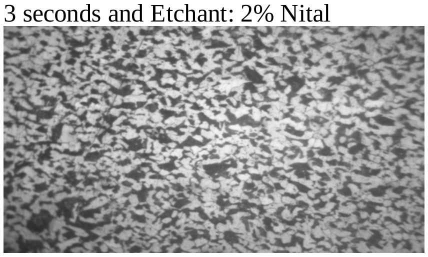

Plate 4: Microstructure of 12 mm Diameter of Rolled Ribbed Medium Carbon Steel (X400) Etching time: 3 seconds and Etchant: 2% Nital

As shown in Figures 1 to 6, the 12 mm diameter rolled ribbed rod showed a better strength than that of 16 mm diameter rod despite having very close carbon content. This may have been as a result of the extent of its grain size refinement effect. Here in 12 mm diameter rod, due to its smaller size, it will experience a faster rate of cooling which is dependent on dimension, therefore, brought about a finer grain size as against 16 mm diameter rod that will take slower cooling rate. Therefore, there will be tendency for grain growth in 16 mm rod more than 12 mm diameter rod will experience. This also accounted for the relatively higher yield strength and tensile strength for 12 mm than 16 mm diameters rods. The hardness values, both transverse and longitudinal were also higher for 12 mm than 16 mm diameters rods.

This observation was in agreement with the scientific analysis of the relationship between grain size and strength of Hall-Petch and the theory of yield point which involve the breaking away of dislocation from interstitial carbon atmosphere. The grain size effect on yield strength can therefore be explained by assuming that a dislocation source operates within a crystal causing dislocations to move and eventually pile up at the grain boundary. The grain size therefore determines the distance dislocations have to move and the number of grain boundary it has to cross in order to propagate. This implies that the bigger the grain size, the easier it will be to propagate the yielding process. It therefore holds practically that the finer the grain size, the higher the resulting strength (Oyetunji and Alaneme, 2005).

However, in the case of 20 mm and 25 mm diameters rods, the 25 mm diameter rod displayed higher strength than did 20 mm diameter rod. And this may have been due to the effect of composition. The 25 mm diameter rod contains higher content of carbon and even manganese than 20 mm diameter rod. These two elements are strengtheners. Though, the cooling effect ought to have favoured 20 mm diameter rod to have higher strength value, but the composition had a dominant effect on it. These also account for the highest value recorded for the hardness values of 25 mm diameter rod. But for the hardness values and strength of 20 mm diameter rod, there seems to be a presence of flaws like blow holes in the material which may have accounted for the drop in the hardness values and the strengths.

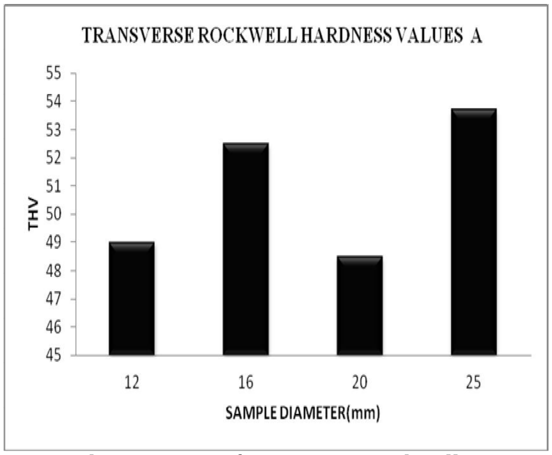

Fig. 1: The Variation of Transverse Rockwell Hardness Values (THV) A with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods.

