HEAT TREATMENT EFFECTS ON THE MECHANICAL PROPERTIES OF ROLLED MEDIUM CARBON STEEL

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ABSTRACT

Recent urban building in Nigeria have become taller for more effective utilization of above ground space and have increased in size and complexity through the adoption of new structural design. These trends have led to demand for steel of greater strength, good ductility and toughness Investigations were carried out to study heat treatment effects on the mechanical properties of rolled medium carbon steel. The steel was heated to the austenizing temperature of 830^0C and water quenched; It was reheated to the ferrite – austenite two phase region at a temperature of 745^0C below the effective Ac3 point. The steel was then rapidly quenched in water and tempered at 480^0C to provide an alloy containing strong, tough, lath martensite (fibres) in a ductile soft ferrite matrix. The result shows that the steel developed has excellent combination of tensile strength, impact strength and ductility which is very attractive for structural use.

1. INTRODUCTION

Steel is an alloy of iron and carbon, where other elements are present in quantities too small to affect the properties. The other alloying elements allowed in plain-carbon steel are manganese (1.65% max) and silicon (0.60% max) (Adewuyi, Afonja and Adegoke, 2005). Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises, the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers steel melting point and its temperature resistance in general (Callister, 1987).

Rolled medium carbon steel products are produced through a forming process called rolling. The process is carried out in rolling mills which consist of a complex machine for deforming metal in rotary rolls and performing auxiliary operations such as transportation of stock to rolls, disposal after rolling, cutting, cooling, piling or coiling etc. Carbon billets are charged into a reheating furnace with the aid of charging devices, the roller tables takes the billet to the reheating furnace one at a time, the billets are preheated and latter discharged and made to pass through the working group of stands where reduction is effected. Heat treatment involves the application of heat, to a material to obtain desired material properties (e.g. mechanical, corrosion. electrical, magnetic, etc.). During the heat treatment process, the material usually undergoes phase micro-structural and crystallographic changes (Rajan, Sharma and Sharma, 1989). The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength tensile strength and impact resistance. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process.

The standard strengths of steels used in the structural design are prescribed from their yield strength. Most engineering calculations for structure are based on yield strength (Mamoru, Yukito, Hitoshi and Yuji, 1990). Recent urban building in Nigeria have become taller for more effective utilization of above ground space and have increased in size and complexity through the adoption of new structural design. These trends have led to demand for steel of greater strength, good ductility and toughness. The special objectives of the research work are to carry out heat treatment process on locally produced rolled medium carbon steel, evaluate the effect of heat treatment processes on the mechanical properties such as tensile strength, ductility, toughness and hardness of the rolled steel and determine high strength, high ductility and low yield ratio of the rolled medium carbon steel.

2. MATERIALS AND METHODS

The material used in this study was 12mm diameter rolled medium carbon steel bars. Samples of the material were collected and prepared into tensile, impact and hardness specimens. The spectrometric analysis of the steel was carried out to determine its chemical composition. The result is shown in Table 1.

2.1 Determination of operating Temperature.

The lower critical temperature (AC1) and upper critical temperature (AC3) were determined by Grange empirical formula (Gorni, 2004) as presented here;

$$AC1\ (^0C) = (133 - 25Mn + 40si + 42Cr - 26Ni) - (32)\ 5/9 \qquad [1]$$

$$AC3\ (^0C) = (1570 - 323C - 25Mm + 80si - 3Cr - 32Ni) - (32)\ 5/9 \qquad [2]$$

The carbon equivalent and estimate of austenite carbon in equilibrium are calculated from the chemical composition as given by [1] and [2]

$$Ceq = \%C + \frac{\%Mn}{6} + \frac{(Cr+Mo+v)}{5} + \%\frac{(Ni+Cu)}{15}. \qquad [3]$$

$$Co = \frac{T\gamma - 0.17Si}{420} - 0.95. \qquad [4]$$

Where T_γ = Austenite Temperature

The results are presented in Table 1.

Table 1: Chemical Composition of As- Rolled Medium Carbon Steel.

C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Co**
0.353	0.290	0.987	0.050	0.057	0.071	0.0050	0.110	0.025	0.015
Cu	Nb	Ti	V	W	Pb	Sn	Zn	Fe	
0.185	0.0050	0.0037	0.0057	0.010	0.0050	0.026	0.0076	97.805	

Table 2: Carbon equivalent (Ceq) and Estimate of Austenite Carbon in Equilibrium (Co) of the Steel.

