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**ENVIRONMENTAL CRACKING BEHAVIOUR OF
Pd-BEARING Ti-7%A1-2%Nb-1%Ta ALLOY**

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PHYSICAL METALLURGY DIVISION

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Ti-7%Al-2%Nb-1%Ta ALLOY

by

G. J. Biefer* and A. J. Williams**

ABSTRACT

Alloys of Ti-7%Al-2%Nb-1%Ta (Ti-721) containing 0.26 to 1.56% Pd were tested in two different heat-treatment conditions. For one of these, termed "sensitized", the heat treatment was designed to favour the precipitation of α_2 (Ti_3Al), whereas for the other, termed "desensitized", the heat treatment was designed to suppress Ti_3Al precipitation.

In tests on unstressed specimens of Ti-721, it was found that an alloying addition of 0.26% Pd was sufficient to bring about passivity in strongly acid 3.5% NaCl solutions. However, improvements in resistance to environmental cracking (EC) in 3.5% NaCl solution were shown only by alloys containing 0.38 to 1.56% Pd. Ti-721 alloy containing α_2 (Ti_3Al) is known to be highly sensitive to EC. Despite moderate improvements imparted by palladium, the sensitized Ti-721 Pd alloys remained unacceptable in so far as resistance to EC was concerned. Desensitized Ti-721 Pd also showed improved resistance to EC at 0.38 to 1.56% Pd, these alloys showing a more acceptable level of resistance.

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Probably because of a solid solution strengthening mechanism, 0.75 to 1.56% Pd brought about minor increases in yield and ultimate tensile strength and also in fracture toughness. An additional slight increase in yield strength was caused by the sensitizing heat treatment at all palladium levels.

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COMPORTEMENT DU PALLADIUM
A LA FISSURATION EN MILIEU CORROSIF
ALLIAGE de Ti-7%Al-2%Nb-1%Ta

par

G. J. Biefer* et A. J. Williams**

RESUME

Des alliages de Ti-7%Al-2%Nb-1%Ta (Ti-721) contenant 0.26 à 1.56% de palladium ont été mis à l'épreuve dans deux différentes conditions de traitement thermique. Dans l'une des conditions dite "sensibilisée" le traitement thermique a été conçu dans le but de favoriser la précipitation de α_2 (Ti₃Al), alors que dans l'autre, dite "désensibilisée", le traitement thermique a été conçu dans le but de supprimer le précipité Ti₃Al.

D'après des essais sur des échantillons de Ti-721 exempts de contraintes, on a découvert qu'une addition de 0.26% de palladium s'est avérée suffisante pour rendre l'alliage passif dans de fortes solutions acides à 3.5% NaCl. Par contre, c'est seulement dans les alliages contenant 0.38 à 1.56% de palladium qu'on a enregistré des améliorations dans la résistance à la fissuration en milieu corrosif (EC) dans une solution de 3.5% NaCl. L'alliage Ti-721 contenant α_2 (Ti₃Al) est reconnu pour sa sensibilité à la fissuration en milieu corrosif (EC). Les alliages "sensibilisés" du Ti-721 sont demeurés inacceptables quant à leur résistance à la fissuration en milieu corrosif (EC), malgré les faibles améliorations causées par le palladium.

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Les alliages du palladium Ti-721 "désensibilisés" ont aussi démontré une résistance à la fissuration en milieu corrosif (EC), ces alliages étant plus résistants.

Une teneur de 0.75 à 1.56% de palladium a causé de faibles augmentations de la limite d'élasticité, de la charge limite de rupture et aussi de la résistance à la rupture. Ceci est dû probablement au traitement de consolidation en solution solide. Il y a eu aussi une faible augmentation additionnelle de la résistance à la rupture, à tous les niveaux de palladium, causé par le traitement de sensibilisation.

