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BEHAVIOR OF PACK CARBURIZING WITH BONE BUFFALO CHARCOAL AND BACO3 AGAINST MECHANICAL PROPERTIES OF LOW CARBON STEEL

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ABSTRACT

Carburizing Pack method is one method to improve mechanical properties of carbon steel lace that is hardness value and value of tensile strength of low carbon steel at surface. In this process the low carbon steel remains strong and resilient at the stadium. This study aims to determine the effect of carburizing media with the percentage variation of bone powder of buffalo bones as carbon in carburizing process to mechanical properties of low carbon steel. The temperature used in the carburizing process lasts is 900 ^{0}C with a holding time of 60 minutes. In this process the carbon obtained from the buffalo bone char is made into a fine powder and combined with $BaCO_3$ as its the energizer. In the percentage study of buffalo bone powder as carburizing medium is 65% ATK + 35% $BaCO_3$, 75% ATK + 25% $BaCO_3$, 80% ATK + 20% $BaCO_3$ from the weight of buffalo bone charcoal used in carburization process. In this study steel will be added with barium carbonate and heated buffalo bone charcoal in a furnace with a temperature of 900 ^{0}C. Then tested hardness Vickers sensitivity and tensile strength. From the research result of hardness for normal material or without treatment equal to 74,333 kg/mm^2 and tensile strength 636,94 N/ mm^2. While after experiencing the method of carburizing pack treatment then the hardness has increased, the highest hardness at percentage 80% ATK + 30% $BaCO_3$ that is 91,667 kg/mm^2. Likewise in tensile strength after pack carburizing process is the largest value in percentage 80% ATK + 30% $BaCO_3$, it is 1233,78 N/ mm^2. This research results show that the percentage of buffalo bone charcoal powder as a medium in the method of carburizing pack can improve the mechanical properties of hardness and tensile strength of low carbon steel.

Keywords: pack carburizing, buffalo bone charcoal, hardness, carbon steel, tensile strength.

1. INTRODUCTION

The carburizing pack method is a heat treatment process in which the heating and cooling processes of the metal (Figure-1) are solid in order to change the physical and mechanical properties of the metal. With the right heat treatment, the inner stress can be reduced, the grain size can be enlarged or reduced, the strength is increased or a hard surface is produced around the ductile core. Cooling rate is a controlling factor, where cooling faster than critical cooling will result in a hard structure whereas slow cooling will result in a softer structure. To allow for appropriate heat treatment, the chemical composition of the steel must be known because the change in chemical composition, in particular the carbon element can lead to changes in physical properties and mechanical properties. In general, other than carbon elements of steel contain nickel (Ni), chromium (Cr), manganese (Mn), molybdenum (Mo), tungsten / wolfram (W), silicon (Si), vanadium (V), copper (Cu), sulfur (S), zinc (Sn) and phosphor (P) with different levels.

If a piece of steel with a carbon content of 0.20% is heated evenly and temperature is recorded at a certain time interval, curves will be obtained as shown below:

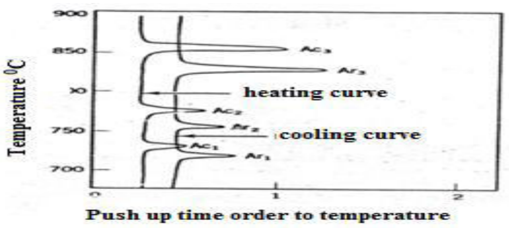

Figure-1. The rate curve - inverse to Baja SAE 1020 (Amstead, B.H., *et al*, 1992).

The changes that occur at critical points are allotropic changes. Based on the definition, an allotropic change is a reversible change in the atomic structure of a metal followed by a change in properties. The change of these points should be known, because the heat treatment on the steel covering on this area. Steel can not be hardened unless it is heated above the lower critical area and sometimes above the upper critical area. Take an example, a piece of 0.20% carbon steel is heated at a temperature of 870 ^{0}C, above the point Ar_3 steel is a solid solution of carbon in gamma-iron, it is called austenite. The iron atoms form a face centered cubic lattice and non-magnetic. When cooled to a temperature below the point of Ar_3, the atoms will form a body centered cubic lattice. This new structure is called ferrite or iron-alpha and is a solid solution of carbon and iron - alpha. The solubility of carbon in iron - alpha is much lower than when carbon is in iron - gamma.

