Pertanika J. Sci. & Technol. 25 (S): 91 - 98 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Correlation of Case Depth with Mechanical Properties of Low Carbon Steel Using Paste Carburizing Method

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ABSTRACT

Powder carburising compound used for pack carburizing has limited potential in producing thicker case depth. Paste carburizing has proved to be an option to replace powder in conventional pack carburizing as it requires less time and temperature to diffuse carbon atoms, and thereby produce greater case depth. The correlation between case depth and mechanical properties using paste carburising is the objective of this paper where the relationship between case depth with mechanical and tribological properties using powder, paste 1:1 and paste 3:1 compounds at 1000°C for 9 hours are studied. Samples were subjected to microhardness tests, tensile tests and wear tests. Results showed paste 1:1 compound produced the highest case depth (>0.5 mm), allowing us to greater tensile strength, 6.61% and high wear resistance, 49%.

Keywords: Carburising compound, case depth, low carbon steel, pack carburizing, paste carburizing, wear

INTRODUCTION

Carburizing is a case hardening process to maintain substrate's ductility of steel by increasing the carbon content of its interior. It is a process usually applied to components that require greater wear resistance such as gears and shafts. The component that need to be carburised is heated to austenite phase temperature (800°C-1000°C) and soaked for 3 to 10 hours for carbon to diffuse on the steel's surface before proceeding to the next process i.e. quenching, normalizing or annealing (Kalpajian & Schmid, 2010). Carburizing compound is a source medium for supplying carbon atoms (carbon monoxides) during the carburizing process. Compounds come in various forms and properties, such as solid, fluid and gases (Lou, 2009). The most

ARTICLE INFO

Article history:
Received: 28 September 2016
Accepted: 03 February 2017

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ISSN: 0128-7680

effective carburizing compound was by using gases as it already in the form of carbon monoxide gases. For pack carburizing, solid or powder compound requires additional temperature and time before they compose into carbon monoxides gases.

Paste compound made of e.g. nitrogen, silicon, boron, carbon, can be used to replace powder for pack case hardening process. For pack carburizing, paste compound consists of a mixture of a carbon resource powder, an inert powder, one or more catalyst and a binder solution (Campos et al., 2005). Paste compound has better diffusion rate than powder compound because of the formability of medium structure, allowing the medium to release more carbon monoxide (CO) and produce thicker carbon-rich layer up to 10-25% on carburized steels (Chen, 2000). Carbon atom diffusion also depends on the level of carbon concentration in the carburizing compound. The ratio of the solute and soluble, the size of the powder and the surface of the sample influences the concentration of the compound and effect the dispersion of carbon during carburizing process. Lou et al. (2009) stated that paste compound was contributory as a self-protective diffusion paste. By using paste carburizing compound, the case depth was thicker compared to conventional pack carburizing. The application of paste has resulted in less distortion since it requires non-intensive temperature. The activation energy of paste compound was less than that of conventional thermal diffusion and the concentration-mixing ratio of paste was ranged from 30% to 70%. The existence of water (H_2O) in the paste mixture has astounding effect in the diffusion of carbon during the case hardening process. The production of hydrogen (H_2) from water-powder mix of the paste relatively speeds up the carburizing rate of the charcoal gas to steel. The production of N_2+CO+H_2 was faster than N_2+CO (Jumadin et al., 2015). However, there are limits to the maximum amount of H_2O that can be present since higher water content in the mixture may reduce the compound's ability to produce the carbonaceous gas from the charcoal because of reduction of carbon concentration (Chen, 1992).

Aswani (2001) and Panda (2014) observed carburizing improves the hardness of low carbon steel. The precipitation of carbon particles to iron, has formed a carbon-based Fe element that allows carbon to be bonded without breaking. Mechanically, the formation of cementite, Fe_3C is very hard and brittle. Another factor contributing to increasing hardness of steel is the formation of martensite achieved by controlling the cooling rate and process parameters. Jumadin et al. (2015) found carburised steel has its highest hardness level at 950°C-1000°C.

Elzanaty (2014) found that the tensile strength of low carbon steel is improved using pack carburizing to 441 MPa-1960 MPa. The higher carbon content has indirectly increased the tensile strength of carburised steel.

