



Influence of heat treatment on microstructure and sliding wear resistance of high chromium cast iron electroslag hardfacing layer



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ABSTRACT

In this study, hypoeutectic high chromium cast iron (HCCI) is deposited on low alloy steel by using electroslag welding. The yielded mixture is furthered introspected by exposing it to range of temperatures (i.e. 440 °C, 480 °C, 520 °C, 560 °C, 600 °C). The respective microstructures are studied after the heat treatment, subsequently. Additionally, microstructures are also examined in terms of their hardness and wear resistance. The results demonstrate that hardness, wear resistance and coefficient of friction (COF) are correlated and these attributes reaches to their maximum value when the mixture is found to be composed of secondary carbides and martensite. It is evaluated that, when the HCCI hardfacing layer is post weld heat treated (PWHT) at 520 °C then the secondary carbides ($M_{23}C_6$) and martensite quantities are quantified as maximum and by comparing it with HCCI hardfacing layer, hardness, COF and wear resistance are found to be increased by 11.88%, 25% and 30%, respectively. Wear resistance is also found to be at the maximum value at PWHT 520 °C holding crack at maximum depth of 2 μm . These findings reveal that HCCI hardfacing layer with PWHT temperature 520 °C can achieve the best outcome.

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1. Introduction

High chromium cast iron (HCCI) is extensively used for the deposition i.e. hardfacing layer on low alloy steel because of good abrasive and sliding wear resistance [1,2] and to carry this process shielded metal arc welding (SMAW) and submerged arc welding (SAW) are mostly used. However, due to high carbon equivalent (CE) of HCCI, it becomes difficult to avoid cracks in hardfacing layer [3]. As is well known that in electroslag welding due to high heat input, temperature gets evenly distributed all over the work piece surface, which reduces the cooling rate during solidification of hardfacing metal following reduction in residual stresses and cracking tendency.

The HCCI hardfacing layer as-welded has higher concentration of austenite than martensite, which makes it soft and limited in sliding wear resistance [4]. However, a proper heat treatment could possibly raise the martensite and carbide content by reducing austenite. From thorough study, it is found that destabilization treatment at 920–1060 °C significantly destabilizes the austenite and stimulates second phase carbide precipitation and martensitic transformation [5–8]. This would increase the hardness and wear resistance, but on the other hand, grain size of low alloy steel grows fast by degrading the properties. So, during the process of heat treatment, temperature should not exceed the critical austenitization temperature. In general, austenitization

temperature should be near A_{C1} in Fe–C phase diagram. Sun et al., reported that after heat treatment at 580 °C, the austenite in 2.7C–16Cr–1Mo–1Cu castings decomposes and transforms to martensite [9]. However, it is still unknown that what would be the microstructural transformation in HCCI electroslag hardfacing layer when heat treatment temperature is below A_{C1} and also how the sliding wear resistance of HCCI hardfacing layer would be after subcritical heat treatment.

In this study, 2.6C–22Cr–Fe–Fe hypoeutectic HCCI hardfacing layer is deposited on low alloy steel plate by using electroslag welding. The interface, effect of different heat-treatment temperatures below A_{C1} (440–600 °C) on microstructure, hardness and sliding wear resistance of HCCI electroslag hardfacing layer have been discussed in detail.

2. Experimental procedure

In this study, 2.6C–22Cr–Fe hypoeutectic HCCI hardfacing layer is deposited on low alloy steel plate D32 (Thickness: 20 mm) by electroslag welding. The chemical composition of D32 and schematic of electroslag welding is shown in Table 1 and Fig. 1 respectively. Consumable guide tube (ISO-C101, Outer dia. 10 mm, inner dia. 4 mm), Flux cored wire (dia. 3.2 mm) with flux (Sintered base CaF_2 – CaO – Al_2O_3), welding parameters (voltage–40 V, Current–320A), Cooling water flow rate (90 L/h) and Villela's reagent as etchant (5 mL HCl, 1 g picric acid in 100 ml ethanol, for 30s) are used to carry out the experimentation. Specimens are divided into 6 groups having three samples in each group. All the specimens are welded and then post weld heat treated

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Table 1
Chemical composition of low alloy high strength steel D32 and the HCCI hardfacing wt%.

Materials	C	Si	Mn	P	S	Cu	Cr	Ni	Nb	V	Ti	Mo	Al	Fe
D32	0.13	0.22	1.30	0.01	0.01	0.32	0.20	0.39	0.04	0.08	0.02	0.05	0.02	Bal.
HCCI	2.55	0.37	1.53	0.01	0.01	0.06	22.33	...	0.06	0.07	...	0.02	0.07	Bal.

(PWHT) at different temperature (440 °C, 480 °C, 520 °C, 560 °C and 600 °C for 2 h and then cooling with the furnace), whereas group 1 is welded only.

Optical microscope (OM, for microstructural observation), X-ray fluorescence spectrum analyzer (XRF, for measuring chemical composition of electroslag hardfacing shown in Table 1), Scanning electron microscope (SEM, for microstructural observation and worn morphology) and X-ray diffraction (XRD, with Cu K α radiation for measuring phase constitution) are used. According to ASEM E1245-03, the volume fraction of eutectic carbide, austenite and martensite present in the microstructure was measured by image analysis software “Image Pro Plus” using digitalized pictures taken on an scanning electron microscope (SEM).

Samples of size 20 × 30 × 5 mm are taken from HCCI hardfacing layer and then polished to 0.25 μ m. Macrohardness and microhardness are calculated by using conventional Rockwell tester in C scale (1470 N load and a diamond cone indenter typical for this scale) and Vickers hardness tester (by using load of 490 g for 15 s) respectively. Six measurements are taken for one sample for macrohardness, whereas, the mean value of microhardness has taken based on 3 different areas of one typical microstructure.

