Short Communication

An investigation of abrasive wear and corrosion behavior of surface repair of gray cast iron by SMAW

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ABSTRACT

In this work, improving the abrasion–corrosion behavior of gray cast iron used in centrifugal pumps was studied. These pumps are usually made of gray cast iron (BS:1452Gr220) and are repaired by Shielded Metal Arc Welding (SMAW). Three different typical welding electrodes including Ni electrode (DIN8563), Carbon Steel electrode (DIN1913), and Hardening electrode (DIN8555) were used to compare the weldability of the base metal. Microstructural differences for three types of electrodes were studied and forming of different phases was analyzed. Corrosion and abrasion tests were conducted and related to welding conditions. Experimental results showed that using Ni substrate electrode reduce the unwanted phases (martensitic and carbides). Furthermore, in comparison with the base metal, the abrasion behavior of all weldments was improved. It was also determined that the carbon steel electrode has a higher corrosion resistance in zero-resistance ammeter (ZRA) test compared to other electrodes.

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1. Introduction

Centrifugal pumps are important industrial components that are used to move fluids in petroleum, hydraulic, agriculture, and gas industries. One of the main problems with centrifugal pumps is corrosion and abrasion due to high working speed and corrosive liquids [1–3]. Repair welding is done specially at the inner layer of casing to restore the damaged areas [2–4].

One of the most favorable materials for manufacturing the casing is cast iron. Cast iron advantages are low melting temperature, machinability, low price, and high damping capacity. As a disadvantage, it has poor weldability. On the other hands, welding is one of the most important processes to repair and recover the damage in cast iron instruments. Martensitic phase and brittle iron carbide growth are two main problems of cast irons welding [5–8]. Pouranvari [9] concluded that formation of carbides and martensitic phase in the fusion zone

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are prevented by using the Ni filler material. He also concluded that preheating to 573 K (300 °C) result in forming bainitic HAZ and discontinuous carbides [8]. Also there are other problems associated with welding of gray cast iron. Ghaini et al. [5] showed that residual stresses can control the crack generation during the welding process in ductile cast iron. They also used powder welding process to characterize the kind of crack formed in welding process. He claimed that the cracks in powder welding process are differing in morphology from the cold cracks in the case of arc welding of ductile cast irons [10].

Ebrahimnia et al. [11] have also studied the effect of cooling rate on micro cracks in the heat affected zone (HAZ) of ductile cast iron. They expressed that the cracks generated at interface of graphite and propagate through martensitic matrix.

Winiczkeno and Kaczorowski [12] used friction welding of ductile iron with stainless steel. They concluded that friction welding is accompanied by a transport of atoms in both directions across the ductile iron-stainless steel interface. They showed the maximum length of Cr and Ni diffusion in cast iron is 50 μm and the bainitic matrix improves this transition.

Thorntona et al. [13] studied the effect of cryogenic processing on the wear resistance of gray cast iron. They concluded that the wear rate of gray cast iron can improve from 9.1 to 81.4%, due to the depth of cryogenic treatment.

The wear behavior of ductile cast iron was investigated by Fontanari et al. [14]. They have concluded that both the lubrication condition and the microstructure of materials have a strong effect on crack initiation and propagation. They showed that the graphite nodules, as well as the ferritic phase influence the subsurface crack initiation, their preferential propagation and branching [14].

A common method for repair welding of cast iron is shielded metal arc welding (SMAW). This method is rather cheap and easy. In this method, usually carbon steel fillers are used to repair the damaged areas [2–4]. However, using filler materials increases the risk of galvanic corrosion and welding must be performed under controlled condition when the environment is corrosive.

Despite of the influence of welding conditions on abrasion and corrosion behavior of welded cast iron, this issue has not been assessed adequately. Therefore, the main purpose of this work is to investigate the effect of filler materials in SMAW process on tribocorrosion behavior of cast irons. For this reason, three different typical filler metals were used to repair welding of gray cast iron according to standard condition. The microstructures of cross section specimens were studied. Evaluations of different phases were compared for different filler materials after welding procedure. The wear behaviors of the surfaces were recorded using pin-on-disk test. Potentiodynamic polarization measurements and zero-resistance ammeter (ZRA) tests were used to measure the corrosion resistance and galvanic potential of specimens, respectively.

