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Hardness and microstructure investigation of steel rod ST 42 coated by chrome steel using wire arc spray coating

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ABSTRACT

Purpose: This research aimed to examine the hardness, surface roughness and microstucture in the Steel Rod ST 42 coated by chrome steel using wire arc spray coating with variations in spraying current of 140, 155, 170 and 180 Ampere.

Design/methodology/approach: There was 12 specimens consisting of 3 specimens for each variation of the electric current coating. The specimens were cut to 30 mm in length and 27 mm in diameter; as many as 4 x 3 pieces, each specimen was cut to a size of 30 mm and put on a lathe to be drilled 1 mm deep. The hardness testing employed the Brinell hardness test method. The hardness testing process was followed by microstructure observation and SEM-EDAX testing.

Findings: The highest hardness was 110.77 HRB by coated at 155 A and it contained many reinforcing inclusions and larger Cr. The lowest current of 140 A had many porosity holes and partially-melted particles, causing Cr grains did not attach perfectly. The current with 170 A had few inclusions and hence a decrease in hardness and at 180 A consisted of a low carbon content and evenly distributed inclusions and Cr and relatively large grain size, and thus the hardness rose.

Research limitations/implications: The material of steel rod ST 42 coated by chrome steel.

Practical implications: The variation of current should be prepared wisely in term because it will effect the hardness, surface roughness and microstucture. This research can be improved by varying the voltage, gas pressure, particle velocity, particle temperature, and molten wire width.

Originality/value: Simple route of making steel rod ST 42 coated by chrome steel using wire arc spray coating and also the investigation of hardness, surface roughness and microstucture in steel rod ST 42 coated by chrome as the result.

Keywords: Wire arc spray coating, Thermal spraying, Chrome steel

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PROPERTIES

1. Introduction

Metal wear on machine tools is inevitable. Metal wear occurs due to ageing process and load. Several examples of losses incurred by metal wear are high-frequency vibrations in the machine and a decrease in production because the machine is not working optimally. Improving wear resistance of components can be done in various ways that essentially are to thicken the surface or restore the worn surface diameter to its original state.

One method that is commonly used in the world of industry is surface welding or welding the surface of the worn object to proper levelling. Material coating technology has been very much a subject in today's research and industry because it is a cost-effective way to prevent degradation, such as wear, oxidation, corrosion and failure under excessive heat, without sacrificing the underlying substrate [1], so increase the labor productivity [2].

The most frequently used type of coating in the industry is the thermal spray method. Based on its energy source, the thermal spray method can be divided into several main groups, i.e. plasma spray: atmospheric plasma spraying (APS), vacuum plasma spraying (VPS), and low pressure plasma spraying (LPPS), flame spray: combustion flame spraying, high velocity oxy/air-fuel (HVOF/HVAF), arc spray and others [3].

Wire arc spray coating is also included in the thermal spray group, which is a coating process whereby the raw material is heated and dripped onto the surface. In this process, two wire electrodes are connected to an energy source with a DC and then incorporated into a spray gun to form an arc between the two electrodes to be used to melt the coating material. Wire arc spray coating is an engineering solution for reconditioning, corrosion and heat protection, or surface modification by spray coating with other materials under certain conditions resulting in the diameter of the workpiece back to its original state. Wire is more economical and easy to use than powder [4].

The metal coatings used are all kinds of metal materials including Aluminium (Al), Bronze, Babbitt, Copper (Cu), Nano Composite, Nickel (Ni), Chrome Steel (Cr), Titanium (Ti), Wolfram (W), etc. Chrome steel (Cr) is corrosion- and wear-resistant metal that is commonly used in industry as a shaft coating material and component exposed to friction. This type of steel is also relatively cheaper compared to Nickel and is available in simple carbides (Cr_2C_3, Cr_4C) or complex one ($[FeCr]_3C$). The carbides have a high hardness and are resistant to wear [5]. In this study, therefore, we made use of chrome steel as a coating material in the wire arc spray coating.

