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Experimental Investigation of the Effect of Pack Carburization on Impact Strength and Hardness Property of ASTM A516/516M-05 Steel Plate Weldment

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Abstract: This study investigates the effect of pack carburization on hardness property of ASTM A516/516M-05 steel plate weldment. Sixteen (16) samples were structured, prepared and machined into twelve (12) and four (4) for impact and Vickers hardness tests, respectively. Eight (8) samples were carburized at a constant temperature of 920oC, withholding time of 15 minutes and the other eight (8) samples act as a control. The result obtained shows that the welded and heat-treated (WHT) sample has the highest impact strength with an average impact value of 218 J, closely follow by the non-welded but heat-treated (NWHT) sample with an average impact strength of 198 J. The Welded but not heated treated (WNHT) sample has an average impact test of 176 J whereas the as-received recorded a value of 168 J. Also, the Vickers hardness result shows that the welded and heat-treated, non-welded but heat-treated and the as-received samples have an average hardness numbers of 218, 213.7 and 181.4, respectively. Also, the hardness values were uniformly distributed across the surface layers of the steel. However, for the welded but not heat-treated samples, it has a hardness number of 193.9 with an appreciable variation of hardness value from the fusion zone to the heat-affected zone (HAZ) and the parent metal. It was observed that the carburization of ASTM A516/516M-05 steel increases the hardness and impact strength of the material.

Keywords: carburization, Impact Strength, Hardness Property, ASTM A516/516M steel

1. Introduction

Carburizing is one type of heat treatment processes which involves enriching the surface layer of steel with carbon to harden the surface layer of the material to withstand impact load, high-pressure, shock, resist to wear while retaining a substantially lesser hardness in the core and maintaining the required toughness and strength [1-3]. Different types of carburization processes exist, namely; pack, liquid, and gas [4]. Pack carburizing process involves the steel been packed in a high carbon content environment mainly of solid carbon. An attempt has been made by researchers to determine the effect of carburization on steel. [3] examined the effects of pack carburizing using charcoal on properties of mild steel. And observed that the core zone of the material was the same as the raw material and that longer holding time would result in a deeper case zone and stronger material. [4] studied the effect of paraffin wax (sulfur and phosphorous free)

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and kerosene used as carburized material for low carbon steel and observed that paraffin wax has more carburized surface layer depth than kerosene for the same steel. [5] investigated the effect of holding times of pack carburizing process on fatigue characteristic of v-notched shaft steel and found that the holding time of the carburizing process influences the fatigue strength of the material. [6] evaluated the suitability of using palm kernel shell, animal bone, and seashell materials as carburizers for case hardening of 0.078% Carbon mild steel. And they found that carbon obtained from palm kernel shell and animal bones are potentially suitable carburizers than seashell at high temperatures above 1000ºC withholding time above one hour. Relatedly, the effects of carburization time and temperature on the mechanical properties of carburized mild steel, using activated carbon as carburizer have been investigated by [7] and they observed that the mechanical properties of mild steels were intensely influenced by the process of carburization, carburizing temperature and soaking time. [8] Determined the interface structure of bonded duplex stainless steel and medium carbon steel couples and found that depending on the carbon content of steels, the differences in the cooling rate could affect the microhardness of steels. Equally too, the effect of carburizing medium on the carbon dispersion layer of ASTM A516 Steel has been studied. From their findings carburized samples induced deeper carbon diffusion on the material [11, 12]. The determination of corrosion and mechanical properties of carburized low carbon steel were optimally examined by [13] using the Taguchi design approach and they observed that Taguchi design assisted in achieving maximum hardness and depth penetration, with minimum wear and corrosion rates. Also, the effects of quenching and tempering on mechanical characteristics of hot-worked tool steel of AISIH11/H13 were assessed by [14]. And they deduced that low silicon content of about 0.55% might have a favorable effect in the tempering of the material. In another study, the effects of different carburizer media on the fatigue strength of mild steel were examined and they observed that the tempering process followed by quenching in 30% NaCl solution after pack carburizing, could increase the fatigue strength of material [15]. However, the effect of carburization on the impact strength and hardness property of welded ASTM A516/516M-05 steel has rarely been studied. ASTM A516/516M-05 steel is usually used for boilers, high-pressure vessels, and pipes where, surface hardness, toughness, etc., are required. Hence, in this work, an attempt is made to determine the hardness and impact strength of carburized and uncarburized ASTM A516/516M-05 grade 60 steel plate weldment.