Abrasive wear occurs when two different materials come into contact. This study investigates the series of grooves in between carbon steels and stainless steel and observe the wear particles and weight loss. The high hardness value influences the wear rate of a coating subjected to a steady state of wear. Wear resistance on carburised steel has shown great potential due to the formation of cementite towards the surface of the steel, thereby making it harder. Elzanaty (2014) found that weight loss was higher for uncarburised low carbon steel because of its low carbon content. Panda et al. (2014) found that carburised steel at 950°C has better wear properties compared to untreated low carbon steel, reducing wear by up to 45%. Georgieva et al. (2004) thus indicate carburizing when used in sintered gear wheels subjected to contact stresses of 250 MPa no wear was detected.

In this research, the case depth production on low carbon steel using powder carburizing and paste carburizing is studied to better understand the potential of paste carburizing process.

METHOD

In this research, low carbon steel, ASTM 850 Grade 70 steels was used. Experiments were conducted for microhardness, tensile and wear using dog-bone type, pin-type and cube-type samples.

For the microhardness test, a load of 1 kg and 15-second indention time was set at Hardness Vicker Tester Machine model Mitutoyo MCK-H1. Ten microhardness indentions were taken from the steel's surface towards the core, and the distance between each indention was 0.05 mm. Average microhardness values were calculated. The procedure for finding the hardness value of carburised samples were based on standard ASTM E2834 – 11e1 and referred to the method used by Lou et al. (2009). In tensile test, sample of dog-bone type was prepared according to the standard ASTMA283-A283M-12. The sample was pulled until the sample failed with a speed rate of 2 mm/min. Three samples were tested for each carburizing parameter and average data recorded. The procedures for this test follow ASTMA283-A283M-12a. Pin-on-disc tribometer was used to define the friction coefficient and wear properties. A pin-type sample was prepared and a load of 2 kg was applied on a sample which was in contact with a rotating stainless steel counterpart. Initial speed of 200 rpm and test duration of 3600 seconds was set for this experiment. Standard ASTM G190-06 and ASTM G118-02 was used as a reference for the test.

As for carburizing heat treatment process, three different carburizing compounds were prepared; (1) powder compound; (2) paste 1:1 compound; and (3) paste 3:1 compound. These compounds were selected based on the carbon concentration for each sample. Paste 1:1 has 52.8 M and Paste 3:1 has 17.6 M. Powder compound was the combination of charcoal powder with sodium carbonate (Na_2CO_3) and barium chloride ($BaCO_3$). Paste compound refers to the mixture of powder compound with distilled water. The paste compounds were prepared according to the weight ratio of distilled water to powder. Samples were placed inside a steel box and covered with the carburizing compound, heated with temperature of 1000°C for 9 hours inside furnace. At temperature 1000°C, steel is in the austenite phase where solubility is at an optimum, and carbon diffused up to 2.03% C (Kalpajian & Schmid, 2010) deep inside the steel surface at 9 hours. The sample was cooled at room temperature. Table 1 shows the label for different carburizing compound used in this research.

Table 1
Carburizing parameter with different type of compound

Sample	Carburizing Compound
A	Untreated
B	Powder
C	Paste 1:1
D	Paste 3:1

RESULTS AND DISCUSSION

In order to choose the optimum compound, carburizing soaking time and temperature had to be fixed. Microhardness profile was plotted to determine the case depth of carburised low carbon steel. Figure 1 presents the microhardness profile based on the compound used. Sample A shows the microhardness values along 0.5 mm from the surface does not exceed 150 HV. The addition of carbon particles to iron has formed a carbon based Fe element, cementite, Fe_3C that is hard and brittle, resulting from more α-ferrite being transformed to cementite. (Alias et al., 2013).

Paste compound shows a stimulating trend where it has greater case depth and microhardness value compared to powder compound. Sample C and sample D indicate the formation of case depth of up to 0.5 mm while sample B only produces a depth of 0.25 mm. Paste compound has lower activation energy on carbon medium reaction to produce carbon monoxide compares to powder compound (Jumadin et al., 2015). From Figure 1, it can be seen the pattern of sample B and sample D indicates that both microhardness has increased at 0.1 mm and decreased at 0.15 mm, showing the collection of cementite and carbon atoms is at a maximum at 0.1 mm hardness value. However, carbon diffusion was limited and the transformation of cementite started to fade at 0.15 mm due to the low carbon concentration on both paste compound, thus causing the hardness value to decrease from this point onwards. Paste compound has better diffusion rate than powder compound because of the formability of medium structure, allowing the medium to release more CO and produce thicker carbon-rich layer up to 10-25% on carburised steels (Chen, 1992). The ratio of the solute and soluble, 1 parts of waters and 1 part of powder is the optimum composition for paste carburising process. The carbon atom diffusion was also determined by the level of carbon concentration of the carburizing compound (Kulka et al., 2011).

