Effects of Weldment Layer on the Tungsten Carbide Hardfacing Microstructure

Mohd Tobi A L1, Nagentrau M2, Kamdi Z2, Ismail M I3, Omar A S3

1Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia,
2Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia,
3Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia,
abdlatif@uthm.edu.my

Abstract: Hardfaced carbon steel blade is used to mix ilmenite ore with sulphuric acid as part of a production process inside a digester tank. The carbon steel blade wear life is improved by applying tungsten carbide (WC) hardfacing using shielded metal arc welding (SMAW). This study addresses the effect of welding layers on the microstructure and distribution of WC hardfaced. The influence of different number of welding layer (1 layer, 2 layers and 3 layers) on WC hardfacing microstructure and hardness value were analysed using scanning electron microscope (SEM) and micro-Vickers hardness tester respectively. It is revealed that the growth of large-sized carbide and distribution uniformity of small-sized carbide in hardfacing region is increasing with number of welding layers applied during the hardfacing. The volume fraction analysis of the WC in the hardfacing region shows linear increase with the increase of number of layers. Small-sized carbide grows larger with increasing number of welding layer applied in the matrix region. The continuous supply of heat energy from multiple layers of welding assists on the growth of WC in the hardfaced region increasing its hardness and subsequently increasing the wear resistance.

Keywords: Hardfacing, tungsten carbide, layer, carbon steel blade

1. Introduction

Surface coating has been considered as an effective approach in increasing the lifetime of engineering components [1-3]. In addition, surface treatment technology is widely used in the industry for protecting working tools from wear and resisting corrosion [4]. Hardfacing welding technique is one of the surface treatments commonly practiced in the industry [5]. The service life of components subjected to abrasive wear can be extended by hardfacing deposit on the parts exposed to the wear process [6]. Components operating under severe condition and exposed to wear and corrosive environments can be hardfaced with coating material in order to provide wear protection [7]. Tungsten carbide (WC) is widely used as hardfacing material because of its high hardness, high thermal conductivity and good wettability [8, 9]. Katsich and Badisch reported that WC coatings are broadly utilized in enhancing the lifetime of engineering components that operate in severe environment [10-11].
Numerous studies have attempted to explain the effect of number of welding layers influences on the performance of hardfacing coating. Coronado et al. highlighted that abrasive wear resistance will be higher if three layers of welding is applied [12]. Buchely et al. states that higher number of hard-facing layer will give a better wear resistance of the coating [13]. Microstructural characteristics, especially carbide distribution influences the wear resistance of hardfacing coating. Desai et al. [14] and Shetty et al. [15] investigated the dependency of abrasive wear mechanism on the microstructure of hardfacing coating. They discovered that the amount, size and distribution of carbides have great influence on the wear rate. Leech et al. shows that high uniformity of WC distribution in a WC-Ni based metal matrix composite is able to provide better resistance against wear in the condition of pure abrasion [16]. It is found that closely spaced uniformly distributed carbide ensured abrasives cannot penetrate effectively into the coating matrix, resulting in higher wear resistance [17].

The presented research work has the main goal to evaluate the influence of WC welding layers on the overall carbide distribution in the coating. Elemental composition, micrograph and volume fraction analyses were conducted. The number of welding layers influence on carbide distribution in the coating are studied along with its hardness values in order to improve the wear resistance of the hardfaced coating.

2. Sample preparation

2.1. Blade and electrode

Figure 1 illustrates the BS3100 carbon steel Grade A3 blade that acts as the base metal in the hardfacing process. Carbon percentage in the blade determines the grade of the blade. Carbon (C) and Manganese (Mn) are the major elements in carbon steel. Meanwhile, other minor elements are also present as provided in Table 1. WC electrode enclosed in tubular mild steel is used as the hardfacing electrode. WC is hard material with excellent corrosion resistance which is suitable for hard surfacing of speed mullers, pump impellers cutter knives, and construction machineries. The electrode is approximately 6 mm diameter and 350 mm long. Table 2 presents the electrode chemical composition.