INTRODUCTION

As indicated by the simplified Pourbaix diagram of Figure 1⁽¹⁾, titanium and its alloys passivate spontaneously and are almost completely resistant to corrosion in sea water and in the neutral NaCl solutions often used in laboratory testing. When smooth tensile specimens are used in such media, high resistance to environmental cracking (EC)[⊗] is exhibited. However, the pioneering work of B. F. Brown showed that, for notched and precracked specimens of some titanium alloys in 3.5% NaCl, EC occurs readily at a stress intensity much lower than that causing fracture under dry conditions⁽²⁾. Brown subsequently pointed out that the solution pH and the metal potential at the tip of an environmental crack can differ markedly from those outside the crack. For a titanium alloy specimen freely corroding in nearly neutral salt solution, he has reported that the pH at the tip of an EC crack may be about 1.6 and the potential about -1.05 V (in this paper, all potentials are with respect to the saturated calomel electrode (SCE)). He attributes such an acidification to hydrolysis of the ions of one or more components of the metal or alloy within the restricted volume of the crack^(3,4). Similarly, referring to titanium-aluminum alloys, M. Pourbaix has suggested that the solution at the crack tip will be "very" acid and that the potential will be in the range -0.85 to -1.25 volts⁽⁵⁾.

The foregoing indicates that the metal-solution interface at the environmental crack tip will be well within the corrosion region of the Pourbaix diagram, and that active corrosion at the advancing crack tip could be an integral part of the EC process in titanium and its alloys. If this is correct, measures to maintain the crack tip interface at potentials and pH values within the passivation region might mitigate or even eliminate the EC susceptibility. One method which warrants consideration is the use of a suitable noble metal alloying addition. It has been demonstrated, for example, that 0.1 to 0.2% Pd, alloyed with titanium,

⊗ The general term "environmental cracking" (EC) - a shortened form of environmentally induced stress cracking - includes all the different cracking mechanisms which have been proposed, e.g., active path corrosion, hydrogen embrittlement, stress-sorption, etc.

accelerates the cathodic reduction of hydrogen ions so greatly that spontaneous passivation, with relatively noble potentials and low corrosion rates, can occur in acid solutions in which ordinary titanium corrodes at appreciable rates⁽⁶⁾.

If a palladium addition to a high-strength titanium alloy had a similar effect within the precrack of a stressed specimen, EC might be inhibited at the passivated precrack tip. To test this suggestion, it was decided to prepare a number of heats of Ti-721 alloy - - some free of palladium and some containing palladium at different levels - - and to conduct EC tests, using precracked specimens immersed in nearly neutral salt solutions. Ti-721 alloy has been shown to be highly susceptible to EC, especially when the heat treatment is such that the formation of α_2 (Ti_3Al) has been favoured⁽⁷⁾.

EXPERIMENTAL

1. Alloy Preparation

Seven 25-lb (11.3 kg) heats of Ti-721 alloy were produced, two without palladium addition and five with target palladium levels ranging from 0.25% to 1.5%*. The materials used were titanium sponge, titanium sheet, aluminum shot (99.5% grade or better), Dupont D3 niobium granules, melting-grade tantalum powder, and palladium ingot (99.9% grade or better). The most significant impurities were 0.08% Fe in the titanium sheet, 0.33% O_2 in the aluminum shot, 0.12% O_2 in the titanium sheet, 0.055% O_2 in the titanium sponge, 0.059% O_2 in the tantalum powder, and 0.10% Si in the aluminum shot.

Each alloy was made up from its constituents in the form of five consumable electrodes for arc melting. Each electrode consisted of the weighed ingredients enclosed in a titanium sheet cylinder which, after isostatic pressing, was approximately 28 in. (711 mm) long and 2 1/2 in. (63.5 mm) in diameter. To ensure homogeneity, each electrode was formed by means of ten charges, each accurately weighed to the target composition.

*All percentages quoted are wt% unless otherwise stated.

The alloys were triple melted in a consumable-electrode vacuum-arc furnace under dynamic vacuum in the range of 1×10^{-3} to 2×10^{-3} torr*. The final ingot was 4 1/2 in. (112 mm) in diameter.

After cropping and machining of the surfaces, the ingots were extruded to 2-in. (51 mm) diameter rounds (extrusion ratio of 4.5:1) at 1125°C and rolled to 1/2-in. (12.7 mm) plate at 1000°C. Seven-inch (178 mm) long blanks for cantilever EC test bars and 4-in. (102 mm) long blanks for 1/4-in. (6.35 mm) round tensile test specimens were cut from the plate with their long axes in the rolling direction.

The blanks were all heat treated for 1 hr at 900°C, followed immediately by a water quench (i.e., "desensitized"), to avoid, as much as possible, the formation of α_2 (Ti₃Al). One blank of each size was then reheated to 650°C for 8 hr and air cooled (i.e., "sensitized") in order to promote the formation of α_2 (Ti₃Al). The blanks were then machined to tensile and EC test specimens of the types shown in Figures 2 and 3.

