Wear characteristic of WC hardfacing on carbon steel: effect of weldment current and layer

A S Omar¹, M Nagentrau²,₃, A L M Tobi² and M I Ismail⁴

¹Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia
²Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia
³School of Engineering, KDU University College, Shah Alam, Malaysia
⁴Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia

Abstract. Tungsten carbide (WC) hardfacing is performed to improve the wear resistance and operating life of the carbon steel blade which operates under acidic and abrasive environment. The effect of weldment current and layer number on wear characteristic of WC hardfaced carbon steel are the focus of this study. Different hardfacing welding parameters such as 200 A and 150 A weldment current and 1, 2 and 3 layer numbers are studied in detail. Microstructure and elemental composition are characterized by scanning electron microscope (SEM). Meanwhile, hardness test is performed using micro-Vickers hardness tester. The abrasive slurry wear test is implemented to investigate WC coating wear behaviour. The results revealed that the coating is made up of carbide and non-carbide region. The carbide region has highest W content, while non-carbide region consists of combination of Fe and W. High weldment current and higher number of layers can enhance the wear resistance of WC hardfacing.

1. Introduction

Wear can be defined as a process where the material solid surfaces removed from one or two surfaces that contact and occur when the solid surfaces sliding or rolling in motion together [1]. Wear is the progressive damage, involving material loss, which occurs on the surface of a component as result of its motion relative to the working parts. Yuan et al. found that the wear failure analysis gives further insight into the mechanism of the property enhancement [2]. Abrasion is the process of scratches, wear, and rubbing. It can be imposed in a process using an abrasive material. The undesired effect can be occurring as a result of normal exposure or exposure to other elements. Abrasive wear occurs when a harder material is rubbing against a softer material [3].

Surface coatings have been commonly used in engineering applications such as the manufacturing, automotive, aeroengine and electrical applications [4-7]. Increasing the wear resistance of coatings is often achieved through increased hardness which in turn reduces the rate of abrasion in the wear process [8]. Hardfacing welding technique is one of the surface coatings commonly practiced in the industry [9, 10]. The service life of components subjected to abrasive wear can be extended by hardfacing deposit on the parts exposed to production process [11, 12]. Tungsten carbide (WC) is one of the preferred hardfacing material used regularly due to its favourable properties. Katsich and Badisch reported that tungsten carbide coatings are widely utilized in prolonging the lifetime of engineering parts that operate in harsh environment [13].
There is a consensus among researchers that welding techniques and parameters greatly influence hardfacing performance. Deng et al. conducted a research on the fatigue properties of steel deposited with Co-based alloy hardfacing coating and concluded that welding technique and temperature are significant factors that contribute to hardfacing performance [14]. It has been shown conclusively that the wear properties of hardfacing can be governed by welding techniques and procedures [15, 16].

Previous research studies on hardfacing suggested that welding current and layer number can control the carbide/matrix formation. Just et al. reported that the mechanical behaviour of metal matrix composites (MMC) and its wear mechanism can be influenced by welding current [17]. Furthermore, it is noted that high welding current (three times higher) is able to increase the WC phase content in hardfaced coating, thus wear resistance can be improved [17]. Coronado et al. highlighted that abrasive wear resistance will be higher if three layers of welding is applied [18].

In this study, the influence of weldment current and layer number on wear characteristic of WC hardfaced carbon steel is presented. Microstructural, elemental composition and hardness analyses are performed along with abrasive slurry wear test to address the effect of weldment current and layer number.

2. Experimental details

2.1. Blade
The base material is made up of BS3100 carbon steel blade (Grade A3) as shown in Figure 1. Medium carbon steel has a distinctive grade that is determined by the percentage of carbon content in the steel. Medium carbon steel contains two main elements, namely carbon (C) and manganese (Mn), meanwhile other elements such as sulphur (S), molybdenum (Mo), phosphorus (P), nickel (Ni) and chromium (Cr) present in small portions. The chemical composition of the BS3100 carbon steel is presented in Table 1.