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At point Ar_2 steel is magnetic, and when steel cooled to the Ar_1 line, the formed ferrite will increase. On the existing Ar_1 austenite line will transform into a new structure called pearlite. The pearlite appears as layers consisting of ferrite plates and alternating iron carbides. When the carbon content of steel exceeds 0.20% where the ferrite begins to form and precipitates from the austenite. The 0.80% carbon steel is called eutectoid steel and the structure is 100% pearlite. At the eutectoid point is the lowest temperature in the metal where there is a change in the solid solution state, and is the lowest equilibrium temperature in which the austenite decomposes into ferrite and cementite (Amstead, B.H. *et al*., 1992).

Austenisation temperature hardening temperature and recrystallization temperature of a steel, the amount is determined based on the percentage of carbon content. The guidelines for determining these hardening temperatures may use several methods such as iron-iron carbide diagrams (Fe-Fe3C) for carbon steels (Figure-2) the hardening temperature is at 30 ^{0}C – 50 ^{0}C above the critical temperature (see section shaded) Hot materials (eg AISI) and by using product catalog. Steels with carbon content below 0.35% can not be hardened unless a carbon element is added to the material to be hardened by carburizing process. Steel components and structures have problems not only in the case of hardness, tenacity or toughness, but also in terms of fatigue caused by wearing surface due to alternating stress and arc Stress. To solve these problems need to provide hardness on the surface of the component, which can be done by carbonizing, high frequency current, or flame and so forth. In the process of pack carburizing in the box, using charcoal mixed with certain solutions such as $NaCO_3$, $CaCO_3$ or $BaCO_3$ which serves as a material activator and as well as energizer elements, then into the mixture is inserted in the form of steel specimens to be harden. The box is then tightly closed to avoid air from outside and then heated 750-950 ^{0}C, thus the steel surface will have higher carbon content. Since the steel structure becomes rough cause of long heating, then after first hardening at 750-950 ^{0}C, then smoothed by second hardening or quenching at 800 ^{0}C (figure 2), and tempering at 150-200 ^{0}C (Figure-3) before Used.

The carbonizing explained below:

$$2C + O_2 \longrightarrow 2CO \tag{1}$$

Then CO dissociates into C_at:

$$2CO \longrightarrow CO_2 + C \tag{2}$$

The gas produced by the energizer may occur with the reaction equation:

$$BaCO_3 + hot \longrightarrow BaO + CO_2 \tag{3}$$

Then carbon dioxide (CO_2) gas reacts with a solid carburizer to form carbon monoxide (CO) gas with the reaction equation:

$$CO_2 + C\ (charcoal) \longrightarrow 2CO \tag{4}$$

Where C is soluble into steel (Surdia, T. and Shinroku, 1992)

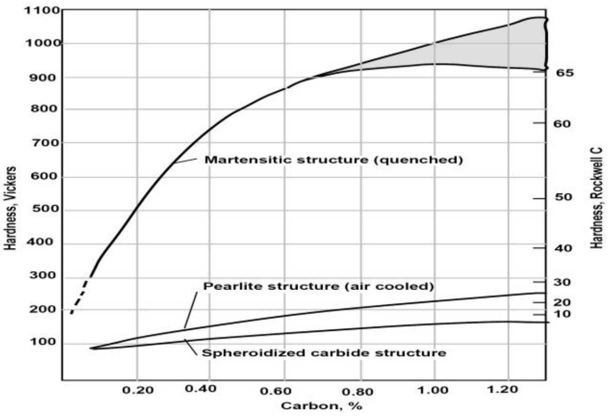

Figure-2. Hardness due quenching process (Meyrick, G. and Wagoner, R. H., 2001).