2. Experimental method

Gray cast iron is usually used for manufacturing of centrifugal pumps body (casing). The pumps body in this study were made of cast iron grade BS:1452Gr220. Therefore, the base metal for welding procedure was chosen from this grade. Composition of the base metal (wt%) was Fe-3.20C-2.01Si-0.60Mn. The size of each sample was 100 × 100 × 20 mm³ and all specimens were prepared before welding by grinding and oil removing.

Three different typical filler metals were used to repair welding using shielded metal arc welding process. The type and chemical composition of filler metals are given in Table 1. The condition of welding and the abbreviation of the tests are presented in Table 2. All samples were heated at 573–673 K (300–400 °C) for 15 min before welding to prevent heat shock during welding.

For metallographic examination the section was prepared perpendicular to the weld surface in order to examine the microstructural variation through the weld thickness. Metallographic preparation including grinding and polishing was performed for each specimen and Nital 2% was used for etching.

For investigating the abrasion properties, pin-on-disk test was performed according to ASTM G99 [15]. Tribological tests were carried out in air under a load of 10 N. The other experimental parameters were as follows: sliding speed = 50 m/min; radius = 5 mm; sliding distance = 650 m.

For corrosion test the specimens were sectioned from welding area as well as base metal. Then the cut samples and base metal were grounded by the 320–1200# SiC abrasive paper sequentially and polished by 2.5 μm emery paste. The specimens were mounted with a work area of 0.6 cm² before the corrosion test. Experiments were carried out in 3.5% NaCl solution at pH 7.2 at room temperature (300 K (27 °C)) according to the working environment of centrifugal pump (river water).

According to the usual potentiodynamic polarization measurements the base or weld metal was taken as a working electrode and the saturated calomel and platinum plate and counter electrode as a reference. ACM instrument potentiotstat (Gill AC) was used in all electrochemical tests.

An initial delay of 60 min was applied for stabilizing in all cyclic potentiodynamic polarization tests. Tafel extrapolation and linear polarization methods (LPR) were used for drawing the cathodic and anodic polarization curves. Each test has been repeated three times to verify the results. Additionally, the galvanic potential and current density of base metal (gray cast iron) and welded specimens has been recorded by built-in zero-resistance ammeter (ZRA). In this test the data was recorded in each 6 h for 24 h and the anode/cathode area ratio was 1/1.

3. Result and discussion

3.1. Microstructure

Fig. 1 shows the microstructure of interface, HAZ and welding zone of specimens. The martensitic phase can be seen in HAZ and interface of base metal and E7018 welding metal, (Fig. 1(a and b)). The use of Ni-electrode (CNI7018) prevents martensitic phase formation (Fig. 1c). In this specimen instead of forming hard martensitic phase, the D and E type of graphite phase has been formed in the interface. Formation of brittle carbides and martensitic phases depends on cooling rate and dilution of alloying elements. Previous studies show that
Table 1 – Chemical composition and classification of filler materials.

<table>
<thead>
<tr>
<th>DIN classification</th>
<th>SFA-5015 classification</th>
<th>Weld metal composition (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>DIN8573</td>
<td>ENi-Cl</td>
<td>0.5</td>
</tr>
<tr>
<td>DIN1913</td>
<td>E7018</td>
<td>0.07</td>
</tr>
<tr>
<td>DIN8555</td>
<td>EN14700</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 2 – Welding parameters and abbreviations of tests.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Abbreviation of tests</th>
<th>Welding parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base metal</td>
<td>C</td>
<td>Current (A)</td>
</tr>
<tr>
<td>Welding by Ni electrode</td>
<td>CNi</td>
<td>Electrode diameter (mm)</td>
</tr>
<tr>
<td>Welding by E7018 electrode</td>
<td>C7018</td>
<td>Travel speed (mm min⁻¹)</td>
</tr>
<tr>
<td>First welding by Ni and after</td>
<td>CNi7018</td>
<td>Polarity</td>
</tr>
<tr>
<td>that welding by E7018 electrode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First welding by Ni and after</td>
<td>CNiHF</td>
<td></td>
</tr>
<tr>
<td>that welding by EN14700 electrode</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 – Microstructure of different welded specimens, (a and b) C7018, (c) CNi and (d) CNiHF.

