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The effects of vibrator quenching (QV) on the carbon content, UDC 621 microstructure, and mechanical properties (surface hardness DOI: 10.15587/1729-4061.2021.244118 number, wear resistance) in the pack carburizing of AISI 9310 steel were studied. The aim of this research is to increase the surface hardness and improve the wear resistance of AISI 9310 EFFECT OF PACK steel. The problem that often occurs in the quenching treatment after pack carburizing is that the thick cooling medium does not CARBURIZING WITH evenly wet the surface of the specimen, so that the cooling rate is not uniform, the impact is the distribution of the specimen surface hardness is not the same. Therefore, it is necessary to research CHICKEN EGG SHELL the implementation of the vibrator in the quenching treatment. The specimens were treated with pack carburizing at a tem- POWDER AGENT AND perature of 875 °C, soaking time for 3 hours. The carburizing agent consisted of chicken egg shell powder (CESP) and rice VIBRATOR QUENCHING husk charcoal (RHC) with various weight ratios of 5 %:95 %, 15 %:85 %, and 30 %:70 %. Followed by quenching treatment ON THE MECHANICAL using a 10 % cane molasses cooling medium and vibrator. Hardness testing was carried out using a Vickers microhardness tester, wear resistance test using the pin-on-disc method, and a PROPERTIES OF AISI scanning electron microscope (SEM-EDX) was used to observe changes in the microstructure and carbon elemental content on 9310 STEEL the specimen surface. The results showed that the application of VQ caused the for- S i n a r e p S i n a r e p mation of a small martensite microstructure while without VQ it Master of Tehnical Sciences, Lecturer* was large martensite and a few of residual ferrite. The highest surface hardness number is 685 kg/mm2, the wear resistance is S u j i t a D a r m o 0.32 cm/mg for pack carburizing, using carburizing agent 70 % Corresponding author RHC, 30 % CESP and VQ. VQ causes a more even distribution of Doctor of Technical Sciences, Senior Lecturer* the thick cane molasses cooling medium so that the cooling rate of E-mail: sujita@unram.ac.id the specimens is uniform *Department of Mechanical Engineering Keywords: AISI 9310 steel, vibrator quenching, pack carbu- University of Mataram rizing, surface hardness number, wear resistance Jalan Majapahit, 62, Mataram, Nusa Tenggara Barat, Indonesia, 83125 Received date 29.10.2021 How to Cite: Sinarep, S., Darmo, S. (2021). Effect of pack carburizing with chicken egg shell powder agent and vibrator quench- Accepted date 03.12.2021 ing on the mechanical properties of AISI 9310 steel. Eastern-European Journal of Enterprise Technologies, 6 (12 (114)), 12–19. Published date 22.12.2021 1. Introduction AISI 9310 steel is low carbon steel with a carbon con- tent of 0.10 % and other alloying elements such as nickel, chromium, and molybdenum. AISI 9310 steel is mainly used as gear material in the automotive and aerospace industries, components for small arms, clutch parts, piston pins and track rod pins because it has the advantages of large elongation, low brittleness, deformability, good weld- ability. However, most of the engineering components of these steels wear out quickly due to their low surface hard- ness. One of the causes of wear is the low hardness number, friction due to surface contact between elements. Surface hardening techniques are widely used to increase friction resistance so that wear due to the contact force (friction) between surfaces decreases and the service life is longer. The study [1] investigated the contact fatigue resistance of hardened ground alloy steel bars. The specimens were of different aircraft grade alloy steels (AISI 8620, 9310, and 4140) and were hardened using different techniques (carburizing, vacuum carburizing and induction harden- ing) at different case depths. The fatigue life of the bars was determined using a fatigue testing machine. After testing, the microstructure of the bars was examined using metallographic techniques. It is concluded that there is a doi: https://doi.org/10.15587/1729-4061.2021.244118 relationship between surface hardness, casing depth, and wear resistance of test specimens that experience fatigue due to contact forces between specimen surfaces. A comparative study of dry shear wear resistance be- tween carbon steel, alloy steel and cast iron was consid- ered [2]. This study used a tribometer (CSM Tribometer) adapted to the pin-on-disc (POD) method. The purpose of this research is to determine the coefficient of friction and wear rate. The specimens used were carbon steel (C25, C45), alloy steel (34CrNiMo6) and cast iron (EN-GJS-400-15). From the research, it was concluded that the coefficient of friction of cast iron is lower, the wear rate of the material is reduced, so that cast iron has better shear wear resistance than carbon steel and alloy steel. The occurrence of wear on mechanical engineering components causes significant economic losses. The wear resistance of equipment components affected by surface hardness has been described in detail [3]. One of the causes of wear is a contact between surfaces so that friction forces occur. The relative motion in one direction or successive mo- tion under the influence of the load causes the stress on the projection to be large enough to cause plastic deformation and adhesion. The adhesion force will increase if the contact surfaces that rub against each other are clean and there are no obstacles during movement [4]. Copyright © 2021, Authors. This is an open access article under the Creative Commons CC BY license The wear resistance properties of low carbon steel can be improved by increasing its surface hardness, with pack carburizing treatment, detailed in [5]. Pack carburizing is a heat treatment process used to increase the carbon concen- tration on the surface of steel specimen, in order to obtain a high hardness and toughness core. One of the methods to achieve these characteristics is pack carburizing using char- coal or mineral coal. In [6], pack carburizing heat treatment on the SAE 1020 mild steel is carried out using rice husk as a carbon source. Pack carburizing is carried out using rice husk charcoal that provides carbon to the surface of the piece of steel. These raw materials are mixed with carbonates (BaCO3, Na2CO3, K2CO3, CaCO3), which are called ener- gizers and are products that accelerate the carburizing reac- tion, the carbon potential and the transport rate of carbon from the carburizing medium to the surface of the piece [7]. Pack carburizing treatment of low carbon steel has weaknesses, among others, the thickness of the carburizing layer on the surface of low carbon steel is uneven, causing a very significant difference in surface hardness [8]. So, it is very urgent to conduct research on the use of vibrator quenching so that the carburizing layer formed is thicker and homogeneous, the surface hardness is better and the wear resistance is also increased. Per capita annual chicken egg consumption in the USA is projected to increase from 242.8 per person in 2010 to 289.9 in 2020 [9]. According to statistics released by the United Nations Food and Agricultural Organization (FAO), the average per capita egg consumption for most countries, computed in kilograms per year (shell weight) has continued to increase over the years. Shells of these eggs constitute an environmental nuisance and end up in dumpsites. A chick- en eggshell weighs 5–6 g on average and contains about 85–95 % calcium carbonate (CaCO3), 1.4 % magnesium, and other elements in trace percentages [9, 10]. Therefore, studies are devoted to determining the influ- ence of the distribution of cooling media on the specimen surface on changes in the mechanical properties (surface hardness number, wear resistance), carbon content and mi- crostructure of the specimen. To increase the distribution of the cooling medium, which is concentrated/high viscosity cane molasses was tested using a vibrator during quenching. 2. Literature review and problem statement Carburizing is a heat treatment process used to increase the carbon concentration on the surface of steel specimen, in order to obtain a high hardness and toughness core. One of the methods to achieve these characteristics is pack carburizing using charcoal or mineral coal. Carburizing heat treatment increases the mechanical and wear resis- tance. Hardening is achieved when the carburizing layer is quenched to form a martensite structure, which results in better wear resistance, fatigue resistance and toughness. Changes in carbon content on the surface of low carbon steel are caused by the phenomenon of carbon diffusion after pack carburizing followed by quenching treatment. Increasing the carbon content increases the surface hardness number. It has been shown that the application of surface treatment in- creases the hardness number, wear resistance, lowers the co- efficient of friction, and increases corrosion resistance [11]. Based on [12], the surface hardness behavior is shown to be in correlation with the grain refinement process accom- panied by strain-induced martensitic transformation and the grain boundary activities involved beginning with a certain grain size. After