2. Methodology

In this study, we conducted hardness testing on 12 specimens consisting of 3 specimens for each variation of the electric current coating. The specimens were cut to 30 mm in length and 27 mm in diameter; as many as 4 x 3 pieces and added with one piece for untreated testing and the making of groove in which the coating was placed. Prior to the spraying of coating, the bonding material was sprayed between the parent metal and the coating material. The coating process was performed at PT. Tunas Harapan Engineering Surabaya. After coating, each specimen was cut to a size of 30 mm and put on a lathe to be drilled 1 mm deep, aimed to obtain the cross-section of the specimen. The hardness testing employed the Brinell hardness test method with reference to the ASTM E18-03 standard hardness test. The hardness testing process was followed by microstructure observation and SEM-EDAX testing.

3. Results and discussion

3.1. Results of hardness testing

The highest hardness value was found in the specimen subjected to a current of 155 Ampere (Fig. 1). This happened because the density between the substrate and the coating layer was so high that the hardness value increased.

The surface density and coating porosity serve to increase the value of hardness [4]. An increase in core hardness occurs due to a rise in the perlite content, and this increase in the number of perlites results from heat input [6]. In this study, the results of hardness testing on the core area of the specimens were relatively the same since the core area was in fact not influenced by variations in current.

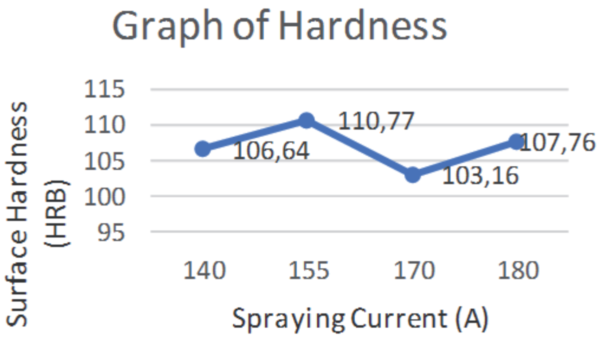

Fig. 1. Graph of hardness number of ST 42 coated with chrome steel

According to Girsang in [7], thermal coatings tend to be highly porous although porosity can be controlled by optimising the variable process. The porosity occurs because the melting of the coating material is not perfect so as to make the substrate form a cavity. The porosity of the coating can affect mechanical properties such as hardness. The higher the porosity, the lower the hardness and thus the higher the density, the greater the hardness [8].

The outside area had a high hardness value. This happened because the molten wire flew off due to air pressure from the wire arc spray coating. The effect of external air oxidation also resulted in the grains of molten wire attached to the specimen and the level of hardness increased. This increased hardness occurred because, during the wire arc spraying, the oxidation content of the sprayed coating was relatively high due to the oxidation of the molten wire.

According to [9], oxidation may also be detrimental to the coating properties because the oxide can reduce the strength of adhesion between the coating and the substrate. Referring to this, a decrease in hardness under a current of 180 A was due to the weakened bond between coating and substrate. The presence of porosity in the coating can also cause a decrease in hardness. An increase in porosity took place because air pressure cannot break the molten particles into fine grains. The smaller the coating particle size, the higher the surface roughness [8].

3.2. Result of surface roughness testing

Figure 2 shows that there was an increase in surface roughness value, though insignificant.

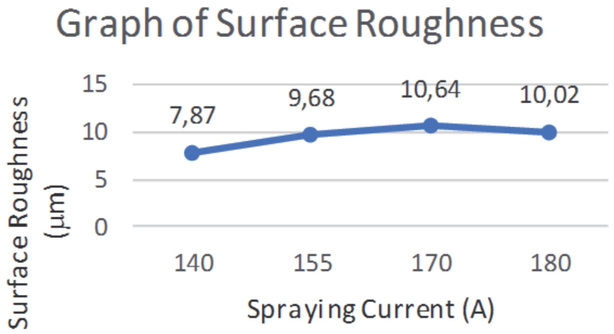

Fig. 2. Graph of Surface roughness of ST 42 coated with chrome steel

According to [10], average surface roughness is highly dependent on the following parameters: current, voltage, gas pressure, particle velocity, particle temperature, and molten wire width. At a current of 180 A, the surface roughness decreased as the wire melted faster, causing the 30 Psi wind pressure unable to decompose the molten wire particles into fine grains upon reaching the substrate. As a result, the particles attached were in the form droplets. Large droplets have a low melting point or only melt partially, this kind of droplets increases the roughness of the substrate surface [11].