2. Materials and Methods

2.1 Materials

This study was carried out at the Petroleum Training Institute Effurun, Delta State, Nigeria. The materials used for the experiment are wood-charcoal, E6010 electrode, ASTM A516/516M-05 60 grade steel purchased at Donasulu Steel Company in Warri, Delta State Nigeria, with the following chemical composition shown in table 1.

Table 1 - Chemical Composition of ASTM A516/516M-05 Grade 60 steel Plate

Alloys	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Nb	N	Sn	Ti	V
Composition	0.12	0.2	1.13	0.02	0.003	0.02	0.002	0.02	0.39	0.01	0.02	0.01	0.003	0.001	0.002

2.2 Methods

Sixteen (16) samples were obtained from the ASTM A516/516M-05 plate for this investigation. The ASTM A516/516M-05 plate was normalized at 890/930 for a minimum of 1.5 minutes per mm of thickness according to manufacturer mill certification. The sixteen samples were structured, prepared and machined into twelve (12) and four (4) samples for impact and Vickers hardness tests, respectively. Eight (8) samples were heat-treated (carburized) while the other eight (8) were not but used as a control, as shown in table 2.

Table 2 - Design of Experiment for Test of ASTM A516/516M-05 Sample

Sample	Welded- Heat treated (WHT)	Welded- Non-heat Treated (WNHT)	Non-welded Heat treated (NWHT)	As-received (AR)	Total
Micro Hardness	1	1	1	1	**4**
Impact test	3	3	3	3	**12**
Total	**4**	**4**	**4**	**4**	**16**

A manual butt weld operation using the shielded metal arc welding (SMAW) process was adopted. An overhead (4G) welding position was carried out on the ASTM A516/516M-05 plate using the E6010 electrode. Two numbers of passes (for the root and hot pass) were done before the joint is allowed to cool in still air. Thereafter, the plate was divided into eight (8) welded samples, grinded and brushed. Prior to pack carburization, the samples were thoroughly polished to eliminate any sharp points and rough surfaces. Six (6) and two (2) samples were prepared for impact and hardness tests, respectively, and were packed into an enclosed metal box environment with carbon powder obtained from wood charcoal as shown in Figures 1 and 2.

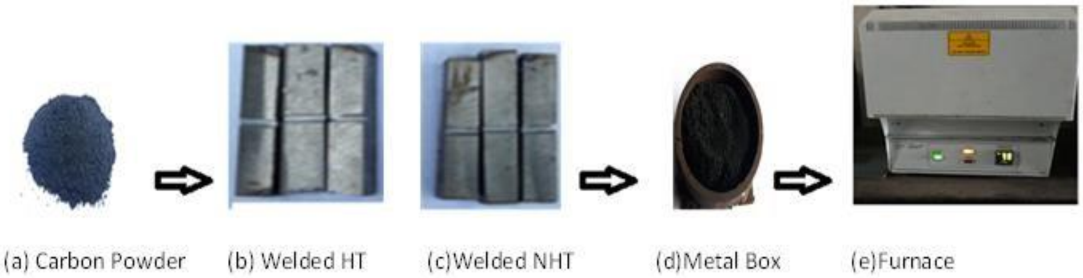

Fig. 1 - Schematic Operation of park carburization of weld and non-welded ASTM A516/516-05 for Impact Test

With the enclosed metal box containing the sample inside the furnace, the temperature was maintained at an average temperature of 920°C, at a holding time of 15 minutes for a uniform cross-sectional diffusion of the carbon in the sample, as shown in figure 3. Thereafter, the samples were then allowed to cool in steel air (normalized).

