JMME. Vol. 11 September 2018 *ISSN: 2006-1919*
pp. 1-7

MECHANICAL PROPERTIES OF CARBURIZED AND NITRIDED MEDIUM CARBON STEEL

Olayide R. Adetunji*[1], Azeez A. Akinbo[1], Olanrewaju M. Adesusi*[1] and Iliyas K. Okediran[2]

[1]*Mechanical Engineering Department, Federal University of Agriculture, Abeokuta, Nigeria.*
[2]*Mechanical Engineering Department, Osun State University, Osogbo, Nigeria.*
*Corresponding Authors: adetunjiolayide@gmail.com, adesusiolanrewaju@yahoo.com

ABSTRACT
This work compared hardening of medium carbon steel by carburizing and nitriding. The comparison was done on samples carburized and nitrided for two and three hours respectively. Microstructural analysis of the samples was carried out using the optical microscope and the mechanical properties such as tensile strength, hardness and impact strength of the samples were tested. A control experiment was also performed on the as-received sample. The carburized samples gave an expanded austenite microstructure with highest hardness value while the nitrided samples gave a tempered microstructure with highest ductility value while the as-received samples gave a pearlite microstructure with highest impact energy value. The sample nitrided for 3hours showed very good hardness property very close to the as-received sample with a good ductility far above that of as received sample, making it suitable for application such as automobile gear, ball bearing shafts, valves, discs and cams where hardness and good ductility of the core is required. The sample carburized for 3 hours showed higher hardness with low ductility, making it suitable for application such as tools making where case hardness is the prevailing requirement.

Keywords; Carburizing, Nitriding, Mechanical property, Microscopy, Carbon Steel

1.0 INTRODUCTION
Steel and its products have many practical applications in every aspect of life which include construction, manufacturing, appliances, automobile etc. It is a very versatile material with a range of desirable properties which can be produced at a very competitive production cost [1]. Steels are classified into different forms one of which is plain carbon steel which is on the basis of their carbon content as their major alloying element. Plain carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication [2]. The plain carbon steel is being divided as low carbon steel, medium carbon steel and high carbon steel on the basis of carbon content.

When there is need for high carbon steel case for special purposes, production of high carbon steel cases locally, using abundant local materials becomes imperative. This reduces the burden on foreign reserves and creates employment opportunities [3]. Most of the previous studies only focus on the effects on surface hardness at certain duration of the nitriding and carburizing processes, effect on strength of coating thickness, corrosion resistance but they have not studied the comparable factor of both carburizing and nitriding which are processes of carbon steel surface hardening.

The surface hardening of steel has an advantage over hardening or quenching because less expensive low-carbon and medium-carbon steels can be surface hardened without the problems of distortion and cracking. For example, the disadvantage of flame hardening includes the possibility of part distortion, while induction hardening requires very small part-to-coil distances, which must be precisely maintained [4]. Diffusion methods modify the chemical composition of the surface with hardening species such as carbon, nitrogen, or boron [5].

Linus et al. [6] studied the variation of effective case depth with holding time of mild steel using various carburizing compounds. The study was undertaken with pack carburization of mild steel using four different carburizing compounds. The result showed that the carburizing compound with80% charcoal and 20% cow bone had the highest average case depth of 2.2 mm and effective case depths increased as the holding time of the samples increased in all the carburizing compounds used. Ihom [7] studied case hardening of mild steel using cow bone as energizer where various carburizing compounds were used to pack carburized mild steel. The result showed that 60 wt% charcoal / 40 wt% cow bone had the best result with an effective case depth of 2.32 mm and the hardness profile plot of the 60 wt% charcoal / 40% cow bone carburized mild steel was also higher than the other compositions. Ohize [8] experimentally studied the effect of carburizing mild steel with coal, bone charcoal and wood charcoal on its hardness, tensile and impact strengths. Coal, bone charcoal and wood charcoal as carburizing materials each had considerable increasing effect on hardness and tensile strengths but a decreasing effect on impact strengths of mild steel. Wood charcoal had the greatest effect while coal had the least effect on hardness and tensile strengths. According to Afolalu et al. [9], "Carburizing High Speed Steel cutting tool has a significant improvement on the wear resistance and wear rate of the samples over the untreated samples." Akhtar et al. [10] evaluated gas nitriding process with in-process variation of nitriding potential for AISI H13 tool steel, commonly used for hot extrusion dies, where he conducted micro-hardness analysis on the nitride samples. He found out that the controlled gas nitriding techniques improve the die performance due to thin effective case depth (on the order of 90µm) with thin compound surface layer (on the order of 4-10µm) and good surface hardness (about 1,160HV).