pack carburizing, quenching was carried out with cooling media such as water, salt solution, SAE 40 oil and 20 % cane molasses. The purpose of quenching is to transform marternsite from a ferrite structure, with a fine grain size. During the quenching treatment, the cooling rate and viscosity of the cooling medium that affect the grain size of the martensite transformation have been described [13]. Quenching treatment using 10 % cane molasses cooling media after pack carburizing caused a significant increase in carbon content, the surface hardness of SS400 low carbon steel [14]. The viscosity of the cooling medium reduces the intensity of quenching. Research [15] increased the quench- ing intensity of 35CrMoV steel with ultrasonic waves. The cooling quenching medium is vibrated to enter the pores of the specimen, so that the cooling rate occurs uniformly. Improvement of the surface layer of low carbon steel by ultrasonic nanocrystal surface modification (UNSM) is discussed in detail in [16]. They showed by ultrasonic nano- crystal surface modification as a more effective means of im- proving surface hardness and decreasing compressive residual stress that the improvement is significantly affected by an increase in energy density during treatment. In [17], pack car- burizing heat treatment on the SAE 1020 mild steel is carried out using rice husk as a carbon source. Pack carburizing was carried out at a temperature of 950 °C with a soaking time of 7 hours. It was observed in the microstructural analysis and in the surface hardness that the charcoal, unlike the rice husk, provides better characteristics in terms of greater penetration of carbon in the piece and greater hardness. Despite the advantages of using ultrasonic waves, ul- trasonic nanocrystal surface modification (UNSM) is ex- pensive, has complicated equipment, and high maintenance costs [16]. The application of a vibrator in the quenching process is an easier and simpler process to modify the hard- ness and wear resistance [18, 19]. The effect of the cooling rate of molasses as a cooling me- dium for high carbon steels was considered [20]. The molas- ses solution has the same viscosity as engine oil. The results showed that the surface hardness of high carbon steel is not uniform, without cracking the components so that molasses can be an excellent alternative to be used as a cooling medi- um, even though the cooling rate is not uniform. The studies that have been carried out have not exam- ined the effect of vibration (ultrasonic, vibrator) on the quenching cooling medium, which is vibrated by the re- search specimen, have not used cane molasses cooling media and also have not used alternative carburizing agents. To date, there are no reports on how to increase the absorption of concentrated cooling media such as cane molasses on the entire surface of the specimen during the quenching process, which are written in the open litera- ture. Therefore, in this study, a vibrator was applied to the quenching process after pack carburizing. The goal is that the increase in surface hardness number occurs uniformly, so that the wear resistance of the specimen (AISI 9310 steel) also increases significantly. 3. The aim and objectives of the study In this study, vibrator quenching was applied after the pack carburizing of AISI 9310 steel with a carburizing agent in the form of a mixture of rice husk charcoal – chicken egg was placed in a carburizing box, which had been filled with a shell powder. carburizing agent. The carburizing agent consists of chicken The objectives of the study that has been carried out are: egg shell flour (CESP) and rice husk charcoal (RHC) with – to determine carbon content changes in the carburiz- various weight ratios of 5 %:95 %, 15 %:85 %, and 30 %:70 %. ing layer on the surface of the specimen; Rice husks are taken from the C4 variety rice plant, which is – to observe changes in microstructure due to vibrator grown by farmers in West Nusa Tenggara, Indonesia. Charcoal quenching treatment; is made of rice husks by burning, then made into powder with a – to determine the effect of vibrator quenching and milling machine. To obtain uniform rice husk charcoal powder, carburizing media on the surface hardness of the specimen; sieving was carried out with a particle size of 0.15 mm. – to determine changes in the wear resistance of the specimen. Supporting screen 4. Materials and methods of the study Quenching Specimen In the present research, AISI media 9310 steel was used as the sam- ple. AISI 9310 steel is low alloy Quenching steel with the chemical composi- tank tion outlined in Table 1. In this study, the