# DETERMINATION OF OPTIMUM SIZE OF RUBBER FRUIT SHELL CHARCOAL POWDER GRAIN TO INCREASE THE VALUE OF SURFACE HARRDNESS OF STEEL ST 37 IN PACK CARBURIZING PROCESS

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**ABSTRACT:** The development of use of *Pack Carburizing* process to increase the value of steel surface hardness has encouraged to be conducted a research to improve the efficiency of process. One of the research conducted by Saparin (2011) by utilizing shell charcoal of rubber fruit as a source of carbon in *Pack Carburizing* process.

*Pack Carburizing* process is carried out by covering the workpiece with rubber fruit shell charcoal powder as a source of carbon, then heated in a furnace until at the austenizing temperature. The use of carbon source in powder form has an effect on the carbon content that can be diffused into the surface of workpiece that will affect the value of surface hardness as revealed in a research conducted by Mujiyono and A.L. Sumowidagdo (2008) and Kuswanto, Bambang (2010). Therefore, this research aims to find out the optimum size of rubber fruit shell charcoal powder grain to increase the value of the surface hardness of steel.

Material used in this research is low carbon steel ST 37 with a carbon content of 0.1367% C. Pack Carburizing process using 100% of carbon media from rubber fruit shell charcoal with a carbon content of 88.52% C. Grain size variations used consist of 18 mesh (1 mm), 30 mesh (0.6 mm), 100 mesh (0.15 mm), and 200 mesh (0.075 mm). Heating temperature of Pack Carburizing process is 925 ° C with a holding time of 6 hours. After that continued to the Hardening process at 860 ° C, 60 minutes of holding time and using water as a quenching media. Tempering process is done after Hardening process at temperature 100 °C for an hour.

The results shows that the optimum size of rubber fruit shell charcoal powder grain to increase the surface hardness value of steel ST 37 is mesh 30 with carbon content diffused that can be generated on the specimen surface after Pack carburizing process is about 0.5253% C from the first carbon content (Non Pack carburizing specimen) in the amount of 0.1367% C. While, the surface hardness value is 223.9 HV after *Pack Carburizing* process and reaches about 832.2 HV after hardening + tempering process from surface hardness value on the first specimen (Non Pack Carburizing specimen) is about 132 HV.

**Keywords :** Steel ST 37, rubber fruit shell, powder grain, *Mesh*, *Pack Carburizing*, *Hardening*, *Tempering*, carbon diffusion, hardness.

## BACKGROUND

Pack Carburizing is a method of adding carbon on the low-carbon steel's surface using solid carbon media as a carbon source to increase the surface hardness value. steel which has processed with Pack Carburizing produces the outer surface which is rich of carbon and hard. [1].

Today, the use of Pack Carburizing to harden the steel surface has extended especially for components that require a hard surface but still tough on the inside, so that then a lot of research to make Pack Carburizing process becomes more effective and efficient.

Saparin (2011), found that the rubber fruit shell charcoal can be utilised as a source of carbon in the Pack Carburizing process to replace the other carbon source such as coal, coconut shell charcoal, and others. Based on the result of research conducted previously, the rubber fruit shell charcoal contains carbon content of ± 61,2% C and can increase the hardness of material ST 37 becomes 362,4 HV after conducted Pack Carburizing process and Case Hardening.

Pack carburizing process is carried out by covering steel with charcoal powder as a carbon source then placed in box or container and isolated from the outside air, heated at austenizing temperature and held for a certain time. Because of the high temperature, carbon will be oxidized by oxygen trapped in container into carbon monoxide (2CO), further carbon monoxide compound is decomposed into $CO_2$ + C. C atom produced in this reaction will be diffused interstitial into the surface of metal [2]. Therefore, the availability of sufficient oxygen in the box carburizing can help reaction of carbonization doing well.

