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Experimental Analysis of the Effect of Tri-Nano Additives on Wear Rate of Mild Steel during Machining

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Abstract

Wear is an indispensable and recurring problem in engineering materials and it depicts its function on the long run. However, alternative method of retooling the materials at reduce cost was the main focus in this research work. Nano additives of 50 kg each of palm kernel, coconut and egg shells were used as carburizer and energizer. Sixty (60) pieces of 100 x 20 mm AISI 5130 mild steel and four (4) boxes of 200 x 150 x 100 mm were charged into furnance of about 2,500ºC max capacity. The tri-nano additives of palm kernel, coconut and egg shells were mixed at percentage ratio of 40:40:20. The elemental compositional analyses of the samples were checked before and after the case-hardening using spectrometric analysis machine. Each of the samples was soaked at a temperature of 950, 1000, 1050, and 1100ºC for 60, 90, 120, and 180 minutes holding time. The obtained treated samples were subjected to elemental analysis, hardness and wear test using the spectrometer, vicker hardness tester and Rotopol-V wear testing machine. The best core and the surface hardness obtained were 117.9 and 140.9 HR compare to the control with 103.6 and 110.9 HR. The minimum wear rate of the sample was 1.22×$10^{-7}cm^2$ while that of the control was 2.03×$10^{-7}cm^2$. The results gave a clear distinction decrease in wear rate and increase in hardness. This showed best economical and environmental friendly way to optimize the property of AISI 5130 steel which can be applied to any other grade of steels.

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Keywords: Energizer, Hardness, Nano additives, Wear

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1. Introduction

The commonly used material for both domestic and industrial application due to its outstanding properties remains steel and one of its major drawbacks are wear and corrosion behavior [1]. Steel is an alloy of iron with a particular carbon content which ranges between 0.15 % and 1.5 %. These carbon steels can be classified considering it's carbon concentration as High, Medium and Low carbon steel [2]. Steels whose carbon content is lower than 0.3% is termed Low carbon steels, those with carbon content ranging between 0.3-0.6 % are termed Medium carbon steel, while those with a carbon content ranging from 0.6-1.5 % are High carbon steels [3]. Steels used in an outdoor environment especially a marine environment with comparatively large temperature changes, are prone to countless cycles of live loading which are regularly vulnerable to corrosive environments and uncontrolled corrosion could lead to an eventual failure in service [4]. Friction and wear are the product of the interaction between surfaces in mechanical or sliding contact and is subjected to numerous factors such as the nature of the mating materials, motion, loading, lubrication, heat dissipation and environment [5]. Zhang et al.[6] described wear as a continuous destructive phenomenon involving the degradation of surfaces occurring in various industrial activities. It is a complex process involving numerous variables such as speed of the mating components, surface finish, lubricant applied, pressure, temperature and corrosion, microstructure, hardness and fatigue amongst others [7]. In a typical saline environment with mild steel present, there is an active dissolution of mild steel in sodium chloride solution (saline environment), mild steel in these corrosive medium passives, and the native oxide film is unstable under prevailing chloride environment [8]. A rough surface is formed basically as a result of rapid corrosion reactions between the mild steel and chloride anions almost encompassing the surface of the steel, leading to the formation of pits and uniform corrosion attack takes place. The rough surface is often accompanied with a brown pigment [1, 9]. The carbon enriched layer can be subsequently enriched by quenching in appropriate medium such as water, air or oil [10-11]. Carburization builds quality and wear resistance by diffusing carbon onto the surface of the steel while retaining a generally lesser hardness in the center and varying of the carburizing temperature usually has an effect on the mechanical properties of the carburized sample. Higher carburizing temperatures and holding time breeds samples with a higher wear resistance as it typically increases the depth of carbon diffusion, whereas lower carburizing temperature and time creates samples with a lower wear resistance. [12-15]. Palm kernel shell is very suitable as a carburizer as it possesses a relatively high fixed carbon content of around 19%w/w and a low ash formation of around 0.1%w/w. This high carbon content and low ash formation means the palm kernel shell is a great choice for the production of quality grade coal as well as being employed as the carburizing agent in this experiment. [16]. Coconut shell is obtained as waste products from coconut fruits from which coconut oil is derived as well as the fruit itself serving other purposes. It has relatively high carbon content of 88.92 % and low ash formation of 1.5 % with moisture content of 2.2 % [17]. The effects of materials wear is present in countless technological sectors such as petrochemical, aerospace, automotive, chemical, mining, automotive, and biomedical industries where it causes damage to prosthetic joints, failure of electrical components, damage to turbine blades, slurry handling equipment and machines, deterioration of dental fillers, failure of safety equipment and many others and thus tribo-corrosion undeniably has great implications for human health, safety, and improved quality of life [18]. The wear of metals is a degrading process concerning the basic modern industrial material with a great importance for the modern industry and in many cases represents a great economic deficit [19-20]. Therefore, it does not come as a surprise that the research on the wear process and wear protection of metallic materials is developed on a large scale in varying directions and a wide range of industrial disciplines [21-22]. This study will assist us in trying to look at methods to combat material wear in steel (AISI 5130) as well as increase its hardness.