specimen Power was AISI 9310 low carbon steel supply Vibrator with the mechanical properties as shown in Table 2. The spec- imen was cylindrical in shape (diameter of 10 mm, length of Fig. 1. Basic principle of vibrator quenching 20 mm), referring to the ASTM (E384) hardness test standard and the ASTM (G99-04) An electric furnace (Carbolite RHF 1700) was used for wear test standard. Tests are carried out at laboratory pack carburizing heating, followed by vibrator quenching room temperature conditions. (VQ), with a 10 % cane molasses cooling medium. The car- Table 1 burizing agent consists of chicken egg shell powder (CESP) and rice husk charcoal (RHC) with a variation of weight ra- Chemical composition of AISI 9310 steel tios of 5 %:95 %, 15 %:85 %, and 30 %:70 %. The illustration Element Content, % Ni 3.00–3.50 Cr 1.00–1.40 Mn 0.45–0.65 Si 0.15–0.30 P 0.025 (max) S 0.025 (max) Mo 0.08–0.15 C 0.08–0.13 Table 2 Mechanical properties of AISI 9310 steel Mechanical properties Value Hardness, Vickers 284 kg/m2 Tensile Strength, Ultimate 910 MPa Tensile Strength, Yield 570 MPa Elastic Modulus 200 GPa Shear Modulus 80 GPa Elongation 18.08 % Impact Energy 119 J Poisson’s Ratio 0.29 Before testing, the specimens were treated with pack car- burizing followed by quenching, using a vibrator, with a layout as shown in Fig. 1. The AISI 9310 low carbon steel specimen of the basic principle of VQ is shown in Fig. 1. The working principle of vibrator quenching is as follows: in the quench- ing process, the cooling medium specimen is vibrated, so that the cooling medium wets the specimen surface evenly because the viscous cooling medium needs vibration. The effect of cooling speed on the surface of a homogeneous spec- imen was studied. After the treatment is completed, tests are carried out including carbon content testing, microstructure observation, surface hardness and wear resistance testing. Microstructure and carbon content observations were carried out by SEM-EDX (Cam Scan MV2300-Canada) equipped with energy dispersive X-ray (EDX), respective- ly. The specimens were wet ground in the sequence of 120, 320, 600, and 1000 grit emery paper and polished with 1 μm diamond suspensions, degreased in ethyl alcohol, rinsed in distilled water, and dried with a stream of hot air. They were then immersed into a nital etchant (2 ml of 70 % nitric acid and 48 ml of anhydrous, denatured ethyl alcohol), treated with alcohol swapping, and dried in an air stream. The etched specimens were placed under a microscope on SEM-EDX. So that the measurement of the thickness of the carburizing layer can be carried out. The microscope eyepiece has a measurement scale in micron meters (1/1000 mm) and the total magnification of the microscope used is 400x. Furthermore, the thickness of the carburizing layer was further analyzed to determine the percentage of carbon content. This Vickers hardness number is calculated by the equa- tion (refer to ASTM E384): HV = {2·Gt ·sdin2(α / 2)} = 1.854· dP2 , (1) 5. Results of the research of vibrator quenching effect on the carbon content, microstructure, and mechanical properties of AISI 9310 steel where Gt – compressive load (kg); d – average diameter (mm); α – angle of indentor peak=136°. 5. 1. Carbon content changes in the carburizing layer Testing the wear of the specimen after pack carburizing on the specimen surface and vibrator quenching treatment using the pin-on-disc The use of a vibrator in the quenching process affects the method as shown in Fig. 2 refers to the ASTM G99-04 carbon content of the specimen. From the analysis of the test standard. The specimen is placed on a steel disc with a results, the carbon content on the specimen surface increased hardness of 58 HRC and rotated at 940 rpm. So there is after pack carburizing treatment followed by quenching using friction between the specimen and the steel disc. The wear vibrator quenching (VQ). Significant changes in the carbon rate is calculated from the following formula (refer to ASTM content on the specimen surface occurred in the pack carburiz- G99-04): ing treatment at a temperature of 875 °C, 3 hours of immersion, ΔW 30 % CESP, 70 % RHS carburizing agent, quenching with Wr = 2πnrt . (2) a vibrator, 10 % molasses cooling medium . In general, the carbon content in specimens was affected by the use of

