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Wear resistance improvement of the roller chain parts at Thai Metro Industry (1973) Co., Ltd.

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Abstract

This research aims to investigate and improve the surface hardness and wear resistance of the roller chain parts, which will result in the chain lifetime extension. The experiments were done by applying the carburizing and carbonitriding technique in the original heat treatment process of the example factory. The hardening media was charged into the industrial rotary retort furnace, which has a capacity of 60 kg/batch. The test samples are the roller chain parts, i.e. pin, bush which made from medium-carbon alloy steel with 0.4%C. The hardened specimens from the experiments were investigated by Micro Vickers hardness test, wear test, double shear test, Scanning Electron Microscope (SEM) and Energy-dispersive X-ray spectroscopy (EDS) technique. The results show that the hardened specimens have better wear resistance property than the original product with an accepted shear strength and toughness.

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Keywords: Surface hardening; Wear resistance; Roller chain parts; Industrial rotary retort furnace

1. Introduction

Roller chain is the component in a machine that is most used for power transmission equipment in industry. The main components of a roller chain are pin, bush, roller, inner link plate and outer link plate which are assembled together as shown in Fig. 1 (a). Normally, a roller chain enters and leaves the sprockets during usage and the wear

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take place at the surface contact between pin and bush as shown in Fig. 1 (b). As material is worn away from these surfaces the roller chain will gradually elongate [1] and finally results in the expiry of chain lifetime.

In the production of roller chain, each component is usually heat treated to improve the mechanical properties. During this process, decarburization can take placed at the surface of the steel components. With the low carbon content at the surface of the pin specimen, it can cause a problem, as the weaker surface layer reduces wear resistance, enabling fatigue failures to occur more easily [2]. In many engineering applications, a steel part is needed to have a hardened surface for wear resistance. At the same time, high toughness inside materials are required in order to absorb any shock load [3]. The manufacture of roller chain has been standardized by the American National Standards Institute under standard B29.1 [4].

The experiments in this research were done at Thai Metro Industry (1973) Co., Ltd. which is the roller chain manufacturing plant. The aim of this research is to investigate and improve the surface hardness and wear resistance of the pin, which could extend the lifetime of the chain. At the same time, the other material properties, e.g., toughness, shear strength were also investigated and controlled to meet the specification of the company.

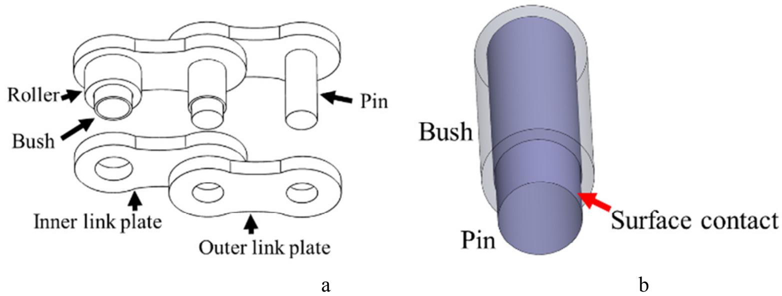


Fig. 1. (a) Assembly of roller chain; (b) The surface contact between pin and bush.

2. Experimental Procedure

2.1. Material

Carbon steel is the most common type of steel which could provide material properties that are acceptable for many applications. The AISI 4340 steel is used commercially as a high-strength steel. It is a material that combines deep hardening (high hardenability) with high ductility, high resistance, good toughness, and good weld ability. It has high fatigue resistance, when properly hardened and tempered [5]. The raw materials used to produce the pin part which is the test specimen in this study is AISI 4340. Fig. 2 shows the size of a test specimen.

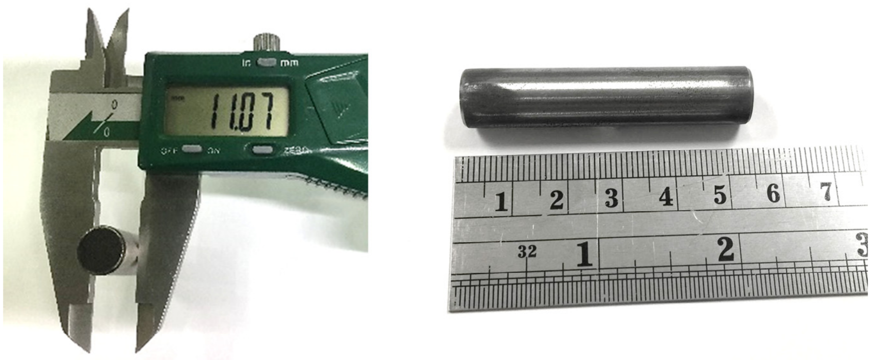


Fig. 2. Size of specimens.