Akhtar et al. [11] in their work, where they compared single, double and triple nitriding, affirmed that the surface hardness was high and then decreased towards the core. They further stated that beyond the 15µm depth, multiple-nitrided samples and single-nitrided samples showed the highest hardness value at the surface within the initial 15µm depth which reduced monotonically towards the core with higher hardness-depth profiles.

The investigation carried out by Kahraman and Karadeniz [12] on the characterization and wear behaviour of plasma nitrided nickel based dental alloy revealed that surface hardness of the nitrided samples increased between 4.7 and 5.7 times depending on the process parameters and went further to state that wear resistance of the plasma nitrided samples are higher than the untreated samples while the weight loss decreased compared to the untreated samples. Materials and components failure resulting from inappropriate strength and hardness are often catastrophic and result in economic loss.

The purpose of this work is to compare the effect of using charcoal as carbon additive in carburizing and ammonia gas in nitriding. It focuses on comparing carburizing and nitriding surface treatment of a carbon steel so as to be able to select the right method to use for a particular application of carbon steel.

2.0 MATERIALS AND METHODS

The materials used in this work are medium carbon steel of 0.35% C with 3 mm thickness, acetone, water, ammonia gas, $BaCO_3$ (250g) powdered, charcoal, Nital's Reagent, cleaned crucible, a large muffle electric furnace with a temperature sensitivity of ±5°C, hack saw, meter rule, ammonia gas cylinder, grinders and polishing disc, Rockwell Micro hardness testing Machine, impact tester, optical microscope, measuring cylinder, beaker, petri dish, quenching baths and measuring tape.

2.1 Carburizing

Carbon Steel was primarily heat-treated to create matrix microstructures and associated mechanical properties not readily obtained in the as-cast condition. The specimens were placed in a clean crucible for carburizing. Charcoal and barium carbonate in powder form were mixed in 10:1 ratio by weight in the stainless cup. The charcoal would provide the carbon which will diffuse into the sample surface, and $BaCO_3$ will act as an activator in this reaction. The samples were placed in this cup and were surrounded the by charcoal mixture from all sides. Space was provided between the samples so that the rate of carbon diffusion is uniform across the sample. The stainless cup and its contents were placed in the crucible inside the furnace and heat-treated to a temperature of 950°C above the critical temperature and was held at this temperature to soak for 2 hours. This gives sufficient time for the samples to absorb the carbon.

After the elapsed time, the furnace was switched off and the stainless cup and its contents were taken out of the furnace. The samples were quenched in water. Same procedure was repeated for samples soaked for 3 hours. The samples were then placed back inside the furnace for tempering. They were then heated to a temperature of about 600°C for 1 hour so as to increase ductility and remove internal stress incurred during machining.

Hardness tests were carried out on the samples to observe the change in surface hardness as well as across the thickness for samples carburized for 3 hours. Impact test, tensile test, micro-structural examination and wear analysis were also performed on the samples.

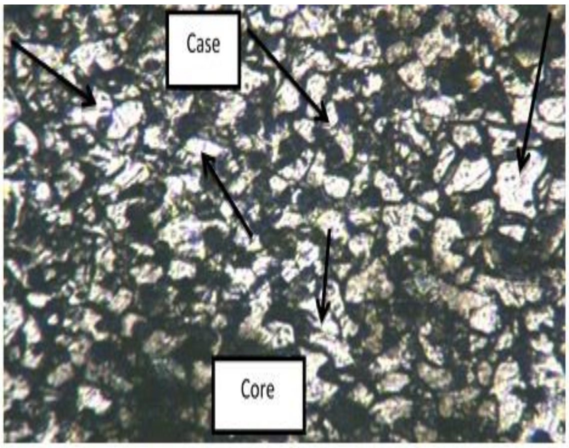
Nitriding

The samples were placed in a cleaned crucible. The crucible and the specimen were placed inside furnace and the furnace was turned on from an electric supply. The samples were tempered to a temperature of about 650°C so as to increase ductility and subsequently air cooled. The air cooled sample were returned to the furnace, with the hose connecting the ammonia cylinder with the furnace; the air in the furnace was purged before heating with the ammonia for about 15 minutes to prevent oxidation of samples. Heating was started immediately after purging was completed until temperature reached 560°C for 2 hours. At the end of the process, ammonia flow was stopped and the samples were removed from the furnace and quench into the water. Same procedure was repeated for other set of samples held at temperature of 560^{o}C for duration of 3 hours. Also, Hardness tests on the surface as well as across the thickness for samples nitride for 3 hours, Impact test, tensile test and micro-structural examination were carried out on the samples.