Ceq	Co(735^0C)	Co(745^0C)	Co(840^0C)
0.55	0.790	0.82	1.05

2.2 Heat Treatment Processes

Representative samples of as-rolled medium carbon steel were subjected to heat treatment processes.

2.2.1 Quenching + Quenching + Lamelarizing + Tempering (Q+Q+L+T).

The steel specimens were heated to the austenizing temperature of 830^0C, soaked for 20 minutes and quenched in water, this process was repeated again before the specimens were thereafter heated to the dual phase region at a temperature of 745^0C, soaked for 20 minutes and quenched in water. The specimens were finally tempered at a temperature of 480^0C for 30 minutes.

2.2.2 Quenching, Lamelarizing and Tempering (Q+L+T).

The steel specimens were heated to 830^0C, soaked for 20 minutes and quenched in water, the specimens were reheated to the dual phase region at a temperature of 745^0C, soaked for 20 minutes and quenched in water. The specimens were tempered at temperature of 480^0C for 30 minutes.

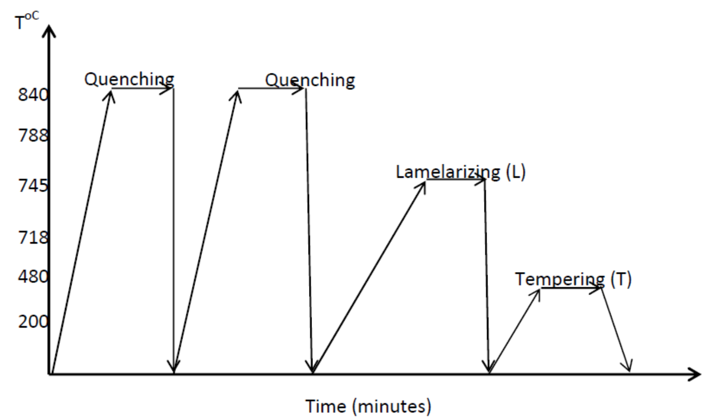


Figure 1: Temperature – Time Graph involving Quenching, Quenching Lamelarizing and Tempering (Q+Q+L+T).

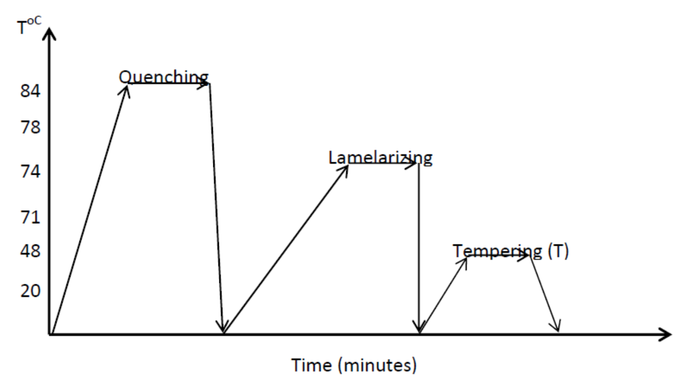
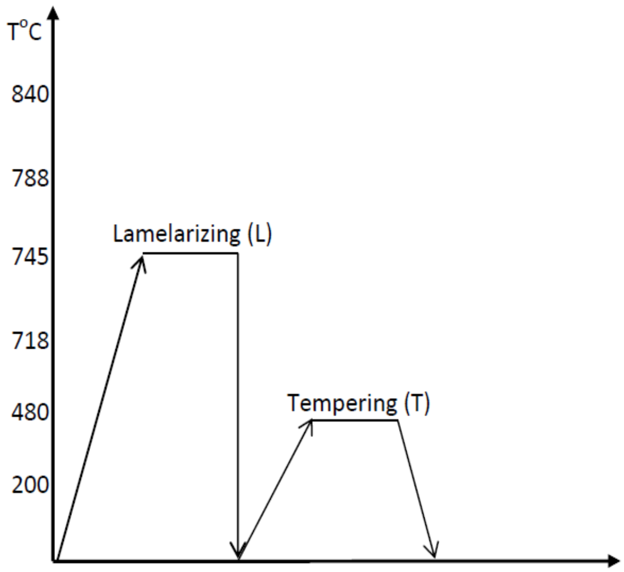


Figure 2: Temperature – Time Graph involving Quenching Lamelarizing and Tempering (Q+L+T).