2.2. Heat treatment process

The heat treatment furnaces of the factory are rotary retort furnaces which have a capacity of 60 kg/batch as shown in Fig. 3. In the current study, we directly use this furnace to run the test experiments. Small amount of charcoal was charged at the begin of heat treatment process as a reducing agent to reduce oxygen of the atmosphere inside furnace and to prevent oxidation of the steel product. Some amount of barium carbonate ($BaCO_3$) are charged together with charcoal to promote the Boudouard reaction. In the experiments, the different mixtures of charcoal+$BaCO_3$ with and without adding of urea were charged during heat treatment process as hardening agent to perform carburizing and carbonitriding reactions [6] at the surface of the specimens. The chemical reactions related to the hardening agents are shown in Table 1. The information of the 4 mixtures of hardening agent used in the current study is shown in Table 2.

Table 1. Chemical reactions related to the hardening agents.

Hardening agent	Chemical reactions
Charcoal	$C + CO_2 \longrightarrow 2CO$
Barium carbonate	$BaCO_3 \longrightarrow BaO + CO_2$
Urea	$(NH_2)_2CO \longrightarrow NH_3 + 0.5H_2 + 0.5N_2 + CO$

Fig. 3. Rotary retort furnace at the factory.

Table 2. Mixture composition of the hardening agent.

Code of experiment	Mixtures of hardening agent	Ratio of mixture	Mixture weight
C-01	Charcoal : $BaCO_3$	80:20	100
C-02	Charcoal : $BaCO_3$	85:15	120
CN-01	Charcoal : $BaCO_3$: Urea	75:15:10	100
CN-02	Charcoal : $BaCO_3$: Urea	75:15:10	50

The original heat treatment process of the factory is shown in Fig. 4 (a) The specimens and 20 g of the charcoal-$BaCO_3$-mixture are charged into the furnace in the beginning with temperature of 800 ^oC. After the temperature dropped and raised up to 830 ^oC, the holding period is started. At 830 ^oC the austenitizing takes place [7]. The holding period time depends on the size of specimen. After that, the specimens are quenched by oil. The heat treatment process of the test experiment is shown in Fig. 4 (b), which is similar to the original process in Fig. 4 (a), except an additional charging of the hardening agent at the half of holding period. The furnaces used for heat treatment in the factory are the rotary retort furnace with a capacity of 60 kg/batch. In the experiment, we use the same furnace in the factory to run the tests. After quenching, all specimens are tempered at 200-230 °C for 30 minutes. The temperature used for tempering process are controlled to be lower than 300 °C in order to avoid tempered embrittlement [8].

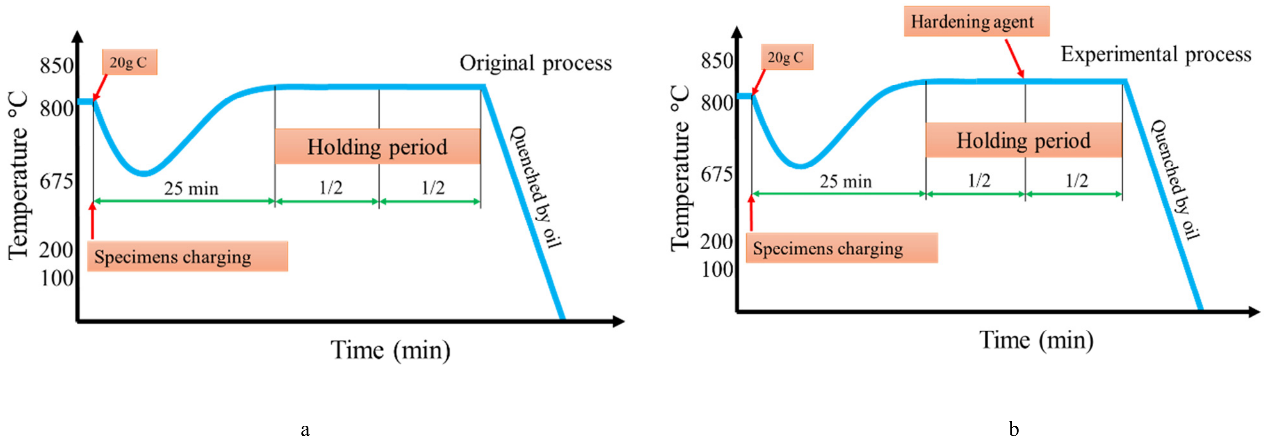


Fig. 4. (a) Original heat treatment profile of the factory; (b) heat treatment profile of the test experiment.