3.0 RESULTS AND DISCUSSION

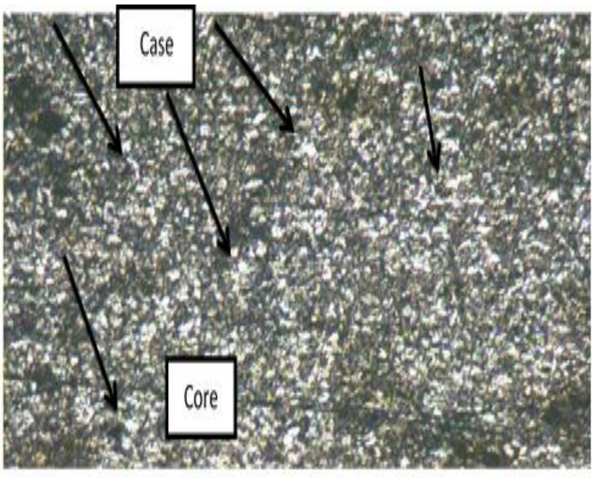
3.1 Results

The microstructural investigation of the as-received sample, sample carburized for 2hours at 950°C, sample carburized for 3hours at 950°C, sample nitride for 2hours at 560°C and sample nitrided for 3hours at 560°C were as given in Plates 1-5. Table 1 has the summary results of tensile test carried out on the samples. The results of the brinell hardness



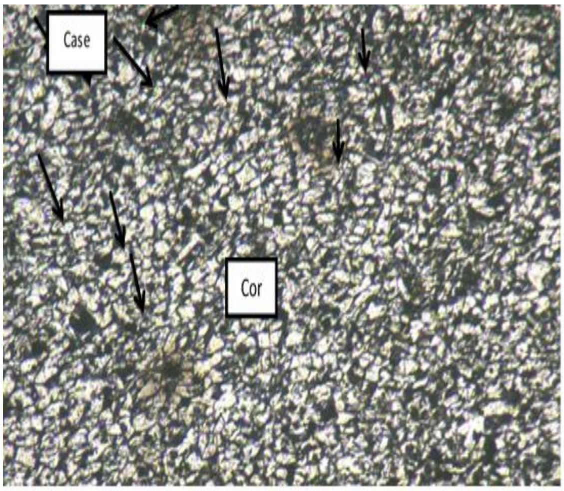
X100

Plate 1 Microstructure of as-received sample; cementite (dark arrowed) in ferrite matrix



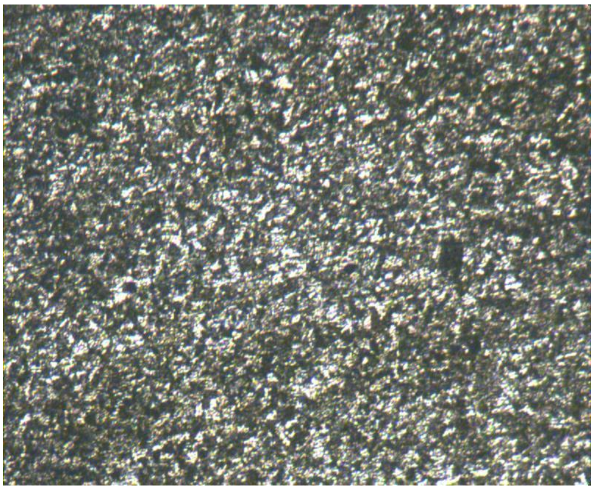
X100

Plate 2. Microstructure of the carburized carbon steel for 2 hours: Fine grains of cementite at the surface with a ferrite microstructure while the core has lower quantity of cementite.