![Blade and electrode](image)

**Figure 1.** Hardfaced carbon steel blade.

| Element | C  | Mn | Si  | S  | Mo | P  | Ni  | Cr  | Fe  |
|---------|----|----|-----|----|----|----|-----|-----|-----|
| Composition (%) | 0.32 | 0.74 | 0.25 | 0.01 | 0.02 | 0.02 | 0.17 | 0.29 | balance |

| Element | C  | Si  | Mn  | W   | Fe  |
|---------|----|-----|-----|-----|-----|
| Composition (%) | 3.1 | 0.4 | 1.5 | 60.2 | balance |
2.2. Hardfacing method and welding condition

Shielded Metal Arc Welding, better known as SMAW, was assigned for this particular welding condition due to its extensive usage in the industries. The portability of its welding equipment and relative simplicity of SMAW welding makes it more economical without requiring any complex equipment compared to other welding methods. Besides that, SMAW welding is well-known for its versatility as it is readily applied to different applications with wide electrode choices. The low cost SMAW welding is also adaptable to remote locations and confined spaces. Horizontal welding direction in a flat position approach is practiced during hardfacing deposition of WC on carbon steel blade as shown schematically Figure 2. The position of weld deposit and specimen cut location is presented in Figure 2. Table 3 shows the hardfacing condition using SMAW welding. 1, 2 and 3 layers of hardfacing are employed to examine the influence of number of layer on the microstructure of WC hardfacing coating. Welding current, blade pre-heat and electrode drying are maintained to investigate welding layer effect on the hardfacing. Table 4 exhibits the welding parameters employed.

![Figure 2. Schematic diagram of hardfacing deposit on carbon steel blade.](image)

### Table 3. Welding conditions using SMAW welding method.

| Welding size | Welding speed | Polarity | Electrode feed rate | Welding length | Electrode length |
|--------------|---------------|----------|---------------------|----------------|------------------|
| 2.0 cm       | 0.0025 m/s    | DC       | 0.0035 m/s          | 8 cm           | 35 cm            |

### Table 4. Specimens with different number of welding layer.

| Specimen | Layer | Current (A) | Blade Preheat | Electrode drying |
|----------|-------|-------------|---------------|------------------|
| 1        | 1     | 150         | Yes           | Yes              |
| 2        | 2     | 150         | Yes           | Yes              |
| 3        | 3     | 150         | Yes           | Yes              |

2.3. Sample cross section

Three specimens at various locations from hardfaced carbon steel blades are sectioned as illustrated in Figure 3. The specimens are sectioned using EDM (Electrical discharge machining) wire cutting with a dimension of 10 mm x 10 mm x 25 mm as shown in Figure 3a. The rough surface of sectioned...
specimens are flattened using grit paper starting from 100, 240, 500, 800, 1000, 1200 and 2000, which are of particle size of 162.0 µm, 58.5 µm, 21.8 µm, 18.3 µm and 10.3 µm respectively and followed by polishing process. Three positions A, B, and C are focused on each specimen for microstructure analysis as illustrated in Figure 3b.

![Figure 3](image)

**Figure 3.** (a) Schematic view of the sectioned specimen from carbon steel blade and (b) specimen cross-section schematic position for coating thickness and SEM analyses.

3. Results and discussion

3.1. Micrograph of the WC hardfacing

SEM is used to investigate the microstructure of the specimens. The carbide distribution pattern is observed from the SEM images. Figure 4 shows general WC hardfacing cross-sectional view. It is noted that hardfacing specimen is made up of carbide region, non-carbide (matrix) and substrate regions. The substrate region is distinguished as being darker compared to the coating region due to the absence of tungsten element. Large-sized carbide (of about 1 mm in diameter) tends to concentrate at the lower portion of coating region (near the coating-substrate interface).
Figure 4. General WC hardfacing cross-sectional SEM image view; a) large-sized carbide region, b) non-carbide (matrix) region, and c) substrate.

EDS analysis is conducted to determine the elemental composition of the substrate and the coating. EDS analysis results are presented in Figure 5a, 5b and 5c for the carbide region, non-carbide (matrix) region and substrate region, respectively (as annotated in Figure 4). It is apparent from the figures that tungsten (W), carbon (C), oxygen (O) and iron (Fe) are identified in the EDS analysis. As expected, a high percentage of W is found in the carbide region. The non-carbide (matrix) region is rich in both W and Fe indicative of carbide and binder in close proximity. The substrate region mainly consisted of Fe.