Roughness may occur due to the presence of some materials which have not fully melted completely upon reaching the substrate, resulting in some particles still in the shape of spheres attached to the surface; this increases the surface roughness of the coating Renault [12].

However, some researchers believe that gas pressure also affects the surface roughness of the specimen. The molten particles sprayed on the specimen may not be completely attached even in powder form. Particles sprayed at high speeds produce a good surface coating consisting of many small particles of molten wire, which is a major factor in decreasing porosity and surface roughness [13]. The coating material is sprayed to create a deformation effect and rapid freezing of molten wire droplets so that the coating structure comprises a series of overlaps. Particle velocity and temperature determine the structure of the coating on the substrate [9].

Table 1.
Result of hypothesis testing on surface roughness of steel rod ST 42

ANOVA					
Hardness Value					
	Sum of Squares	ddf	Mean Square	F	sig.
Between Groups	12.704	3	4.235	1.931	.203
Within Groups	17.546	8	2.193		
Total	30.250	11			

The value of significance was 0.203> 0.05, and thus H_{o1} was accepted. It indicates that there was no difference in surface roughness due to variations in electric current (140 A, 155 A, 170 A, 180 A). A similar result was also found in the post hoc test. The `*` sign did not appear in the Mean Difference column of the Multiple Comparisons Table 1, meaning that there was no significant difference.

However, as shown in Figure 2, the testing results of specimens coated with chrome steel suggested a likely effect of variations in electric current on surface roughness.

3.3. Microstructure testing

The microstructure test was conducted to identify the grain type and shape of specimens which are not visible to the naked eye. Also, it aimed to examine the layers formed on the specimens – Figures 3-6.

Photomicrography aims at observing the specimen structure at the microscopic scale. Images of specimens in this study were taken at a visual magnification of 100x after the specimens went through the process of smoothing and levelling and were given the etching solution.