Analytical samples were machined from a location in the plate corresponding closely to the centre of the ingot. Because several of the aluminum analyses (Table 1) appeared to deviate seriously from the target composition, a series of carefully controlled button melts were made in an argon-arc furnace and later submitted for analysis in an attempt to establish whether the other additions were interfering with the aluminum analysis. The results (also shown in Table 1) did not establish a pattern but showed an unexpected scatter. Check analyses were then requested on the samples from both sources that had shown the highest deviation and the results, shown in the last column of Table 1, fell within a reasonable scatter band around the target aluminum content. Furthermore, in ASTM specifications (B348, B367, B381, B265), the allowable deviation between laboratories for check aluminum analyses is 0.4%, i.e., over an order of magnitude greater than for other titanium alloy additions. It was therefore concluded that the aluminum content of the alloys was within the specified limits for Ti-721 alloy and that the significance of compositional differences would be minor. The niobium and tantalum contents were within specifications with the exception of the niobium in Heat 2053. Three of the tantalum results were near the upper limit.

*Approximately 0.13 to 0.26 Pa

2. Methods

(a) Tensile Tests

Tensile tests were performed on standard ASM 1/4-in. tensile test bars (Figure 2) using a 10,000 lb-capacity Instron tensile testing machine. The strain rates used were 0.01/min through the yield point and 0.1/min to failure.

(b) Potential Measurements on Unstressed Coupons

These were carried out on 3 x 1/2-in. (76 x 12.7 mm) coupons cut from the 1/2-in. (12.7 mm) plate. A hole was drilled at the end of each coupon, and tapped so that a threaded support rod (isolated by paraffin wax) could be inserted. All coupon surfaces were wet-ground on 120-grit silicon carbide papers, then cleaned and degreased prior to immersion, 4 or 5 at a time, in 10 liters of solution contained in a wide-mouthed jar which was at room temperature and open to the atmosphere. Using a multimeter with 10^9 ohms input impedance, potential measurements were made at intervals until a steady state was reached. This took from 30 to 50 hr.

The test solutions were 3.5% NaCl (pH of about 6.4) and 3.5% NaCl acidified with H_2SO_4 (pH 0 to 1.94).

(c) Rising-Load Cantilever Tests

The cantilever EC test, developed by B. F. Brown⁽²⁾, involves the use of a notched bar, precracked in the notch by fatiguing and loaded as a cantilever. In this work, the specimens (see also Figure 3), were 7 in. (178 mm) in length and 3/8 in. (9.5 mm) thick, and were cut from 1/2-in. (12.7 mm) plate so that the specimen length lay in the rolling direction and the plate thickness in the "h" direction. Specimens were both side- and top-notched, such that through-thickness L-S cracking (according to the nomenclature recommended by ASTM Committee E-24) was favoured under cantilever loading. Specimens were precracked using a Krouse Plate Fatigue Testing Machine at a nominal stress of 20 to 30 ksi (138 to 207 MPa) for 10,000 to 30,000 cycles.

To get a definite result for each specimen in a reasonable length of time, specimens were fractured by means of a steadily rising load. Previous rising-load EC tests had indicated that the nominal stress intensities K^* at fracture (based on the original specimen geometry and the final load) are a reasonably good general index of resistance to EC^(8,9). The rising-load cantilever test methods have been described in detail⁽¹⁰⁾ and it might be remarked that the approach is similar in principle to the constant strain rate testing of EC which has been used with striking success by R. N. Parkins⁽¹¹⁾ and others.

In the present series of EC tests, the corrosive was 3.5% NaCl solution which was in contact with the atmosphere and replenished continuously at the rate of about 6 liters per day. The unstressed specimen was always immersed in this solution before applying the initial load, which gave a stress intensity of 16 to 20 $\text{ksi}\sqrt{\text{in.}}$ (17.6 to 22 $\text{MPa}\cdot\text{m}^{1/2}$). The stress intensity was then increased at a rate of 0.6 $\text{ksi}\sqrt{\text{in.}}/\text{hr}$ (0.66 $\text{MPa}\cdot\text{m}^{1/2}/\text{hr}$) or less, until the specimen fractured. For specimens broken in air, the rate of increase of stress intensity was over 200 $\text{ksi}\sqrt{\text{in.}}/\text{hr}$ (220 $\text{MPa}\cdot\text{m}^{1/2}/\text{hr.}$). In the tests in NaCl solution, the time to fracture varied from 15 to 180 hr, depending upon the initial specimen geometry and the resistance to EC shown, while the air tests took only about 1/4 hr.