Oxygen in the box carburizing contained in the cavities between the grains of charcoal powder which is used as a media of carburization. The larger the size of the powder, the greater the cavity, so that the amount of oxygen to be more and will ensure freedom of movement of gases in the box carburizing, but the large of powder will reduce the effectiveness of Pack Carburizing process because the charcoal powder grain will be more difficult to turn into the gas phase, thereby reducing the number of carbon atoms in box carburizing. On the other hand, the smaller the size of powder the smaller the cavity, thereby reducing the amount of oxygen contained in box carburizing and make the movement of gases formed becomes more difficult. However, a small grain of powder accelerates the formation of a gas phase from charcoal powder. Therefore, in order to the Pack Carburizing process becomes more effective the availability of cavities (empty space) needs to get the attention because it is very necessary to ensure the movement of gases that arise and the availability of oxygen during the process in box carburizing [3].

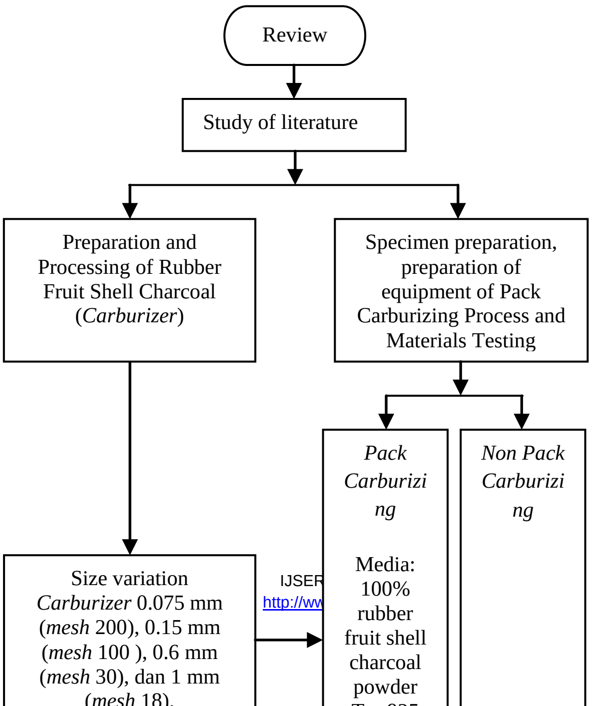
Based on the description above, it is necessary to research the optimum size of rubber fruit shell charcoal powder grain for used on the Pack Carburizing process because the research previously has not included the optimum size of rubber fruit shell charcoal powder grain that can be used to increase the surface hardness value of steel ST 37 in Pack Carburizing process.

## RESEARCH METHOD

Pack Carburizing process is done by using steel ST 37 material with carburizing media using 100% of rubber fruit shell charcoal. In this research the testing conducted involves testing of charcoal powder carbon content by using SEM-EDS method, testing of carbon content on specimen by using *optical emission spectrometer*, testing of specimen surface hardness by using rockwell B for Non Pack Carburizing specimen. and after the Pack Carburizing process and micro vickers method for specimen which has undergone a process of hardening + tempering, and testing of microstructure.

The series of research activities are described as follows:





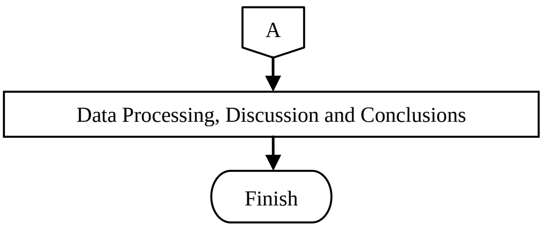



*Figure 1. Flowchart of Research*

## RESULT AND DISCUSSION

### Testing of carbon content of rubber fruit shell charcoal powder.

Based on the testing result of carbon content carried out, is obtained the following result:

*Table 1. the testing result of carbon content of rubber fruit shell charcoal powder*

| ***Testing at area*** | ***Element*** | ***Wt %*** | ***At %*** |
|---|---|---|---|
| $1^{st}$ | C | 86.85 | 89.79 |
| $2^{nd}$ | C | 88.19 | 91.30 |
| $3^{rd}$ | C | 90.52 | 92.71 |
| Average | | 88.52 | 91.27 |

The percentage of carbon content contained in the rubber fruit shell charcoal amounted to 88,52% by weight carbon and 91,27% number of carbon atoms. Content of carbon contained in charcoal powder is a potential carbon content which will be turned into a gas phase and oxidized by oxygen to form CO gas during the heating process is carried out in accordance with the reaction at Pack Carburizing process follows [2]:

$$2C + O_2 \longrightarrow 2CO$$

Thus, the higher the content of carbon contained in charcoal powder, the higher the content of CO gas formed resulting the carbon content can diffuse into the steel surface, will also be more and more and will affect the value of the surface hardness of the steel.