3.2. Effect of welding layer on carbide growth

Figure 6 exhibit the effect of hardfacing layer on the microstructure of the coating. The present study indicates higher number of weld layers (three layers) caused more large-sized carbide presence in in the coating region compared to lower number of layers. It can be seen progressively the large-sized carbide presence in the coating increasing with increasing number of layers applied. Figure 7 illustrate the weldment layer effects on the WC hardfacing coating microstructure in non-carbide (matrix) region. The results of the present study show that as the number of layers increased, the nucleation and growth of the WC particle is increasing in size. The SEM images shown in Figure 7 highlight the nucleation process of the WC in dendritic shape for 1 layer case. As the number of layers increases to 2 and 3 layers, the WC particles become larger. Continuous deposition of multiple weld layers (three layers) can supply continuous heat energy for the carbide to nucleate and growth.
Figure 5. EDS elemental composition analysis of (a) carbide region, (b) non-carbide (matrix) region and (c) substrate region.
Figure 6. Microstructure of overall coating region for different number of welding layer.

Figure 7. Microstructure of non-carbide (matrix) region for different number of welding layer.
3.3. Volume fraction analysis

WC volume fraction analysis on WC hardfaced microstructure was conducted. The volume fraction analysis is performed to calculate WC particle percentage in overall coating region. The higher percentage of WC volume fraction indicates the abundance of WC particles in the coating region. Table 5 presents the volume fraction of WC (%) with different number of welding layer. Higher WC volume fraction is registered for high number of weld layers (3 layers). Heat energy supplied due to continuous deposition of multiple weld layers (three layers) enable carbide growth, hence increasing the carbide content in overall coating region in almost linear rate of increase.

Table 5. Volume fraction of WC (%) with different number of welding layer.

| Specimen | Layer | Volume fraction of WC (%) |
|----------|-------|--------------------------|
| 1        | 1     | 3.4                      |
| 2        | 2     | 26.64                    |
| 3        | 3     | 50.12                    |

3.4. Microhardness analysis

Hardness tests are performed using micro-Vickers hardness tester of 0.5 HV load on specimens for different position on substrate, carbide and non-carbide (matrix) regions respectively. Figure 8 shows the hardness values of the substrate, carbide and non-carbide regions. As expected, the carbide region had higher hardness compared to the non-carbide region. The hardness value registered for the carbide regions is higher (1795 HV) compared to the non-carbide region (814 HV). The hardness value will be higher if the indentation is biased toward on carbide region.

![Figure 8. Hardness value for different regions of the hardfaced carbon steel blade specimen.](image)

The hardness value of non-carbide region on the hardfaced blade with different number of weld layers is illustrated in Figure 9. Higher hardness value is registered for high number of weld layers (3 layers) compared to lower number of layers (1 layer). This supports the evidence of growth of carbide in non-carbide (matrix) region (Figure 7). Hardness is frequently used as an indicator of wear resistance of a material. Higher hardness will lead to greater wear resistance for the hardfaced blade [18]. Thus, high number of weld layers can increase the hardness of the hardfacing and subsequently enhancing the wear resistance.
A microstructural analysis of tungsten carbide (WC) hardfacing on a carbon steel blade is examined. The influence of number of weld layers on coating microstructure, elemental presence, volume fraction and hardness are studied in details. The presented results allow the following conclusions to be made:

- Large-size carbide is presence in the coating near the substrate interface and the volume is increasing linearly with increasing number of weldment layers.

- Continuous welding of multiples hardfacing layers supplies continuous heat energy to the weldment causing WC to nucleate and growth in the non-carbide (matrix) region. This subsequently increases the overall coating hardness.

- Increasing number of layers will increase the hardness of the non-carbide (matrix) region thus increasing the overall coating hardness. This will provide better wear resistance of the hardfacing.

Acknowledgement

The authors acknowledge the financial support by the Ministry of Education Malaysia and Universiti Tun Hussein Onn Malaysia. This research is supported by the Short Term Grant (STG), Vot. No. U643 and Knowledge Transfer Programme (KTP), Vot. No. 1483.

References

1. Mohd Tobi, A. L., Harimon, M. A., Ismail, A. E., Saad, A. A., & Azalan, A. A. (2015). Investigation on the Fretting Wear of a Coated Substrate: Interlayer Stress Behaviour. In Applied Mechanics and Materials (Vol. 699, pp. 311-317). Trans Tech Publications.