2.3. Micro Vickers hardness test

Comparison between the hardness of test specimens and the original products has been carried out by measuring the Vickers hardness along the cross section diameter of the specimens for 13 points plus 2 more points at the edge as shown in Fig. 5 (a). The picture of the Vickers hardness test points on the specimen is shown in Fig. 5 (b). Its purpose is to investigate the improvement of hardness profile near the surface which is related to the wear resistance [9]. The applied test load used in this test is 500 g, which is generally used for this material [10].

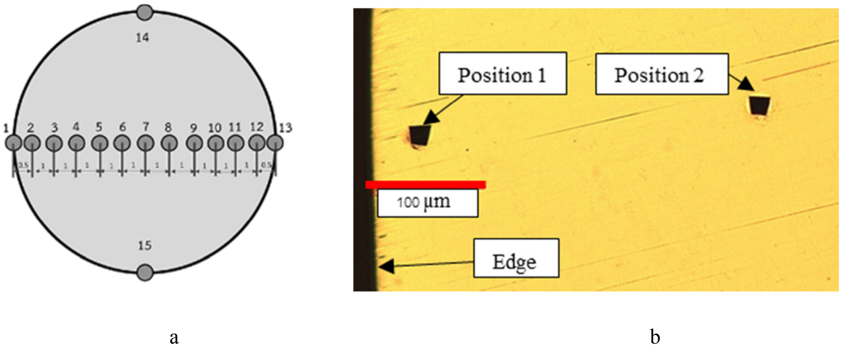
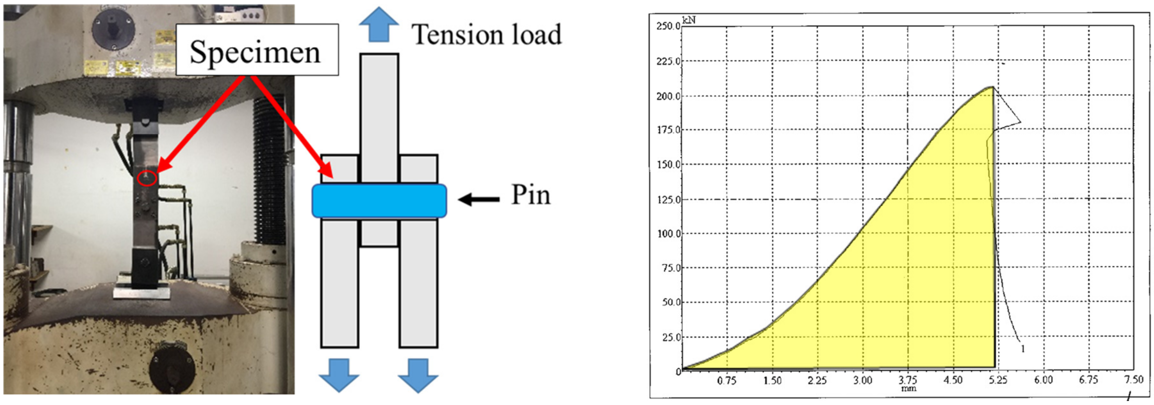


Fig. 5. (a) Position measurement of specimen; (b) Vickers hardness test points on the specimen.

2.4. Double shear test

During the actual use of the chain, the pin is subject to shearing and bending forces transmitted by the chain link plate. The design of the specimen holder equipment for double shear test is shown in Fig. 6 (a). The specimen holder consists of 3 metal plates with the holes that have same size as the pin diameter. The tension load is applied to the 3 metal plates. The thickness of the middle plate is as same as the length of roller part in the chain. Toughness results are analyzed by the area under the graph from double shear test as shown in Fig. 6 (b).



a b

Fig. 6. (a) double shear test machine and specimen holder equipment; (b) double shear test result.

