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Hardness and Microstructural Characterization of Pack Carburizing AISI 1020 Low-Carbon Steel by Temperature and Holding Time Variations

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Abstract. Recently, low-carbon steel is often used as a basic material for automotive spare parts on the market. This study aims to improve the quality of carbon steel which is not inferior to that made by manufacturers where the price is relatively affordable by carrying out pack carburizing. This study used the pack carburizing method, AISI 1020 low-carbon steel as a starting material and used fine coconut shell charcoal powder as a carbon source mixed with Na_2CO_3 as an energizer. Pack carburizing uses temperature variations of 850ºC, 875ºC and 900ºC, aims to find out how the results of hardness and microstructure values for variations of temperature and holding time. And also use SAE 20w-40 oil as a quenching medium. The highest hardness results were obtained on specimens with a heating temperature of 900ºC with a holding time of 60 minutes, with an average hardness value of 54.21 HRC. Accompanied by the phase formed, namely 61% pearlite 39% ferrite.

Keywords: heat treatment, pack carburizing, AISI 1020, hardness, microstructural

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1. Introduction

The need for metal materials in the industry is currently increasing. The metal material must have good mechanical and physical properties. However, metal materials that exist today do not fully have the desired properties and characteristics. The industrial sector is highly dependent on the use of steel, for example, the use of steel in machines and construction components. This proves that steel currently plays an important role in technological progress and human life. A treatment process is needed for steel to obtain changes in the mechanical properties and physical properties of steel so that it can be used as needed [1], and [2].

Steel is a Fe–C alloy which may contain other alloying elements, according to the application. Even low variations in composition can lead to large differences in mechanical properties, as the final structure may change according to the manufacturing process and heat treatment cycle applied [3]. Therefore, carbon steel is required to be modified or improved in properties such as hardness on the surface and

wear resistance to friction.
AISI 1020 steel is included in the low carbon steel class which is soft and weak in strength but has very good ductility and toughness. AISI 1020 steel is commonly used in gears, shafts, and bolts because of its ease of machining and ductility [4]. The chemical composition of AISI 1020 steel is shown in the table 1.

Table 1. Chemical composition of AISI 1020 steel [4]

Fe	**C**	**Mn**	**Si**	**P**	**S**	**Ni**	**Cu**
Balance	0.20	0.32	0.21	0.009	0.042	0.15	0.15

In many usage applications, ductility or toughness is often needed, in addition to its wear resistance properties. In this case, it is necessary to adjust the hardening process through heat treatment of the steel to obtain increased hardness in certain areas, wear resistance, and a ductile and tough core area [5]. Heat treatment is a process to change the metal structure by heating the specimen in an electric muffle furnace at the recrystallization temperature for a certain period and then cooling it in a cooling medium such as air, water, brine, oil, and diesel fuel, each of which has a different cooling density. One way to increase the surface hardness of steel is through the process of adding carbon elements which are heated to a temperature and held at that temperature for a certain time, which is known as the pack carburizing process [6].

Research related to pack carburizing of metals has been carried out by previous researchers, Sundari et al. [7] analyzed the effect of pack carburizing on the mechanical properties of motorcycle sprockets with a catalyst using gelam wood charcoal and mussel shell powder. Pack carburizing is carried out at temperatures of 850°C and 900°C with cooling media in the form of water, used oil, silicon oil, and air. Based on the research results, it was found that the increase in the optimum hardness value of the imitation sprocket with the carburizing process at a temperature of 900 °C with a holding time of 1 hour with a water cooling, the hardness increased by 43.07% compared to the imitation sprocket without the carburizing process, and 13.94% higher above the hardness value of the original sprocket.
Research on ST41 steel was treated with pack carburizing with temperature variations (700°C, 750°C, and 800°C) and holding time for 30 minutes in reference [5]. This study analyzes the effect of temperature in the pack carburizing process on hardness and impact strength. Based on the research results, it was found that the highest hardness value was obtained in samples with a heating temperature of 800 °C, which was 32 HRC and had an impact strength value of 1.993 J/mm^2. When compared to the sample before the pack carburizing process, there was an almost double increase in hardness while the impact strength value also increased by 10%. Based on the results of these previous studies, temperature and holding time have an impact on the mechanical properties and microstructure of steel that is given heat treatment in the form of pack carburizing. Therefore, in this paper research is carried out on the effect of temperature and holding time on the hardness and microstructure of low-carbon steel AISI 1020 by providing heat treatment in the form of pack carburizing.

