Biaxial pressure pack carburizing method to modification local low carbon steel’s mechanical properties

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Abstract. The absolute requirement for steel material can be hardened directly is the carbon content of this material is more than or equals to 0.3 %. This steel material is recognized as medium carbon steel and above. Carburizing process is an effort to increase low carbon content in soft steel material which have less than 0.3 % it can be done by adding carbon content up to 0.3 % and above. The tool commonly used for this process called pack carburizing device and the process occur in furnace atmospheric pressure. In this research, carbon content adding process held on pressurized pack carburizing container, and the pressure was given mechanically from two axial direction named biaxial pressing carburizing process. The specimen material used in this research is local low carbon steel (ST.37) and coconut shell active charcoal powder. Process parameter The process parameter are pressure, temperature, and holding time. The best result is achieving at a process temperature of 1000 ºC with 3 hour holding time and biaxial pressure of 2 MPa with 115.4 HRB, 823,6 N/mm2, and 0,41 % the incensement of carbon content from 0,27 % to 0,40 %.

1. Introduction

Local low carbon steel, usually known as ST.37, has approximately carbon content average of 0.27 %. This condition becomes an obstacle if the low carbon steel want to be harden directly, because the steel must have carbon content ≥ 0.3%, to be able to harden the specimen’s surface directly on heat treatment process. The process of adding carbon content on ST.37 steel will be carried out by the biaxial pressure case carburizing method. By this method, a heat treatment process to increase carbon content by “burried” the soft steel specimens in active coconut charcoal powder containers and pressured from two axial directions, then heated to specified temperature and holding time. The pressure on carbon powder is predicted will distributed more evenly the absorption of carbon to the specimen than pressureless pack carburizing which used in previous research.
Figure 1. Biaxial pressure pack carburizing process scheme.

Figure 2. Pressureless pack carburizing process scheme used in previous research.

This biaxial pressure pack carburizing’s method is predicted that the diffusion and penetration of carbon atoms into the surface of the specimen will be deeper. This method is believed will increase more carbon content at the surface of the specimen than the open pressureless pack carburizing method used in previous studies.

Steel is an alloy of iron (Fe) and carbon (C) with a carbon element content of between 0.2% up to 2.1%. And steel is classified into 3 main groups, namely soft steel is steel with carbon content ≤ 0.20% and does not contain other elements besides Si and Mn, low carbon steel is steel with carbon content of 0.10% ~ 0.25 % and high carbon steel is with a carbon content of 0.56% ~ 1.70% with the addition of other elements to the composition [1]. Meanwhile, soft steel and low carbon steel is very difficult to increase the value of hardness if the heat treatment process is carried out directly [2]. To be able to increase the value of steel hardness through the heat treatment process (heat treatment) is determined by the carbon content in the steel itself. If the carbon content in steel > 0.30% [3], the steel will not be able to increase its hardness value by means of direct heat treatment process.

One of the ways to increase carbon content in low carbon steel is to increase the carbon content by wrapping low carbon steel specimens with carburized material which is generally carbon powder, graphite powder, or activated charcoal powder in a heat-resistant container to be heated to temperatures between 800 °C ~ 1050 °C. If the process temperature has been reached, this temperature must be maintained for 2 hours to 3 hours (holding time). The next process is to cool specimens that have been heated for a certain period of time suddenly, this cooling process is known as a quenching process [4].

To increase carbon content’s in steel composition, a carburizing process on low carbon steel must be conducted using carburized material in the form of a mixture of coconut shell charcoal powder and calcium carbonate powder (CaCo3) at 900 °C and 1000° C [5]. The result is the carbon content in low carbon steel increases up to 70% greater than the initial carbon content. The carburizing process is an effort to add carbon content to the specimen by wrapping the specimen with active charcoal powder from a coconut shell [6]. The result achieved is an increase in the hardness value of the specimens up
to 80% with a process temperature of 950 °C with a holding time of 2 hours. And an effort to improve mechanical properties on low carbon steel surfaces (0.19% C) by wrapping specimens using carburized material mixture. The results achieved increased carbon composition on the surface of the specimen by 80% from 0.19% C to 0.35% C as thick as 1.2 mm [7]. Some of the research carried out above is very in line with the objectives of this study, namely modifying the material of soft steel and low carbon steel into materials that meet the requirements of making tensile link components that must have a certain hardness value and adequate wear resistance.

Biaxial pressurized pack carburizing use in this research is a method for distributing pressure which applied from two opposite directions axially in a pressing tube as shown in the image below. The purpose of this compression method is that the density of the object being pressed in the pressure tube is more evenly distributed when compared to the pressure in the pressure tube only given from one direction which is commonly called uniaxial pressure method.