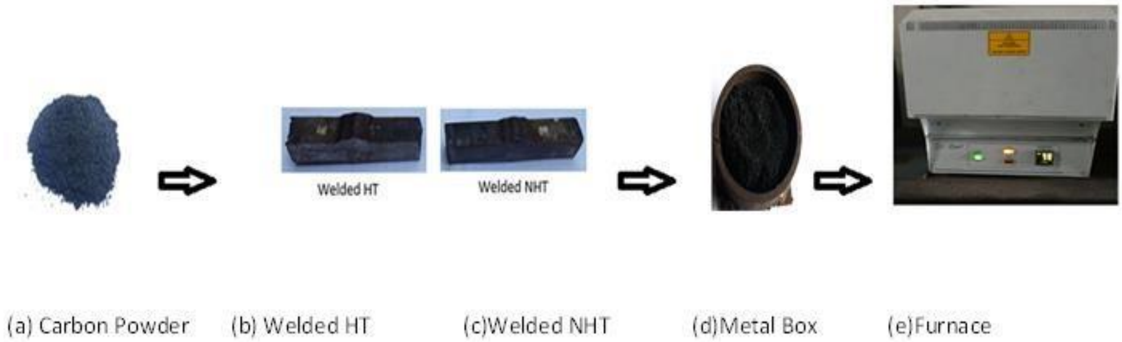

Fig. 2 - Schematic Operation of park carburization of weld and non-welded ASTM A516/516-05 for Hardness Test

To ensure that the carburized sample did not descale when removing from the furnace; the carbon powder and the metal cover were shielded. This helps to improve the dimension of the impact test sample and the initial surface finish of the Vickers hardness samples.

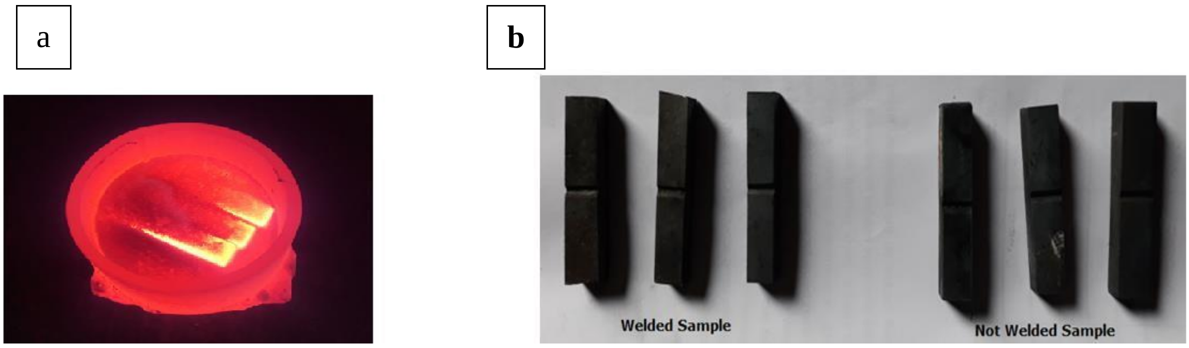

Fig. 3- (a) Sample During Carburizing Process; (b) After Carburizing Process

The impact sample was prepared in accordance to the standard test method of ASTM A370 specification with dimensions 10mm x 10mm x 55mm, centrally V- notched 2 mm deep at an angle of 45^0 with 0.25 mm radius along the base, as shown in figure 4. An impact testing machine with model number: MAT21/IT3U and serial number: 010340, (Honsfield Balance) was used for the impact test experiment. Thereafter, the impact strength (the amount of impact energy the sample absorbed before yielding) was determined.

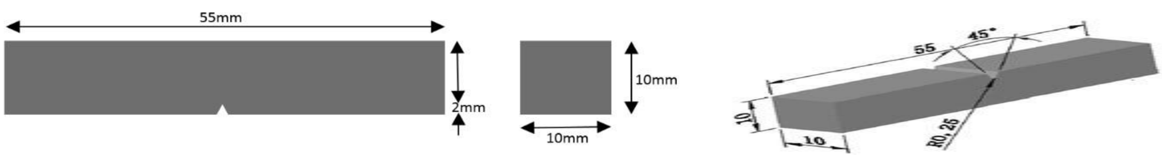

Fig. 4 - Charpy Impact Test Sample Dimension

Figures 5 to 8 are the failed samples after the impact test experiment was conducted for the Welded and Heat treated (WHT), Welded but not heat-treated (WNHT), Non-welded but heat-treated (NWHT) and the As-received (AR)) categories, respectively.