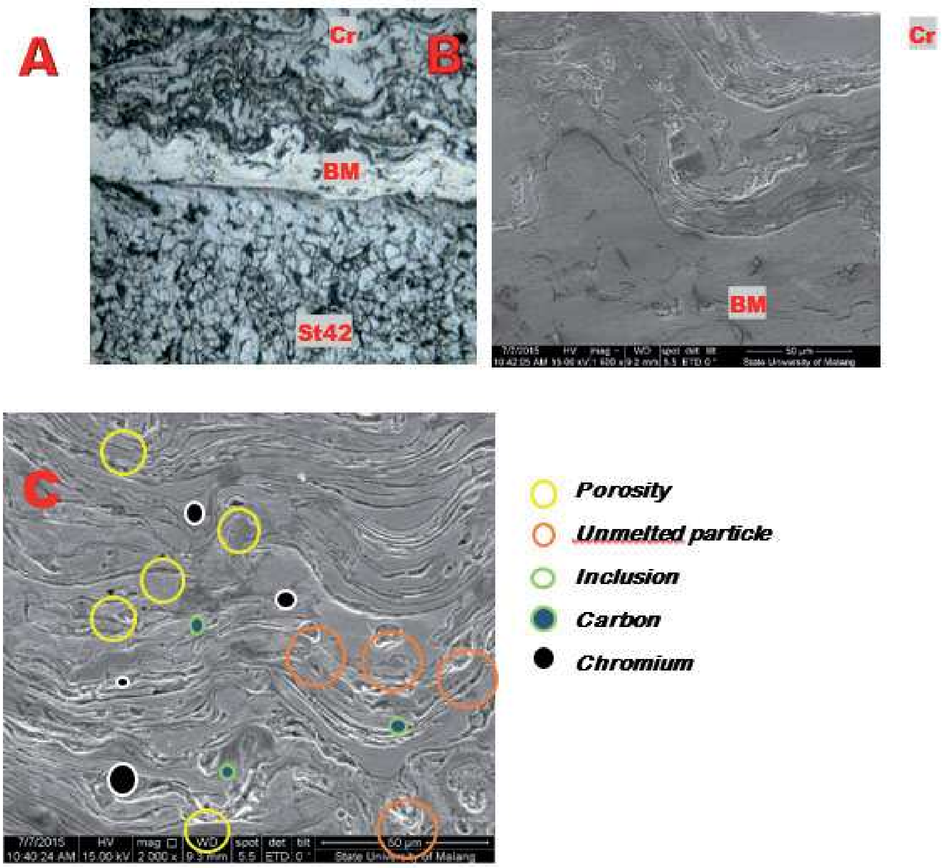

Fig. 3. Photomicrographs of the results of wire arc spray coating at 140 A: (A) bonding of chrome steel, bonding material, and steel ST 42 at 100x magnification; (B) SEM image of bonding between chrome steel and bonding material at 1600x magnification; (C) SEM image of chrome steel at 2000x magnification

Cr grain is a type of body centred cubic (BCC) which is softer but has a higher tensile strength than other grain types [14]. The structure of BCC unit consists of atoms at each corner of the cube and one in the centre, and this is called α or ferrite iron. The most components are ferrite, pearlite and carbon.

Most metal coatings undergo oxidation during normal thermal spraying in ambient air. Oxidation products are usually included in the coating. In general, oxides are harder than the parent metal. A coating containing a high content of oxide tends to be tougher and more wear resistant. This oxidation takes place in the inclusion that occupies the formed cavity [15]. Sprayed particles can attach to the substrate because of the atomisation by air and high particle velocity. Inclusion trapped when particles hitting the object has favourable properties for Chrome Steel layer because it adds hardness and strengthens the bond between molecules inside. Thermal spray coatings tend to be porous although porosity can be controlled by optimising the variable process. This coating can be adjusted to the desired thickness and applied to the structure created [16]. This is in line with [16], stating that Chromium exhibits a good adhesion bond with steel, nickel and copper.

Moreover, [17] revealed that in terms of characteristics, the most optimal spraying process in some specimens was difficult to estimate the strength of coating adhesion. This occurs when the adhesion strength of the coating is greater than the adhesive bond between the Bonding Material and the surface of the object.