[7–9] using Ni electrode help carbon to precipitate in its free form as graphite. D and E type of graphite can form in association with higher cooling rate [16]. In fact, by using Ni electrode, the experimental cooling rate is below the critical rate, which is necessarily for the martensitic phase formation, but it is still higher than the normal cooling rate. Thus the graphite phase at interface tends to form into dendrite shape (D and E type).

Also the low thermal expansion coefficient of nickel as a filler metal can help to reduce the risk of HAZ cracking [9].

The microstructure of martensitic phase at the interface of Ni and hardening electrode (CNiHF) is shown in Fig. 1(d). Martensitic phase is formed in welding zone, because of high alloying elements such as Cr. Furthermore, as it can be seen in Fig. 1(d), the width of martensitic phases and retained austenite (white areas) increases when approaching to interface. It is related to the step down in cooling rate and high concentration of Ni near the interface. Increasing the Ni content in steel composition caused stabilization of the austenite phase and therefore the retained austenite is increased [17,18].

3.2. Abrasion properties

Fig. 2 shows the results of pin-on-disk test. According to ASTM G99 the abrasion resistance of the samples is calculated by the weight loss of the specimen in a specific distance. The list of samples and the welding procedure are presented in Table 2. Lower weight loss shows a higher abrasion resistance. It was observed that the weight loss of the base metal and CNI is higher than the other ones. It was also detected that, for shorter sliding distances, the weight loss of CNIHF specimen is the lowest one. It means that the abrasion resistance of the hardening electrode is higher than the other ones. It is due to its high alloying elements like Cr that result in generation of martensitic phase at the surface.

It can be seen that the abrasion resistance of CNI7018, for shorter sliding distances, is approximately the same as the C7018 and after that it increases for C7018. As it is shown in Fig. 1, welding of the base metal by E7018 and EN14700 electrodes generate those hard phases in fusion zone, interface and HAZ. Indeed, this could be the reason for differences in abrasion resistance of C and CNI compared to the other specimens. This is to say that the low abrasion resistance of C and CNI is related to the lack of martensitic and carbide as hard phases in the matrix.

It can be also seen in Fig. 2 that the weight loss for CNIHF and CNI7018 increases after approximately 120 m. For both CNI7018 and CNIHF the weight loss rate decreases between 250 m and 390 m. This is due to the presence of hard phases in the weld interface.

On the other hand, C7018 showed the highest abrasion resistance over longer sliding distances. This is because Ni electrode was not used for C7018. Using Ni electrode results in decreasing the cooling rate below a critical cooling rate for martensitic phase formation. Thus the presence of hard martensitic phase has increased the abrasion resistance for C7018. By contrast, using Ni electrode for CNIHF and CNI7018 has decreased or eliminated the martensitic phase; therefore, the weight loss was increased as compared to C7018. The weight loss for CNI7018 is higher than CNIHF, this is due to absence of martensitic phase.

3.3. Corrosion behavior

Curves of potentiodynamic polarization tests of samples in river water are shown in Fig. 3. Corrosion current densities were derived by Tafel extrapolation and linear polarization methods and the results are shown in Table 3. As can be seen, under corrosion potential range in the cathode branch, the reaction is diffusion-controlled, which may result from a reduction of soluble oxygen as a cathodic reaction [19,20].

Table 3 shows that the C7018 specimen has a higher corrosion current density ($i_{corr} = 0.019 \text{ mA cm}^{-2}$) as compared to CNI ($i_{corr} = 0.01 \text{ mA cm}^{-2}$), CNIHF ($i_{corr} = 0.01 \text{ mA cm}^{-2}$) and C.

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Table 3 – Corrosion parameters of samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>$E_{corr}$ (mV vs. SCE)</th>
<th>$\beta_a$ (mV/decade)</th>
<th>$\beta_c$ (mV/decade)</th>
<th>$B^*$</th>
<th>Rp (LPR) (Ω·cm²)</th>
<th>$i_{corr}$ (LPR) (mA/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>−722</td>
<td>105</td>
<td>565</td>
<td>38.5</td>
<td>2352</td>
<td>0.0163</td>
</tr>
<tr>
<td>C7018</td>
<td>−635</td>
<td>95</td>
<td>581</td>
<td>35.5</td>
<td>1797</td>
<td>0.0197</td>
</tr>
<tr>
<td>CNI</td>
<td>−385</td>
<td>90</td>
<td>446</td>
<td>32.6</td>
<td>3129</td>
<td>0.010</td>
</tr>
<tr>
<td>CNIHF</td>
<td>−357</td>
<td>80</td>
<td>393</td>
<td>28.9</td>
<td>3037</td>
<td>0.010</td>
</tr>
</tbody>
</table>

$a$ Gradient of anodic branch.