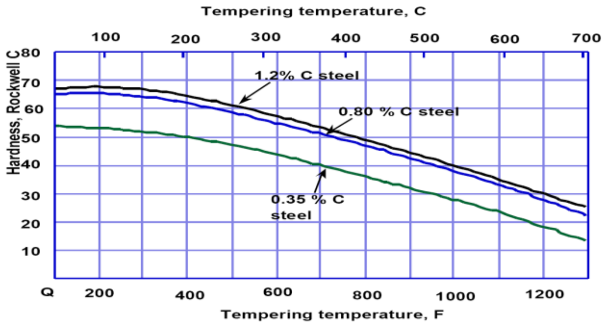

Figure-3. Temperature tempering vs hardness (Meyrick, G. and Wagoner, R. H., 2001).

The heat treatment of low carbon steel is based on the thermo chemical principle with the diffusion system, it is a way to change the surface properties of the substrate, it needs additional material and the additive will diffuse onto the surface of the substrate. Heat treatment in steel is also based on the principle of physical metallurgy relating to processes, properties and microstructures. In the heat treatment process, the whole process uses heat to change the steel structure. To change the properties of steel surfaces can be done by changing the surface structure and shape with thermo mechanical treatment.

Chemical heat treatment in steel is a steel heating process by adding certain substances during heating, then cooled. Chemical heat treatment can be (1) carburizing, (2) nitriding, (3) cyaniding or carbo nitriding, and (4) diffusion coating. Carburizing is the process of coating steel surfaces with carbon through steel heating at a temperature of 750-950 ^{0}C. The carbon used may be in the form of a solid, liquid or gas powder. The thickness of the

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carbon layer formed on the surface depends on the duration of the heating, which varies from 0.5-2 mm with a coating rate of 0.1 mm/hr. This carburizing process will increase the carbon content in the surface layer of steel about 0.75 - 1.20%. Carburizing process can not be performed on any steel, depending on the carbon content contained in the steel and generally carburizing process is done on low carbon steel (> 0.35% C). "This carburizing process is often done to harden the surface of the gears and cam (Malau, V., 1999)". To accelerate the penetration of carbon into the specimens during the carbonization process, it is necessary to add other elements such as $BaCO_3$, $NaCO_3$ and others.

Research on the effects of the carburizing pack process against ST60 fatigue using wood charcoal and barium carbonate ($BaCO_3$) plus sodium carbonate ($NaCO_3$), 850'C and 950 ^{0}C temperatures retained for 5 hours.

The results showed that the hardness on the surface increased from 220, 856 HVN to 417,139 HVN and fatigue life also increased from 2,017,451 to 4,154,577 cycles (Yasa, I.N., 2000)". "The study of the relation between carbonizing carbon depth case and carburizing strength on SAE 8620 steel fatigue. Carburizing process run with 940 ^{0}C temperature for 45 minutes, 3 and 5 hours followed by quenching at 850 ^{0}C at 15, 30 and 60 minutes. The results show that the longer of holding time, case depth and fatigue strength of SAE 8620 carbon steel is higher (Asi, O., *et al,* 2007)".

Research on the effect of solid carburizing holding time on AISI - SAE 1522 steel surface hardness with coconut shell charcoal and $NaCO_3$ by 20% as activator. The result is 570 HV (2 hours), 753 HV (3 hours) and 773 HV (4 hours) (Sudarsono, 2003)". "The study of the effect of carburizing media composition of barium carbonate wood charcoal on the hardness and worn out of low carbon steel. Barium carbonate ($BaCO_3$) was varied 15%, 20%, 25% and 30% with treatment temperature 850'C, 900 ^{0}C and 950 ^{0}C and held for 2 hours. The result obtained is the highest surface hardness, that is 66,7% and the wearing resistance of 81,6% is mainly obtained at carburization process at 950 ^{0}C with 20% barium carbonate added (Suryanto, H. *et al,* 2005).