Fig. 5 - Welded-Heat treated (WHT) After Impact

Fig.6. -Welded-Non-heat Treated (WNHT) After Impact

Fig. 7 - Non-welded Heat treated (NWHT) After Impact

Fig. 8 - As-received (AR) After Impact

To determine the hardness of the welded and non-welded samples (24mm x 10mm dimensions), a Vickers Microhardness tester (Struers Duramin Micro Hardness Machine) with special microhardness testing microscope was used. For the welded samples, the Heat Affected Zone (HAZ), Parent Metal and the Fusion Zone (FS) were accommodated. Subsequently, to obtain a mirror image, the samples were subjected to grinding operation (from 220 microns to 600 microns, and thereafter polished (3 microns) and etched with Nital enchant. A micro load of 2000 N from dwell time to 10 seconds was used to make the indentation on the samples at nine (9) different surface layer positions and the hardness number was determined.

3. Results and Discussions

3.1 Impact Test

From the plot in figure 9, it was observed that the welded heat-treated (WHT) sample has the highest impact strength with an average impact value of 218 J; closely follow by the non-welded-heat treated (NWHT) sample with an average impact strength of 198 J. The Welded but not heated treated (WNHT) sample has an average impact test of 176 J while the as-received (AR) recorded 168 J. This result shows that an increase in carbon content of ASTM A516/516M-05 steel increase the impact strength of the material.

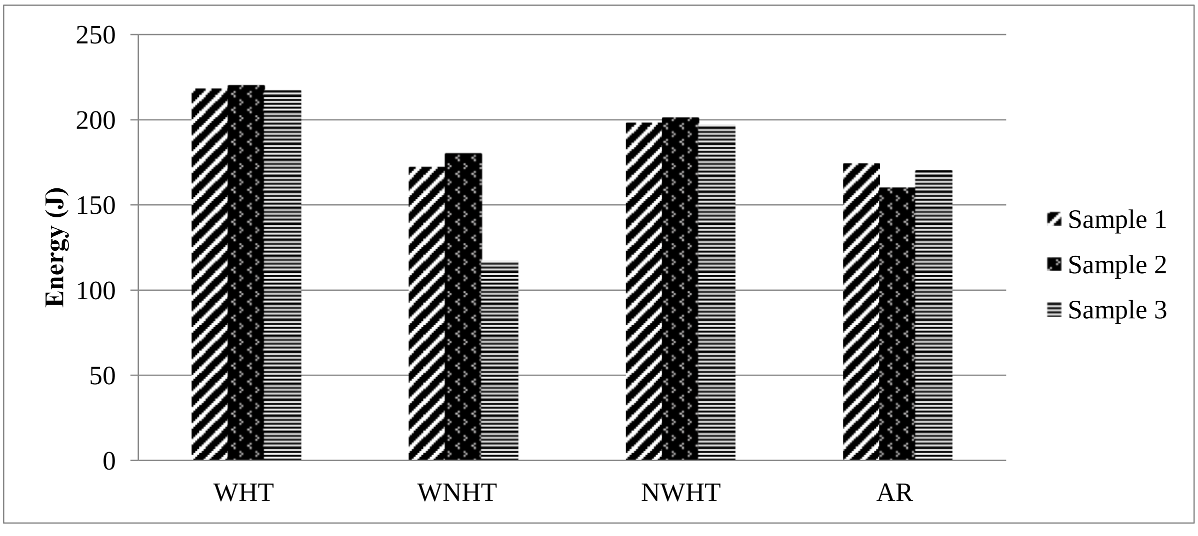

Fig. 9 - Plot of Charpy Impact Result for Various Categories of Welds

3.2 Vickers Hardness Result

Figure 10 shows comparative trends of the various categories of hardness results of the samples examined. The hardness result indicates that the welded-heat treated (WHT), non-welded-heat treated (NWHT) and the As-received (AR) samples have an average hardness numbers of 218, 213.7 and 181.4, respectively, also their hardness values were relatively and uniformly distributed across the surface layer of the steel material as shown in figures 11 (a), (b) and (c). However, for the welded-non-heat treated samples, it has hardness number 193.9 with a variation of hardness value distribution from the fusion zone to heat affected zone and the parent metal, as shown in figure 11(d).