2.2.3 Lamelarizing + Tempering (L+T)

The specimens were heated to the dual phase region at a temperature of 745^0C soaked for 20 minutes, quenched in water and tempered at 480^0C for 30 minutes.



Time (in minutes)

Figure 3: Temperature – Time graph involving Lamelarizing and Tempering (L+T)

2.3 Mechanical Testing of Specimen

Representative sample of the material were tested in various testing machine.

2.3.1 Tensile Test.

The heat –treated specimens and as-rolled medium carbon steel were tested in tension to failure on the tensometer. The initial gauge length and diameter were measured before subjecting them to tension. The yield and maximum loads were recorded directly from the resulted graph, the broken ends of each of the specimens were fitted and the final gauge length and also the smallest diameter of the local neck were measured. The reading thus obtained were used in the determination of the yield strength (□y), ultimate tensile strength (□u), percentage elongation (%E) and Yield Ratio (YR)

2.3.2 Impact Test

Representative sample of as-rolled specimens and heat-treated specimens were subjected to impact test on an Izod V-Notch impact testing machine. The pendulum of the machine is allowed to swing freely through a known angle, some energy was used to break the specimen, the energy was recorded directly on the scale attached to the machine.

2.3.3 Hardness Test

The hardness of as-rolled specimens and heat-treated specimens were measured with the aid of Rockwell hardness tester (Indentec, 2007 model). This machine measures the resistance to penetration by measuring the depth of impression and the hardness is indicated directly on the scale attached to the machine.

3. RESULTS AND DISCUSSION

3.1 Tensile, Hardness and Impact Properties

The tensile, hardness and impact properties of the steel specimens after various heat treatment processes are shown in Table 3 and Figures 4-9.

Table 3: Tensile, Hardness, and Impact Properties of As-Rolled Medium Carbon Steel and Heat Treated Specimens

Heat Treatment Process	Lamelarizing Temperature (0^{o} C)	Test specimens Designation	%Reduction in Area (%)	Yield Strength (N/mm^2)	Ultimate Tensile Strength (N/mm^2)	Yield Ratio %	% Elongation	Rockwell Hardness (HRA)	Impact Strength (Joules)
Q+Q+L+T	735	A1	67	478	603	79	22	61.30	58.70
	745	A2	72	489	618	79	22	61.50	57.90
Q+L+T	735	B1	75	401	569	71	27	56.70	60.30
	745	B2	66	484	614	79	25	59.70	58.60
L+T	735	C1	65	404	529	76	26	58.50	57.60
	745	C2	61	444	607	73	24	58.70	56.70
As-Rolled		D	63	480	598	80	19	51.70	55.50

Heat Treatment Process	Lamelarizing Temperature(0^{o}C)	Test Specimens Nomenclature	Rockwell Hardness(HRA)	Impact Strength (Joules)
Q+Q+L+T	**735** **745**	**W1** **W2**	**61.20** **61.60**	**58.60** **57.90**
Q+L+T	**735** **745**	**X1** **X2**	**56.80** **59.80**	**60.40** **58.50**
L+T	**735** **745**	**Y1** **Y2**	**58.60** **58.80**	**57.60** **56.80**
As-Rolled		**Z**	**51.70**	**55.60**

