ELECTROCHEMICAL ASSESSMENT ON CORROSION BEHAVIOUR OF ELECTROCHEMICALLY JOINED DISSIMILAR METAL JOINTS

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Three dissimilar metals viz., aluminium, stainless steel and titanium were chosen for electrochemical joining and two of the above metals were joined by adopting nickel plating. The corrosion behaviour of the three metal joints was evaluated by potentiodynamic polarisation method and the results are presented and discussed.

INTRODUCTION

The joining of dissimilar metals by electroplating is gaining importance due to its wide applications in aerospace and nuclear industries [1]. This technique is used when the two metals cannot be joined by conventional methods like welding or brazing due to metallurgical incompatibility. Since, the electroplating process can be done at low temperatures, the shrinkage stress and distortions associated with high temperature joining operations are eliminated. Also in many instances the properties of the joints can be tailored to meet specific requirements. Successful joining of stainless steel to aluminium, copper, uranium-titanium alloys [2], titanium to titanium and uranium alloy [3], berilium to berilium [4] and brass to stainless steel [5] have been reported in literature.

In the work on electrochemical joining of dissimilar metals, three different metals viz., aluminium, stainless steel and titanium were taken and two of them were electrochemically joined by adopting heavy nickel plating after suitable pre-treatment. The corrosion behaviour of the three metal joints was evaluated by potentiodynamic polarisation method. The results are presented and discussed.

EXPERIMENTAL

The three metals, aluminium (commercial grade), stainless steel (SS 316) and titanium (grade II) were joined by plating, in the form of flats, as shown in Fig. 1. First the two metals to be joined are machined with specific taper and are given thin copper coating. The plating sequences for the individual metals are given in the Table I. After nickel plating, the two metals are joined and heavy nickel deposition in sulphamate bath was continued to the required thickness and finally machined for the uniform surface.
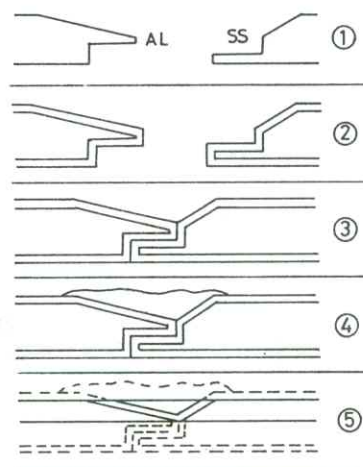

Fig. 1: Steps involved in electrochemical joining of aluminium to stainless steel
(1) Machine piece parts (2) Plate with thin copper (0.0005 in)
(3) Assemble (4) Plate with thick nickel (0.080-0.1000 in)
(5) Machine to final tolerance

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A conventional three electrode electrochemical test cell was used. The experiments were performed on 1 cm² area using platinum as the counter electrode. The potentials of each specimen were measured relative to saturated calomel electrode carrying a Luggin Capillary. The electrolyte used was 5% neutral sodium chloride. Polarisation was carried out potentiodynamically using Bio Analytical System 100 A. USA, at a scan rate of 5 mV/sec.

Open circuit potentials were noted initially by immersing the electrode for nearly 4 hours in the electrolyte till they assume a steady state condition. Scanning was done to a potential of 150 mV from the open circuit potential on both cathodic and anodic direction [3]. The corrosion currents were measured by Tafel extrapolation method.

TABLE I: Flow chart for nickel plating on Al, SS and Ti

For aluminium	For stainless steel	For titanium
Mechanical polishing	Mechanical polishing	Shaping
↓	↓	↓
Milling and shaping	Shaping	Degreasing
↓	↓	↓
Degreasing	Degreasing	Anodic etching
↓	↓	↓
Soak clean	Woods strike	Nickel plate (25 μm)
↓	↓	↓
Nitric acid dip	Nickel plate (25 μm)	Heat treat
↓	↓	↓
Double zincating	Heat treatment	Activate
↓	↓	↓
Copper strike	Activate	Nickel plating
↓	↓	
Nickel plating (25 μm)	Nickel plating	
↓		
Heat treatment		
↓		
Activate		
↓		
Nickel plate		

RESULTS AND DISCUSSION

Three different metals aluminium. stainless steel and titanium were selected for the electrochemical joining and two of the above metals were joined by heavy nickel plating after suitable pre-treatments as discussed in experimental section. Polarisation experiments were conducted on (i) the parent metals viz.. nickel. aluminium. titanium and stainless steel. (ii) their couples with nickel and (iii) at the three metal junction of the joined metals. Open circuit potentials and corrosion currents are collected in Table II. The polarisation behaviour of the parent metals and their junctions are shown in Figs. 3-5.