Carburizing process on steel chisel ST37 with temperature 950 ^{0}C charcoal media and held for 2 hours followed by quenching process. The result concluded that ST37 steel subject to carburizing process can be used to cut steel or other softer materials (Rumendi, U. and Purnawarman, O., 2006) ". "The study of the effect of the carburizing process on the austenite stainless fatigue behavior of AISI 316 austenite. The results show that the fatigue resistance of the carburized sample increased compared with the untreated sample (Akita, M. and Tokaji, K., 2006).

1.1. Hardness

Hardness is the ability of the material to withstand scratching, erosion, wear, indentation, penetration and able to withstand loads until the occurrence of plastic deformation. Hardness testing aims to evaluate heat treatment, and detect hardening or softening due to overheating, decarburization or surface hardening.

The method of measuring hardness is by indenting the material using the indenter on the surface of the specimen with a certain load and then measure the compression mark. "Indentors are usually made of hardened steel, tungsten carbide and diamond-shaped diamond pyramid with a top corner between two opposite sides of 136^0.

In general, hardness test uses the Vickers method with micro scale (micro hardness) which is based on ASTM standard. In Vickers test, the load is given slowly without a shock load and held for 10-15 seconds. After the indenter is lifted, then measure the two diagonals and get the average measurement, then Vickers indentation hardness (HV) is calculated by the equation:

$$HV = \frac{2.P.\sin(\theta/2)}{d^2} \quad (5)$$

$$d = \frac{d_1 + d_2}{2} \quad (6)$$

$$HV = \frac{1,854P}{d^2}\left(\frac{kgf}{mm^2}\right) \quad (7)$$

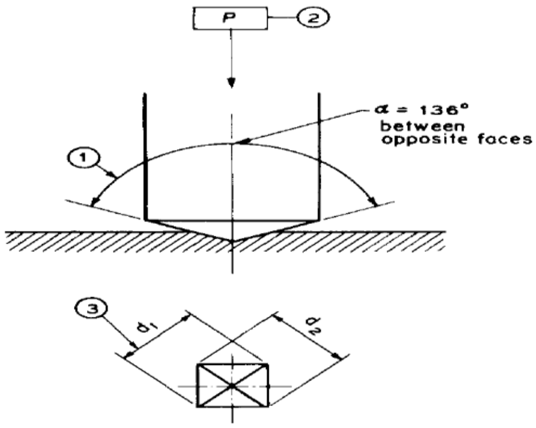

Figure-4. Micro vickers hardness testing methods (ASTM E-92).

Table-1. Vickers hardness testing variables.

Number	Symbol	Designation
1	...	Angle at the vertex of the pyramidal indenter (136°)
2	P	Test force in kilograms-force
3	d	Arithmetic mean of the two diagonals d^1 and d^2

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Table-2. Hardness relationship layers with carbon content.

The carbon content (%)	Coating hardness (HR_C/HV)
0,28 – 0,32	35/345
0,33 – 0,42	40/392
0,43 – 0,52	45/446
≥0,53	50/513

Source: Boyer & Gall, 1985

1.2 Strength tensile

The tensile strength (ultimate tensile strength) is the ability of a material to withstand tensile loads. It is measured from the load / maximum force inversely proportional to the cross-sectional area of test material, and has units of Mega Pascal (MPa) or N/mm^2 or kgf/mm^2 or Psi.

Tensile test was done by giving a load on both ends of the test specimen is slowly increased until the test specimen broke. This can be ascertained by testing tensile strength, yield load and modulus of elasticity (Young's modulus) strength, a reduction in cross-sectional area and the length.

The test aims to determine the strain and stress of particle board that has been made. The results of this testing is the graph of load against extension (elongation). Strength (σ) can be formulated into:

$$\sigma = \frac{P}{A_0} \qquad (8)$$

Strain (ε) can be formulated into:

$$\varepsilon = \frac{\Delta L}{L_0} \qquad (9)$$

where P is the applied load (N), A_0 is the initial cross-sectional area (mm), L_0 is the initial length (mm), ΔL is the length(mm).

Modulus of elasticity (E) can be formulated into:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \qquad (10)$$

where Δσ is the stress (MPa), ΔƐ is strain (%), E is the modulus of elasticity (GPa).