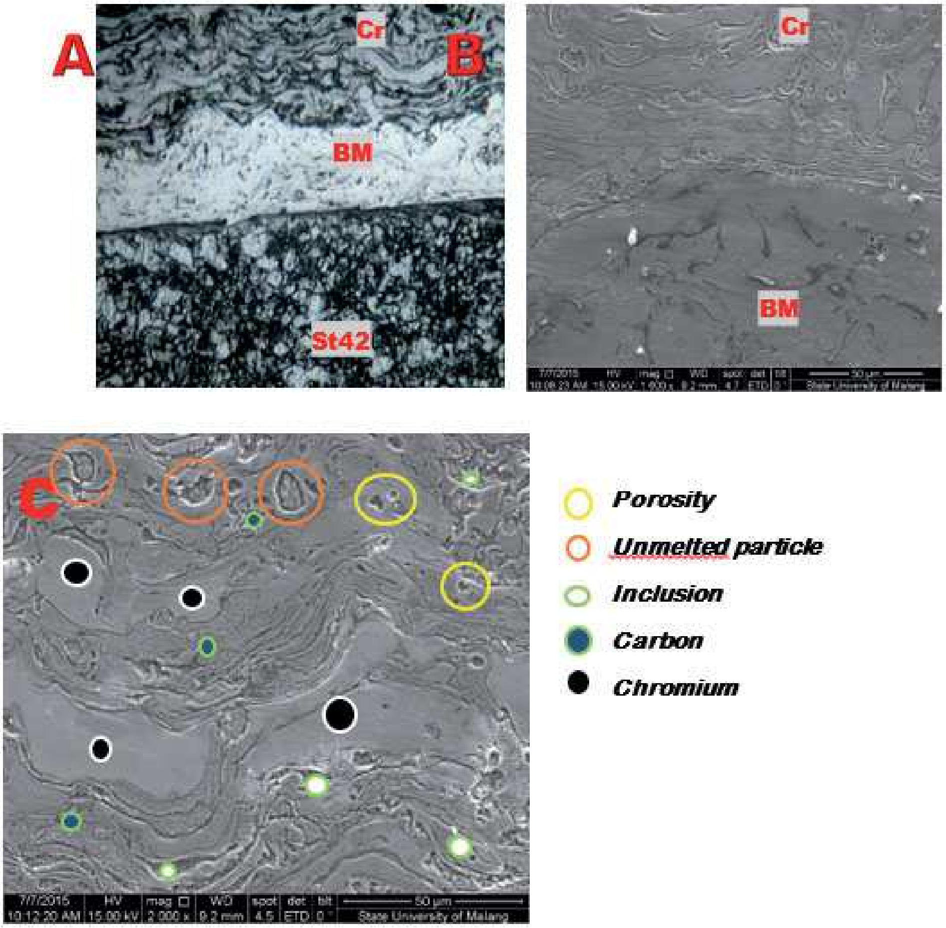

Fig. 4. Photomicrographs of the Results of Wire Arc Spray Coating at 155 A: (A) bonding of chrome steel, bonding material, and steel ST 42 at 100x magnification; (B) SEM image of bonding between chrome steel and bonding material at 1600x magnification; (C) microstructure image of chrome steel at 2000x magnification