2.5. Wear test

The pin-on-disk wear test has been conducted using the tribology testing machine as shown in Fig 7 (a). During the test, the top surface of the test specimen is back-and-forth scratched by a tungsten carbide ball. Afterward, the wear specimen is measured the surface roughness profile in the perpendicular direction to the scratch line by using the surface roughness measuring device. The degree of wear is analyzed by using the wear loss area of zone-B_1 [11] as shown in Fig. 7 (b). Normally, the wear mechanism of material depends on the relative velocity between the sliding surfaces, temperature, hardness and roughness of the materials [5]. In this study, each wear test has the same test condition as shown in Table 3.

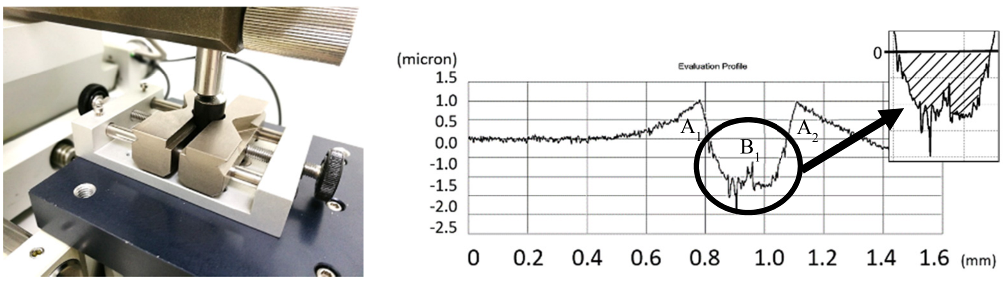


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Fig. 7. (a) Pin-on-disk test; (b) Cross section area measured by surface roughness measurement device.

Table 3. Test condition of wear test.

Test condition	
Mode	Linear
Load	10 N
Speed	2 cm/s
Time	15, 30 min

3. Result and Discussions

3.1. Micro Vickers hardness test

Vickers hardness profiles were measured on the cross-sectional diameter of the specimens as shown in Fig. 8 (a-e). The Vickers hardness at the center of the diameter has a minimum hardness of around 560 HV. Fig. 8 (f) shows the comparison between the hardness at the rim point (50 microns from edge) on the cross section surface of the test specimens and the original product. It shows that hardness at the rim point of the original product has the lowest value at around 556 HV and the hardness of experiment specimens are higher. CN-01 specimen yields a maximum hardness of 599 HV as shown in Fig. 8 (f).

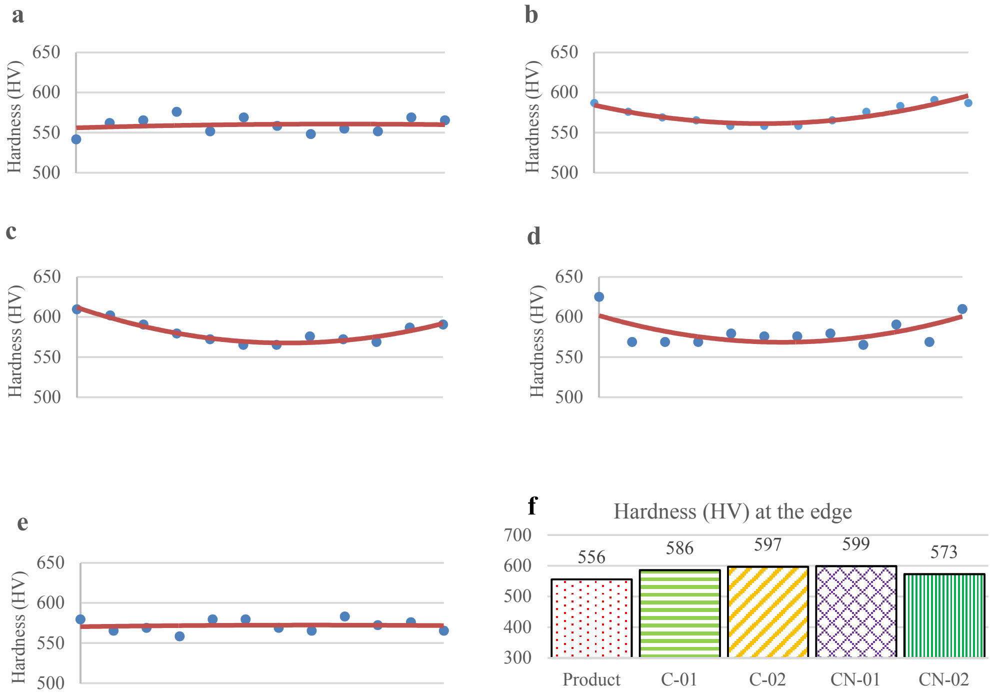


Fig. 8. Hardness profiles of (a) original product, (b) C-01, (c) C-02, (d) CN-01, (e) CN-02; (f) Comparison of Vickers hardness at the edge point of original product and experiment specimens.