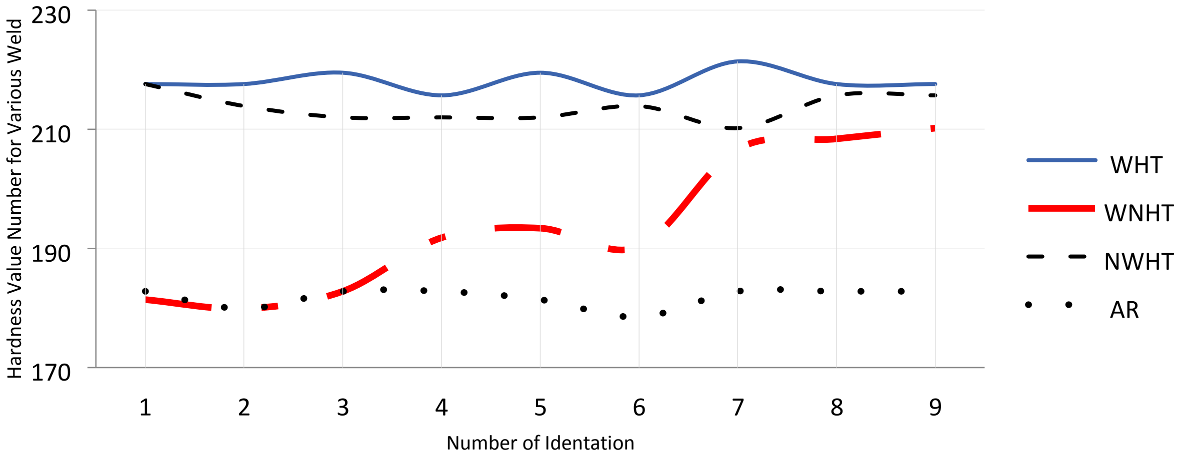

Fig. 10 - Hardness Values of ASTM A516/516M-05 Steel for Various Categories of Welds