$b$ Gradient of cathodic branch.

$c$ $B = \beta_a \beta_c/2.3(\beta_a + \beta_c)$.

$d$ $i_{corr} (LPR) = B/Rp$. 

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Table 4: The corrosion current densities and the corrosion potential of various galvanic couples obtained from intersection of polarization curves.

<table>
<thead>
<tr>
<th>Galvanic couples</th>
<th>C-C7018</th>
<th>C-CN</th>
<th>C-CNHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current densities (mA/cm²)</td>
<td>0.013</td>
<td>0.024</td>
<td>0.019</td>
</tr>
<tr>
<td>Corrosion potential (mV vs. SCE)</td>
<td>−685</td>
<td>−675</td>
<td>−680</td>
</tr>
</tbody>
</table>

(based metal) \( i_{\text{corr}} = 0.016 \text{mA cm}^{-2} \) under same conditions. The table also shows that the base metal, in comparison with CNi and CNiHF samples, has lower corrosion resistance. This behavior is similar to the linear polarization results. These data were obtained immediately after the potential have become stable.

The high corrosion resistance of CNi and CNiHF compared to C7018 is due to alloying elements. In general, Ni compared to E7018 (carbon steel) has a higher corrosion resistance. Furthermore, alloying elements contained in EN14700 electrodes such as Cr can raise the corrosion resistance of weld metal \([21,22]\). The corrosion resistance of gray cast iron, due to its high carbon content and generation of graphite in matrix, is lower \([19]\). Because the corrosion potential of the base metal is lower, coupling of the two causes corrosion of the base metal as an anodic part in the electrolyte \([20]\). Under this condition, the corrosion potentials and corrosion current densities of different couples can be calculated from the curves shown in Fig. 3. Results of different couples obtained from potentiodynamic polarization curves are shown in Table 4. These results were obtained immediately after stabilization of the potential thus the \( E_{\text{corr}} \) and \( i_{\text{corr}} \) for various couples are corresponding to those first moments.

ZRA test results are shown in Fig. 4. The \( E_{\text{couple}} \) and \( i_{\text{couple}} \) for the beginning \( (t=0) \) is in a good agreement with the amount of \( E_{\text{corr}} \) and \( i_{\text{corr}} \) of galvanic couples obtained from intersection of polarization curves (Table 4).

As can be seen in Fig. 4, at the starting of ZRA test, the \( i_{\text{couple}} \) and \( E_{\text{couple}} \) are not stable but have become stable at the end of test \( (24 \text{ h}) \). The \( i_{\text{couple}} \) of C-C7018 in the galvanic couples is lower than the others, while the current density of the others is approximately the same. These results confirm the higher corrosion resistance of the C-C7018 couple.

The driving force in galvanic corrosion depends on the corrosion potentials differences of two metals. Higher corrosion potentials differences of two samples result in lower corrosion resistance of the couples \([23]\).

Due to a large difference in corrosion resistance for C-CNi and C-CNHF, the \( i_{\text{couple}} \) was the highest for these couple. The value of \( i_{\text{couple}} \) for C-C7018 was much smaller since the difference in corrosion resistance of this couple is relatively small (see Fig. 3 and Table 3). Therefore, the galvanic corrosion of this couple is the lowest of all three.

4. Conclusion

In this research work the microstructure, abrasion behavior and corrosion resistance of welded gray cast iron was studied. The main purpose of this work was to explore the effect of filler materials in SMAW process on tribocorrosion behavior of cast irons. The following conclusions were drawn from this investigation.

1. Evaluation the microstructure of different zones showed that using Ni electrode as a substrate prevents brittle phase formation such as martensitic phase. Therefore, the probability of crack formation is reduced.
2. Wear resistance of repaired cast iron was improved by all three repair electrodes. However, for Ni electrodes the weight loss increases after a distance of 120 m in the abrasion test.
3. The results of polarization test showed that the corrosion resistance of Ni and hardening electrode were higher than both the base metal and simple steel electrode.

ZRA test results showed that the galvanic corrosion in base metal and simple steel couple was the lowest one.

Conflicts of interest

The authors declare no conflicts of interest.
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