![Hardfaced carbon steel blade](image)

**Figure 1.** Hardfaced carbon steel blade

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

2.2. Electrode
The electrode used for hardfacing is BK-1200 tungsten carbide (WC) electrode. The application of the electrode can be seen widely in construction machineries, hard surfacing of cutting knives and blades.
The diameter of the electrode is 6 mm with length of 350 mm. Table 2 shows the chemical composition of tungsten carbide (WC) electrode.

| Element | C  | Si | Mn | W  | Fe  |
|---------|----|----|----|----|-----|
| Composition (%) | 3.1 | 0.4 | 1.5 | 60.2 | balance |

2.3. Hardfacing procedure

Shielded Metal Arc Welding (SMAW) method is employed for carbon steel blade hardfacing. SMAW welding procedure is a low cost and simple general fusion welding technique that widely utilised in many industries. The WC hardfacing coating is deposited on base material (carbon steel blade) in horizontal position as demonstrated schematically in Figure 2. The carbon steel blade is preheated using torch for 3-5 minutes with temperature of 300 °C. Meanwhile, the WC electrodes are dried at 100 °C for 45 minutes in an oven before hardfacing procedure. Table 3 presents the SMAW welding condition for WC hardfacing. The influence of weldment current and layer on wear characteristic of WC hardfacing is focused in this particular study. Different weldment current (150 A & 200 A) and layer (1 layer, 2 layer & 3 layer) are assigned to investigate its effect on wear characteristic of WC hardfacing. Table 4 presents the hardfacing welding parameters assigned for different specimens.

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

**Figure 2.** Schematic diagram of hardfacing deposit on carbon steel blade

| 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 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 hardfacing welding parameters
2.4. Specimen preparation

Six (6) specimens are sectioned from the hardfaced carbon steel blade using Electrical Discharge Machining (EDM). The specimens are marked according to the desired size in different places on the welded blade area. The dimension of specimen is 10 mm × 5 mm × 15 mm as illustrated in Figure 3a.

The sectioned specimens are mounted in order to obtain perfect edge-retention as shown in Figure 3b. The specimens are mounted with cold mounting technique. Epoxy resin (Cat. No. ERF-300-128) and hardener (Cat. No. EHF-300-32) are mixed with the ratio of 2:1 respectively. The mixture of epoxy resin and hardener is poured in mounting mould containing sectioned specimens and cooled in room temperature for 24 hours to obtain best mounting results. The cold mounted specimen is shown in Figure 3b. The cross-section and surface of the mounted specimens are grinded using several grits of silica 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. After proper grinding, polishing process is performed using Liquid Buehler Polishing Suspension to eliminate fine scratches from the specimens. Microstructure and elemental composition characterisation are performed on the prepared specimens using SEM and EDS analyses respectively.

![Specimen Mounting](image)

**Figure 3.** Hardfaced blade specimen, (a) sectioned specimen and (b) cold mounted specimen

2.5. Wear test

The abrasive slurry wear test is performed using Metkon Forcipol 2V grinder-polisher with the purpose of investigating abrasion resistance of the prepared specimens as shown in Figure 4. Silicon carbide (SiC) is used as abrasive slurry as it increases the friction coefficient of contacting bodies during the wear test. The SiC used is 200-450 µm in mesh particle size. Three (3 g) of SiC is mixed with one litre of water to prepare the slurry. The experimental equipment is set up as shown in Figure 4 where the surface of the specimen is fixed as in contact with the stainless steel plate. The machine will rotate according to the predefined parameters such as desired time and loading, meanwhile pump machine will supply the slurry on the stainless steel plate. Abrasive slurry wear test condition is presented in Table 5. The initial and final mass of the specimens are recorded to calculate the mass loss during wear test. The wear volume is calculated by taking 10.2734 g/cm³ as density of the specimen. The wear volume against the sliding distance is plotted to calculate the wear rate.
3. Results