3.2. Double shear test

The results of shear strength and toughness from double shear tests are shown in Table 4, which are compared between original products and experiment specimens. Shear strength of all test specimen are nearly the same. Toughness of C-02 and CN-01 are the lowest. All results still meet the specification of company.

Table 4. Results from Double shear test

Double shear test	Shear Strength (N/mm^2)	Toughness (J)
Original product	1080	478
C-01	1079	487
C-02	1091	440
CN-01	1087	454
CN-02	1103	482

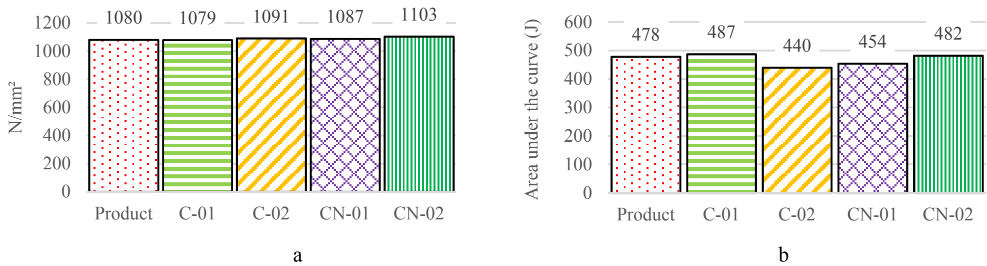


Fig. 9. (a) Shear strength of specimens; (b) Toughness of specimens.

3.3. Wear test

The results from pin-on-disk wear test at the surface of specimens after 15 and 30 minutes obtained by measuring the wear loss area are shown in Fig. 10. The original product shows the highest wear loss area for both cases. After 15 minutes of wear test, the experiment specimens have better wear resistance ability than the original products for approximately 2 times. The specimens C-02 and CN-01, which have a similar amount of wear loss area (177 and 175 µm²), show the best wear resistance ability. The reasons could be that both cases have much enough charcoal to prevent decarburization and carburizing/carbonitriding reactions also take place during heat treatment process. After 30 minutes of wear test, the measuring wear loss area of all specimens are increased nearly doubled compared to the test after 15 minutes.

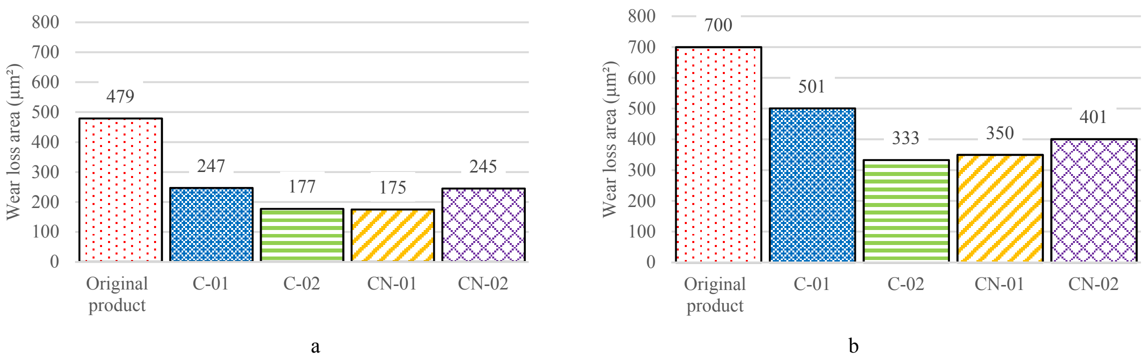
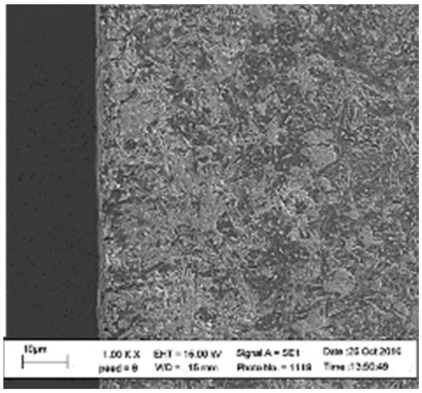


Fig. 10. (a) Wear loss area after 15 minutes; (b) Wear loss area after 30 minutes.

