Performance of aluminium anodes under heat treatment

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THE USE OF aluminium alloy anodes for sacrificial protection of marine and offshore structure is well established. In some cases, for example during installation, the alloys are prone to be heated due to the welding of the anode to the structure. This paper concentrates on identifying the cause for the deterioration of the performance of the anode, which undergo such heating.

Samples of the aluminium alloy anode were subjected to different heat treatments. Along with X-ray-diffraction and metallographic studies. The results were then correlated with those of the untreated anode, to understand the behaviour of the anode under heat treatment.

Introduction

Alloys of aluminium are extensively used for applications ranging from small articles such as pins to highly-sophisticated components, as in spacecraft. One of the major applications of these alloys is in the field of corrosion control. Here, specific alloys of aluminium are used to sacrificially protect steel structures which are exposed to marine environment. The list of structures that are protected by aluminium alloys is very extensive, and includes offshore platforms, piles, jetties, harbour installations, etc. Many of these alloys are patented in various countries [1,2] and have been commercialized throughout the world. The aluminium alloys are chosen for this application are based on their electrochemical performance characteristics. The major parameters are the open-circuit potential, closed-circuit potential, anode-current capacity, and its consumption rate. Extensive studies have been carried out to better understand the performance of these anodes; their electrode characteristics are adapted to a variety of saline environments, such as marine mud and brackish water.

Many articles have been published with regard to the use of aluminium anodes for use in cathodic protection [3-13], and discuss the various aspects of the system such as current requirements, anode-testing procedures, anode development, etc. However, there is little information on the performance of these anodes when they are subjected to thermal treatment during fabrication or during service. The present work investigates the effect of solution treatment and the cooling procedure on the performance of anodes.

Experimental details

The aluminium alloy anodes used in this research were first tested for their impurity content using at atomic-absorption spectrophotometer. Three sets of anode specimens were solution treated at 763±5°K [14-17]. After this treatment, one set of specimens was quenched in water, a second set was cooled in air, and the third was cooled in the furnace. Specimens from each batch were prepared for metallographic study: 1-cm diameter by 1-cm long specimens were cut, ground, and polished using different grades of emery paper, up to 4/0 emery. The specimens were then polished using the polishing wheel to achieve a bright, smooth, surface, which was degreased, dried, and etched to analyse the microstructure.

Impurity element	Weight %
Iron	0.097
Silicon	0.052
Copper	< 2 x 10^{-4}
Nickel	< 2 x 10^{-4}
Manganese	0.0049
Titanium	< 2 x 10^{-4}

Table 1. Impurity content in the anode.

Treatment	Open circuit potential (V vs. Sce)	Closed circuit potential (V vs. Sce)	Anode efficiency (%)	Anode current capacity (Ahr/kg)	Anode consumption rate (kg/Ayr)
Untreated	-1.105	-1.078	88.39	2634.45	3.325
Water quenched	-1.114	-1.066	85.01	2503.60	3.508
Furnace cooled	-1.114	-1.077	80.97	2413.23	3.633
Air cooled	-1.092	-1.057	75.38	2246.59	3.890

Table 2. Anode characteristics.

Treatment	Phases present	JCPDSN*
Untreated	Al	40787
Solution-treated and quenched in water	Al	40787
Solution-treated and cooled in air	Al, Al2Zn & Al In	40787, 190057 & 21261
Solution-treated and cooled in furnace	Al & Al In	40787 & 21261

**JCPDSN = Joint Committee for Powder Diffraction standard numbering*

Table 3. X-ray diffraction analysis.

From each set, specimens sized 10mm x 10mm x 3mm were prepared and subjected to x-ray diffraction. The diffraction pattern obtained was analysed to identify the changes in crystal, and the phases.

Anode specimens from each heat-treated set of were subjected to anode-efficiency tests, as outlined in the DNV 702 RP B401 standard, to determine the effect of heat treatment on the performance of the anodes. Synthetic seawater, recommended by ASTM, was used for the test. The open-circuit potential, closed-circuit potential, anode-current capacity, anode-consumption rate, and anode efficiency were determined.

Results and discussion

The impurity contents of the aluminium alloys anode studied are presented in Table 1. These impurity contents are observed to be in the acceptable range, as compared with those reported in the literature [18].