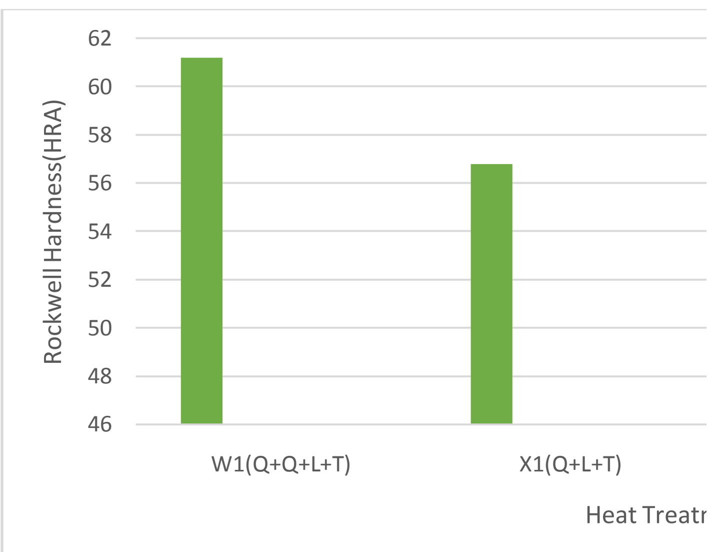


Figure 6: Rockwell Hardness number after various Heat Treatment Processes

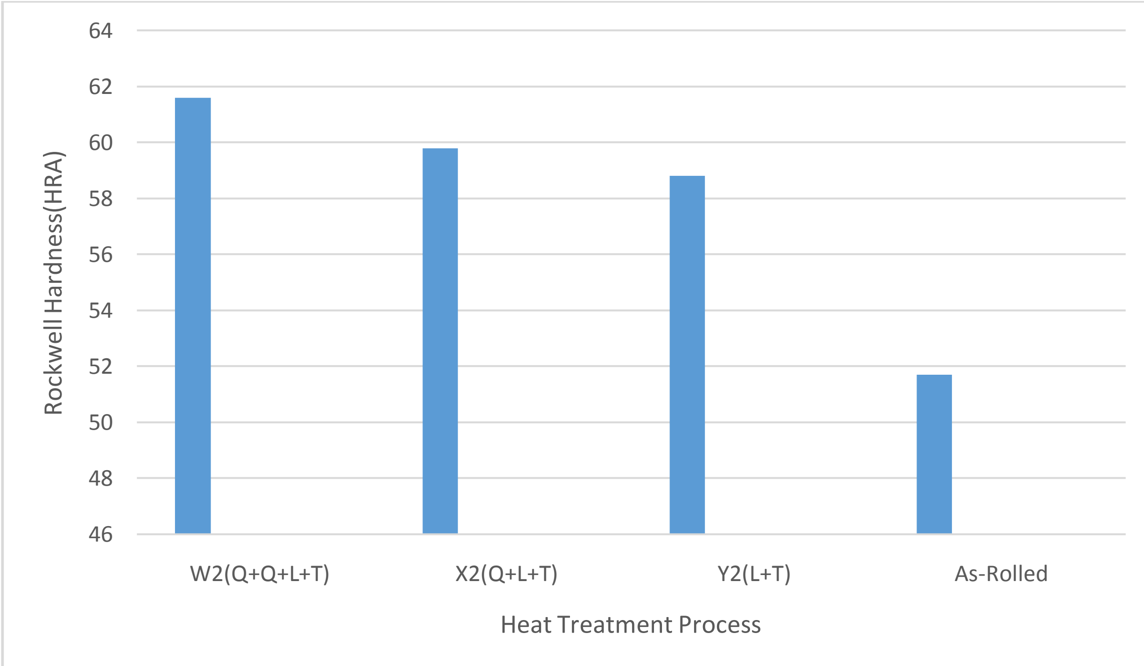


Figure 7: Rockwell Hardness number after various Heat Treatment Processes

Figures 6-7 present the changes in the hardness values of the specimens. The rockwell hardness of the heat treated steels are higher than that of the as-rolled steel, this was probably due to the higher volume fraction of the harder martensite in the developed steel; The transformation of austenite to martensite by a diffusionless shear type transformation in quenching is also responsible for higher hardness obtained and this property is attributed to the effectiveness of the interstitial carbon in hindering the dislocation motion (Saleh, 2001).