**Testing of carbon content of specimen**

Result of testing the carbon content of specimen is as follows:

*Table 2. Testing result of the carbon content of specimen*

| ***Element ( % )*** | ***Non Pack Carburizing Specimen*** | ***Pack Carburizing Specimen*** | | | |
|---|---|---|---|---|---|
| | | ***Mesh 18*** | ***Mesh 30*** | ***Mesh 100*** | ***Mesh 200*** |
| C | 0.1367 | 0.5067 | 0.5253 | 0.4334 | 0.4510 |

Based on the results of testing the carbon content of specimen, the increase of carbon content occurs on specimen surface where the highest content of carbon diffused is generated by carburizer mesh 30, and the lowest by carburizer mesh 100. The difference in carbon content diffused due to the influence of charcoal powder grain size, Meanwhile, increase of carbon content on the specimen surface due to carbon atom diffused interstitial from rubber fruit shell charcoal into steel surface. Diffusion process of carbon atom occurs because the carbon atom has sufficient activation energy so that it can move (diffuse). Carbon atom has activation energy caused by vibration of carbon atom because of the increased temperature due to the heating process in Pack Carburizing process.

**Testing of Surface Hardness of Specimen**

**Results of Surface Hardness Testing of Non Pack Carburizing specimen.**

*Table 3. Results of Surface Hardness Testing of Non Pack Carburizing specimen.*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|
| 1 | 72.55 HRB = 134.2 HV |
| 2 | 71.17 HRB = 126.4 HV |
| 3 | 70.83 HRB = 130.7 HV |
| 4 | 70.55 HRB = 130.2 HV |
| 5 | 72.28 HRB = 133.7 HV |
| Average | 71.48 HRB = 132 HV |



Based on the results of testing that has been done on Non Pack Carburizing specimen known that the value of surface hardness is 71.48 HRB = 132 HV. The hardness value is influenced by content of carbon contained in Non Pack Carburizing specimen that is equal to 0.1367% C. The hardness values are also influenced by microstuctur formed. Based on Fe-$Fe_3C$ diagram, steel with carbon content of 0.1367% C has microstructure of ferrite + pearlite. Low surface hardness due to the formation of ferrite phase is more than the pearlite phase, which the ferrite phase is a phase with pliancy and ductile while pearlite phase is hard and brittle.

**An average result of surface hardness testing for specimen after Carburizng Pack process with carburizer variation of mesh 18.**

*Table 4. an average result of surface hardness testing for specimen after Carburizng Pack process with carburizer variation of mesh 18.*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|
| 1 | 93.89 HRB = 211.5 HV |
| 2 | 95.22 HRB = 219.9 HV |
| 3 | 94.55 HRB = 215.6 HV |
| 4 | 93.5 HRB = 209.1 HV |
| 5 | 94.77 HRB = 217 HV |
| Average | 94.39 HRB = 214.6 HV |

**An average result of surface hardness testing for specimen with carburizer variation mesh 18 after *Hardening* + *Tempering process.***

*Table 5. an average result of surface hardness testing for specimen with carburizer variation mesh 18 after Hardening + Tempering process.*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|
| 1 | 817.27 HV |
| 2 | 811.35 HV |
| 3 | 832.82 HV |
| 4 | 803.76 HV |
| 5 | 821.92 HV |
| Average | 817.43 HV = 64.5 HRC |



Based on the testing result, the value of specimen surface hardness after done the Pack Carburizing process with carburizer mesh size of 18 showed that an increase in hardness value when compared to the hardness value of Non Pack Carburizing specimen that is becoming 214.6 HV. It was due to the rising content of carbon on specimen surface that is resulted from diffusion in Pack Carburizing process to be 0.5067% C resulting the more phase cementite ($Fe_3C$) were formed. While the value of the specimen surface hardness after Hardening + Tempering process showed a big enough increase in the amount of 817.43 HV. The increase in surface hardness value that is high enough on specimen after specimen through the Hardening process because the martensite phase was formed as result from rapid cooling (quenching) that done on specimen.