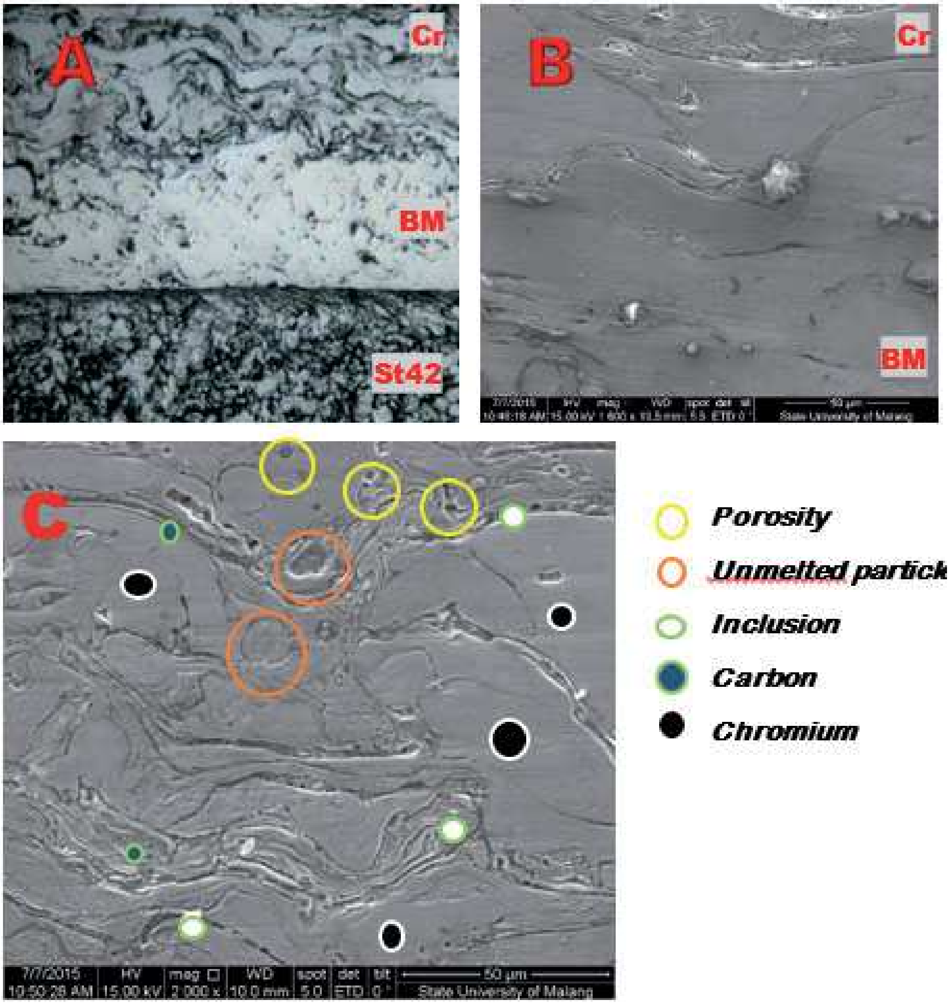

Fig. 5. Photomicrographs of the results of wire arc spray coating at 170 A: (A) bonding of chrome steel, bonding material, and steel ST 42 at 100x magnification; (B) SEM image of bonding between chrome steel and bonding material at 1600x magnification; (C) microstructure of chrome steel at 2000x magnification

Based on the results of microstructure and SEM testing in Figures 3-6, the relationship between the hardness with the structure formed is described as follows:

1. The specimen coated at 140 A had the second lowest hardness, i.e. 106.64 HRB. This occurred because a high number of grains did not melt (Figure 3 [c]) and the current transmitted was not strong enough to melt all Cr materials. This specimen also had many porosity defects spread throughout the object. The Cr matrix grains were small and evenly distributed, so they did not strengthen the specimen. There were many inclusions found which were supposed to strengthen the workpiece. However, the number of inclusions coupled with the number of unmelted grains become the primary factor of the low hardness.
2. The specimen coated at 155 A had the highest hardness, i.e. 110.77 HRB. As shown in Figure 4 [c], there were many reinforcing inclusions acting as ferrites that strengthened the specimen. The toughness of the steel can be improves without the decrement of strength and hardness by existence ferrite [18]. Among the other specimens, this specimen had the lowest number of unmelted particles. Large Cr grains, which served as a matrix, were equally distributed, so that added the value of hardness as well. The relatively large matrix size indicates a better grain growth than the previous specimen. However, many crystalline grains appeared and hence many black cavities.
3. The specimen coated at 170 A had the lowest hardness, i.e. 103.16 HRB. Figure 5 shows a brighter specimen; it

was because only a small number of pearlites were formed and the amount of carbon was less than Cr that acted as a matrix. A high level of porosity was also found. The number of inclusions formed was low and hence minor contribution to hardness. Some particles were found to be melted partially; it was because some oxidation of the spray material occurred before attaching to the surface of the specimen.

4. The specimen coated at 180 A had the lowest hardness, i.e. 107.76 HRB. Figure 6 shows bright specimen structure with low carbon content, evenly distributed inclusions and Cr, and relatively large grain size. It indicates a balanced combination of matrix and binder, which could increase hardness. This specimen did not exhibit the highest hardness due to the high level of porosity.