2. MATERIALS AND METHOD

The nano particles of carbon additives contained 50 kg each of palm kernel, coconut and egg shells were grinded, sieved and milled as carburizer and energizer respectively. Sixty (60) pieces of 100 x 20 mm AISI 5130 mild steel buried in four (4) boxes of 200 x 150 x 100 mm were charged into furnance of about 2,500ºC max capacity. Nano particles were mixed at percentage ratio of 40:40:20. The elemental compositional analyses of the samples were checked before and after the case-hardening using spectrometric analysis machine. Each of the samples was soaked at a temperature of 950, 1000, 1050, and 1100ºC for 60, 90, 120, and 180 minutes holding time.

3. Experimental Design

The experimental effects of wear rate and hardness on independent parameters of carburizing temperature and holding time on AISI 5130 steel were checked. The experimental independent variables for maximum and minimum variables are shown in Table 1. The obtained treated samples were subjected to elemental analysis, hardness and wear test using the spectrometer, Vicker hardness tester and Rotopol-V wear testing machine respectively.

Table 1: Levels of the Independent Variables for Case hardening

Variables	Levels	
	Lower	Upper
Carburizing Temperature (ºC)	950	1100
Carburizing Time (min)	60	180
Speed grit (mm/min)	270	560

Table 2 : Composition of AISI5130 steel before carburization

Elements	Composition (%)
C	0.32
Si	0.85
Mn	0.95
P	0.05
S	0.045
Cr	1.01
Ni	0.210
Mo	0.210
Al	0.206
Fe	96.18

4. EXPERIMENTAL RESULTS AND DISCUSSION.

The results obtained after carrying out hardness and wear tests on the steel samples are shown below

Table 3: Template for wear rate and hardness

TEMPERATURE (0ºC)	TIME (mins)	WEAR RATE (cm^2)	HARDNESS (AVG) HR
950	60	1A	1A
1000	60	2B	2B
1050	60	3C	3C
1100	60	4D	4D
950	90	5E	5E
1000	90	6F	6F
1050	90	7G	7G
1100ºC	90	8H	8H
950ºC	120	9I	9I
1000	120	10J	10J
1050	120	11K	11K
1100	120	12L	12L
950	180	13M	13M
1000	180	14N	14N
1050	180	15O	15O
1100	180	16P	16P

	Control	17Q	17Q

Table 4: Temperature and time interface effects on hardness and Wear rate

TEMPERATURE (0ºC)	TIME (mins)	HARDNESS (HR)	WEAR RATE ($X10^{-6}cm^2$
950	60	79.65	297
1000	60	100.9	239
1050	60	105.45	180
1100	60	114.35	122
950	90	91.4	282
1000	90	108.6	224
1050	90	141.05	116
1100ºC	90	128.4	135
950ºC	120	105.9	268
1000	120	119.25	210
1050	120	117.8	151
1100	120	126.8	149
950	180	112.4	253
1000	180	123.35	195
1050	180	121.7	137
1100	180	129.4	162
	Control	107.25	240

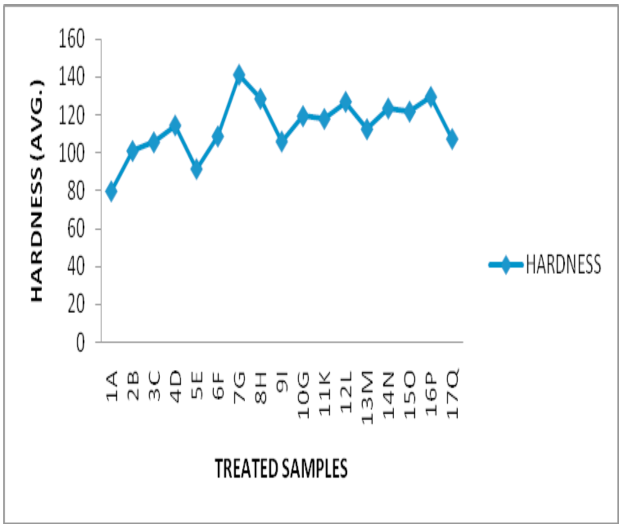

Figure 1: Variation effect of temperature and time on hardness of AISI 5130 mild steel