**An average result of surface hardness testing for specimen after Carburizng Pack process with carburizer variation of mesh 30.**

*Table 6. an average result of surface hardness testing for specimen after Carburizng Pack process with carburizer variation of mesh 30.*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|
| 1 | 95.33 HRB = 220.7 HV |
| 2 | 95.72 HRB = 223.3 HV |
| 3 | 96.16 HRB = 226.3 HV |
| 4 | 96.27 HRB = 227 HV |
| 5 | 95.55 HRB = 222.1 HV |
| Average | 95.81 HRB = 223.9 HV |

**An average result of surface hardness testing for specimen with carburizer variation mesh 30 after *Hardening + Tempering process.***

*Table 7. an average result of surface hardness testing for specimen with carburizer variation mesh 30 after Hardening + Tempering process.*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|
| 1 | 837.25 HV |
| 2 | 820.61 HV |
| 3 | 829.73 HV |
| 4 | 833.83 HV |
| 5 | 839.59 HV |
| Average | 832.20 HV = 64.7 HRC |

The results of testing that has been done on specimen after Pack Carburizing process by the size of *carburizer mesh* 30 is 223.9 HV. It was due to the rising content of carbon on the specimen surface which is the result of diffusion in Pack Carburizing process to be 0.5253% C resulting the more phase cementite ($Fe_3C$) were formed. While the hardness value of specimen after Hardening + Tempering process is 832.20 HV due to the formation of a martensitic structure after Quenching process.

*Table 10. an average result of surface hardness testing for specimen with carburizer variation of mesh 200*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|

| | |
|---|---|
| 1 | 93.28 HRB = 207.8 HV |
| 2 | 92.44 HRB = 202.9 HV |
| 3 | 94.99 HRB = 218.4 HV |
| 4 | 95 HRB = 218.5 HV |
| 5 | 94 HRB = 212.2 HV |
| Average | 93.94 HRB = 211.8 HV |

**An average result of surface hardness testing for specimen with carburizer variation mesh 30 after *Hardening + Tempering process.***

*Table 11. an average result of surface hardness testing for specimen with carburizer variation mesh 200 after Hardening + Tempering process.*

| Specimen | The average of Surface Hardness for every specimen |
|---|---|
| 1 | 812.1 HV |
| 2 | 793.43 HV |
| 3 | 824.11 HV |
| 4 | 837.83 HV |
| 5 | 811.62 HV |
| Average | 815.82 HV = 64.5 HRC |



The results of testing that has been done on specimen after Pack Carburizing process by the size of *carburizer mesh* 200, the surface hardness value of specimen is 211.8 HV. It was due to the rising content of carbon on the specimen surface which is the result of diffusion in Pack Carburizing process to be 0.4510 %C resulting the more phase cementite ($Fe_3C$) were formed. While the hardness value of specimen after Hardening + Tempering process is 815.82 HV. The increase of surface hardness value that is high enough on specimen after specimen through the Hardening process because the martensite phase was formed as result from rapid cooling (quenching) that done on specimen.