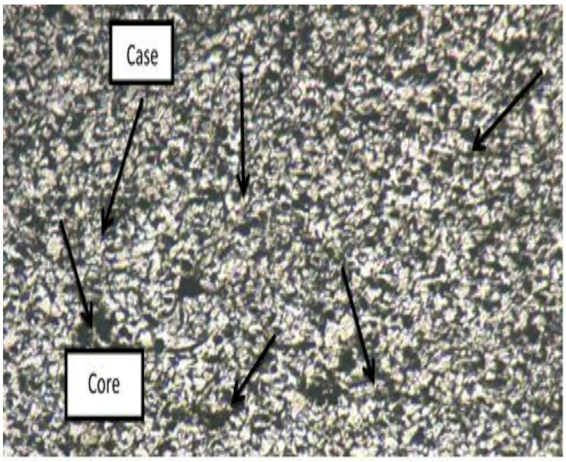
X100

Plate 4 Microstructure of the samples nitrided for 2 hours obtained



X100

Plate 3 Microstructure of the carbon steel carburized for 3 hours



X100

Plate 5 Microstructure of the samples nitraded for 3 hours

Table 1 Tensile Test on Samples

Mechanical Properties	Carburized for 2h @ 950º	Carburized for 3h @ 950º	Nitrided for 2h @ 560º	Nitrided for 3h @ 560º	As Received Sample
Load at Peak (N)	1152.07	839.99	9642.10	8956.95	8967.65
Stress at Peak (N/mm^2)	91.67	66.84	767.29	712.77	713.62
Strain at Peak (%)	1.635	3.21	25.96	25.59	17.90
Energy at Peak (J)	0.171	0.256	41.36	40.18	24.36
Load at Break (N)	20.17	282.41	6471.85	6186.06	5824.11
Elongation at Break (mm)	2.36	1.77	9.24	8.93	7.09
Stress at Break (N/mm^2)	1.61	22.47	515.01	492.27	463.47
Strain at Break (%)	8.73	6.57	34.23	33.06	26.27
Energy at Break (J)	0.731	0.675	60.96	56.76	42.77
Load at Yield (N)	1152.07	839.99	2090.02	8956.95	8967.65
Stress at Yield (N/mm^2)	91.68	66.84	166.32	712.77	713.62
Young Modulus (N/mm^2)	11675.23	4844.81	14660.59	5282.64	17296.30

Table 2 Penetration depth and hardness values for Carburized, Nitrided and As received samples

S/N	Depth µm	Carburized HV	Nitrided HV	As received HV
1	0	45	34	29
2	50	43	32	28
3	100	41	31	27
4	150	39	30	27
5	200	37	29	26
6	250	35	28	26

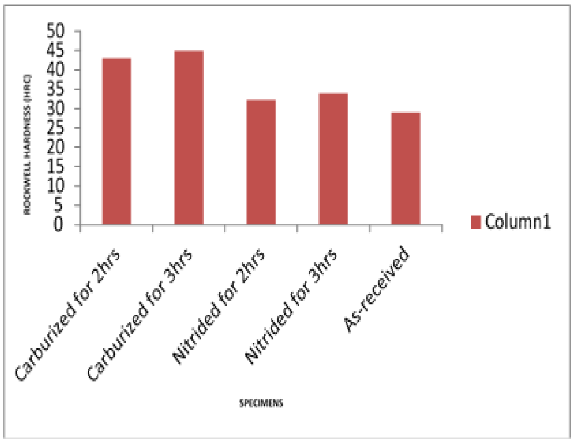


Figure 1Bar chart of Rockwell hardness Tests for samples for 3 hours obtained Carburized, Nitrided and As-Received Sample

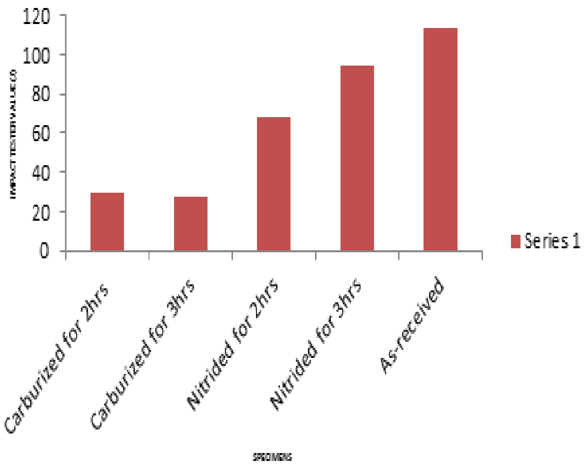


Figure 2 Bar Chart of Impact Tests for Carburized, Nitrided and As-Received Sample