The characteristics of the aluminium alloy anode with and without heat

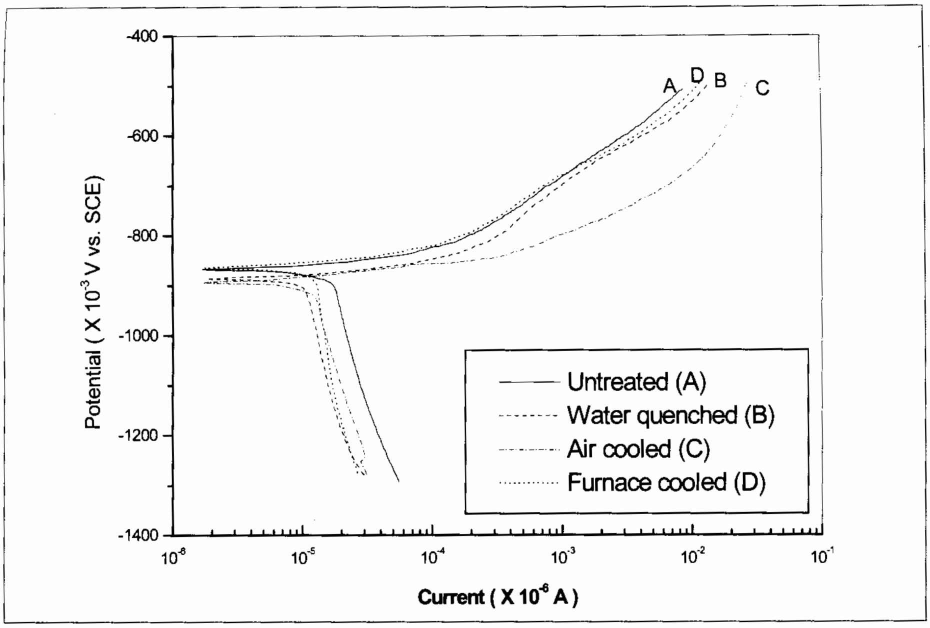

Fig. 1. Polarization behaviour of the aluminium anodes after different heat treatments.

treatment, evaluated using DNV 702 RPB403, are presented in Table 2. It can be seen that these specimens, air-cooled after heat treatment, exhibit the lowest anode current capacity, and correspondingly the highest consumption rate, and the least-negative open- and closed-circuit potentials. As compared with the untreated specimens, the anode characteristics are observed to be reduced and deteriorated to the maximum extent, while still being at a satisfactory level.

It is also observed that the anode current capacity is lowered and the consumption rate is increased for the anode specimens cooled in the furnace after heat treatment. Even though the deterioration in the anode characteristics is relatively low when compared with that of the air-cooled anode samples, they are still at an unsatisfactory level.

The anode specimens quenched in water after heat treatment also exhibited lower anode current capacity and higher consumption rate when compared with the untreated specimens. However, these anode characteristics, along with the open- and closed-circuit potentials are within the satisfactory limits, i.e. after heat treatment water quenching does not lead to significant deterioration in the anode characteristics unlike for the air-cooling or furnace-cooling samples.

The results of the x-ray diffraction (XRD) studies conducted on samples with the different treatments are summarized in Table 3, and show that the as-cast alloy (untreated) and the water-quenched after heat treatment alloy exhibit a single phase of aluminium, i.e. a solid solution of other elements in aluminium. The alloy that was air cooled after heat treatment exhibits two additional phases: Al_2Zn and AlIn. The alloy that was furnace cooled after heat treatment exhibits one additional phase: AlIn.

Considering and comparing the anode performance with the results of the XRD, it can be inferred that the presence of additional phases in the alloy leads to severe deterioration in the anode characteristics. As observed, the more the number of additional phases in the alloy, the more the performance deteriorates. This can be attributed to the formation of local galvanic cells which increase the dissolution/consumption of the anode [19, 20]. An increase in the number of phases results in an increase in the formation of local galvanic cells. Further, when these additional phases are present, the surface film on the aluminium matrix gets weakened and renders the alloy more active. This substantiates the poorest performance of the air-cooled alloy (containing two additional phases), and the poor performance of the surface-cooled alloy (containing one additional phase). The least reduction in anode performance in the water-quenched alloy can be attributed to the absence of additional phases. However, reduction in anode characteristics may probably be due to increased lattice strains, arising from quenching.

The potentiodynamic polarization curves of this anode after different heat treatments are illustrated in Fig.1. The corrosion potential for the water-quenched and air-cooled anode samples are shifted towards the more-negative direction when compared to that of the untreated anode sample, whereas the corrosion potential of furnace-cooled anode sample is shifted towards the less-negative direction. The cathodic polarization curves of the water-quenched, air-cooled, and furnace-cooled samples are all shifted towards the left of the cathodic curve of the untreated sample.

Fine grains were exhibited in the water-quenched alloy as compared with that of the as-cast alloy; the grains are relatively coarser in the air-cooled alloy. Some pits were observed, indicating particle pull-out, and these particles could be the precipitates that would have formed. In the case of the furnace-cooled alloy, larger number of pits were observed, and the grains were more coarse than in the air-cooled alloy.

Conclusions

- Heat treatment is observed to change the anode characteristics and the polarization behaviour to a considerable extent.
- The least reduction in the anode current capacity occurs when the solution-treated anode is later quenched.
- This behaviour can be attributed to the precipitation of Al2Zn and AlIn phases in the anodes, and their distribution.

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