When a metal is immersed in any corrosive solution the rate of corrosion of the metal usually adjusts itself to the rate of cathodic reaction and the metal assumes the corrosion potential at which the rate of corrosion equals that of cathodic reaction. When metals 1 and 2 are coupled they will assume a corrosion potential between E_1 and E_2 i.e. E_3 as given in Fig. 2. At E_3 the rate of corrosion of metal 1 is i_3 and the rate of corrosion of metal 2 is i_1. Since $i_3 < i_1$ and $i_1 > i_2$. coupling two metals of different reactivities. reduces the corrosion of less reactive metals. The more reactive metal protects the less reactive metal by sacrificial protection. Hence. it is a common practice to depend on the measurements of electrode potentials in the test solutions to

TABLE II: Open circuit potentials and corrosion currents of parent metals and their joints

Material	OCP (V) vs SCE	I_{corr} (A / cm²)
Ti	1.730	3.403×10^{-7}
SS	1.709	7.597×10^{-7}
Al	1.239	2.520×10^{-5}
Ni	-0.107	2.015×10^{-6}
Ti-Ni	-0.159	5.105×10^{-6}
SS-Ni	1.650	1.031×10^{-5}
Al-Ni	-0.513	3.050×10^{-5}
Ti-SS-Ni	-0.041	9.510×10^{-3}
Ti-Al-Ni	-0.501	1.490×10^{-4}
SS-Al-Ni	-0.504	3.240×10^{-5}

determine the order of reactivity of metals. This represents only a beginning towards estimating the magnitude of galvanic action that may be a major factor in the corrosion behaviour of the coatings. However, electrode potentials cannot be used as such for predicting the behaviour of the coupled metals, as other factors also influence overall corrosion rate and morphology. One important point is that the dissimilar metals involved in the corrosion process are subjected to different polarisation effects [7]. For this reason, it is advisable to determine not only the static potentials of individual metals, but also to connect electrically with the dissimilar metals involved in the same corrosive media and determine their corrosion currents.

Table II gives the open circuit potentials of different metals and their combinations. It is very well known that titanium and stainless steel form a passive film in air which is responsible for their positive potentials. Aluminium also forms a passive oxide film, but the film breaks down in chloride solution and aluminium loses its passivity. The potential of nickel is the least noble indicating that it will dissolve more easily in chloride media than the other three metals.
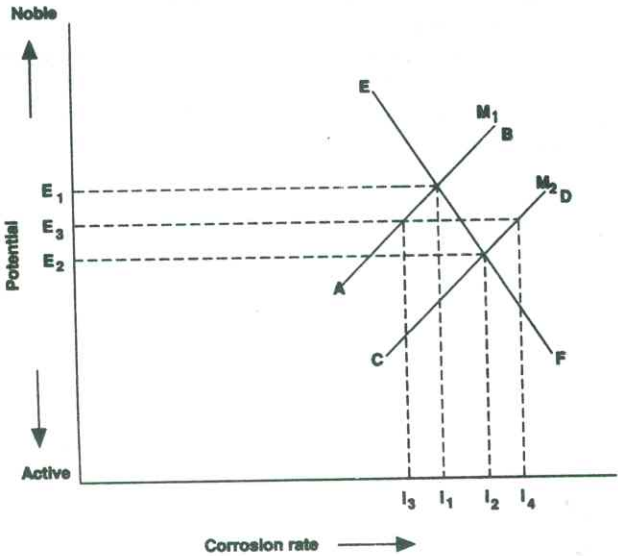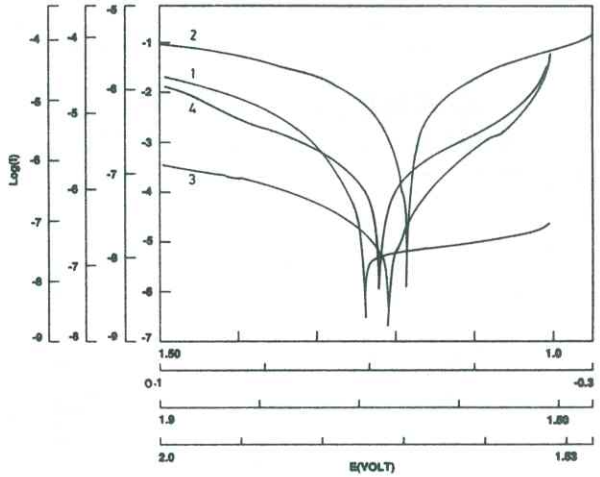