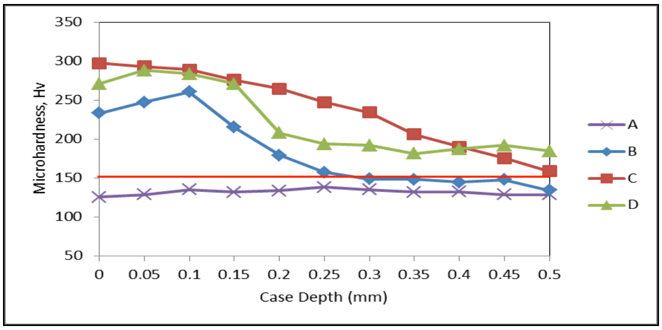

Figure 1. Microhardness and case depth profile

Tensile test was conducted in order to determine the maximum load, tensile stress and strain of the carburised samples. The stress-strain curve shown in Figure 2 shows that untreated sample (sample A) has the typical structural steel stress-strain for low carbon steel (Oyetunji & Adeosun, 2012), demonstrating that sample A was more ductile and has elastic deformation. The ultimate tensile strength sample A was 458 MPa. Sample A has the highest strain, which was 21.91 %.

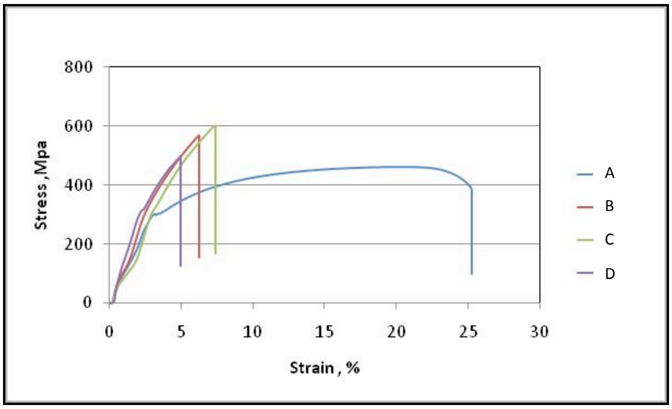

Figure 2. Stress-strain curve

Table 2 and Figure 3 shows the values and the correlation between elongation and tensile strength for carburised samples. Figure 3 shows that elongation was reduced linearly as the case depth increased. Carburising process increased the hardness of the surface material and its brittleness (Aramide et al., 2009). Nevertheless, powder carburising has higher tensile strength compared to untreated low carbon steel. Sample C has the highest tensile strength of 6.61% due to the practice of paste 1:1 compound. Carburising helped to increase the hardness and tensile strength of steel proportionally. The relationship between hardness and strength were also determined by the microstructure of the material. Thus an increase in the microstructure transformation from ferrite to cementite influences tensile strength as ferrite is more ductile compared to cementite which has a more brittle microstructure.

Table 2
Elongation and tensile strength of carburised low carbon steels

Sample	A	B	C	D
Elongation (mm)	21.91	6.28	7.22	5.98
Tensile Strength (MPa)	458.15	558.91	596.02	507.33

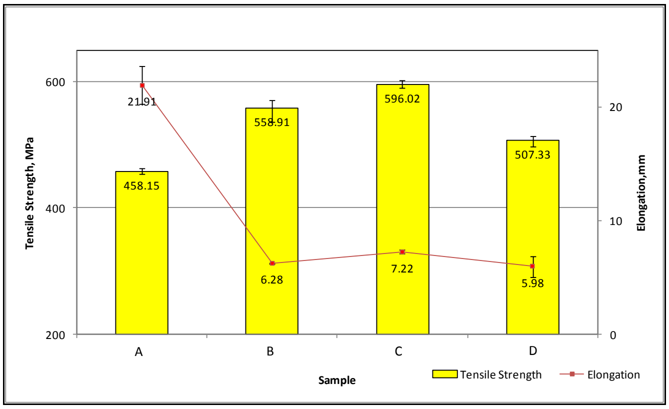

Figure 3. Correlation between tensile strength and elongation

Pin-on-disc test was conducted to investigate the wear properties and the results are tabulated in Table 3. Untreated sample shows the highest weight loss up to 1.7 g after the carburizing process since no case hardening to protect the sample during the friction process between pin and disk.