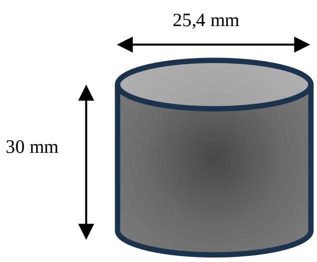
The purpose of this study was to analyze the hardness and microstructure of low carbon steel AISI 1020 after heat treatment in the form of pack carburizing with temperature variations of 850°C, 875°C, and 900°C as well as variations in holding time 40, 50, and 60 minutes.

2. Methods

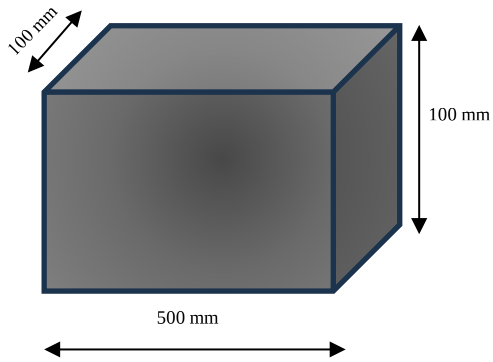
2.1. Materials
Materials in this study is used AISI 1020 carbon steel purchased from SeAH Besteel Corporation with a chemical composition as shown in table 1, charcoal powder from refined coconut shells as a carbon source mixed with Na_2CO_3 from EMSURE® ISO MERCK as an energizer and oil SAE 20w-40 as a cooling media in the pack carburizing process.

2.2. Specimen Preparation

The pack carburizing process was carried out at varying temperatures of 850^{0}C, 875^{0}C and 900^{0}C with varying holding times of 40, 50 and 60 minutes. AISI 1020 steel is cut to a diameter of 25,4 mm and thickness of 30 mm as shown in Figure 1.a. The preparation of the specimen as shown in Figure 1 was carried out carefully and measured using a screw micrometer to ensure that the specimen dimensions were uniform. The vessel for the pack carburizing process is made of low carbon steel with a thickness of 10 mm with a length of 500 mm, a width of 100 mm and a height of 100 mm as shown in Figure 1.b. Later, the AISI 1020 steel specimen is inserted into the vessel and then subjected to a heat treatment process using a muffle furnace with control of temperature in 850^{0}C, 875^{0}C and 900^{0}C. 30 specimens were prepared, 3 specimens of AISI 1020 steel without pack carburizing (raw material) and 27 specimens for the pack carburizing process with temperature and holding time shown in table 2. Specimen for hardness test using ASTM E18-15 [8] standard for Rockwell hardness testing.



(a)



(b)

Figure 1. (a) specimen of pack carburizing; (b) vessel for pack carburizing process

Table 2. Specimens test

No	Temperature (°C)	Holding Time (minute)	Specimens test
1	850	40	3
	850	50	3
	850	60	3
2	875	40	3
	875	50	3
	875	60	3
3	900	40	3
	900	50	3
	900	60	3

2.3. Pack Carburizing Process

Pack carburizing process begins with charcoal powder from refined coconut shells as a carbon source mixed with Na_2CO_3 as an energizer. addition of Na_2CO_3 which functions as an activator to speed up the pack carburizing process. The activator used is 20% of the total carbon weight. The prepared activated carbon is carried out mixing with the specimen in a previously made vessel. The pack carburizing process is carried out at temperatures of 850^{0}C, 875^{0}C and 900^{0}C with and holding times of 40, 50 and 60 minutes in a heating furnace. Then the specimen was cooled quickly in SAE 20w-40 oil media and the surface of the specimen was smoothed using a grinding machine. Then the specimen is ready to be tested for hardness and characterization of its microstructure.