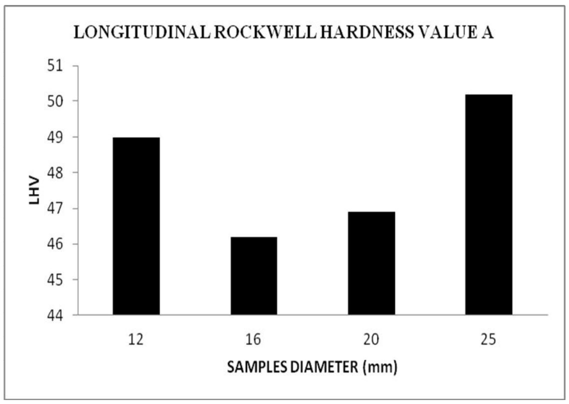

Fig. 2: The Variation of Longitudinal Rockwell Hardness Values A with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods

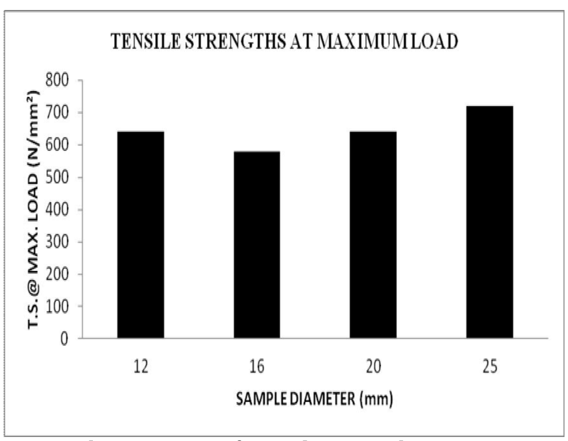

Fig. 3: The Variation of Tensile Strength at maximum load (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods

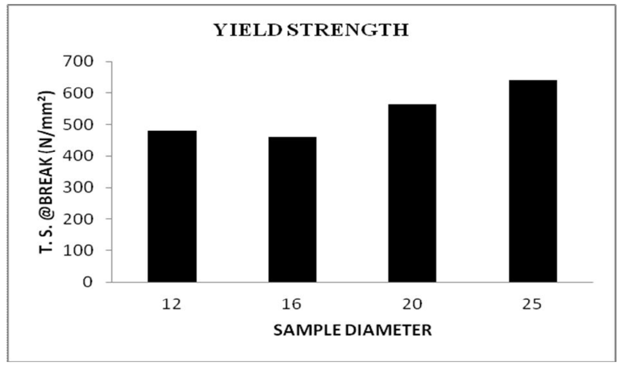

Fig. 4: The Variation of Tensile Strength at Break (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods

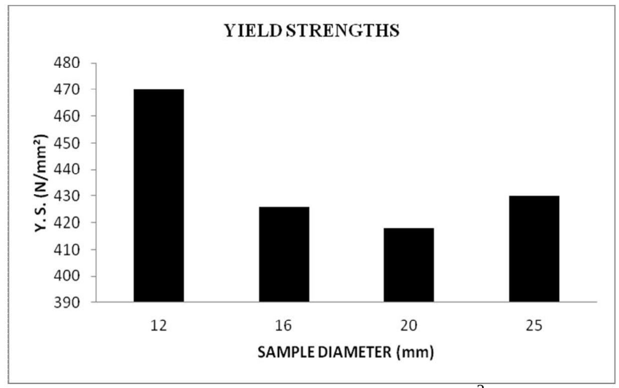

Fig. 5: The Variation of Yield Strength (N/mm^2) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods

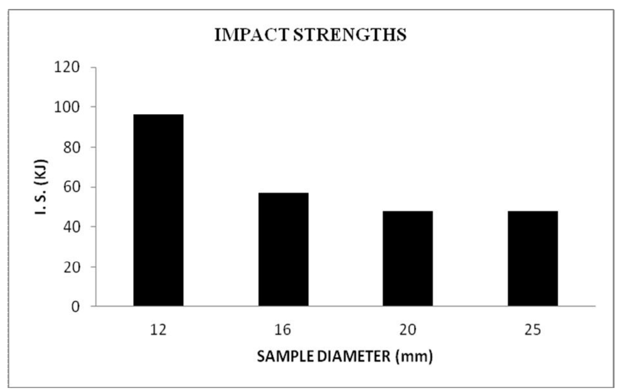

Fig. 6: The Variation of Impact Strength (KJ) with Samples Sizes of Rolled Ribbed Medium Carbon Steel Rods.