VQ. The percentage increase in carbon content in the specimens Explanation of the equation symbols: Wr – wear rate was 0.08 %, 0.12 % and 0.26 %, respectively for no treatment, (mg/cm); 2πr – sliding distance (cm); t – test duration (min- quenching without VQ, quenching using VQ. utes); n – number of revolutions; 1/Wr – wear resistance Table 3 shows that the percentage of carbon content on (cm/mg); ΔW=w1–w2 – weight loss, and n=900 (rpm). the specimen surface after treatment increased compared to the initial specimen (0.08 % LVDT without treatment). The per- centage of carbon content on the surface of the specimen is influ- enced by the percentage of RHS, CESP in the carburizing agent Specimen and VQ used in the quenching Steel disc treatment. The difference in weight percentage of RHC and Base plate CESP in the carburizing agent affects carbon diffusion. Because RHC is a carbon source, CESP is a source of CaCO3, which serves to accelerate the diffu- sion of carbon on the surface of the specimen, according to the Frame results of the study [10]. Due to Weights the vibration of the transduc- Motor er, the boiling stage of the film is significantly affected, which leads to an increase in the cool- ing rate. The occurrence of vi- Fig. 2. Pin-on-disc wear testing machine bration quenching increases the The computer-controlled pin-on-disc method is used to carry out a wear test according to the ASTM adhesion wear test standard (G99-04) with dimensions of 10 mm in diameter and 15 mm in length. The specimens were placed on stainless steel discs with load variations of 15, 20, 25 and 30 N, different shear speeds of 1.413, 1.884 and 2.356 m/s, disc rotations of 300, 400 and 500 rpm, test duration of 15 minutes and radial shear distance of 90 mm. Direct contact occurs between the specimen surface and the disc by creating roughness on the speci- men surface. Discs and samples were cleaned with acetone prior to testing. Before the experiment, the weight of the specimen was measured as w1 and the weight of the specimen after the wear test was recorded as w2 with the help of an electronic weighing machine with an accuracy of 0.001 mg. The difference in the weight of the test object before the wear test and after the wear test is called the weight loss (ΔW). solubility of carbon elements in iron compounds, so that the carbon content on the surface of the specimen increases significantly. Table 3 Carbon content change in the specimen Element Untreated Without VQ Using VQ Ck Wt % 0.08 0.12 0.26 At % 20.35 20.35 20.35 Ok Wt % 18.37 18.33 18.19 At % 38.86 38.86 38.86 MnK Wt % 0.43 0.43 0.43 At % 0.25 0.25 0.25 FeK Wt % 81.12 81.12 81.12 At % 40.54 40.54 40.54 Matrix Wt % Correction Correction Correction At % ZAF ZAF ZAF The research results are in accordance with the state- ment of research that have been carried out by [18]. The quenching parameters that affect the carbon content of the specimen surface are the cooling rate and the viscosity of the cooling medium [15, 17]. 5. 2. Changes in microstructure due to vibrator quenching treatment Vibrator quenching also affects the formation of the spec- imen microstructure. Changes in the microstructure of the specimens were observed using SEM-EDX. The test refers to the ASTM E3 microstructure testing standard. Prior to me- tallographic analysis, the appropriate specimens were etched in 2 % nital solution. Fig. 3 shows SEM-EDX observations of the surface of specimens treated with pack carburizing, cooling at 875 °C, soaking time of 3 hours, compotition of carburizing agent 70 % RHC, 30 % CESP. Followed by quenching with variations using VQ and without VQ, im- mersed in 10 % molasses as a cooling medium. Changes in microstructure on the specimen surface after pack carburiz- ing quenching treatment with VQ and without VQ are shown in Fig. 3, a, b, respectively. In Fig. 3, a, the microstructure is shown, the specimen without VQ quenching is still domi- nated by residual ferrite. The microstructure of ferrite is an interstitial solid solution of carbon atoms in pure iron, so it is commonly called Fe-α. The maximum solubility of carbon in ferrite is 0.025 % at 723 °C, and at room temperature, it has a solubility limit of 0.008 % for carbon. In Fig. 3, a, ferrite microstructure (brighter color) changed to pearlite (darker color) and residual ferrite, due to pack carburizing treatment followed by quenching with 10 % cane molasses cooling medi- um without using a vibrator. By using vibrator quenching, a martensite microstructure is formed, which has a finer grain structure than the ferrite microstructure as shown in Fig. 3, b. The different grain sizes in the martensite (darkest color), pearlite and ferrite structures are not only caused by the use of