**Testing on Microstructure**

**Testing Result of Microstructure For specimen of Non Pack Carburizing.**

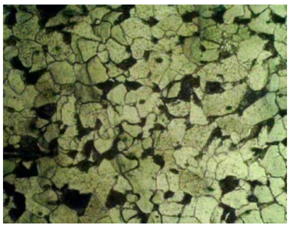
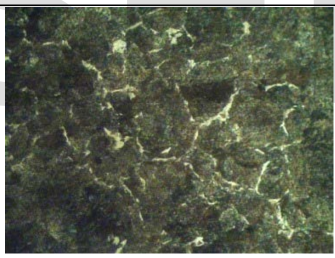
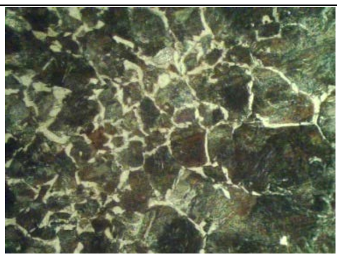
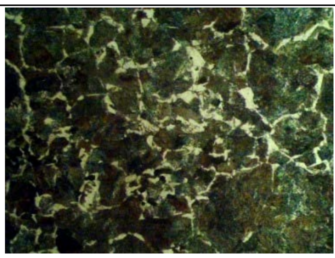


*Figure 2. Testing Result of Microstructure For Non Pack Carburizing specimen.*

Microstructure formed on Non Pack Carburizing specimen based the microstructure test with a microscope is ferrite + pearlite. microstructure of specimen of Non Pack Carburizing is still dominated by the ferrite phase due to carbon element contained is still little that is 0.1367% C.

**Testing Results of Microstructure For specimen after the Pack Carburizing process.**



| | |
|---|---|
| *Mesh* 18 |  |
| *Mesh* 30 |  |
| *Mesh* 100 |  |

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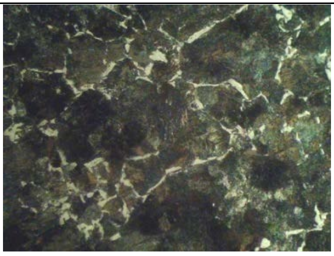
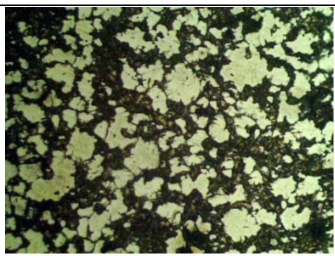
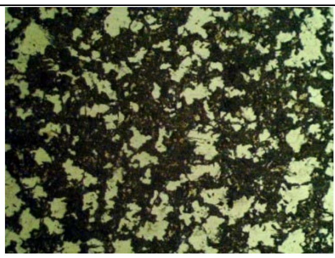
| | |
|---|---|
| *Mesh* 200 |  |

*Figure 3. Microstructure of specimen After Pack Carburizing Process*

Based on the testing of result for microstructure conducted, microstructure formed on the specimen after the Pack Carburizing process and before Hardening is ferrite + pearlite. However, when compared with microstructure of Non Pack Carburizing specimen, it appears that the phase of perlite is more. This is because of the increase of carbon content on the surface resulted from the diffusion of carbon atom of the rubber fruit shell charcoal so that the phase cementite ($Fe_3C$) which is formed to be a lot more. The more Cementite phase ($Fe_3C$) the more also will affect the hardness of specimen surface because the cementite is hard.



**The testing results of Microstructure of specimen After Hardening + Tempering Process.**

| | |
|---|---|
| *Mesh* 18 |  |
| *Mesh* 30 |  |

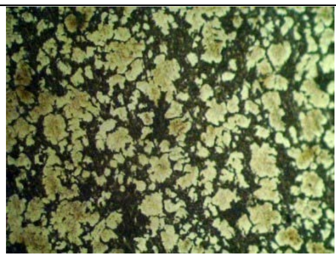
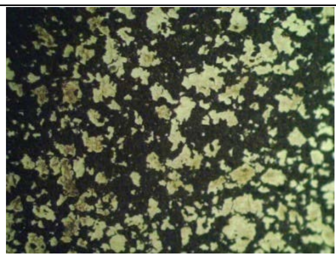
| | |
|---|---|
| *Mesh* 100 |  |
| *Mesh* 200 |  |

*Figure 4. Micro Structure of specimen After Hardening + Tempering Process*

Microstructure formed after Hardening + Tempering process is the ferrite + carbide or commonly called tempered martensite. Tempered martensite formed from a martensitic structure which is undergoing a process of reheating (Tempering) resulting in partial discharge of carbon atoms from BCT cubic to carbide transition. This microstructure is hard yet tough. The formation of Tempered martensite microstructure results in increased hardness value on the surface of specimen.



