

## ANODIC BEHAVIOUR OF INCONEL 600 AND 601 IN SULPHURIC ACID SOLUTIONS

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The corrosion behaviour of inconel 600 and 601 alloys has been evaluated by anodic polarisation and impedance studies in 0.01 to 10 M H<sub>2</sub>SO<sub>4</sub> solutions at room temperature. Inconel 601 showed a substantial higher corrosion resistance than that of Inconel 600 alloy. A rapid passivation from rest potential itself was observed for Inconel 601 except in 10 M H<sub>2</sub>SO<sub>4</sub> while I<sub>crit</sub> - I<sub>pass</sub> transition state was generally found before passivation for Inconel 600 from 0.01 to 10 M H<sub>2</sub>SO<sub>4</sub>. Impedance studies have also indicated that Inconel 601 alloy is more corrosion resistant.

**Keywords:** Inconel, corrosion and sulphuric acid

### INTRODUCTION

Inconel (nickel-chromium-iron based alloys) 600 and 601 are generally used as structural materials especially in high temperature applications because of their high temperature corrosion resistance and high mechanical strength etc. Presence of a substantial amount of chromium in these alloys offers a good corrosion resistance to aqueous corrosion. Therefore, these alloys are also used extensively in various chemical and petrochemical industries. In many chemical processes, use of sulphuric acid either becomes necessary or it is generated as a by-product. Keeping in view, the present study has been undertaken to examine the corrosion behaviour of Inconel 600 and 601 alloys in dilute to concentrated sulphuric acid.

### EXPERIMENTAL

Inconel 600 (Cr-15.5%, Fe-8%, Ni-73%, C,Si,Mn,S,Cu remainder) and 601 (Fe-14.4%, Cr-23%, Al-1.4%, Ni-63%, C,S,Mn,Si,Cu remainder) were used in the present study. The specimens were polished well upto mirror finish and degreased by trichloroethylene. The remaining area of the exposed surface (working area 1 cm<sup>2</sup>) was covered by lacquer. The solutions used for the study were 0.01 M, 0.1 M, 1 M and 10 M H<sub>2</sub>SO<sub>4</sub> and tripple distilled water. All the experiments were carried out at 298 ± 1 K.

The conventional three electrode cell with working electrode (area, 1 cm<sup>2</sup>), counter platinum electrode (area 2 cm<sup>2</sup>) and

saturated calomel reference electrode was employed in the present study. The anodic polarisation curves were recorded potentiodynamically at 5 mV/sec from -100 mV from the rest potential. All the polarisation measurements were carried out after the attainment of steady corrosion potential under the open circuit potential conditions. All the polarisation measurements were carried out with using a PAR 173 potentiostat, PAR 175 programmer and Rikadenki 0363 X-Y recorder. The A.C impedance measurements were also carried out under open circuit potential state after 1/2 hr of immersion by using A.C impedance system (PAR 385) in the frequency range of 0.1 mHz to 100 Hz.

### RESULTS AND DISCUSSION

Figs. 1 and 2 show the anodic polarisation behaviour of both the alloys in 0.1 M and 10 M H<sub>2</sub>SO<sub>4</sub>, respectively. The various corrosion parameters related to the anodic polarisation curves, are summarised in Table I. The corrosion rates (I<sub>corr</sub>) were obtained by Tafel extrapolation method in the potential ± 100 mV from E<sub>corr</sub>. An increase of I<sub>corr</sub> values and shift of E<sub>corr</sub> in negative direction with the increase of concentration of acid are observed. It clearly predicts the decrease of corrosion resistance properties for both alloys with the increase of concentration of acid. Perhaps, the decrease of corrosion resistances was quite less for Inconel 601 than that of Inconel 600 as evident from Table I. Inconel 600 showed a I<sub>crit</sub> - I<sub>pass</sub> transition state before the onset of