VQ, but also due to the different percentages of carburizing agent materials in the pack carburizing treatment. Pearlite a In Fig. 3, a, b, the microstructure of the two specimens was quite different. The specimen without VQ consisted of pearlite and residual ferrite, while the VQ specimen was all small martensite. This is because AISI 9310 steel belongs to low carbon steel. Therefore, if the specimens are wanted to cool from the complete austenite temperature to room temperature without high-temperature transformation, the quenching medium must have a higher quenching intensity. Although the 10 % cane molasses cooling medium had a certain quenching intensity, some local high-temperature changes still existed during the quenching process. When the VQ wave was added, the hot steam film on the surface of the specimen was ruptured in advance due to its cavitation and sound effect [19, 21]. Therefore, the microstructure of the VQ sample was all small martensite, while the micro- structure of the specimen without VQ was bulky martensite and a small amount of residual ferrite. 5. 3. Effect of vibrator quenching and carburizing agent on the surface hardness The vibrator quenching treatment after pack carburizing also resulted in a change in the surface hardness number of the specimen (AISI 9310 steel). The surface hardness testing of the specimen was carried out using the Vickers hardness test method referring to the ASTM E384 standard. The specimen was pressed with a diamond indenter in the shape of a pyramid with a rectangular base and a face angle of 136°. The pressure of the indenter creates a mark on the specimen surface. The test result data is in the form of the diameter of the pressure mark with the indenter, then calculated by equation (1). The results of the calculation of surface hard- ness to a certain depth are described in a graph, as shown in Fig. 4, a, b. In Fig. 4, a, b, the hardness number tends to increase from the surface of the core specimen. The highest hardness number is found on the surface of the specimen. At a distance of 800 m from the surface, the hardness number is constant as the starting material (without treatment), the hardness number is 284 kg/mm2. Fig. 4, a is the result of testing the hardness of the specimen at a certain depth from the surface. The test was carried out after the pack carburiz- ing treatment at a temperature of 875 °C, 3 hours of soaking time, with carburizing agent materials RHC, CESP and quenched with 10 % mo- lasses sugar cane cooling medium, without VQ. According to Fig. 3, a, the surface hardness number of the specimen increases. The distribution of the increasing number of surface hardness starts from the surface (0 μm depth) to 800 μm from the speci- men surface. At depths above 800 μm to the core, there is no increase in hardness. Or the hardness number is the same as the initial material (untreated specimen), the hardness b number is 284 kg/mm2. Application of carburizing agent materials (RHC, Fig. 3. Surface microstructure of the AISI 9310 steel after pack carburizing quenching (carburizing agent 70 % RHC, 30 % CESP) at 875 °C, soaking time of 3 hours: a – without vibrator quenching; b – using vibrator quenching CESP) with different percentages in the pack carburizing treatment significantly increased the surface hardness number. They were 425, 450 and 475 kg/mm2, accordingly, for the percentage of carburizing agent 95 % RHC 5 % CESP:85 % RHC:15 % CESP, and 70 % RHC:30 % CESP. The difference in surface hardness num- ber is caused by the difference in the percentage of CESP, which contains CaCO3 compound, which functions as an energizer (accelerates the diffusion of carbon on the surface of the specimen), so that the carbon content and hardness number also increase. 500 5% CESP 450 15% CESP 30% CESP 400 UUnnttrreeaattmedent 350 300 250 200 1200 1000 800 600 400 200 0 Depth (μm) a 800 5% CESP 700 15% CESP 30% CESP 600 UUnnttrreeaattmedent 500 400 300 200 100 1200 1000 800 600 400 200 0 Depth (μm) b Surface Hardness Number (Kg/mm2) Surface Hardness Number (Kg/mm2) Fig. 4. Effect of carburizing agent on the surface hardness of the specimen: a – quenching without vibrator; b – quenching with vibrator Based on the analysis of variance, there is a correla- tion between the addition of CESP and the use of VQ in quenching on the surface hardness of the specimen as shown in Fig. 4, b. The surface hardness numbers were 550, 610 and 685 kg/mm2, accordingly for 5 %, 15 %, 30 % CESP carbu- rizing agent and using VQ in quenching. 5. 