3.2 Discussion

Microstructural Analysis

The as-received specimen showed cementite (dark arrowed) in ferrite matrix that often form colonies and these colonies are oriented in the same direction. This kind of microstructure is known as Pearlite (coarse).
Sample carburized for 2 hours at 950°C consist of fine grains of cementite at the surface with a ferrite microstructure while the core has lower quantity of cementite. On the other hand, samples carburized for 3 hours at950°C consist of finer grains of cementite at the surface with a pearlitic microstructure at the core.
Samples that were nitrided by heating for 2 hours produced a sphere-like cementite in a ferrite matrix carried out at 560°C. The nitrided samples consist of a cementite grains at the surface with a tempered pearlite structure which is characterized by a high values of hardness and ductility. The surface consists of a fine grains of cementite embedded in a ferrite matrix. Fernandes et al. [13] reported production of expanded austenite from nitriding and nitro carburizing on a super austenitic stainless steel. He added that the metastable phase had higher hardness and toughness which is in line with the findings of this research.

Tensile Test

The steel carburized for 2hours had values for Young's modulus, elongation at break, force at yield, stress and strain at break of 11675.23 N/mm^2, 2.36 mm, 1152.07 N, 1.61 N/mm^2 and 0.087 respectively. The steel carburized for 3hours had values for Young's modulus, elongation at break, force at yield, stress and strain at break of 4844.81 N/mm^2, 1.77 mm, 839.99 N, 22.47 N/mm^2 and 0.066 respectively. The result obtained for the nitriding specimens for 2hours had values for Young's modulus, elongation at break, force at yield, stress and strain at break as 14660.59 N/mm^2, 9.24 mm, 2090.02 N, 515.01 N/mm^2 and 0.342 respectively. The nitrided steel for 3hours had values for Young's modulus, elongation at break, force at yield, stress and strain at break of 5282.64 N/mm^2, 8.93 mm, 8956.95 N, 492.27 N/mm^2 and 0.331 respectively. The as-received sample had the highest tensile stress i.e. it can still withstand the highest tensile load when compared to the treated sample.

Hardness Test

The as-received (control) sample had the least hardness value of 29.0 HRC, followed by the sample nitrided for 2hours and the samples nitrided for 3hours with hardness value of 32.23 and 33.97 HRC respectively. The specimens carburized for 2hours had the hardness value of 43.03 HRC and the carburized specimens for 3hours had highest hardness value of 44.88 HRC. Table 2 shows the hardness values across depth. The nitrided samples retained hardness values across depth than carburized samples. Nitrogen in interstitial solid solution increases the hardness of steel much in the same way as carbon in solid solution [14].

The as received samples also maintained a near constant hardness value across depth. The sample carburized for 3hours had the highest hardness of 44.88 HRC and the hardness increased with temperature and the soaking time. Carburizing does not only increase hardness but increases tensile strength of low carbon steel [15].Nitriding leads to an increase of the surface hardness compared with that of the matrix as a result of iron nitrides formation [16].

This hardness value shows that it had excellent case depth, surface hardness and wear resistance which are in accordance with the work carried out by Sanjib [17].

Impact Test

Sample carburized for 3 hours had the least impact value of 37.968J, followed by the sample carburized for 2hours with impact value of 40.68J, sample Nitrided for 2hours had impact value of 92.208J and sample Nitrided for 3hours had impact value of 127.464J. The Control sample had highest impact value of 154.584J which make it tougher and ductile compared to the carburized and nitride samples.

4.0 CONCLUSION

The following conclusions are drawn based on the results obtained from the investigations carried out.

- The longer the carburizing and nitriding time the finer the microstructures of steel samples obtained between two and three hours. The tensile properties of the carburized steel in terms of yield, ultimate stresses and elongation reduced from two to three hours of carburizing and nitriding. The tensile properties of nitrided steel samples were higher than the carburized ones.
- The carbon steel sample nitrided for 3hours showed a very close stress at yield of 712.77 $N/mm^2$to the as-received sample of 713.62 N/mm^2yet with a good hardness value of 33.97 HRC far above the as-received sample.
- The impact test value of the as received samples was highest followed by nitrided samples for 3 hours, which had higher value to the one for 2 hour. The carburized samples for 3 hours had the least impact toughness. Therefore, nitriding is recommended for applications such as in gears, ball bearings, shafts, valves, discs and cams where both hardness and toughness are needed property. On the other hand, where an application (for example tool making) requires that toughness of the core be sacrificed for hardness and wear resistance, carburizing is the best method of heat treatment of such a sample.
- The hardness values of carburized steel was highest followed by the nitrided ones while as received steel samples had the least. The longer the carburizing and nitriding time the harder the steel samples became.