2.4. Hardness and Microstructural Characterization

In this research, hardness testing used a Bowers Rockwell Hardness Tester EW-200 hardness testing machine. Hardness testing uses the Rockwell method with an illustration of the testing process as shown in Figure 2. Microstructural characterization was carried out by taking pictures using an optical microscope with 500x magnification, then the optical microscope images were analyzed regarding the microstructure using ImageJ.

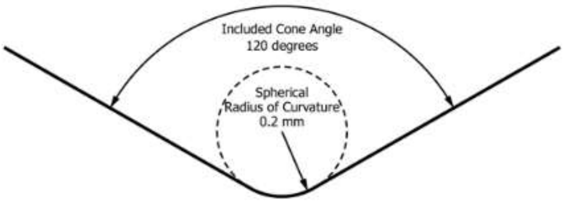


Figure 2. Illustration of Rockwell hardness test [9]

3. Results and Discussion

3.1. Hardness Characterization

Characterization of hardness values uses Rockwell hardness testing regarding ASTM E18-15 standards. The results of the hardness testing are then presented in Figure 1 for a temperature of 850°C, Figure 2 for a temperature of 875°C, and Figure 3 for a temperature of 900°C.

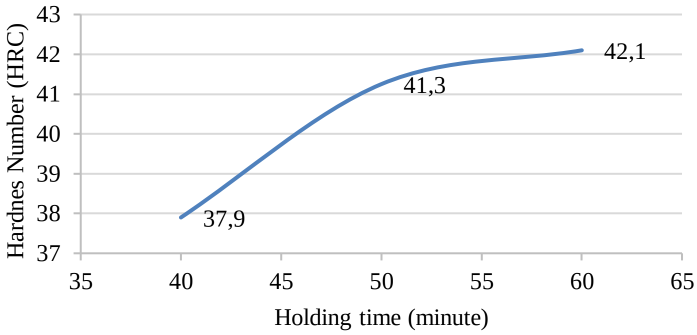


Figure 3. Hardness number (HRC) vs Holding time at 850°C pack carburizing temperature

AISI 1020 steel is given pack carburizing heat treatment with heating at 850°C with varying holding times of 40, 50, and 60 minutes respectively as shown in Figure 3. It can be seen from Figure 3 that a holding time of 40 minutes has a hardness value of 37.9 HRC, 50 minutes has a hardness value of 41.3 HRC and 60 minutes has a hardness value of 42.1 HRC. It can be concluded that the highest hardness value obtained in the pack carburizing process with a temperature of 850°C was at a holding time of 60 minutes of 42.1 HRC. Research related to the pack carburizing process on AISI 1020 steel at a temperature of 850 C was also carried out by Joni [10], the pack carburizing process was carried out with a holding time of 3 hours then quenching was carried out at a temperature of 840 C. The hardness value was obtained at 49 HRC. The higher hardness value obtained is possible due to the quenching process and longer holding time.

Pack carburizing process by heating 875°C with holding time variations of 40, 50 and 60 minutes respectively as shown in Figure 4. It can be seen from Figure 4, a holding time of 40 minutes has a hardness value of 42.6 HRC, 50 minutes has a hardness value of 43.4 HRC and 60 minutes has a hardness value of 43.8 HRC. It can be concluded that the highest hardness value obtained in the pack carburizing process with a temperature of 875°C was at a holding time of 60 minutes of 43.8 HRC. Research related to the pack carburizing process on AISI 1020 steel at a temperature of 875 C was also carried out by Fikri, et al [11]. The pack carburizing process is carried out with a holding time of 120 minutes. The hardness value was 43 HRC. The lower hardness value obtained is possible because the cassava peel waste activator used did not work optimally when compared with the activator in this study. With the same temperature, namely 875 C with a shorter holding time, the hardness value obtained in this study was higher.