1.3. Strength and strain curves

The line shows the deformation in a tensile test specimen as shown in Figure-5. When the load is applied to the first, stretched specimen is proportional to the load; this effect is hereinafter referred to as linear elastic properties. If the load is removed, the object back to its original shape.

Nominal strength or strength technique, described as the ratio of the load applied to the initial cross-sectional area of the test specimen. When the load starts to increase at a certain strength level, the specimen experience permanent deformation (plastic). At that rate, the strength and strain is no longer proportional as in the elastic region, where the incident occurred is known as the yield stress. The term yield strength is used to determine the point where the stress and strain is no longer comparable.

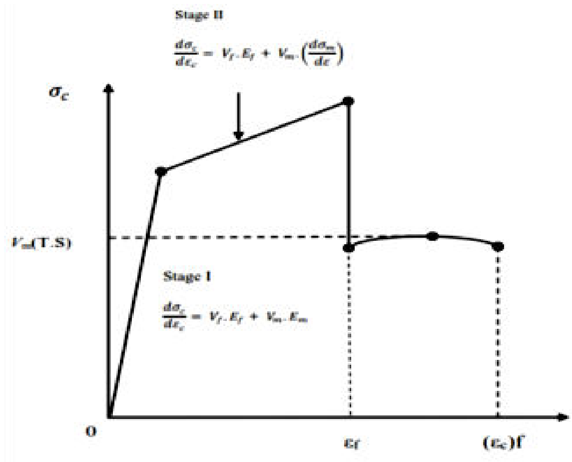

Figure-5. Strength-strain curves pull.

The maximum tensile strength (ultimate tensile strength) is the maximum strength that can be borne by the composite material prior to the fracture. The maximum tensile strength values are determined from the maximum load divided by the initial cross-sectional area.

$$\sigma_{max} = \frac{P_{max}}{A_0} \qquad (11)$$

where σ_{max} a maximum tensile strength (N / mm^2), P_{max} is the maximum tensile load (N), A_o is the initial cross-sectional area(mm^2).

If the specimen burdened beyond its maximum tensile strength, then necking will occur. Throughout the area necking specimen cross-sectional area is no longer uniform in length and smaller in the necking area. When the test is passed, the strength drops further techniques and specimen finally broken in the necking area. strength current techniques referred to as the fracture strength fracture or break up.

1.4. Strength and strain actually

After the point of maximum strength, become localized plastic deformation (necking) and strength engineering fell as a result of localized reduction in cross-sectional area. But the real strength (true strength) widened in cross-sectional area decreases. The true strength-strain curves obtained from the conversion of

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tensile strength and strain in real value can be determined by using the following equation:

$$\sigma_t = (1 + \varepsilon)\ \sigma \quad (12)$$

$$\varepsilon_t = \ln(1 + \varepsilon) \quad (13)$$

where σ_t is a real tension (N/mm^2), ε_t a real strain (%), σ is engineering strength (N/mm^2), ε is engineering strain(%).

The test aims to determine the strain and strength of particle board that has been made. The results of this testing is the graph of load against extension (elongation).

2. MATERIALS AND METHODS

This study used the furnance as a heating media with a carburizing steel box made of 5 mm steel plate with temperature resistance up to 1500 ^{0}C, micro hardness test method of Vickers (micro hardness), tensile strength test, Electric drill holder for sample handles when sanded, saws for cutting material, and spring scales.

The materials used in this study are low carbon steels that conform to the ASTM E-466 standard. The percentage of carburizing media varies between buffalo bones and Barium Carbonate ($BaCO_3$), which is 65% ATK + 35% $BaCO_3$, 75% ATK + 25% $BaCO_3$, 80% ATK + 20% $BaCO_3$ where buffalo bone is from traditional ceremony of Toraja and slaughterhouse in Toraja. Then Process of cleansing and drying, cutting of buffalo bones for charcoal making and Refinement bone mesh 30 buffalo bone charcoal as a source of carburizing pack energy.