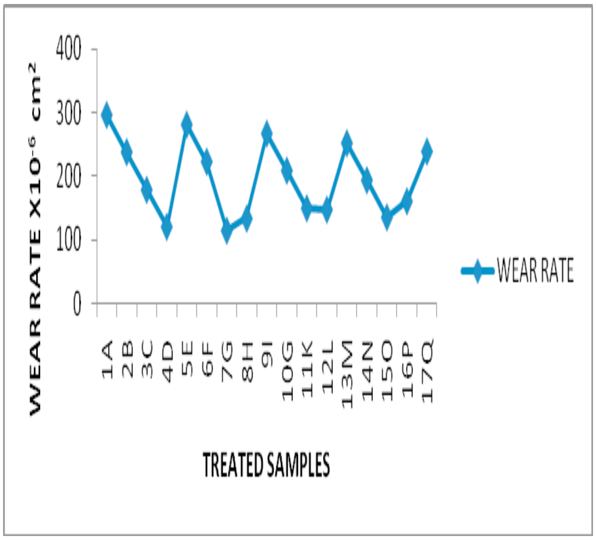

Figure 2: Variation effect of temperature and time on wear rate of AISI 5130 mild steel

5. DISCUSSION

Application of using tri-nano additives contained palm kernel, coconut and egg shell as carburizer and energizer respectively has really put the process on balance in the treatment of surface, interface and core of AISI 5130 mild steel. The sustainability *of nano additives in the machining process of mild steel was as result of its availability and richness in carbon content.* Elemental composition of the steel was checked using spectrometer 675 x321 as results shown in Table 2. Considering the trend of the variation movement of the hardness in Table 4, it can be observed that the hardness increases with an increase in the holding temperature and time. The same effect was observed for the intermediate and core hardness which is in agreement with earlier researchers like Abdulrazzak et al., (2016). Carburizing the steel samples enriches the hardness of both surface, intermediate, and core layers of the sample. The application of egg shell as energizer increased the rate of carbon penetration into the layers of the steel in agreement with research carried out by Xu et al., (2018). The hardness of the sample at a holding temperature of 1050^{0}C and a holding time of 90 minutes was observed to have the best hardness of 141.05 HR compare to the control of hardness 107.1 HR as indicated in Table 4 and figure 1. It was also observed from Table 4 that as the holding temperature and time increases, there exists a corresponding dropped in the weight loss of the AISI5130 steel. The graph shown in Figure 2 agreed with Table 4to show that the wear rate of the AISI5130 steel samples reduces as the carburizing temperature and time elevates. The wear rate of the sample subjected to holding temperature of 950 ^{o}C at a holding time of 60 minutes was 2.97cm^2 while the wear rate of the sample at a holding temperature of 1050 ^{o}C and a holding time of 60 minutes was 1.80cm^2 and this presumed that the wear rate of the sample reduces with an increase in the holding temperature utilized in the carburization process. Considering the behaviour of the process it could be observed that the best wear rate of 122 HR was at holding temperature and time of 1100 ^{o}C and 60 minutes respectively compared with the control of wear rate 240 HR. Comparing the holding times of the carburization process across the same holding temperature, we can observed that the wear rate of the sample reduces as the holding time increases which accompanied by an increased hardness in the surface, intermediate and core. This experiment proved an obvious effect of the holding temperature and time on the hardness and wear of the selected AISI 5130 steel using tri-nano particles additives.

6. CONCLUSIONS

The use of palm kernel, coconut and egg shells as carburizer and energizer in the case-hardening of AISI 5130 steel has exhibited a significant improvement in the hardness and wear resistance with a higher core hardness and surface hardness of 141.05 HR over the control sample used which has a hardness of 107.25 HR. The carburized AISI 5130 steel showed higher value in hardness, wear resistance and a lower wear rate than the control specimen proving that the carburization of the AISI5130 steel led to a higher hardness, a reduced wear rate and a higher wear resistance. The carburization of the steel at a higher holding time and holding temperature shows great positive impact on the wear resistance, wear rate and hardness of the steel. The tri-nano additives particles processed from palm kernel, coconut and snail shells can be utilized in place of foreign expensive carbon additives to serve as carburizer and energizer in the case-hardening and this is economically advantageous.

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