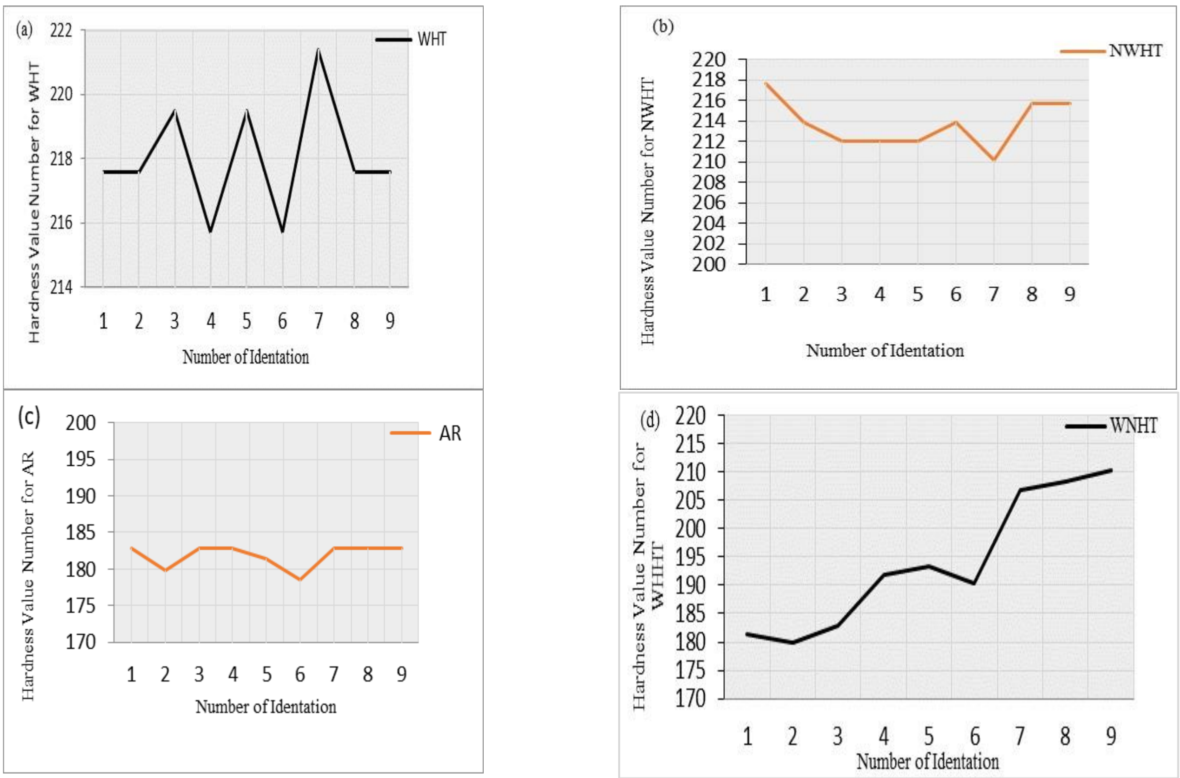

Fig. 11 - Hardness Values Distribution across the Surface Layer of the Steel Material: (a) WHT; (b) NWHT; (c) AR; (d) WNHT

A plot of the average impact energy against the average hardness, as shown in figure 12 indicates a significant increase in the impact energy and the hardness value of the WHT (sample 1) closely follow by NWHT(sample 3) and WNHT (sample 2) whereas (AR sample 4) has the lowest impact energy and the hardness value. The characteristic of the fractured WHT, NWHT and WNHT samples suggest its high toughness and ductility properties. The higher carbon content on the surface layer hardness could be as a result of the transformation from austenite to martensite, while the core remains soft and tough as ferritic or pearlite microstructure. The result indicates that the carburizing process accelerates the diffusion of carbon atoms into the surface, thus increasing the thickness of the carburized layer as well as the surface hardness.

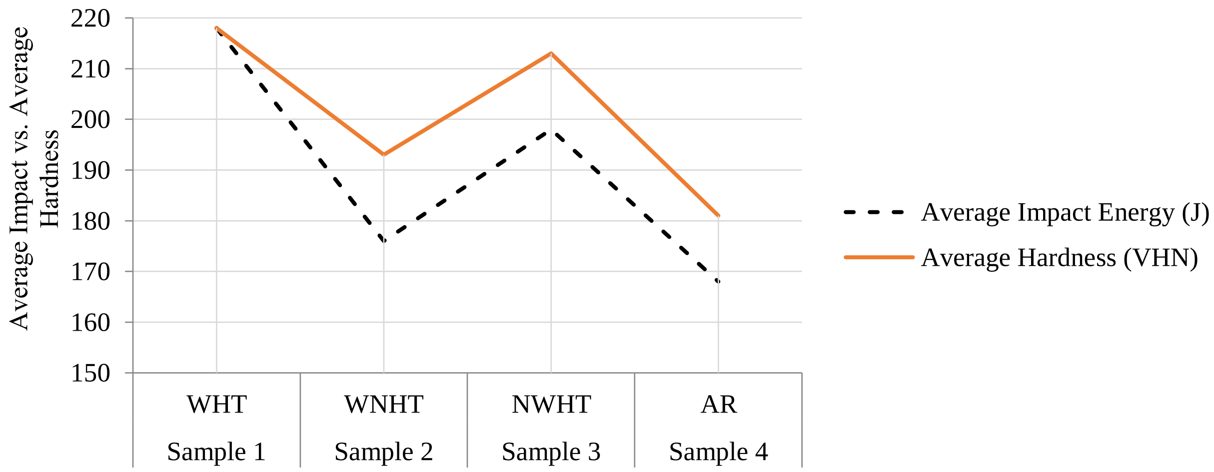

Fig. 12 - Plot of Average Impact Energy against the Average Hardness for Various Categories of Welds

Conclusion

This study has experimentally studied the effect of pack carburization on the impact strength and hardness property of A516/516M-05 steel plate weldment at a temperature of 920oC, with at a holding time of 15 minutes for three categories of samples namely; welded and heat-treated (WHT), welded but not heat-treated (WNHT), non-welded but heat-treated (NWHT) and the as-received (AR) that acts as the control. From the study, it was observed that pack carburization of A516/516M-05 steel of the welded and heat-treated (WHT) and the Non-welded but heat-treated (NWHT) samples have improved impact strength and hardness properties as compared to the uncarburized samples- the welded but not heat-treated (WNHT) and the as-received (AR). This is due to the formation of the hard carburized layer at the surface of the material.

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References

[1] Priyadarshini, S., Sharma, T., and Arora, G. (2014) Effect of Post Carburizing Treatment on Hardness of Low Carbon Steel," Int. J. Adv. Mech. Eng., vol.4, no. 7, pp. 763–766.