Pack carburizing process by heating 900°C with holding time variations of 40, 50 and 60 minutes respectively as shown in Figure 5. It can be seen from Figure 5, a holding time of 40 minutes has a hardness value of 53.6 HRC, 50 minutes has a hardness value of 53.7 HRC and 60 minutes has a hardness value of 54.2 HRC. It can be concluded that the highest hardness value obtained in the pack carburizing process with a temperature of 900°C was at a holding time of 60 minutes of 54.2 HRC. Research related to the pack carburizing process on AISI 1020 steel at a temperature of 900 C was also carried out by several researchers including Fikri, et al[11]. Obtained a hardness value of 48.2 HRC, Joni [10] with a hardness value of 56 HRC, Nasution, et al[12]. Obtained a hardness value of 55 HRC, Rizky, et al[13]. Obtained a hardness value of 48.2 HRC and Setiawan, et al[14]. The hardness value was 58 HRC. The differences in hardness values obtained by several researchers are due to the use of activators and the presence or absence of a quenching process in the pack carburizing process.

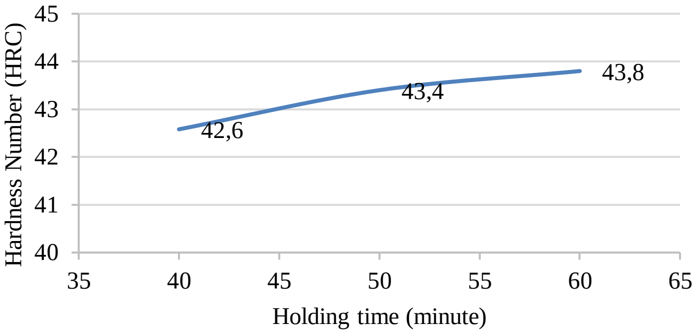


Figure 4. Hardness number (HRC) vs Holding time at 875°C pack carburizing temperature

Based on temperature variations in the pack carburizing process of 850°C, 875°C, and 900°C which are shown in Figures 3 to Figure 5, the hardness values are different. Of the three temperature variations of 850°C, 875°C, and 900°C, each has the best hardness value at a holding time of 60 minutes of 42.1 HRC, 43.8 HRC, and 54.2 HRC. It can be concluded that the temperature and holding time in the pack carburizing heat treatment process on AISI 1020 steel has an influence on the hardness value of AISI 1020 steel. This is in line with research conducted by several researchers that temperature and holding time can influence the increase in the hardness value of AISI 1020 steel in the pack carburizing process. [10-14].