Fig. 3: Polarisation behaviour in 5% NaCl solution
(1) Al   (2) Ni   (3) Stainless steel   (4) Ti

Couples of the above metals with nickel, except SS-Ni and all the three metal joints showed negative open circuit potentials, probably due to dissolution of the least noble metal in the composite.

Figs. 3-5 depict the potentiodynamic polarisation behaviour of the above systems and the corrosion currents are given in Table II. It can be seen that though aluminium has a noble open circuit potential, it dissolves readily in sodium chloride showing a corrosion current higher than nickel. Hence, it is expected that in Al-Ni couple.

Fig. 2: Effect of coupling two metals on their corrosion behaviour
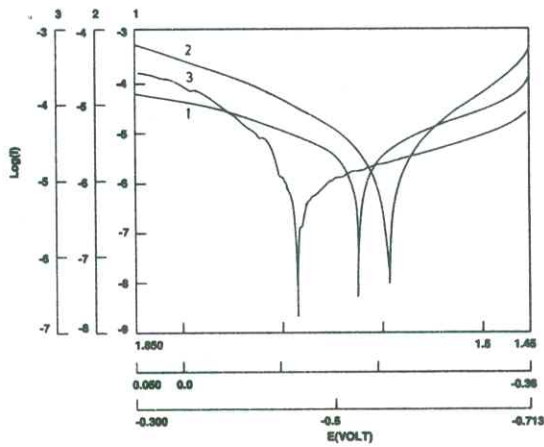

Fig. 4: Polarisation behaviour in 5% NaCl solution
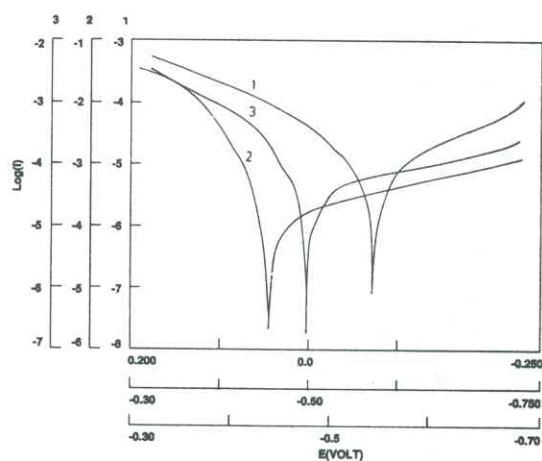(1) SS-Ni   (2) Ti-Ni   (3) Al-Ni

Fig. 5: Polarisation behaviour in 5% NaCl solution
(1) SS-Ni-Ti   (2) Al-Ni-Ti   (3) Al-Ni-SS

aluminium would show preferential dissolution in comparison with nickel. Examination of this couple after the test showed that the dissolution of aluminium had formed pits. In Ti-Ni and SS-Ni couples, nickel dissolved preferentially, the rate being much lower in the former system.

In the trimetal system containing aluminium, viz., Ti-Al-Ni and SS-Al-Ni, the dissolution of aluminium was greater in the former than in the latter. This may be due to the more passive nature of titanium, accelerating the dissolution of aluminium. Ti-SS-Ni system showed relatively a low value corresponding to the dissolution of nickel.

CONCLUSION

Corrosion behaviour of the electrochemically joined two and three layer metallic systems were evaluated by potentiodynamic polarisation studies.

It is shown that aluminium dissolved preferentially in NaCl solution compared to nickel in Al-Ni joints, resulting in pits whereas nickel dissolved preferentially in Ti-Ni and SS-Ni systems. In trimetallic systems containing aluminium, the rate of dissolution is greater in Ti-Al-Ni than in SS-Al-Ni.

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