![Biaxial pressing process](image1)

**Figure 3.** Biaxial pressure distribution and uniaxial pressure distribution scheme.

1.1. **Test of chemical composition of specimens**

Emission spectrometer is one of the chemical analysis tools for the determination of metal elements in a massive metal and metal alloys, both qualitatively and quantitatively [8]. Spectrometer tests were performed to determine the chemical composition of genuine tensile links, specifically the carbon content of C so that it can be known the type of material used. In addition to genuine tensile link, ST.37 material was also tested by a spectrometer to prove that ST.37 material is low carbon steel with carbon C content below 0.3%. To determine the mechanical properties of metals and non-metals one of the tests used is a tensile test. Tensile testing is a method used to test the strength of a material by giving the force load in the opposite direction [8]. And hardness testing is one of several types of testing used because it can be carried out on small test specimens without difficulty regarding specifications. The most widely used test is to press the penetrator or indenter with the shape and load according to the predetermined standard of the object and to measure the dimension of the former stressor indenter formed above it [9].

The value of the tensile strength test results can be converted to the value of violence in the Brinell scale with the following equation [10]:

$$TS_{,MPa} = 3.45 \times HB$$

with: $TS =$ Tensile Strength, N/mm$^2$; and $HB =$ Hardness Brinell Number, HB

To solve the problem of adding carbon content on a local low carbon steel (ST.37), several researchers do some research as mentioned above and no one use the carburizing process which enclose the pressure in the process. The suggested strategies in pack carburizing process with pressure enclosed are effective and can be implemented in the material hardening shop, because the super fine coconut active carbon charcoal size 500 mesh ASTM have a character like fluids [11].
2. Methods

Research implementation in the form of Ishikawa diagram

![Ishikawa Diagram](image)

**Figure 4.** Ishikawa research’s diagram.

2.1. Experiment’s material
The material used in this experiment is local soft steel that is easily found on the local market, namely ST.37 which has a maximum carbon content up to 0.27% with an average tensile strength of 500 N/mm² and a surface hardness of 79 HRB. The carburiser material is active coconut shell charcoal powder of 500 mesh ASTM.

2.2. Research equipment
Research equipment used in this experiment is placed in the Lab. Of Machining and Lab. of Materials Testing at Politeknik Negeri Semarang. Whereas the carbon content test is carried out in the Material Test laboratory Ceper Polytechnic of Manufactur.

2.3. The experimental variables
The variables carried out in this study are the pressure on the carburising tube, the carburizing process temperature, and the carburizing process time. All of these variables will affect the mechanical properties, especially the hardness of the specimen.

2.4. The experimental steps
The experimental steps carried out in this study are as follows:

- Low carbon steel type ST.37 is formed according to ASTM E8/8M-15a standard
- Perform carburizing process by means of case hardening methods using biaxial pressure pack carburising equipment units with the specified variables, namely temperature, pressure, and processing time.
- Test the composition of carbon on the surface of the specimen.
- Test the hardness of specimens by the Rockwell B testing method
- Analyze data from all specimen hardness test results.

2.5. Research output
The annual output of the study is the data of specimen hardness values and recommendations of the carburizing process that are most suitable for ST soft steel material. 37 as material for making machine components.

2.6. Outcome indicator
The expected outcome indicator of this research is the hardness value of the specimen reaches 80 to 110 HRB such as the value of the hardness of the machine component material in general.
3. Results and discussion

3.1. Initial material’s data

3.1.1. Spectrographic test data

Table 1. Chemical composition of local soft steel material (ST. 37) “as received”.

| Element | Fe  | C  | Si  | Mn  | P   | S   | Cr  |
|---------|-----|----|-----|-----|-----|-----|-----|
| %       | 98.8| 0.266| 0.147| 0.428| 0.0485| 0.0285| 0.0116|

Source: Politeknik Manufaktur Ceper

3.1.2. Tensile strength test data

Table 2. Tensile strength values of local soft steel materials (ST. 37) “as received”.

| Type of test | Ultimate Tensile Strength (N/mm²) | Average UTS (N/mm²) |
|--------------|----------------------------------|---------------------|
| Tensile test | 505                              | 480                 |
|              | 520                              | 495                 |
|              | 500                              |                     |

3.1.3. Surface hardness test data

Table 3. Surface Hardness values of local soft steel materials (ST. 37) “as received”.

| Type of hardness Test | Rockwell B Hardness Number (HR₉) | Hardness Number Average (HR₉) |
|-----------------------|----------------------------------|-------------------------------|
|                       | 1  | 2  | 3  | 4  | 76 | 75 | 78 | 78 | 76,75 |

3.2. Results

3.2.1. Carbon content test results. The initial grade value of local ST. 37 soft steel material is 0.26%, while the carbon content of local ST. 37 steel material after undergoing the process of biaxial pressure pack carburizing is highest at 0.45% at a temperature variation of 800°C with a holding time of 3 hours at pressure biaxial of 2 MPa and the lowest carbon content value of 0.35% is at a temperature variation of 1000°C with a holding time of 2 hours with biaxial pressure of 3 MPa.