4. Changes in wear resistance after vibrator quenching The vibrator quenching treatment after pack carburiz- ing also affects the wear resistance of the specimen. The wear resistance test was carried out with the pin-on-disc wear testing machine referring to the ASTM adhesion wear test standard (G99-04). The test results are in the form of weight loss (ΔW), then calculations are carried out based on (2). The result is shown in Fig. 5. Wear testing is carried out on specimens treated by pack carburizing at optimum conditions, i.e. at a temperature of 875 °C, soaking time 3 hours, carburizing agent 70 % wt RHC, 30 % wt CESP, based on Fig. 4, a, b. 0.35 Wear Resistance 0.3 0.25 0.2 0.15 0.1 0.05 0 10 Untreated Without VQ Using VQ 15 20 25 30 35 Load (N) Fig. 5. Effect of vibrator quenching on the wear resistance of the specimen after pack carburizing treatment at optimum conditions Generally, vibrator quenching (VQ) used in pack car- burizing treatment has an effect on wear resistance. It is increased compared to untreated specimens. Fig. 5 shows the effect of VQ on the wear resistance of specimens after pack carburizing treatment at optimum conditions. It rep- resents the relationship between load and wear resistance. It is shown that pack carburizing treatment with VQ gives the highest wear resistance equal to 0.32 cm/mg while the spec- imen without VQ and the untreated one give the lowest wear resistance equal to 0.13 and 0.11 cm/mg, for a load of 30 N. 6. Discussion of the effect of using vibrator quenching after pack carburizing on the mechanical properties of AISI 9310 steel Pack carburizing treatment and using VQ in the quenching process increase the percentage of carbon con- tent on the surface of the specimen as shown in Table 3. The diffusion process causes the percentage of carbon content on the specimen surface to increase. Diffused carbon elements come from rice husk charcoal (RHC) contained in the carburizing agent mixed with chicken egg shell powder (CESP). Rice husk charcoal is a carbon source and CESP is a source of calcium carbonate (CaCO3), which functions as an energizer that accelerates the diffusion pro- cess. The rice husk charcoal provides better characteristics in terms of greater penetration of the carbon in the piece and greater hardness [17]. The tissue structure of a chicken egg consists of a protective shell, which contains nearly 68 % calcium carbonate (CaCO3), as discussed in detail in [9, 10]. Diffusion is actually also a chemical reaction between Fe3C (carbon steel) and CaCO3 at carburizing temperature, as shown in [7]. Fig. 3 shows SEM-EDX observations of the surface of specimens treated with pack carburizing, cooling at a tem- perature of 875 °C, soaking time of 3 hours, compotition of carburizing agent 70 % RHC, 30 % CESP. Followed by quenching with variations using VQ and without VQ, im- mersed in 10 % molasses as a cooling medium. In Fig. 3, a, the microstructure is shown, the specimen without VQ quench- ing is still dominated by residual ferrite. The microstructure of ferrite is an interstitial solid solution of carbon atoms in pure iron, so it is commonly called Fe-ɑ. The different grain sizes in the martensite (darkest color), pearlite and ferrite structures are not only caused by the use of VQ, but also due to the different percentages of carburizing agent materials in the pack carburizing treatment. Although the 10 % molasses cooling medium has a certain cooling intensity, some local high-temperature changes are still present during the cool- ing process. When VQ vibration is added, the hot vapor layer on the specimen surface breaks first due to cavitation and vibration effects [19, 21]. Martensite is a metastable phase formed when austenite is cooled very rapidly, where in the carbide deposition is suppressed. This occurs when carbon steel or low alloy steel is cooled rapidly [20]. The vibrator quenching treatment after pack carburiz- ing also resulted in a change in the surface hardness num- ber of the specimen (AISI 9310 steel), as shown in Fig. 4. The surface hardness number is affected by carbon content and microstructure, after pack carburizing and quench- ing processes [17]. Therefore, vibrator quenching (VQ) is used in the quenching after pack carburizing treatment, to vibrate the cooling medium (10 % cane molasses). Be- cause the vibration in the quenching tank can increase the absorption of molasses as a cooling medium to the entire surface of the test object. The cooling medium wets the en- tire surface evenly, due to the vibrator, the cooling speed in the quenching process is evenly distributed on the surface of the specimen. AISI 9310 is low carbon steel with a percentage of 0.008 % carbon. The wear resistance of the specimen (AISI 9310) steel is influenced by the surface hardness number [4, 13]. Fig. 5 represents the relationship between load and wear resistance. It is shown that using