Effects of Chemical Composition on Mechanical Properties

Plates 1-4 show that the materials consist of pro-eutectoid ferrite and pearlite with 25 mm rod containing more proportion of pearlite than others, followed by 20 mm, 16 mm and lastly 12 mm diameters rods. This confirms that they were all subjected to a relatively slow cooling regime to avoid the formation of metastable phases. The morphology

however was governed by the rate of cooling, which is, normalizing. These structures were obtained because the materials were primarily plain carbon steels (medium carbon steels) and the other alloying elements were only in traces made for steel making purposes. Though, they may still play minute strengthening role as well. The plain carbon steels essentially are materials which depend for their mechanical properties on carbon content (0.05% – 1%) and manganese (0.25% - 1.7%) and particularly medium carbon steels contain carbon content of 0.3% - 0.6% where in this work the average percentage carbon contents in 12 mm, 16 mm, 20 mm and 25 mm diameters rods gotten from Table 1 were 0.357, 0.360, 0.390 and 0.418 respectively. Therefore, the concentrations of these two elements in 12 mm and 16 mm diameters rods were observed to have been responsible for the higher strength of 12 mm than 16 mm diameters rods as displayed in Figures 7 to 12. The same trend occurred in the tensile and yield strengths. Observations on Plates 2 and 3 showed that 25 mm diameter rod contains highest portions of pearlite, and pearlite provides substantial contributions to strength, which is, tensile and yield strength. This was due to the fact that there is a linear relationship between work hardening rate and pearlite content which arises because pearlite work hardens much more rapidly than ferrite. All these accounted for the higher strength of 25 mm than 20 mm diameters rods which have relatively closer chemical composition as presented in Table 1. The hardness values were also of the highest due to the combination of the composition of the two elements.
The drop in the hardness values of 20 mm diameter rod when compared to those of 16mm rod despite higher carbon and manganese contents may have been due to flaws in the materials. However, the case of impact strength was quite different as shown in Figures 6 and 12 as the lowest values were recorded for the 25 mm rod despite having highest values in the other properties estimated. This may have been as a result of its largest proportion of pearlite which has been known to have adverse effect on toughness and ductility of plain carbon steels. The higher the pearlite content, the more the impact transition temperature is raised and the less the impact energy absorbed. This is due to the fact that the presence of pearlite in the micro-structure provides sites for easy nucleation of cracks, particularly at the ferrite-cementite interfaces. But, a crack can only propagate a short distance in ferrite before encountering another cementite-lamella. Energy is absorbed during the propagation. The result is that there is a wide transition temperature. This implies that the low energy absorbed in the overall impact tests on the more pearlite structures arises from the fact that many nuclei would have occurred at the pearlitic interface which, together with the high work hardening rate, restricts plastic deformation in the vicinity of the crack (Honeycombe and Bhadeshia, 1995).

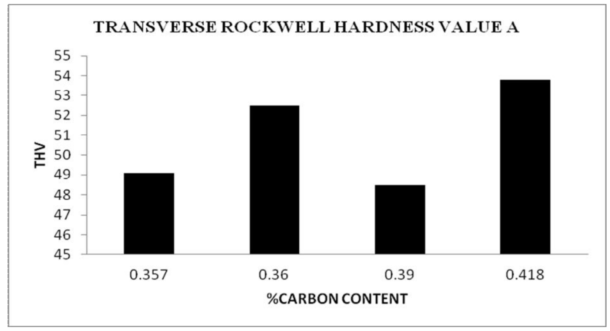

Fig. 7: The Variation of Transverse Rockwell Hardness Values A with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods

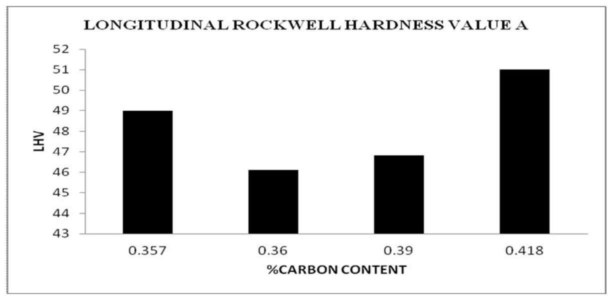

Fig. 8: The Variation of Longitudinal Rockwell Hardness Values A with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods

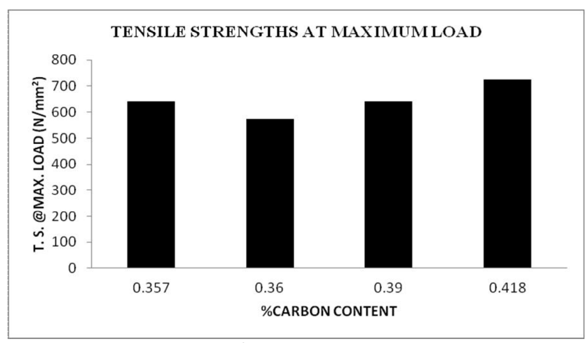

Fig. 9: The Variation of Tensile Strength at maximum load (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods

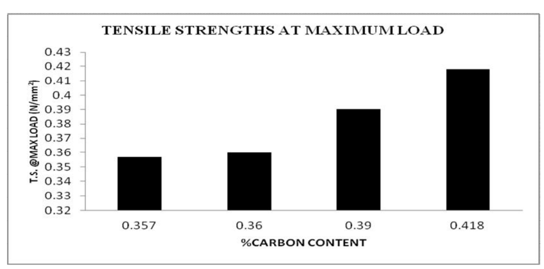

Fig. 10: The Variation of Tensile Strength at Break (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods

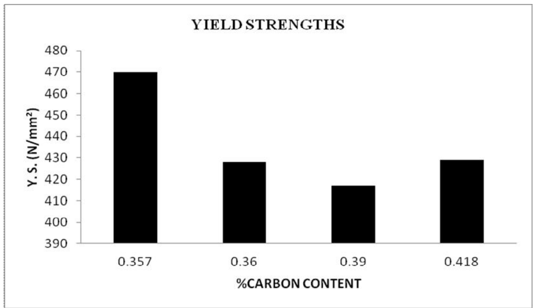

Fig. 11: The Variation of Yield Strength (N/mm^2) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods

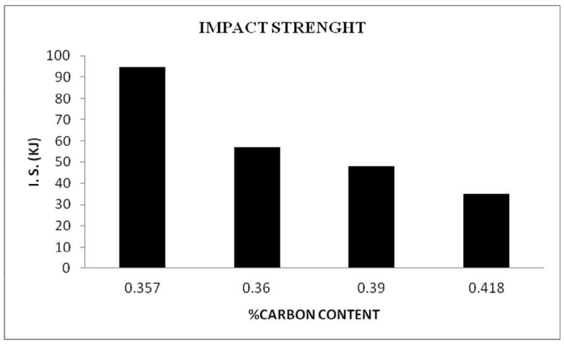

Fig.12: The Variation of Impact Strength (KJ) with %Carbon Content of Samples of Rolled Ribbed Medium Carbon Steel Rods

CONCLUSIONS

The influence of microstructures which is governed by the rate of cooling and chemical composition as well as rod diameters on the modelled mechanical properties of rolled ribbed medium carbon steels have been studied. From the results, it was concluded that;

1. The percentage carbon content has great influence in determining the mechanical properties of the materials as they all increased with increase in carbon content except impact strength which decreased with increase in carbon content.
2. The section sizes in diameter of the rods also have great effect on the mechanical properties of the materials since the rate of cooling is a function of size of the rod.

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