2. Mohd Tobi, A. L., Harimon, M. A., Saad, A. A., & Karim, R. M. (2013). Investigation on the Fretting Wear of A coated Substrate with Interlayer. In Applied Mechanics and Materials (Vol. 315, pp. 909-913). Trans Tech Publications.

3. Mohsin, M. L., Tobi, A. L. M., Siswanto, W. A., & Tamin, M. N. (2014, November). Finite element analysis of stress intensity factor of pre-cracked coated substrate under contact sliding. In Electronics Manufacturing Technology Conference (IEMT), 2014 IEEE 36th International (pp. 1-4). IEEE.
4. Mohd Tobi, A. L., Harimon, M. A., Saad, A. A., & Azalan, A. A. (2013). Fretting Wear of Coated Substrate with Interlayer: Substrate Stress Behaviour. In Applied Mechanics and Materials (Vol. 372, pp. 516-521). Trans Tech Publications.

5. Nagentrau, M., Tobi, A. M., Kamdi, Z., Ismail, & Sambu, M. (2017, June). Microstructure Analysis of Tungsten Carbide Hardfacing on Carbon Steel Blade. In IOP Conference Series: Materials Science and Engineering (Vol. 203, No. 1, p.012014). IOP Publishing.

6. Marimuthu, K., & Murugan, N. (2013). Prediction and optimisation of weld bead geometry of plasma transferred arc hardfaced valve seat rings. Surface Engineering, 19(2), 143-149.

7. Bharath, R. R., Ramanathan, R., Sundararajan, B., & Srinivasan, P. B. (2008). Optimization of process parameters for deposition of Stellite on X45CrSi93 steel by plasma transferred arc technique. Materials & Design, 29(9), 1725-1731.

8. Upadhyaya, G. S. (1998). Cemented tungsten carbides: production, properties and testing. William Andrew.

9. Jankauskas, V., Antonov, M., Varnauskas, V., Skirkus, R., & Goljandin, D. (2015). Effect of WC grain size and content on low stress abrasive wear of manual arc welded hardfacings with low-carbon or stainless steel matrix. Wear, 328, 378-390.

10. Katsich, C., & Badisch, E. (2011). Effect of carbide degradation in a Ni-based hardfacing under abrasive and combined impact/abrasive conditions. Surface and Coatings Technology, 206(6), 1062-1068.

11. Mohd Tobi, A. L., Kamdi, Z., Ismail, M. I., Nagentrau, M., Roslan, L. N. H., Mohamad, Z. & Latif, N. A. (2017, January). Abrasive Wear Failure Analysis of Tungsten Carbide Hardfacing on Carbon Steel Blade. In IOP Conference Series: Materials Science and Engineering (Vol. 165, No. 1, p. 012020). IOP Publishing

12. Coronado, J. J., Caicedo, H. F., & Gómez, A. L. (2009). The effects of welding processes on abrasive wear resistance for hardfacing deposits. Tribology International, 42(5), 745-749

13. Buchely, M. F., Gutierrez, J. C., Leon, L. M., & Toro, A. (2005). The effect of microstructure on abrasive wear of hardfacing alloys. Wear, 259(1), 52-61.

14. Desai, V. M., Rao, C. M., Kosel, T. H., & Fiore, N. F. (1984). Effect of carbide size on the abrasion of cobalt-base powder metallurgy alloys. Wear, 94(1), 89-101.

15. Shetty, H. R., Kosel, T. H., & Fiore, N. F. (1982). A study of abrasive wear mechanisms using diamond and alumina scratch tests. Wear, 80(3), 347-376.

16. Leech, P. W., Li, X. S., & Alam, N. (2012). Comparison of abrasive wear of a complex high alloy hardfacing deposit and WC–Ni based metal matrix composite. Wear, 294, 380-386.

17. Scandella, F., & Scandella, R. (2004). Development of hardfacing material in Fe-Cr-Nb-C system for use under highly abrasive conditions. Materials science and technology, 20(1), 93-105.

18. Chotěborský, R., Hrabě, P., Müller, M., Válek, R., Savková, J., & Jirka, M. (2009). Effect of carbide size in hardfacing on abrasive wear. Research in Agricultural Engineering, 55(4), 149-158.