Table 3
Pin-on-disc weight loss, wear rate and wear resistance

Samples	Weight Loss (g)	Wear Rate (mm^3/Nm)	Wear resistance (Nm/mm^3)
A	1.70	3.62E-06	2.77E+05
B	0.16	3.62E-07	2.77E+06
C	0.08	1.81E-07	5.53E+06
D	0.12	2.65E-07	3.77E+06

Figure 4 shows the wear rate and wear resistance for sample A, B, C and D. Sample A has highest wear rate value of 36.2 x 10^{-7} mm^3/Nm. Carburizing process has reduced the wear rate of low carbon steel. As expected, paste carburizing has better wear resistance compared to powder carburizing because the deeper case depth prevents the surface material from detaching during contact with another surface. Sample C shows the highest wear resistance, 53.3 x 10^7 Nm/mm^3. The relationship between the wear rate and wear resistance indicates that where the wear rate of the material is high, wear resistance is low.

Carburizing process based on paste 1:1 compound provides better wear resistance because of high carbon content, greater case depth and microhardness, influencing the properties of low carbon steels by constructing cementite (Georgieva et al., 2004).

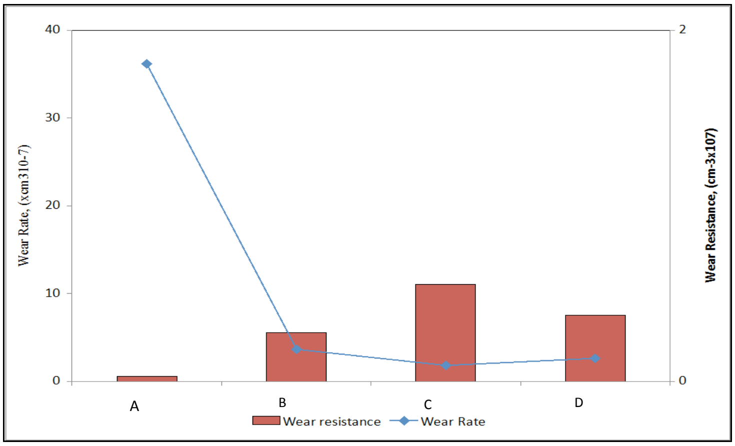

Figure 4. Wear rate and wear resistance of carburised samples

Figure 5 indicates the coefficient of friction versus time of each sample. From the pin-on-disc test result, sample A shows high coefficient of friction compared to the other samples. Higher weight loss indicated low resistance to friction. The figure also shows that the carburizing process increases the wear resistance of low carbon steel. From the test, it can be perceived that paste carburizing improves better wear resistance up to 49%. Wear resistance of carburised steel increases due to greater carbon dispersion on the surface thus providing better coverage from erosion.

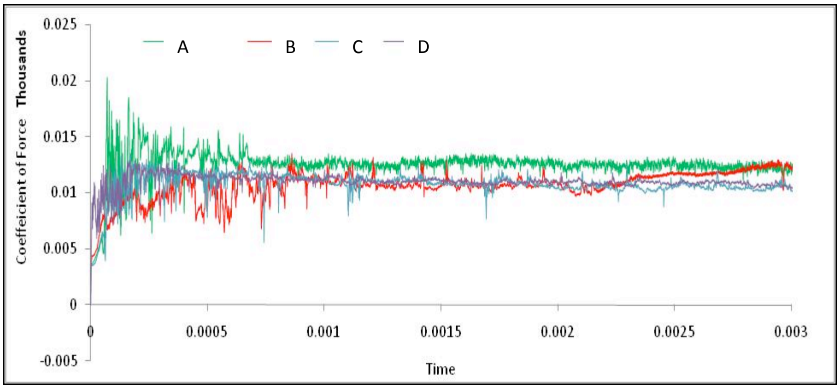

Figure 5. Coefficient of friction versus time for wear analysing wear behaviour

CONCLUSION

In this paper, the correlation between case depth with mechanical and tribological properties using paste carburizing method shows that paste 1:1 has the highest performance compound, generating a case depth of carburised steel up to 0.5 mm. By diffusing more carbon, greater case depth was produced and the microhardness values of steel increased up to 300 HV. The higher case depth from paste 1:1 compound led to increased tensile strength of up to 6.61%. Paste 1:1 carburizing has higher hardness value and wear resistance of up to 49%.