3.4. Microstructure and Elemental analysis

The SEM micrographs of original product specimen and experiment specimen CN-01 are shown in Fig. 11 (a) and (b) respectively. The pictures show the microstructure at the edge of cross section of the specimens. In case of original product, the microstructure in the zone of 30 micron decarburization depth consists mainly of retained austenite phase, while in case of the CN-01 specimen, the microstructure consists mainly of martensite. All the hardened test specimens have same microstructure as of CN-01 specimen. Fig. 12 shows the elemental analysis results from Energy-dispersive X-ray at the edges of the original product and the experiment specimen CN-01. Higher peak of carbon and the peak of nitrogen are found from specimen CN-01.



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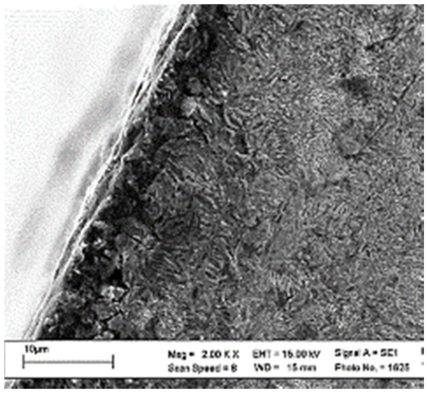

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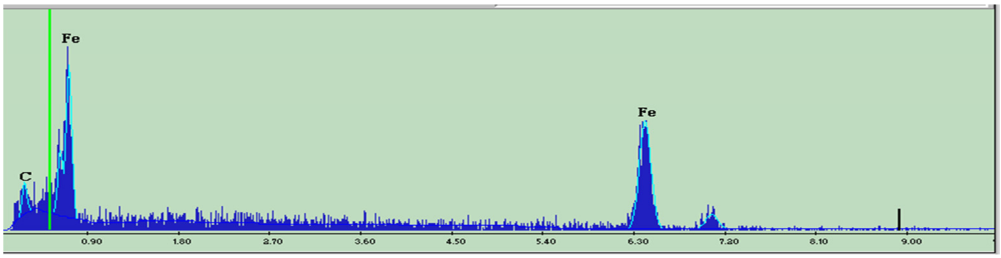
Fig. 11. Microstructure of (a) the original product and (b) the experiment specimen CN-01.



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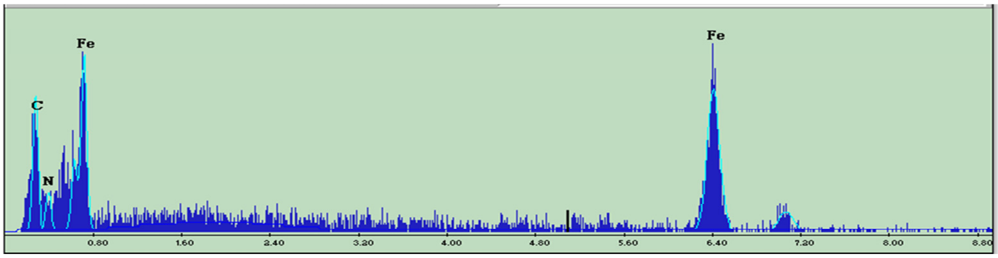

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Fig. 12. The elemental analysis results from Energy-dispersive X-ray: (a) Original product, (b) experiment specimen CN-01.

4. Conclusion

Decarburization still occurs in the original heat treatment process of the plant, since only 20 gram of charcoal mixture charging in the begin cannot prevent the oxidation reaction during the whole process of heat treatment.

From the hardening process experiments, the results show that the composition and amount of each hardening agent mixture (as shown in Table1) have quite a lot of effect on mechanical properties. Charging of hardening agent during the heat treatment process improves wear resistance of the specimens for around 2 times when compared to the original product specimen. The specimen C-02 (hardened by charcoal) and the specimen CN-01 (hardened by mixture of charcoal + urea) have the highest hardness and wear resistance ability at the edge of pin specimens due to the suitable amount of hardening agent mixture. The carbonitrided specimen CN-01 gives slightly better results than the carburized specimen C-02.

Shear strength of all test specimens have no big difference among each other. Although C-02 and CN-01 specimens have the best wear resistance, their toughness are a bit lower than other specimens. However, all mechanical properties such as shear strength and toughness of all test specimens still meet the specification of the plant.

Acknowledgements

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