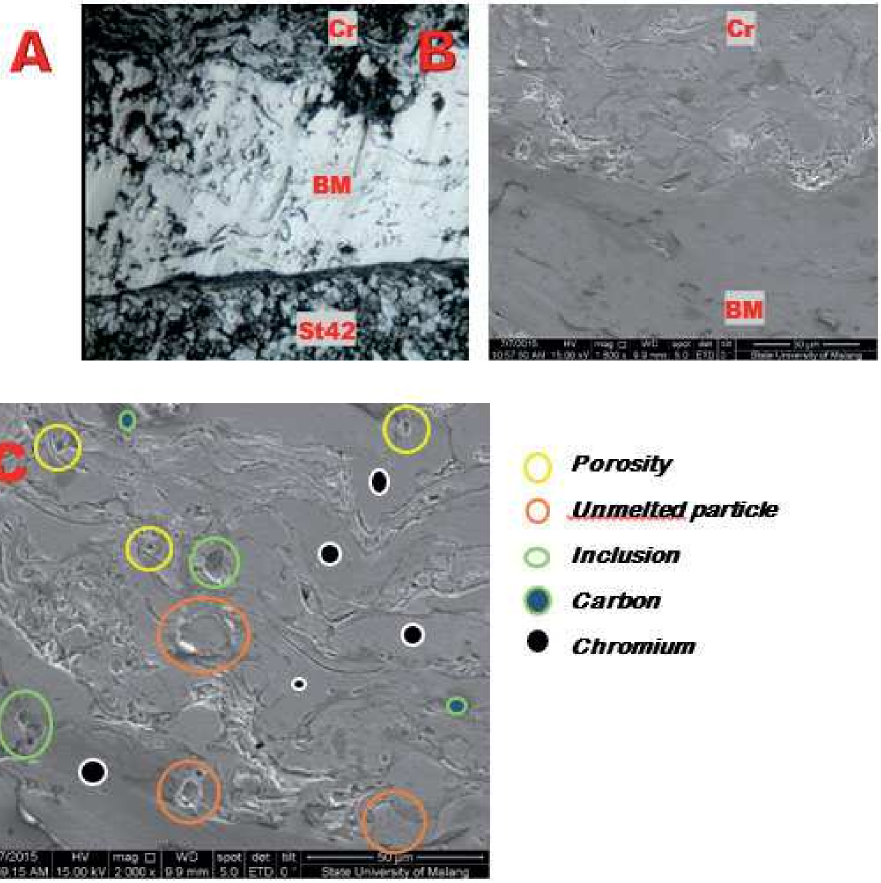

Fig. 6. Photomicrographs of the results of wire arc spray coating at 180 A: (A) bonding of chrome steel, bonding material, and steel ST 42 at 100x magnification; (B) SEM image of bonding between chrome steel and bonding material at 1600x magnification; (C) SEM image of chrome steel at 2000x magnification

The layer boundary in each specimen was also different; a layer boundary is a boundary formed between the surface of Bond Material and Chrome Steel deposit—the greater the current transmitted, the thicker the layer boundary. This layer boundary is called Thermally Grown Oxide or TGO [19]. As shown in Figure 3 (B), the use of the lowest current (140 A) generated the thinnest layer boundary as well. The coating at 155 A resulted in a wider layer boundary than the previous specimen, as shown in Figure 4 (B). Figure 5 (B) as the result of coating at 170 A shows a layer boundary wider than the previous two specimens. The widest layer boundary was found in the specimen coated at the highest current of 180 A.

4. Conclusions

Based on experiment, it can be concluded that:

1. The hardness value obtained after spraying Chrome Steel with the Wire Arc Spray Coating method was in the range of 103.16 HRB to 110.77 HRB. The specimen coated at

155 A had the highest hardness, whereas the specimen coated at 170 A had the lowest hardness. There were two groups of currents that had an increased hardness tendency: the low-current group included the variations of 140 A and 155 A, whereas the high-current group consisted of the variations of 170 A and 180 A. The hardness values of specimens in the low-current group were 106.64 HRB and 110.77 HRB and those in the high-current group were 103.16 HRB and 107.76 HRB.

2. The specimen sprayed at the lowest current of 140 A had many porosity holes and partially-melted particles, causing Cr grains did not attach perfectly. The specimen sprayed at 155 A contained many reinforcing inclusions and larger Cr. The specimen subjected to the spraying at 170 A had few inclusions and hence a decrease in hardness. The specimen sprayed at 180 A consisted of a low carbon content and evenly distributed inclusions and Cr and relatively large grain size and thus the hardness rose.

References

[1] G. Sundararajan, K.U.M. Prasad, D.S. Rao, S.V. Joshi, A Comparative Study of Tribological Behavior of Plasma and D-Gun Sprayed Coatings under Different Wear Models, Journal of Materials Engineering and Performance 7/3 (1998) 343-351.

[2] A. Li, Effect of Pre-Quenching and Pre-Normalization on Microstructures And Mechanical Properties of 40Cr Steel After Zero-Time-Holding Quenching, Engineering Review 32/2 (2014) 69-74.