ACKNOWLEDGEMENTS

This research was funded by the Ministry of Education (MOE), Malaysia and Faculty of Mechanical Engineering, Universiti Teknologi MARA, Malaysia, via grant no. 600-RMI/RAGS 5/3 (160/2014) and part supported by grant no. 600-RMI/RAGS 5/3 (50/2013).

REFERENCES

Alias, S. K., Abdullah, B., Jaffar, A., Latip, S. A., Kasolang, S., Izham, M. F., & Ghani, M. A. A. (2013). Mechanical properties of paste carburized ASTM A516 steel. *Procedia Engineering, 68*, 525-530.

Alias, S. K., Abdullah, B., Abdullah, A. H., Latip, S. A., Wahab, N. A., & Ghani, M. A. A. (2013). The Effect of Carburizing Medium on Carbon Dispersion Layer of ASTM A516 Steel. In Applied Mechanics and Materials (Vol. 393, pp. 212-216). Trans Tech Publications.

Aramide, F. O., Ibitoye, S. A., Oladele, I. O. & Borode, J. O. (2009). Effects of Carburization Time and Temperature on Mechanical Properties of Carburized Mild Steel, Using Activated Carbon as Carburizer. *Material Research, 12*(4), 483-87.

Aswani, K. G. (2001). *A Textbook of Material Science (For B.Sc., B.E. and AMIE Students)*. New Delhi: S. Chand & Company Ltd.

Campos, I., Bautista, O., Ramírez, G., Islas, M., De La Parra, J., & Zúñiga, L. (2005). Effect of boron paste thickness on the growth kinetics of Fe 2 B boride layers during the boriding process. *Applied Surface Science, 243*(1), 429-436.

Chen, F. -S., & Wang, K. -L. (2000). Super-Carburization of Low Alloy Steel and Low Carbon Steel By. *Surface and Coatings Technology, 132*, 36-44.

Elzanaty, H. (2014). Effect of Carburization on the Mechanical Properties of the Mild Steel. *Innovative Space of Scientific Research Journals, 6*(4), 987-994.

Elzanaty, H. (2014). The Effect of Carburization on Hardness and Wear Properties of the Mild. *International Journal of Innovation and Applied Studies, 6*(4), 995-1001.

Georgieva, J., Pieczonkab, T., Stoytcheva, M., & Teodosievc, D. (2004). Wear Resistance Improvement of Sintered Structural Parts by C7H7 Surface Carburizing. *Surface and Coatings Technology, 180-181*, 90-96.

Jumadin, M. H., Abdullah, B., Ismail, M. H., Alias, S. K., & Ahmad, S. (2015). Investigation on temperature effect of carburized steel using powder and paste compound. *Jurnal Teknologi, UTM, 76*(3), 56-61.

Kalpajian, S., & Schmid, S. (2010). *Manufacturing Engineering and Technology, Sixth Edition In Si Units*.

Lou, D. C., Solberg, J. K., Akselsen, O. M., & Dahl, N. (2009). Microstructure and property investigation of paste boronized pure nickel and Nimonic 90 superalloy. *Materials Chemistry and Physics, 115*, 239-44.

Lou, D. C., Solberg, J. K., & T. Børvik. (2009). Surface Strengthening Using A Self-Protective Diffusion Paste And Its Application For Ballistic Protection Of Steel Plates.

Panda, R. R., Mohanty, D. A. M., & Mohanta, D. K. (2014). Mechanical and Wear Properties of Carburized Low Carbon Steel Samples. *International Journal of Multidisciplinary and Current Research, 2*(Jan/Feb 2014), 118-12.

Straffelini, G., & Versari, L. (2008). Brittle Intergranular Fracture of a Thread: The Role of a Carburizing Treatment. *Engineering Failure Analysis, 16*, 1448-1453.