VQ in the quenching process after pack carburizing treatment of spec- imens gives the highest wear resistance while untreated specimens and those without VQ give lower wear resistance. The phenomenon shows the effect of the second parameter (VQ in the quenching process) and carburizing agent. It caused an increase in the plastic deformation in surface tips peaks between two sliding surfaces. The adhesive process of the two tips surfaces depends on applied load. If the load is low, the contact appears in the upper bit and this was very thin during the sliding process that causes a thin layer from oxide working as a protective surface film, which limits the contact between the two sliding surfaces and prevents the direct metallic connection between the surfaces tips. Thus, the required force to cut the occurred connection between the two surfaces tips is less than the force between the metal atoms itself and that will cause a decrease in wear rate [9, 10] for both the discs and the specimen during the sliding pro- cess, which causes a strong metal contact between them making the required force to shear its contact tips more than the force between the metal atoms itself. The advantage of using vibrator quenching is that it is able to stir cane molasses, so that it can be evenly distributed over the entire surface of the specimen. The use of ultrasonic waves in the previous study, which was vibrated by the spec- imen, was not suitable when using a concentrated cooling medium such as cane molasses in the quenching treatment. It agglomerates, it can’t wet the specimen evenly. It is difficult to even out the distribution of the cooling medium (high-viscosity cane molasses) over the entire sur- face of the quenched specimen. Cane molasses is difficult to penetrate the pores on the specimen surface, so the cooling process after quenching is not optimal. The weaknesses of this study are only for cooling media with a maximum concentration of 10 %, carried out at room temperature because cane molasses quickly freezes and evap- orates, resulting in lumps and difficulty to stir. The development of this research is adding a catalyst and increasing the roughness of the specimen, so that the absorp- tion power of the cane molasses cooling medium increases. The use of cane molasses as a cooling medium in the quench- ing treatment is superior to salt water, oil, causing a pungent odor that interferes with breathing and triggers corrosion of low carbon steel. The development of this research is using vibrator quenching (VQ) to vibrate the cooling medium, so that it is evenly distributed, the cooling process is better and the quality of the quenched specimen is better without reducing the viscosity of the cooling medium. 7. Conclusions 1. The application of vibrator quenching (VQ) causes an increase in the percentage of carbon content in the speci- men (AISI 9310). The percentage increase in carbon content in the specimens was 0.08 %, 0.12 % and 0.26 %, respectively for no treatment, quenching without VQ, quenching using VQ. 2. The microstructure of the VQ specimens was all small martensite while the microstructure of the specimen without VQ consisted of pearlite and residual ferrite. 3. The application of vibrator quenching (VQ) after pack carburizing caused an increase in the surface hardness number of AISI 9310 steel dramatically. The hardness number of the specimen before treatment is 284 kg/mm2. The surface hardness numbers after treatment were 550, 610 and 685 kg/mm2, accordingly, for 5 %, 30 ,% 15 % CESP carburizing agent and using VQ in quenching. 4. The quenching treatment with VQ after carburizing pack treatment also causes the wear resistance of the speci- men to increase. It is shown that pack carburizing treatment with VQ gives the highest wear resistance of 0.32 cm/mg while the specimen without VQ and the untreated one give the lowest wear resistance of 0.13 and 0.11 cm/mg, for a load of 30 N. Acknowledgments The authors thank Prof. Rudy Soenoko, Prof. Wahyono Suprapto for invaluable endless collaborations. Prof. I.G.N Wardhana, Director Postgraduate Doctor Mechanical En- gineering Program Brawijaya University for permission to use laboratory and other resource materials. References 1. Xie, L., Palmer, D., Otto, F., Wang, Z., Jane Wang, Q. (2014). Effect of Surface Hardening Technique and Case Depth on Rolling Contact Fatigue Behavior of Alloy Steels. Tribology Transactions, 58 (2), 215–224. doi: https://doi.org/10.1080/10402004.2014.960957 2. Nedeloni, L., Korka, Z. I., Pascal, D. T., Kazamer, N., Nedeloni, M. D. (2018). Comparative Study on Dry Sliding Wear Resistance of Carbon Steel, Alloyed Steel and Cast Iron. IOP

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