3.2.2. The tensile test results

Figure 5. Tensile test specimens according to ASTM E8 / E8M-15a standards.
Table 3. Hardness and tensile strength data of local soft steel (ST. 37) after biaxial pressure pack carburizing process and carbon content, hardness value and tensile strength of local soft steel (ST. 37) after the carburising process at a pressure of 2 MPa.

| Temperature process (°C) | Holding time (h) | Carbon % | UTS (N/mm²) | Hardness (HRB) |
|--------------------------|------------------|----------|-------------|----------------|
| 800                      | 2                | 0.42     | 817.9       | 102.1          |
|                          | 3                | 0.45     | 767.1       | 103.1          |
| 900                      | 2                | 0.38     | 720.1       | 105.4          |
|                          | 3                | 0.41     | 942.3       | 108.1          |
| 1000                     | 2                | 0.38     | 793.8       | 112.1          |
|                          | 3                | 0.41     | 889.0       | 112.3          |

The initial tensile strength value of local ST. 37 soft steel material is 80 HRB, while the highest tensile strength value of local ST. 37 steel material after undergoing the biaxial pressure pack carburizing process is at a temperature variation of 900°C with a holding time of 3 hours that is 942 N / mm² and the lowest tensile strength value of 720 N / mm² is at a temperature variation of 900°C with a holding time of 2 hours and biaxial pressure of 2 MPa.

There was a decrease in the value of the level of tensile strength in the results of the process with biaxial pressure parameters of 3 MPa, carburising temperature of 1000°C and holding time of 2 hours. This case is happened because the fire retardant insulation on the equipment fails to function as a seal of CO gas leakage generated during the experiment.

3.3. Discussion

3.3.1. Carbon content test results. The initial grade value of local ST. 37 soft steel material is 0.266 % carbon content, while the carbon content of local ST. 37 steel material after undergoing the process of biaxial pressure pack carburizing is highest at 0.45% at a temperature variation of 800°C with a holding time of 3 hours at pressure biaxial of 2 MPa and the lowest carbon content value of 0.35% is at a temperature variation of 1000°C with a holding time of 2 hours with biaxial pressure of 3 MPa.

3.3.2. Tensile test results. The initial tensile strength value of local ST. 37 soft steel material is 80 HRB, while the highest tensile strength value of local ST. 37 steel material after undergoing the biaxial pressure pack carburizing process is at a temperature variation of 900°C with a holding time of 3 hours that is 942 N / mm² and the lowest tensile strength value of 720 N / mm² is at a temperature variation of 900°C with a holding time of 2 hours and biaxial pressure of 2 MPa.

3.3.3. Hardness test results. Testing the hardness of the local ST. 37 Soft Steel Material specimens through the carburizing pack process using the Rockwell B scale (HRB) method. The initial hardness value of local ST. 37 soft steel material is 80 HRB, while the local hardness value of ST. 37 steel material after undergoing the highest carburizing pressure pack carburizing process is at a temperature variation of 1000°C with a holding time of 3 hours i.e. 144 HRB at biaxial pressure of 3 The lowest MPa and hardness value of 102 HRB is at a temperature variation of 800°C with a holding time of 2 hours with a biaxial pressure of 2 MPa.

4. Conclusion

- The value of carbon content, tensile strength value, and hardness value which is the mechanical properties of local soft steel (ST. 37) can be increased by the biaxial pressure pack carburising method with active medium sized 500 mesh and 1000 mesh mesh according to ASTM standards. As a parameter of the carburising process temperature used 800 °C, 900 °C and 1000 °C.
While the biaxial pressure chosen is 1 MPa, 2 MPa and 3 MPa. The holding time is determined by 2 hours and 3 hours.

- Biaxial pressured pack carburizing on variations of the process parameters as mentioned above affects the mechanical properties of local soft steel material (ST. 37) in each variation.
- The highest increase in carbon content of the specimen by 0.45% C and also the tensile strength value of 950 N / mm² was obtained when the specimen was processed at 900 °C, holding time for 3 hours and biaxial pressure of 3 MPa. While an increase in the hardness of the specimen of 144 HRB was obtained when the specimen was processed at a temperature of 1000 °C, holding time for 3 hours and biaxial pressure of 3 MPa.

4.1. Recommendation

The recommendations of biaxial pressured pack carburizing parameters for local soft steel material (ST. 37) if will be used as replacement material for machine’s components making is a temperature of 900 °C and holding time 3 hours which has a hardness value of 105 HRB and a tensile strength of 720 N / mm². Because at these mechanical properties the processed materials can still be easily carried out.

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