**The relationship of Carburizer Grain size With Carbon Atom Diffusion**

The previous research conducted by Mujiyono and A.L. Sumowidagdo (2008) and Kuswanto, Bambang (2010) have shown the influence of the carburizer powder grain size on the diffusion of carbon atoms in Pack Carburizing process.

There is relationship between the grain size of carburizer with the diffusion of carbon atoms in the Pack Carburizing process due to the grain size will affect the speed of charcoal powder change into the gas phase so as to affect the availability of the number of carbon atoms in box carburizing and the availability of free space to ensure the availability of oxygen as well as the smooth movement of gases that arise.

The larger the size of charcoal powder used, the larger the empty space between the grains of charcoal powder formed so that the amount of oxygen that is trapped more and more. Trapped oxygen is required as oxidant (carrier) of carbon atoms derived from rubber fruit shell charcoal powder into the specimen surface.

In addition, the larger the empty space formed will ensure the freedom of movement of gases in box carburizing, but the size of the powder that large will reduce the effectiveness of the Pack Carburizing process for charcoal powder grain will be more difficult to change into the gas phase so that the number of carbon atoms that can be oxidized by oxygen in the gas phase to be relatively less. This is because change in solid subtance into gas as a function of temperature increase, influenced by the size of surface area [4].

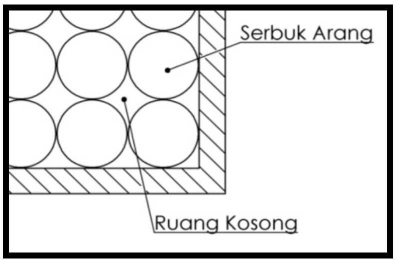



*Figure 5. Illustration of presence Empty space inter Charcoal Powder grain*

On the other hand, the smaller the powder size the smaller empty space formed so that reducing the amount of oxygen that is trapped in a box carburizing and making the movement of gases formed becomes more difficult. However, the size of powder grain that is small speed relative up the formation of gas phase from charcoal powder. So that the powder size of carburizer will so determine the number of carbon atoms that can diffuse into the specimen surface.

The same results are shown in this research where variations in the size of charcoal powder used to produce the carbon content value diffused different as shown in Table 2.

Charcoal powder size of mesh 200 and mesh 100 have the change speed into the gas phase from the carbon atoms that are very good, but the empty space formed is small. A small empty space which causes amount of oxygen trapped decreases and disrupts the smooth movement of gases causing the carbon content can be diffused into the specimen surface becomes less.

The charcoal powder size of mesh 18 has a large empty space so as to be able to ensure the availability of oxygen and the smooth movement of the gas that is formed, but because the grain size that is large makes a change on the carbon atom into the gas phase becomes more difficult, so it will also cause a number of carbon atoms will diffuse into the surface of the specimen becomes less. Meanwhile, the size of charcoal powder which is capable of producing the highest content of carbon diffused is mesh 30.

**The Relationship of Carbon Content With Surface Hardness**

Carbon (C) is the main constituent element in steel. Content of carbon which is owned by the steel has directly proportional with the value of the surface hardness. Based on the

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research result that has been done, the result of the highest surface hardness is given by variations in the grain size of 30 mesh which amounted to 223.9 HV for the specimen after Pack Carburizing and 832.2 HV for specimen after *Hardening + Tempering* with a carbon content contained by 0.5253% C. The value of Surface hardness generated by rubber fruit shell charcoal powder of mesh 30 is the highest hardness values compared to other carburizer size. That is because the carbon content is diffused into the surface of the specimen is more than the size of the other carburizer (Table 2), in which the carbon content contained in the specimen surface will be directly proportional to the increase in surface hardness. Whereas the lowest hardness value obtained from carburizer size of mesh 100. This is because the carbon content is diffused on the specimen surface of mesh 100 is the lowest when compared to other carburizer size.