[3] B.Q. Wang, M.W. Seitz, Comparison in erosion behavior of iron-base coatings sprayed by three different arc-spray processes, Wear 250/1-12 (2001) 755-761.

[4] S. Setiawan, Y. Setiyorini, Effect of Nozzle Angle Variation on Spray Coating Arc on 13% Chrome Steel Layer Abrasive Resilience, J. Tek. Pomits 2/1 (2013) 3-4.

[5] H.A. Avner, Introduction of Physical Metallurgy, Second Edition, City University of New York, New York, 1974.

[6] F. Riyadi, D. Setyawan, Mechanical Analysis and Metallurgical Welding of A36 Carbon Steels with SMAW Method, Institut Teknologi Sepuluh Nopember, 2011.

[7] A.S. Haryono, Wire Arc Spray Coating Current Variation to Hardness and Microstructures of ST 42 Shaft Using Chrome Steel Coating, Universitas Negeri Malang, 2015.

[8] E. Riyanto, B. Prawara, Microstructure and Characterization of Mechanical Properties of Coatings Cr_3C_2-$NiAl$-Al_2O_3 Result of Deposition by Using High Velocity Oxygen Fuel Thermal Spray Coating, Journal of Mechatronics, Electrical Power, and Vehicular Technology 1/1 (2010) 1-4.

[9] I. Gedzevičius, A.V. Valiulis, Influence of the Particles Velocity on The Arc Spraying Coating Adhesion, Materials Science (Medžiagotyra) 9/4 (2003) 334-337.

[10] J. Wilden, J.P. Bergmann, S. Jahn, S. Knapp, F. van Rodijnen, G. Fischer, Investigation about the Chrome Steel Wire Arc Spray Process and the Resulting Coating Properties, Journal of Thermal Spray Technology 16/5-6 (2007) 759-767, DOI: https://doi.org/10.1007/s11666-007-9114-8.

[11] V.V. Sobolev, J.M. Guilemany, A.J. Martín, Flattening of composite powder particles during thermal spraying, Journal of Thermal Spray Technology 6/3 (1997) 353-360, DOI: https://doi.org/10.1007/s11666-997-0070-0.

[12] C. Trijatmiko, H. Pratikno, A. Purniawan, Analysis of the Influence of Abrasive Materials on Blasting Against the Sticky Powers of Cat and Corrosion Resistance in Sea Water Environment, J. Tek. ITS 5/2 (2016) 231-235.

[13] W. Ruijun, X. Lin, Z. Tianjian, H. Xiaoou, The Properties of the High Productive High Velocity Arc Sprayed Coatings and its Applications, Proceedings of the Thermal Spray 2004: Advances in Technology and Application, Osaka, Japan, 2004.

[14] J.E. Neely, T.J. Bertone, Practical Metallurgy and Materials of Industry, Sixth Edition, Prentice Hall, New Jersey, 2003.

[15] H.R. Gordon, M. Wang, Surface-roughness considerations for atmospheric correction of ocean color sensors. II: Error in the retrieved water-leaving radiance, Applied Optics 31/21 (1992) 4261-4267.

[16] M.P. Girsang, Fabrications and Characterization of NiCoCr Layers on Commercial Steel Substrate, Universitas Sumatera Utara, 2012.

[17] I. Gedzevicius and A. V. Valiulis, Analysis of Wire Arc Spraying Process variables on coatings properties, Journal of Materials Processing Technology 175/1-3 (2006) 206-211, DOI: https://doi.org/10.1016/j.jmatprotec.2005.04.019.

[18] A. Li, Modifying the Microstructure and Property of 30CrMNSi Steel by Subcritical Austenite Reverse Transformation Quenching, Engineering Review 35/2 (2015) 97-102.

[19] H.M. Tawancy, Analysis of Thermally Grown Oxide Developed by Thermal Barrier Coatings with the Aid of Selective Deep Etching, Metallography Microstructure, and Analysis 2/2 (2013) 88-95.