[2] Aramide, F. O., Ibitoye, S. A., Oladele, I. O.and Borode, J. O. (2015) Pack Carburization of Mild Steel, Using Pulverized Bone As Carburizer: Optimizing Process Parameters, Leonardo Electron. J. Pract. Technol., vol. 9, no. 16, pp. 1–12.

[3] Supriyono (2018) The Effects of Pack Carburizing Using Charcoal on Properties of Mild Steel. Media Mesin: Jurnal Ilmiah Teknik Mesin Vol. 19, No. 1, 2018: 38-42.

[4] Ahmad Jaleel Kareem (2015) Carburizing of Steel. International Journal of Materials Science and Applications Special Issue: Steel and Direct Reduced Iron (Sponge Iron) Industry. Vol. 4, No. 2-1, 2015, pp. 11-14. doi: 10.11648/j.ijmsa.s.2015040201.13.

[5] Supriyono and Jamasri, (2017) Holding Time Effect Of Pack Carburizing On Fatigue Characteristic Of V-Notch Shaft Steel Samples,AIP Conference Proceedings, 2017, vol. 1855.

[6] Oyetunji, A., and Adeosun, S. O. (2012). Effects of Carburizing Process Variables on Mechanical and Chemical Properties of Carburized Mild Steel, J. Basic Appl. Sci., vol. 8, pp. 319–324.

[7] Aramide, F.O. (2009) Effects of Carburization Time and Temperature on the Mechanical Properties of Carburized Mild Steel, Using Activated Carbon as Carburizer, Material research, 12, pp. 483-487.

[8] Bulent Kurt and Adnan Calik,(2009) Interface Structure of Diffusion Bonded Duplex Stainless Steel and Medium Carbon Steel Couple. Materials Characterization, Volume 60, Issue 9, pp. 1035-1040.

[9] Fares M. L., Athmanib, M., Khelfaouic, Y., Khettacheb, A. (2012) An Investigation into the Effects of Conventional Heat Treatments on Mechanical Characteristics of New Hot Working Tool Steel. Material. Science Engineering, vol. 28 pp. 012-042.

[10] Zhang, P., Zhang, F.C, Yan, Z.G. Wang, T.S. Qian, L.H. (2011) Wear Property Of Low-Temperature Bainite In The Surface Layer Of A Carburized Low Carbon Steel, Wear, 271 pp. 697-704.

[11] Siti Khadijah Aliasa , Bulan Abdullaha , Ahmed Jaffara , Syazuan Abdul Latipa , Salmiah Kasolanga, Mohd

Faizul Izhama, Muhd Azimin Abd Ghania (2013) Mechanical Properties Of Paste Carburized ASTM A516 Steel, The Malaysian International Tribology Conference 2013, Procedia Engineering, 525 – 530 Science Direct Malaysia doi: 10.1016/j.proeng.2013.12.216.

[12] Alias, S. K., Abdullah, B., Abdullah, A. H., Latip, S. A., Wahab, N. A., & Ghani, M. A. A. (2013). The Effect of Carburizing Medium on Carbon Dispersion Layer of ASTM A516 Steel. Applied Mechanics and Materials, 393, 212–216. https://doi.org/10.4028/www.scientific.net/amm.393.212.

[13] Abbas Khammas Hussein, Laith Kais Abbas, Asraa Kareem Hameed (2018) Investigation Corrosion and Mechanical Properties of Carburized Low Carbon Steel. Journal of Engineering and Sustainable Development Vol. 22, No. 2 (part-6). The Fourth Scientific Engineering and First Sustainable Engineering Conference www.jeasd.org (ISSN 2520-0917).

[14] M. L Fares M., Athmani, Y. Khelfaoui, A. Khettache (2012). An investigation into the effects of conventional heat treatments on mechanical characteristics of new hot working tool steel. IOP Conference Series: Materials Science and Engineering 28; 012042doi:10.1088/1757-899X/28/1/012042.

[15] Sujita, Rudy Soenoko, Eko Siswanto and Teguh Dwi Widodo (2018) Study on Fatigue Strength of Pack Carburizing Steel SS400 with Alternative Carburizer Media of Pomacea Canalikulata Lamarck Shell Powder International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 11 pp. 8844-8849.