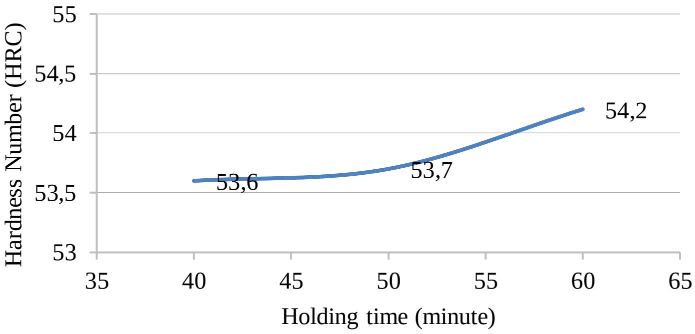


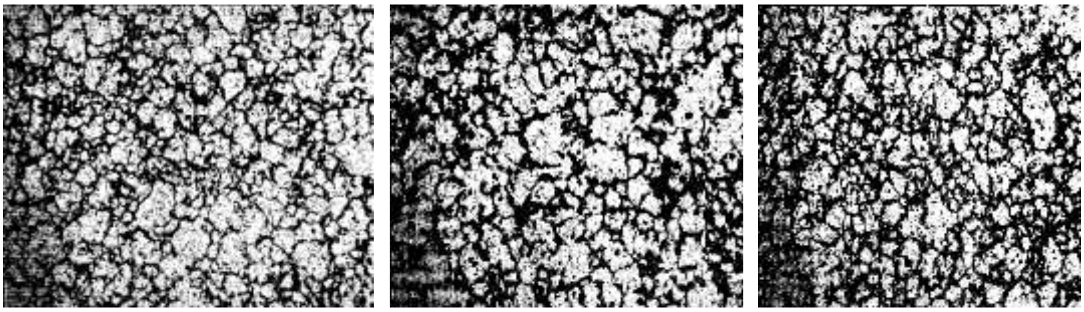
Figure 5. Hardness number (HRC) vs Holding time at 900°C pack carburizing temperature

Taking a hardness testing point located on the surface of the specimen, the higher the hardness value obtained, but the deeper it is from the surface, the smaller the hardness value obtained. If we look at the microstructure image, this can happen because the concentration of carbon diffusion tends to be more concentrated in the surface area and the deeper the penetration, the lower the concentration of carbon addition to the metal. So the hardness value tends to be higher in the surface area even in areas that are equally affected by the addition of carbon in the Pack Carburizing process [15].

Use of Na_2CO_3 mixed into solid carbon. Where from this mixture the reaction occurs during heating as follows: Na_2CO_3 + Heat splits into Na_2O + CO_2 then CO_2 will separate itself from Na_2O, then CO_2 will meet charcoal which is carbon (C) and the CO_2 + C reaction will occur then 2CO in the environment The heat will tend to change back into CO_2 and release the C element. If this reaction is within the steel structure, the C will be left behind. C left by CO_2 gas will be captured by Fe [16]. This event is referred to as element C dissolving in steel. The reaction that occurs is 2CO + Heat becomes CO_2 + C (dissolves in steel). The important role of sodium carbonate when mixed with charcoal is as a provider of CO_2 gas [17].

3.2. Microstructural Characterization

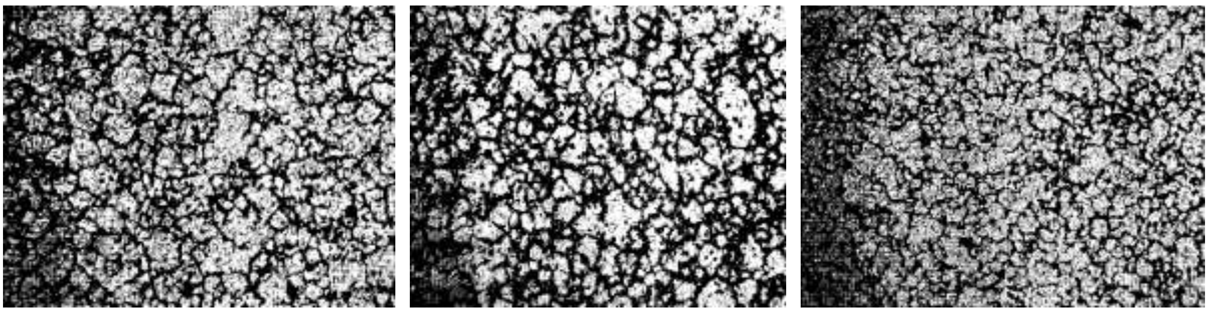
In this research, metallographic testing was carried out on pack carburizing specimens with a mixture of 80% activated carbon in the form of coconut shell charcoal powder and 20% energizer mixture in the form of Na_2CO_3 and this research focused on changes in the microstructure in parts that were not affected by the case of depth. Images were taken using an optical microscope with 500x magnification, then the images were investigated using ImageJ software to determine the ferrite and pearlite content of AISI 1020 steel after the pack carburizing heat treatment process. This is also done by several researchers in identifying microstructures resulting from microscope images [18], [19], and [20].