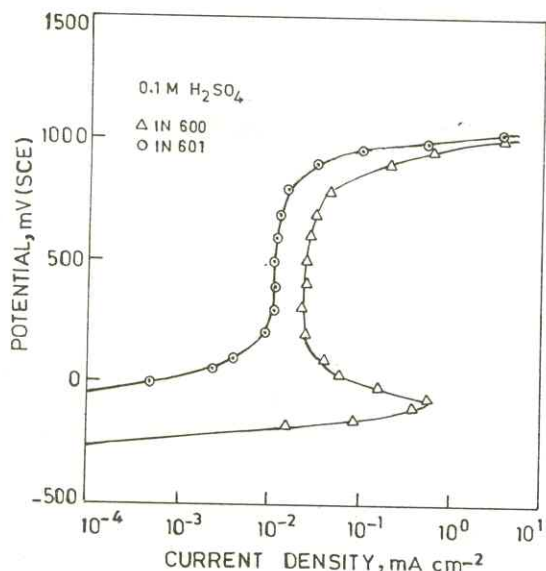


Fig.1 Anodic behaviour of 600 and 601 in 0.1 M H<sub>2</sub>SO<sub>4</sub>

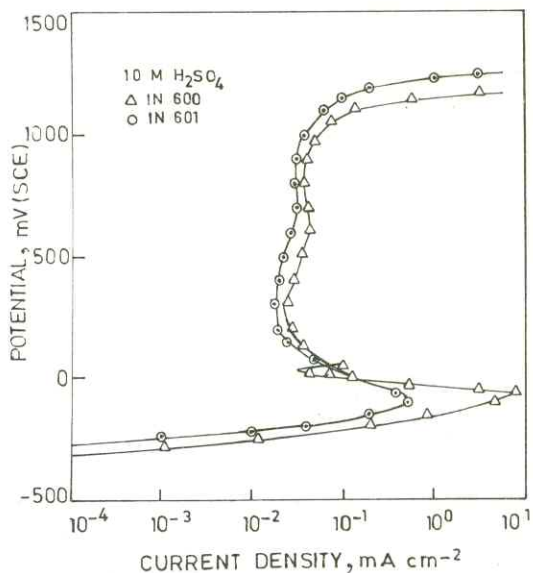


Fig. 2: Anodic behaviour of Inconel 600 and 601 in 10 M H<sub>2</sub>SO<sub>4</sub>

passivation in all the concentrations of the investigated solutions. It is well known that occurrence of  $I_{crit} - I_{pass}$  transition state is generally a result of metal dissolution and their apparent precipitation near the metal surface. Formation of such type of passive film is an entirely a potential dependent phenomenon. Thus, an abrupt reduction of anodic current after  $I_{crit}$  stage and their subsequent limitation upto certain potential region is mainly due to the formation of oxide film of Cr, Ni and Fe and the accumulation of their corrosion products, jointly may act as a diffusion barrier for further dissolution of alloys. Therefore, under the passivation potential region the anodic dissolution of metal may likely be controlled by diffusion controlled kinetics as reported [1]. The occurrence of a rapid passivation from  $E_{corr}$  itself for alloy 601 in 0.01 to 0.1 M and H<sub>2</sub>SO<sub>4</sub> may likely be related to the formation of oxide film containing of Cr, Ni and Fe without participation of their corrosion product since no  $I_{crit}$  state was observed for alloy 601 upto 1 M H<sub>2</sub>SO<sub>4</sub>. Another interesting observation is that an appreciable decrease of  $I_{pass}$  is noted for 601 when specimens are kept in passive potential region. Therefore it may also be suggested that corrosion resistance film formed in alloy 601, get further strengthened when metal is kept in required passive potential region. Because of the occurrence of  $I_{crit}$  stage before passivation for Inconel 601 alloy in 10 M H<sub>2</sub>SO<sub>4</sub> (Fig. 2) the passivation phenomenon is due to the precipitation of corrosion products along with the oxide of Cr, Ni and Fe. Surface film has also been appeared quite thick and black in colour at the end of experiment.

The corrosion resistance properties of both alloys were also evaluated by impedance analysis. Fig. 3a shows the impedance behaviour for alloy 600 in 0.1 M H<sub>2</sub>SO<sub>4</sub>. The existence of depressed semicircle indicates the diffusion controlled kinetics which is an indication of a slow dissolution of metals and alloys. In case of Inconel 601, a distinct semicircle having a very high impedance value has been invariably observed in 0.1 M H<sub>2</sub>SO<sub>4</sub> (Fig. 3b). It is interesting to mention that a perfect semicircle of Nyquist diagram is also noted in 1 M H<sub>2</sub>SO<sub>4</sub> solution for inconel 601. However, semicircle characteristics is appeared to be depressed one when measurement is conducted in 10 M H<sub>2</sub>SO<sub>4</sub> for 601 (Fig. 3c). In case of alloy 600 a well defined semicircle with a high resistance value is only recorded in 0.01 M H<sub>2</sub>SO<sub>4</sub>. A proportionate increase of impedance

TABLE I: Corrosion parameters for Inconel 600 and 601 in H<sub>2</sub>SO<sub>4</sub>

Alloy	Conc. H <sub>2</sub> SO <sub>4</sub> (M)	E <sub>corr</sub> (mV) vs. SCE	I <sub>corr</sub> (μA/cm <sup>2</sup> )	I <sub>crit</sub> (μA/cm <sup>2</sup> )	Passivation range (mV)
In 600	0.01	-220	3.2	0.068	00 to 700
	0.10	-275	5.0	0.300	00 to 1800
	1.00	-295	16.0	0.400	120 to 600
	10.00	-315	82.0	2.500	200 to 900
In 601	0.01	+60	1.1	No I <sub>crit</sub>	OCP to 800
	0.10	+25	3.0	-do-	OCP to 850
	1.00	-40	7.0	-do-	OCP to 875
	10.00	-275	18.0	0.50	00 to 900