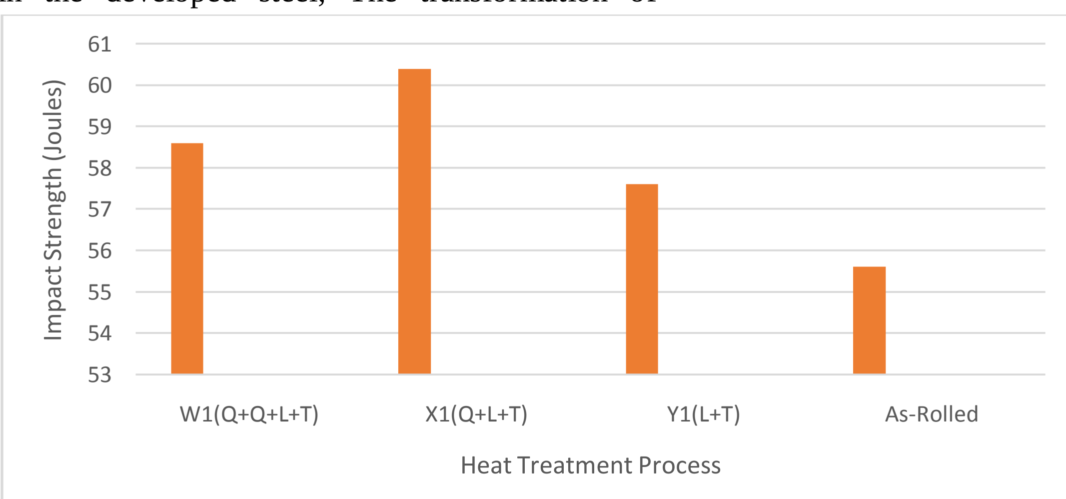


Figure 8: Impact Strength of Heat Treated Specimens and As–Rolled Medium Carbon Steel.

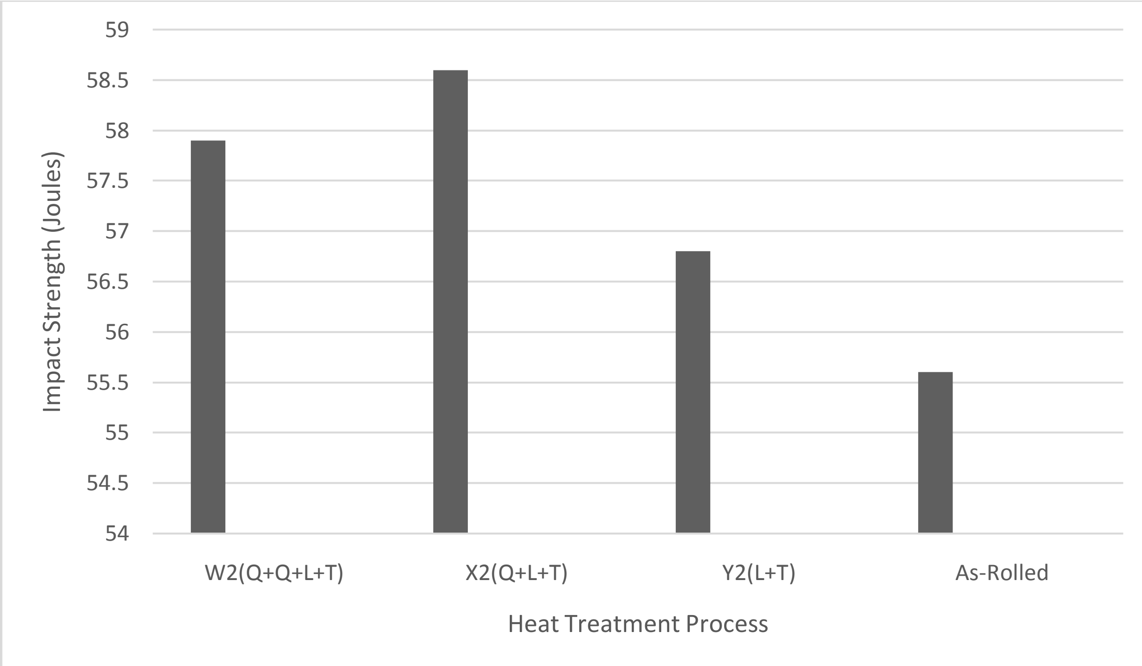


Figure 9: Impact Strength of Heat Treated Specimens and As–Rolled Medium Carbon Steel

Heat Treatment Process

Figures 8-9 present the impact strength of the heat treated specimens and as-rolled medium carbon steel. The impact strength of the heat-treated specimens are higher than that of the As-rolled; This is as a result of the lath martensite alloy formed during the heat treatment processes which is very strong and (Hauang and Gwo, 1989).

4. CONCLUSION

From the findings, the steel developed by Quenching + Quenching + Lamelarizing + Tempering (Q+Q+L+T) process at a lamelarizing temperature of 745^0C has the highest ultimate tensile strength and yield ratio of 79% with excellent combination of impact strength, ductility and hardness which is very attractive for structural use followed by Quenching + Lamelarizing + Tempering (Q+L+T) process and Lamelarizing + Tempering (L+T) process.

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