Study of the Effects of Welding Process on the Microstructure of Worn Carbon Steel Shaft

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Abstract. This paper presents a new procedure to repair a worn, low carbon steel shaft by use of discontinuous arc welding, and studies the effect of the proposed methodology on the microstructure of the welding area. The aim of the proposed methodology is to repair locally the rotary shafts of mechanical equipment, which are usually damaged at the supporting zone. The compensating method is used to repair the damaged area by adding a thin layer of metal to compensate for the shortage in diameter as a result of erosion. The repair should be carried out without exposing to rising temperature, which is the main cause of stress concentrations and initiation of fatigue cracks. The results were obtained by microscopic analysis of the welded area and include mechanical properties for the obtained samples. The repaired area contains soft crystals and an increase in hardness above 41%. This indicates that the wear resistance has been improved, while preserving the tension strength as it was before repair.

Keywords: Microstructure analysis; Worn shafts repairing; Arc welding methodology; Etchant processes.

1. Introduction

One of the key challenges in the maintenance of industrial equipment is the local repair of worn rotary shafts. These are usually damaged at the region of contact with coupled parts, in the supporting area. The wear and abrasion causes material loss on the rotary shaft surface, which causes clearance increase then machine vibration arises.

Many technical methodologies are used to compensate for material lost from the worn shafts. Wang and et al used a sleeve of sheet metal over the damaged area [1]. Cold coating is one of the methods used to make up the shortage in the diameter as a result of erosion [2]. Polymer technology has been employed in repairing mechanical parts, Belzona is one such machinable rebuild composite. Arc welding is one of the commonest methods used to repair damaged parts [3]. Many parameters must be controlled, starting from preparation of the part and ending in the heat treatment because of its influence on the quality of repair.
In the case of rotary shafts, when using the arc welding method, care is required in case of dynamic loads. Fatigue crack growth is one of the risks on the reformer shaft as presented in [4,5]. The cooling rate affects the mechanical properties of the repaired shaft, as a result of its effect on the microstructure characteristics after welding [6]. In some cases, especially for equipment that demands on-site repair, arc welding is a high-risk option because the welded area is the region of crack initiation [7,8] and needs heat treatment before and after repairing. At the heat-affected region, stress concentrations are generated because of the macro and microscopic discontinuities, which causes fatigue failure within a short time after the repair procedure.

In the present work, an arc welding technique is proposed for use in the local repair of worn carbon steel shafts, without disassembling it from the equipment and without heat treatment. The welding operations on the surface of the worn part occur in a sequential and parallel manner, at specific intervals of time to prevent the temperature from rising above 1200 °C for a sustained period. This would disturb the formation of solidified structures with large spacing.

Arc welding operations on eighteen samples of 25mm diameter and 150 mm length of worn shafts are carried out. After the repair of the samples, their microstructure, effects on the tensile strength and hardness are examined. The process consists of several smoothing stages and etchant by use of a suitable solution. The samples are examined under the microscope and the crystalline structures of the samples are tested before and after the repair using the proposed technique.

2. Experimental Work

The repaired shaft was made of steel st37. This type of steel is widely used for rotary shafts for machine parts, especially for fans. The tensile strength of st37 is shown in Table 1.
Table 1: Tensile properties of st37[9]

| Mechanical properties | YS(MPa) | UTS(MPa) | Elongation(%) |
|-----------------------|---------|----------|---------------|
| St37                  | 315     | 372      | 36            |

Before repair welding of the samples of worn low carbon steel shaft with 25mm diameter, in conformity with the proposed procedure, the electrode for the additional material was selected. Welding electrode OK 43.32 (4 mm diameter and 350 mm length) has been used for the sample rehabilitation, and the characteristics of the electrode are shown in Table 2.

Table 2: Electrode specifications[10]

| Classification | Chemical composition % | Mechanical properties |
|----------------|------------------------|-----------------------|
| OK 43.32 (AWS E6013) | C 0.07  Mn 0.5  Si 0.4 | YS(MPa) 460  UTS(MPa) 520  Elongation% 27 |

After preparation of the samples for welding, the arc welding operation on the worn surface began. The proposed welding procedure is done in a sequential and parallel manner (as shown in Figure 1) at 10 to 15 minute intervals of time, to prevent the temperature around the welding area exceeding 1200 °C for a sustained time. The welding procedure disturbs the formation of solidification structures with large spacing.