3.1 WC hardfacing metallography

Scanning Electron Microscopy (SEM) is used to analyse the microstructure of WC hardfaced specimen. The close-up view of coating carbide distribution is exhibited in Figure 5. Three main regions such as carbide, non-carbide and substrate regions are noted in SEM images. The hardfacing coating region is mainly composed of different sizes of carbides at the lower part of coating region (near the coating-substrate interface) with the depth about 1 mm. It is found that bright white colour carbide randomly distributed in the coating region. In fact, the substrate region is darker compared to coating region due to absence of tungsten carbide particles.
Energy dispersive X-ray spectroscopy (EDS) analysis is performed to obtain the elemental composition of the substrate and coating. The elemental composition of the substrate and coating regions are recorded by quantifying the elements under EDS. EDS analysis shown in Figure 6a, 6b and 6c show the carbide region, non-carbide region and substrate region respectively. Tungsten (W), Carbon (C), Oxygen (O) and Iron (Fe) are identified in the EDS analysis. It is noteworthy that high percentage of W is found in carbide region, meanwhile non-carbide region rich in both W and Fe elements indicating combination of carbide and binder. The substrate region is mainly consisting Fe element. In addition, other elements such as C and O are noted in minimum composition at all the regions. Furthermore, the O in both coating and substrate region proves the present of oxide layer that forms as the result of casting process of the blade.
Figure 6. EDS elemental composition analysis of (a) carbide region, (b) non-carbide region and (c) substrate region

3.2. Hardness analysis

The hardness of hardfaced carbon steel blade is tested using micro-Vickers hardness tester of 0.5 HV load. The hardness test is performed 3 times to obtain the average hardness values of substrate, carbide and non-carbide regions respectively. The average hardness value of each region is shown in Figure 7. As expected, the carbide region had higher hardness compared to the non-carbide region. The hardness value registered for the carbide region 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.
3.3. Wear behaviour

Figure 8a and 8b show wear volume against sliding distance of 200 A and 150 A weldment current for different layer numbers. The result reveals that wear volume is directly proportional with sliding distance where higher wear volume is recorded for higher sliding distance. The above finding is consistent with the study by Buchanan et al. [3]. The gradient of the graphs indicates the wear rate of different specimens. The results of the present study reveals that highest wear rate is recorded for specimen 6 which is $0.00173 \text{ mm}^3/\text{mN}$, then followed by specimen 5, specimen 1, specimen 3, specimen 4 and specimen 2 with the wear rate of $0.00169 \text{ mm}^3/\text{mN}$, $0.00135 \text{ mm}^3/\text{mN}$, $0.00130 \text{ mm}^3/\text{mN}$, $0.00096 \text{ mm}^3/\text{mN}$ and $0.00099 \text{ mm}^3/\text{mN}$ respectively. The wear rate is mainly dictated by different weldment current and layer.

The wear rate for the sliding distance of 3000 m to 8000 m is considered as stable wear rates, meanwhile, running in stage is noted for sliding distance of 1000 m and 2000 m. The running in stage occurs due to contact area of the stainless steel plate and specimen surface is relatively low which influences the wear value.
Previous research studies have shown that high weldment current and higher number of layers can result in better wear resistance of WC hardfacing [19]. However, the current findings are contradicting with previous study where lower wear resistance is recorded for higher weldment current and layer. Among the plausible explanation for this finding is that the removal of higher hardness carbide layer during specimen sectioning and grinding process.

4. Conclusion
The present study is designed to determine the effect of weldment current and layer on wear characteristic of WC hardfaced carbon steel. The main finding of this study can be summarized as follows:

- SEM images of the hardfacing revealed that the coating is made up of carbide and non-carbide regions. The carbide region has higher hardness compared to non-carbide region.

- EDS analysis revealed that the carbide region has highest content of W element, while non-carbide region consists combination of Fe and W elements. In the substrate, highest percentage of Fe element is noted.

- High weldment current and higher number of layers can result in better wear resistance of WC hardfacing. However, removal of higher hardness carbide layer during specimen sectioning and grinding process can influence the wear characteristics of WC coating.

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