(a) (b) (c)

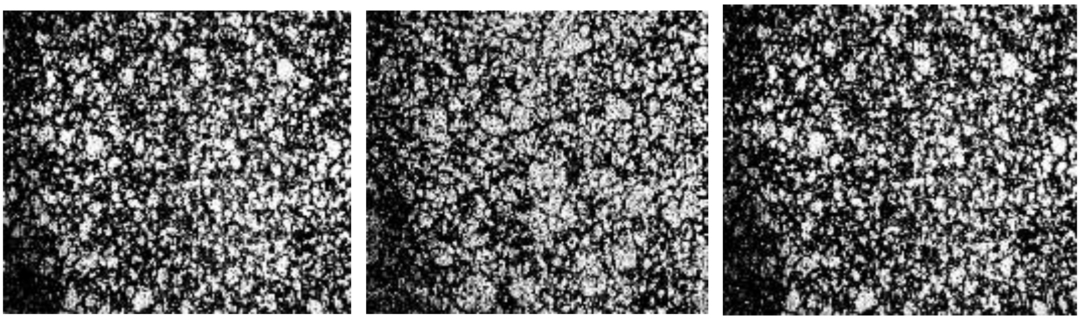
Figure 6. Microstructure image of AISI 1020 steel after pack carburizing 850^oC; (a) 40 minute; (b) 50 minute; (c) 60 minute

Figure 6 shows the Microstructure image of AISI 1020 steel after pack carburizing 850^oC, Figure 6.a shows a holding time of 40 minutes producing 46% Pearlite 54% Ferrite, Figure 6.b shows a holding time of 50 minutes producing 51% Pearlite and 59% Ferrite, and Figure 6.c shows a holding time of 60 minutes produces 54% Pearlite and 46% Ferrite.



(a) (b) (c)

Figure 7. Microstructure image of AISI 1020 steel after pack carburizing 875^oC; (a) 40 minute; (b) 50 minute; (c) 60 minute



(a) (b) (c)

Figure 8. Microstructure image of AISI 1020 steel after pack carburizing 900°C; (a) 40 minute; (b) 50 minute; (c) 60 minute

Figure 7 shows the Microstructure image of AISI 1020 steel after pack carburizing 875°C, Figure 7.a shows a holding time of 40 minutes producing 52% Pearlite and 48% Ferrite, Figure 7.b shows a holding time of 50 minutes producing 54% Pearlite and 46% Ferrite, and Figure 7.c shows a holding time of 60 minutes produces 54% Pearlite and 46% Ferrite.

Figure 8 shows the Microstructure image of AISI 1020 steel after pack carburizing 900°C, Figure 8.a shows a holding time of 40 minutes producing 61% Pearlite and 39% Ferrite, Figure 8.b shows a holding time of 50 minutes producing 60% Pearlite and 40% Ferrite, and Figure 8.c shows a holding time of 60 minutes produces 61% Pearlite and 39% Ferrite.

Based on the explanation in Figures 6 to Figure 8, it can be seen that the pearlite content increases along with increasing temperature and holding time in the pack carburizing process. The highest pearlite content was obtained in the pack carburizing process at a temperature of 900°C with a holding time of 40 and 60 minutes.

4. Conclusion

Based on the analysis of the results and discussions that have been carried out, it can be concluded that temperature and holding time have an influence on the hardness and microstructure values of AISI 1020 steel. As the temperature and holding time increase in the pack carburizing process, the hardness and microstructure values in the form of pearlite also increase and the highest hardness value was obtained at a temperature of 900°C with a holding time of 60 minutes of 54.2 HRC, while the highest pearlite content was obtained at 900°C with a holding time of 40 and 60 minutes of 61% of pearlite.

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