![Figure 1](image1.png)

Fig. 1. The arc welding procedure to repair shaft (a) discontinued welding (b) after machining.

After repair, the samples were cut at the welding zone then grinding of the cross section of the shaft samples was carried out using emery paper with various grits. The papers, all within the range from 400 to 3000 grade, were used in seven steps. First the grinder with 400 grade was used, then the higher grades were used sequentially until the 3000 grade. After the grinding operation, polishing was done to avoid any fine scratches from the samples. The polishing process used a dry polishing pad with 0.03 μm alumina. In order to examine the microstructure...
of the repaired samples, etchant was conducted using a suitable solution (3 ml of HNO₃ in 99 ml ethanol) to ensure clear microscope images [11]. The samples are shown in Figure 2.

Microstructure analysis was implemented for the cross-sectional area of the welded and unwelded samples, using microscope type (NMM-800RF) which was supplied with a digital camera type DCM310, 3M pixels. The samples have been tested with a universal testing machine of type UTEST and hardness test machine of type HVS 1000.

![Fig. 2. The samples after etching (a) original shaft, (b) with discontinuous welding (c) with continuous welding.](image)

3. Results and Discussion

3.1 Microstructure analysis

The effect of the welding procedure over the worn area was focused on. Images were taken of the samples of pure material without welding, the samples which were welded by continuous processing, and the samples welded by the proposed welding operation. Images of two hundred times magnification (200X) were selected to study the microstructure of the specimens.

Figure 3 clearly shows the effect of the welding procedure on the microstructure characteristics of the repaired area in the two cases. In the continuous welding procedure (Figure 3-b) the specimen was exposed to a high temperature level for a long time, and had a low cooling rate. This procedure led to the formation of large grains of austenite during the welding process. Also, when the temperature fell below the upper critical temperature this may have led to formation of proeutectoid ferrite, not only at grain boundaries of the austenite but also inside some crystallographic planes of the austenite. By reducing the temperature to below the lower critical
temperature, all the austenite will transform to pearlite. The figure shows large regions of ferrite and discontinuous regions of pearlite.

For the proposed welding process, the effect on the microstructure can be seen in Figure 3-c. The crystal grain was affected by the rapid heat transformation near the welded area of the specimen body. The structure also consists of pearlite and ferrite, but batches of ferrite and batches of pearlite can be seen and this behaviour may be attributed to the high cooling rate by layering the welding process instead of using a continuous technique. It is clear from the hardness test results that the discontinuous welding processes provided an increase in surface hardness of the treated surface. The surface hardness of the specimens can be observed in Table 3, from which it is clear that a significant increase in the hardness values occurred by application of the intermittent welding process and exceeded 41%.

| The Case                  | Surface Hardness(HV) |
|--------------------------|----------------------|
| Original worn shaft      | 239.79               |
| Continues welding        | 247.13               |
| Discontinuous welding    | 340.48               |
3.1 Mechanical properties

To evaluate the tensile strength of the samples of the original shaft and the repaired one, specimens were prepared for a tensile strength test. A universal testing machine (UTEST) was used. The procedure and the results of the test are shown in Figure 4. From the results, it can be observed that the tensile strength of the shaft was not affected by the repair procedure. Also, the cutting zone outside the welding area was already inside the testing length of the sample, as can be seen in Figure 4. This indicates the absence of residual stresses as a result of repair. The results are presented in Table 4, from which it is clear that the mechanical specifications of the
shaft were not affected by the proposed welding process, because the process prevented the occurrence of thermal stresses which lead to points of crack propagation.

Table 4: Mechanical properties.

| Mechanical properties | YS(MPa) | UTS(MPa) | Elongation(%) |
|-----------------------|---------|----------|---------------|
| Original shaft        | 299     | 413      | 25.1%         |
| Repaired shaft        | 300     | 415      | 24.7%         |

Figure 4. The welded specimen after the tensile test.

4. Conclusions

From this study of the effects of a proposed arc welding methodology, which is based on intermittent welding processes and was used to repair a worn low carbon steel shaft, the following conclusion can be drawn:

1. The structure of the shaft repaired with a discontinuous welding process consisted of pearlite and ferrite batches and this might be because there was no opportunity to form ferrite inside the grains of the pearlite.

2. The tensile strength and the elongation of the repaired shaft were not affected by the discontinuous welding process.

3. The proposed welding procedure conveyed a large increase in the surface hardness.
5. References

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