Procurement of low carbon steel is done by first performing measurements and cleaning of low carbon steel by washing with asethon. Preparation of low carbon steel specimens for hardness and tensile tests, prior to treatment, specimen preparation for testing of hardness experiments and tensile test experiments after treatment with carburizing packs.

After taking the initial hardness and strength data of the material of the low carbon steel test object, the specimen is wrapped with a steel wire as a hook to facilitate the process of removing the specimen in a hot temperature.

The low carbon steel test specimen is placed into a cemented box to cover the specimen surface with carbon (buffalo bone charcoal and barium carbonate ($BaCO_3$).

Insert the cementing box into the furnace and then close. Turn on the furnace, then see the initial temperature 27-30 ºC. Wait until the final temperature of heating is 850 ºC, with a detention time of 60 minutes.

Then turn off and Open the furnace, remove the cementation box from inside by using pliers clamp. Lift the carbon steel test piece out of the cementation box by using the lanc and put it into a cooling medium in the form of aquades until it is cool. After that, then take the specimen out. Clean the specimen from the remnants of the carburization process, then scour one side of specimen by sandpaper before hardness and tensile testing.

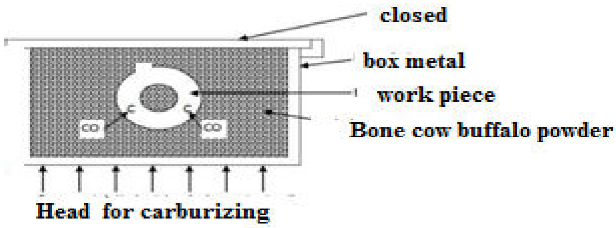

Figure-6. Tool of carburizing process.

This research was conducted at the Laboratory of Physical Metallurgy and Mechanical Technology. Department of Mechanical Engineering, Faculty of Engineering, University of Hasanuddin Makassar in September and October 2016.

3. RESULTS AND DISCUSSIONS

3.1. Hardness

The result showed that the hardness of low carbon steel that is treated with a pack carburizing process at temperatures up to 850^{o}C with a variation of the composition of buffalo bone charcoal carburizing media and $BaCO_3$ can be seen in Table-3 following:

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Table-3. Table hardness low carbon steel due to pack carburizing.

No	Percentage media	specimen	D (cm)	HV (kg/mm^2)	Average HV (kg/mm^2)
1	Normal	1	1.588	72	74.333
		2	1.588	76	
		3	1.588	75	
2	65%BBP+35%BaCO$_3$	1	1.588	82	81.667
		2	1.588	80	
		3	1.588	83	
3	75%BBP+25%BaCO$_3$	1	1.588	86	86.667
		2	1.588	87	
		3	1.588	87	
4	80%BBP+20%BaCO$_3$	1	1.588	92	91.667
		2	1.588	91	
		3	1.588	92	

Based on the above table can be illustrated in a graph in Figure-7 below:

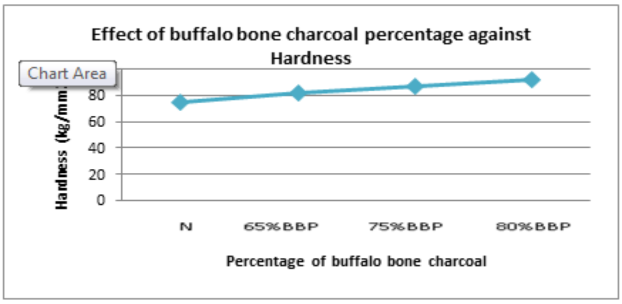

Figure-7. Graph of buffalo bone charcoal percentage effect on low carbon steel hardness.

According to the table and chart above shows that the higher the percentage of bone charcoal buffalo provided in the material of low carbon steel the hardness increases from material hardness normal 74,333 kg/mm^2, and an increase in hardness at a percentage of 65% BBP + 35% BaCO$_3$ amounted to 81,667 kg/mm^2, hardness at a percentage of 75% BBP + 25% BaCO$_3$ amounted to 86,667 kg/mm^2, hardness at a percentage of 80% BBP + 20% BaCO$_3$ amounted to 91.667 kg/mm^2. Can be concluded that the heat treatment of materials of low carbon steel at a diameter of 1, 588 cm with the pack carburizing at heating temperature 850°C with long lasting 30 minutes on the size of the mesh 30 and the load used for the suppression of 60 kg with the variation of the percentage of bone charcoal buffalo effect on the hardness, which the greater the percentage of the hardness of this increasing due to the more carbon that enters the material which causes the material harder and other wise.

