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8. Summary and Conclusions

8.1. Summary

Different methods are available for corrosion control of various systems depending on their nature of existence and the extent of protection required. The present work was aimed to develop a suitable method for the protection of medium scale steel articles by means of cathodic protection by sacrificial anode with reference to their application in marine environments. This work has focused on the protection of submerged and buried pipelines, structures and vessels used for transportation and carrying oils and other materials. As impressed current based cathodic protection method cannot be feasible in such systems, the suitable alternative becomes cathodic protection by sacrificial anode. The present work had the aim to develop high performance sacrificial anode suitable for the protection of steel articles in marine environment.

At the first stage of the present work, a suitable substrate of Al + 5% Zn was selected and evaluated. The interior and surface modifications of the base substrate were attempted to improve the galvanic performance of the anodes. The interior activation was achieved by incorporation of activator metals or metal oxides. Selenium, a good electro-catalyst normally used in battery electrodes was explored as a good activator of Al in Al rich alloy sacrificial anodes. Though the results achieved by the individual influence of Se was good, its combined action along with Sn and Bi yielded very good results of galvanic performance. Two sets of each inert (Al₂O₃ and La₂O₃) and catalytic metal oxides (V₂O₅ and MnO₂) were selected and studied for evaluation of their role to
improve the galvanic performance, when they were incorporated in Al + 5% Zn alloy anodes. Among these oxides, catalytic metal oxides showed good results leaving scope for further significant improvement along with other type of activators also.

Surface activation by RuO$_2$ on the selected substrate was explored and evaluated under wide experimental conditions to suit their application in marine environment. Effect of partial surface activation was also studied after optimizing the activator content and its firing temperature. IrO$_2$ based surface activation was also tried on the Al + 5% Zn alloy substrate and the galvanic efficiency was compared with that of the RuO$_2$ based activation. Since almost same performance of these surface activators was noted, further modification of the catalytic coating on the anode surface was tried only with RuO$_2$ surface coatings, considering the high cost of IrCl$_3$. The mixed coating of RuO$_2$ along with IrO$_2$ was also observed to be slightly superior to the individual metal oxide coatings. Reinforcement of the RuO$_2$ coating by the metal oxides incorporation on the coated layer was also studied. Finally the RuO$_2$ surface coated anodes were further modified by secondary activation by interior incorporation of the metal and metal oxide activators. The performances of the currently developed anodes were compared with few other anodes available commercially or reported in the literature. The current developed anodes are seen to exhibit excellent galvanic performance when compared with other anodes and are found suitable for marine application also.
8.2. Conclusions at a glance

- The best activator combination of 0.5% Se + 0.1% Sn + 0.1% Bi on the Al alloy anodes showed very good galvanic performance including that based on accelerated impressed current galvanic tests. A galvanic efficiency as high as 90% was achieved with a self-corrosion rate as low as $6.7 \times 10^{-6}$ g/cm$^2$/h.

- Incorporation of MnO$_2$ and V$_2$O$_5$ showed good catalytic effect in aluminium activation and the catalytic effect increased with increase in concentration of the catalytic oxides. Higher concentration of these catalytic oxides caused precipitation in the alloy matrix. Among the different anodes studied, the anode incorporated with 0.5% V$_2$O$_5$ showed very good galvanic performance with a galvanic efficiency of 83%.

- The optimum RuO$_2$ content and its firing temperature were found to be 0.175 mg / cm$^2$ and 400 °C respectively. The galvanic efficiency due to the optimum RuO$_2$ surface coating was found to be 85%. The catalytic coating remained on the anode surface even after the anode was reduced to one third of its original mass. The IrO$_2$ as well as IrO$_2$ / RuO$_2$ mixed metal oxide coating were also studied and found to be slightly superior to individual RuO$_2$ coating.

- High performance sacrificial anodes were developed with RuO$_2$ surface coating along with secondary activation due to interior incorporation of the metal and metal oxide activators. These anodes showed very good anodic efficiency as high as 95%.
On comparison with the performance of other five selected anodes, including three commercially available and the other two reported in the recent literature, the performance of the current modified anode is seen to be excellent.

8.3. Scope for further work

The present modified sacrificial anode can also be further improved with fine-tuning of its fabrication conditions and its interior chemical composition while the original substrate and the surface coating are retained as such. The possible other modifications be with synergistic inclusion of metal activators like In as well as with metal oxides other than V₂O₅, MnO₂, Al₂O₃, La₂O₃. Optimizations of the ratio of the activated and unactivated surfaces, geometrical modifications are seemed to be new directions to achieve still better results. However, considering the extent of excellent performance of the currently modified anodes already noticed and the marginal improvement in the galvanic performance that can be resulted due to huge clerical material modifications, the modifications other than geometrical design will not be much worthwhile.

As most of the studies in the present work have been carried out with special reference to NaCl media, the currently modified anode would find its potential application as a good sacrificial anode for cathodic protection of steel based structures in marine environment where the catalytic nature of the RuO₂ prevent the bio-fouling also.