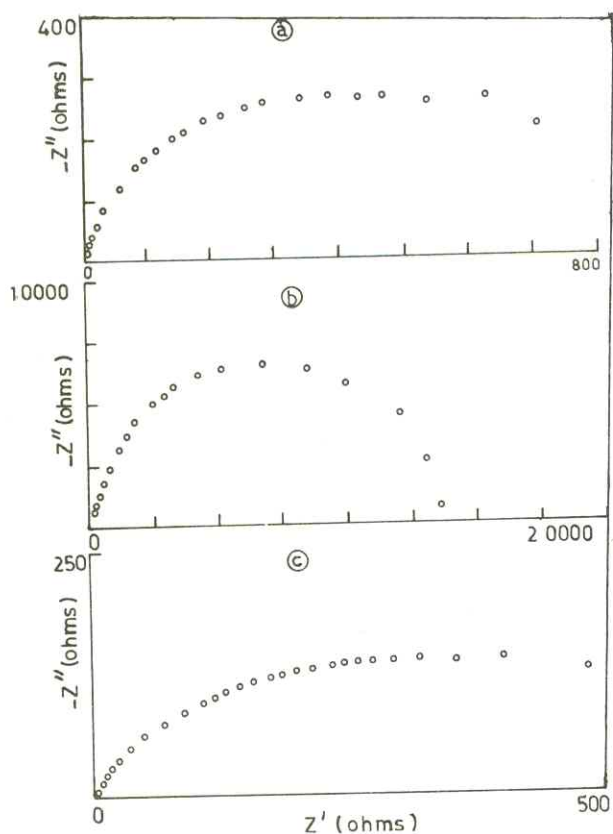


Fig. 3: Nyquist plots of inconel (a) Inconel 600 in 0.1 M  $H_2SO_4$ , (b) Inconel 601 in 0.1 M  $H_2SO_4$  and Inconel 601 in 10 M  $H_2SO_4$

resistance from 1 M to 0.01 M is observed for alloy 601. This also indicates that corrosion resistance of alloy 601 increases with the increase of dilution of acid. The impedance measurements are also in agreement with the observed positive shift of  $E_{corr}$  values shift of from 10 M to 0.01 M  $H_2SO_4$  (Table I). From the present results it may be concluded that the existence of highly corrosion resistance film on Inconel 601 is able to protect the metal even in -1 M  $H_2SO_4$ . However, the corrosion resistance properties of the oxide film gets destroyed in extremely high concentrated acid (10M). Inconel 600 possess a poor corrosion resistance in comparison with Inconel 601.

It is well known that passivation of metals in aqueous system proceeds with the participation of water molecules [2,3]. Water is a source of oxygen for oxide film formation. The passive film formed on the chromium containing alloys is highly protective in nature and is known to consist of chromium oxyhydroxide and bound water in the form of  $(CrO_x(OH)_{3-2x}nH_2O)$  [4,5].

It is also known that presence of nickel generally promote the formation of chromium containing oxide film. Presence of a substantially higher concentration of nickel and chromium in Inconel 601 therefore responsible for its higher corrosion resistance in comparison to Inconel 600. Presence of Al in Inconel 601 may also be responsible for strengthening the passive film. Moreover, inclusion of aluminium in alloys is very much necessary for producing high temperature corrosion resistance because  $Al_2O_3$  improves the stability of oxide film at elevated temperature.

The higher corrosion rates in 10 M  $H_2SO_4$  for both alloys (Table I) are mainly due to complete dissociation of sulphuric acid and most of the water molecules are bound in the hydration shell of hydrogen ions [6]. Passivity in 6 M to 14 M  $H_2SO_4$  is difficult to attain because the concentration of passivating species like water molecules and undissociated acid molecules are not present in the solution. Due to this, dissolution of metal in higher concentration of  $H_2SO_4$  is high. This may be the probable case for the occurrence of an unprecedented higher corrosion rate for both alloys in 10 M  $H_2SO_4$ . To know the composition of oxide film and the corrosion product layer, further analytical study is essential.

## CONCLUSION

The following conclusions may be drawn from the studies:

1. Inconel 601 has got a quite higher corrosion resistance than that of Inconel 600.
2. Inconel 600 is susceptible to corrosion even in 0.1 M  $H_2SO_4$  while 601 alloy maintains its corrosion resistances even upto 1 M of acid.
3. The passive film formed in passivation region may be related to the precipitation of corrosion product along with oxide of main constituents of the alloys.

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