The increase in hardness after the Pack Carburizing process due to an increase carbide compound of iron/cementite ($Fe_3C$) due to the addition of carbon atom (C) which is diffuses interstitial into the crystal structure of iron Fe according to the reaction [5]:

$$3\gamma\ Fe + C_{atom} \longrightarrow Fe_3C$$



Interstitial diffusion of carbon atom (C) into the Fe atom led to increased density between atoms in the crystal structure resulting in increased the hardness value. Increasing the number of cementite ($Fe_3C$) in the steel surface will be directly proportional to the carbon content diffused (Figure 6) and the hardness value of steel surface (Figure 7).

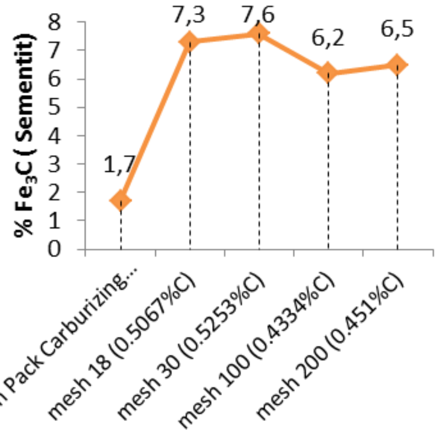


*Figure 6. Graph of Relationship between Carbon Content with Percentage of $Fe_3C$ formed*

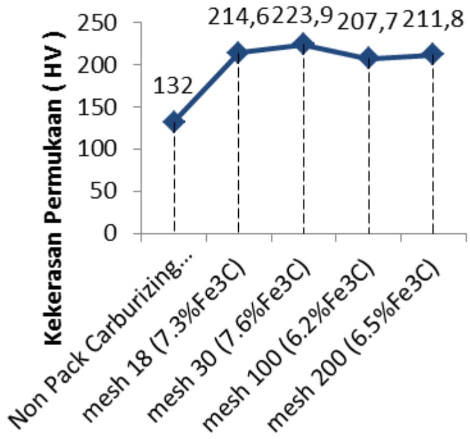


*Figure 7. Graph of relationship between cementite ($Fe_3C$) Content with the Surface Hardness value After Pack Carburizing*

Meanwhile, after the specimen undergoes Hardening + Tempering process, microstructure formed is tempered martensite. The structure of tempered martensite formed because of done rapid cooling (quenching) from austenite temperature, causing the carbon atom trapped/do not have time to diffuse from BCC crystal structure and form a crystal structure of BCT (Body Centered Tetragonal) then carried Tempering process.

Tempered martensite crystal structure consists of two phases, namely ferrite and carbide. The microstructure of ferrite and carbide formed is not lamellae, such as perlite but containing carbide particles dispersed [24]. This microstructure is due to decomposition of martensite because of warming tempered resulting in partial discharge of carbon atoms from BCT structure form transition carbides with the reaction [6]:

M (martensite) $\longrightarrow$ α + karbida (tempered martensite)

With the formation of tempered martensite structure, the surface hardness value of specimen to increase high enough.

## CONCLUSION

Based on the research result that has been done, it can be concluded as follows:

1. The optimum size of rubber fruit charcoal shell powder grain to increase the value of the surface hardness of steel ST 37 is mesh 30.
2. Content of carbon diffused that can be generated on the specimen surface after Pack Carburizing process using rubber fruit shell charcoal powder size of mesh 30 amounted to 0.5253% C from the first carbon content (specimen of Non Pack Carburizing) amounted to 0.1367% C, with the value of surface hardness resulted after Hardening +

Tempering process amounted to 832.2 HV from the first specimen hardness value (specimen of Non Pack Carburizing) amounted to 132 HV.

3. rubber fruit shell Charcoal contains the carbon content of 88.52% C and is an excellent source of carbon for the Pack Carburizing.

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