REFERENCES

1. K. A. Bello,S. B. Hassan, and M.Abdulwahab:'Effects of Tempering on the Microstructures and Mechanical Properties of Low Carbon, Low Alloy Martensite Steel' *Journal of Applied Science Research* 3(12): pp1719-1723(2007).

2. W. F. Smith, and J. Hashemi: Foundations of Materials Science and Engineering. 4th Ed. McGraw-Hill, New York, USA (2006).

3. A. Oyetunji and S.O. Adeosun:' Effects of Carburizing Process Variables on Mechanical and Chemical Properties of Carburized Mild Steel' *Journal of Basic and Applied Sciences* 8 pp 319-324(2012).

4. M. J. Schneider and M. S. Chatterjee: Introduction to Surface Hardening of steels. In *Steel Heat Treating Fundamentals and Processes*. ASM Handbook Vol. 4A. P389-398 (2013).

5. B.Haase:'Control of Surface Condition Prior to Gas Nitriding' *Transactions of Materials and Heat Treatment* 5 pp24-61(2004).

6. O.A. Linus and P.A. Ihom :'Variation of Effective Case Depth with Holding Time of Mild Steel using Various Carburising Compounds '*International Journal of Metal and Steel Research Technology* 1(2) pp12-18(2013).

7. P.A.Ihom:'Case Hardening of Mild Steel using Cowbone as Energizer' *African Journal of Engineering Research* 1(4) pp. 97-101 (2013).

8. E.J.Ohize:'Effects of Local Carbonaceous Materials on the Mechanical Properties of Mild Steel' *AU Journal of Technology* 13(2) pp107-113(2009).

9. S.A. Afolalu, S.B. Adejuyigbe and O.R. Adetunji: 'Impact of Carburizing Temperature and Holding Time on Wear of High Speed Steel Cutting Tools '*International Journal of Scientific and Engineering Research* 6(5) pp905-909(2015).

10. S. S. Akhtar A.F.M. Arif and B.S.Yilbas:'Evaluation of Gas Nitriding Process with In-Process Variation of Nitriding Potential for AISI H13 Tool Steel' *International Journal of Advance Manufacturing Technology* 47(5) pp687-698(2009).

11. S. S. Akhtar, A.F.M. Arif and B.S.Yilbas:'Influence of Multiple Nitriding on the Case Hardening of H13 Tool Steel: Experimental and Numerical Investigation '*International Journal of Advance Manufacturing Technology* 58(1) pp57-70(2012).

12 F. Kahraman and S. Karadeniz: 'Characterization and Wear Behaviour of Plasma Nitrided Nickel Bases Dental Alloy'*Plasma Chemistry and Plasma Processing* 31(4) pp595-604(2011).

13. F.A.P. Fernandes, L.C. Casteletti and J. Gallego : Microstructure of nitride and nitrocarburized layers produced on a superaustenitic stainless steel; *Journal of Materials Research and Technology 2(2); 158-164 (2013).*

14. I. Flodstrom,:Nitrocarburizing and High Temperature Nitriding of Steels for Bearing Applications. Unpublished Master Thesis. Chalmers University of Technology. Goteborg, Sweden, 2012.

15. Y.Bontong, H.Nitha, H. Abbas, R., Syam, H.Arsyad, and H.S.Asmal; Behaviour of Pach Carburizing with Bone Buffalo Charcoal and $BaCO_3$ Against Mechanical Properties of Low Carbon Steel. *ARPN Journal of Engineering and Applied Sciences* 13(14): 4309-4316, (2018).

16. F.Z.Benlahreche and E.Nouicer: Improvement of Surface Properties of Low Carbon Steel by Nitriding Treatment. *ActaPhysicaPolonicaA* 131(1): 20-23 (2017).

17. K. J. Sanjib: 'Heat Treatment of Low Carbon Steel' Unpublished Bachelor Degree Project Report, National Institution of Technology, Rourkela p39 (2009).