3.2 Tensile strength

The result showed that the tensile strength of a low carbon steel that is treated with a pack carburizing process at temperatures up to 850 °C with a variation of the composition of buffalo bone charcoal carburizing media and BaCO$_3$ can be seen in Table-4 below:

Table-4. Table tensile strength low carbon steel due to pack carburizing.

No	Media	Specimen	A_0 /mm^2	Load max (N)	Strength tensile N/mm^2	Average strength tensile (N/mm^2)
1	Normal	1	28,26	18000	636,94	636,94
2	65%BBP+ 35%$BaCO_3$	1	28,26	24200	856,33	966,03
		2	28,26	28300	1001,41	
		3	28,26	29400	1040,33	
3	75%BBP+ 25%$BaCO_3$	1	28,26	29600	1047,41	1060,40
		2	28,26	30400	1075,72	
		3	28,26	29900	1058,03	
4	80%BBP+ 20%$BaCO_3$	1	28,26	38800	1372,96	1233,78
		2	28,26	33600	1188,96	
		3	28,26	32200	1139,42	

Based on the above table can be illustrated in a graph in Figure-8 below:

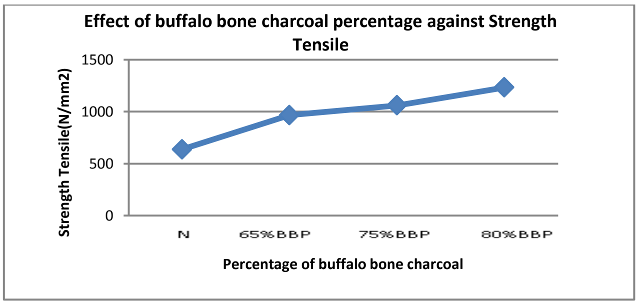

Figure-8. Graph buffalo bone charcoal percentage influence on the tensile strength of low carbon steel.

Based on the table and graph, it shows that the higher percentage of buffalo bone charcoal given to the low carbon steel material, the tensile strength increases from the normal tensile strength of 636.94 N/mm^2, then an increase in tensile strength at the percentage of 65% ATK + 35% $BaCO_3$ of 966.03 N/mm^2, tensile strength value in percentage 75% ATK + 25% $BaCO_3$ of 1060, 40 N/mm^2, tensile strength value at percentage 80% ATK + 20% $BaCO_3$ of 1233,78 N/mm^2. Based on the results it can be concluded that the heat treatment of low carbon steel material on the cross-sectional area of 28.26 mm^2 with Pack Carburizing process at 850 ^{0}C heating temperature with 30 minutes duration of holding time at mesh size 30 with the percentage variation of buffalo bone char content can affect tensile strength of low carbon steel , this shows that the carburizing process is not only increasing the hardness value but also increasing the value of tensile strength of low carbon steel.

So that low carbon steel material that has been treated carburizing process with buffalo bone charcoal media can be used as an alternative material on the use of materials that require hard and strong material, it is material that can withstand penetration, scratches and friction but strong against a large load.

4. CONCLUSIONS

The percentage of buffalo bone charcoal in the carburizing pack process affects on the hardness of the low carbon steel where the higher content of buffalo bone charcoal, the hardness increases and vice versa.

The percentage of buffalo bone charcoal in the carburizing pack process affects the tensile strength of low carbon steel where giving the higher percentage of buffalo bone charcoal to the low carbon steel increasing the tensile strength and vice versa.

Low carbon steels with carburizing process and using buffalo bone charcoal media with percentage of 80% ATK + 20% $BaCO_3$ is very well used for materials in construction that require hard and strong material.

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