The wear resistance of HCCI hardfacing samples at different heat-treatment temperatures is investigated by ball-on-flat pure sliding using the UMT-3 multi-specimen test system shown in Fig. 2. HCCI flat samples are worn for 30 min against a Φ 9.52 mm M2 steel ball (70HRC), at an average sliding speed of 8 mm/s along a reciprocating path of 20 mm. Four tests are carried out on each sample using the load of 150 N. The friction and sliding time (s) is all auto recorded and mass loss value of each sample was measured by electronic balance with accuracy of 0.1 mg to determine volume loss and thus, the wear rate. The wear rate is the ratio of wear volume and frictional work, which is calculated by formula shown in Eq. (1).

$$I = \Delta m / \rho f v t \times 10^6 \tag{1}$$

where I is the wear rate in mm³/Nm; Δm is mass loss in g; ρ is the density of the sample in a constant of 7.9 g/cm³; f is the friction in N; v is the friction velocity in mm/s and t is the friction time in sec.

3. Results and discussion

3.1. Interface of the HCCI electroslag hardfacing layer and low alloy steel plate

Micrograph of HCCI hardfacing layer and low alloy steel is found to be defect-free, smooth and distinct as shown in Fig. 3. In the HAZ area, different microstructures are being observed on each side of the diffusion line. In HCCI hardfacing layer side, an austenite zone of 25 μ m is observed. This austenite zone is a mixture of HCCI (2.55 wt%-C) and D32 (0.13 wt%-C). Since, concentration of C in austenite becomes lower which adds up toughness to its characteristics. In the low alloy steel side, ferrite is appeared in the HAZ region and is found to have toughness much higher than HCCI hardfacing.

3.2. Microstructure of HCCI electroslag hardfacing layer

The microstructure of hypoeutectic HCCI hardfacing layer formed by electroslag welding is shown in Fig. 4. Weld solidification of HCCI hardfacing layer started with the formation of primary austenite followed by simultaneous precipitation of eutectic mixture of austenite and carbide. Thus, as shown in Fig. 4a and b, final microstructure is consisted of primary austenite(I) and eutectic colony(II). SEM microstructural observation shown in Fig. 4c reveals that eutectic colony comprises of eutectic austenite and plate martensite surrounding eutectic carbide (M₇C₃). In electron dispersive spectroscopy (EDS), carbon (C, 5.75 wt%) and chromium (Cr, 48.9 wt%) concentrations is found to be much higher in eutectic carbide (point 1 in Fig. 4c). Whereas, the C and Cr concentration in eutectic austenite is 1.73 wt% and 14.13 wt% respectively while in martensite (point 2 in Fig. 4c), the composition of C and Cr is 0.92 wt% and 11.92 wt% respectively (point 3 in Fig. 4c). Ms temperature and alloying element have relation shown in Eq. (2) [10]. The depletion of C and Cr during the formation of eutectic carbide has allowed the rise of Ms, transformation temperature and the transformation to martensite. The XRD patterns shown by Fig. 4d also illustrates that the hardfacing microstructure is consisted of austenite, martensite and M₇C₃ carbides.

$$Ms (^{\circ}C) = 520 - 320C - 50Mn - 30Cr - 20Mo - 5Cu \text{ (wt\%)} \tag{2}$$

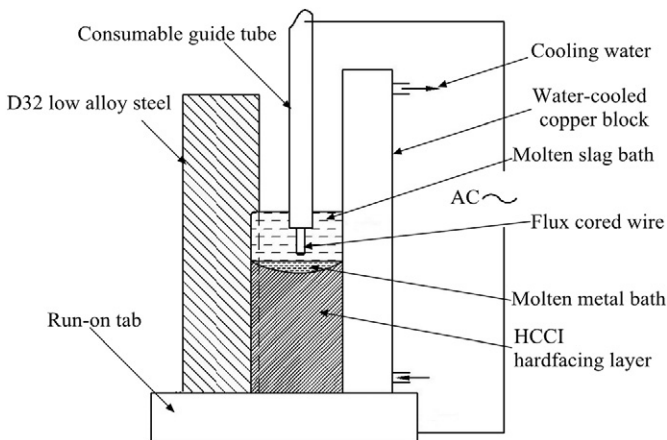


Fig. 1. Schematic of the electroslag welding.

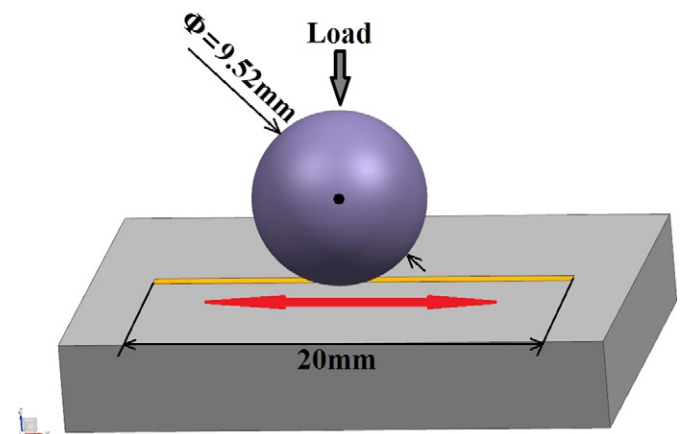


Fig. 2. Schematic drawing of the ball-on-flat wear test.

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