For both Ti-721 and Ti-721-0.75% Pd, rising-load EC tests were conducted in which the corrosion potential of the specimen was monitored continuously up to and after fracture.

RESULTS

1. Tensile Properties

The tensile properties are shown in Table 2 and the ultimate and 0.2% yield strengths are plotted in Figure 4. Each point is the average of two tests. The addition of palladium, in general, mildly strengthens the alloy and slightly reduces its ductility. The alloys have a tendency toward mild age hardening at 650°C but palladium at the levels used does not appear to increase this tendency. Behaviour of the sensitized material appears to be anomalous at the 0.26% Pd level.

2. Optical Metallography

All of the alloys were examined by optical metallography after heat treatment in an attempt to detect precipitates, but, not unexpectedly, no α_2 (Ti_3Al or Ti_2Pd) could be identified by this means and no tendency to β stabilization could be detected at these low levels of palladium.

3. Potential Measurements on Unstressed Coupons

The results obtained are presented in Figures 5 and 6, which show the steady-state potential as a function of solution pH for both sensitized and desensitized alloys. Both figures show two lines taken from the Pourbaix diagram for titanium (Figure 1): the hydrogen line (a) and the line separating regions of passivation and corrosion.

All the palladium-bearing alloys passivated spontaneously in every test solution employed and did not show any evidence of corrosion when examined after testing. The base Ti-721 alloy showed passive behaviour at the three highest pH values but corroded actively at pH values of 0 and 0.4. There appeared to be an increase in the nobility of steady-state potentials with increased palladium, and this helped to bring about the decision to produce alloys containing more than 0.75% Pd.

4. Rising-Load Cantilever EC Tests

The K^* values obtained in the EC measurements are listed in Table 3 and also presented in Figures 7 and 8.

For specimens broken in air, when palladium contents were 0.38% or more, the "dry" K^* values increased slightly with increasing palladium, showing the highest values for the alloy containing 1.56% Pd. All dry specimens showed predominantly flat fracture surfaces.

For specimens broken in 3.5% NaCl, the "wet" K^* values were decreased by an addition of 0.26% Pd, but were increased relative to the palladium-free alloy by an addition of 0.38% Pd. There was a further increase for the alloys containing 0.75% and 1.56% Pd, which showed the highest wet K^* values. At all palladium levels, alloys in the sensitized condition were much more susceptible to EC than alloys in the desensitized condition.

For every specimen of Table 3, the EC type is shown in parenthesis following the K^* values, using terms proposed by C. S. Carter. According to Carter⁽¹²⁾, Type 1 cracking indicates that the ratio K_{ISCC}/K_{IC} exceeds 0.5. In the sensitized condition, only Ti-721-1.56 Pd shows Type 1 cracking and this alloy may therefore have the highest K_{ISCC} value.

Periodic potential measurements were performed on the specimens before EC had started and bulk solution pH was measured at the same time. For specimens that had been immersed overnight, or longer, there did not appear to be any differences in potential as a function of alloy composition or heat-treatment condition. Potentials were in the range -0.231 to +0.081 volts and solution pH values were from 5.52 to 6.77.

For several sensitized specimens of Ti-721 and Ti-721-0.75% Pd, the specimen potential was recorded continuously during a rising-load test. Typical potential vs time plots at fracture are reproduced in Figure 9. Characteristically, a few tenths of an hour before fracture, the potential suddenly began to shift in the negative direction, presumably indicating the start of EC crack propagation. (Simultaneous measurements of cantilever beam deflection, not reported here, always showed an increase in beam deflection rate shortly after the shift in potential, as illustrated in Ref. 13). With occasional short pauses and more rarely reversals, the potential then became increasingly negative until fracture, at which time a negative spike was shown. Extreme values of the spikes ranged from -0.935 to -0.975 volts. After fracture, potential values became more noble, rapidly at first, then at a steadily diminishing rate as the steady-state value prior to crack propagation was approached.

For the Ti-721 specimen referred to in Figure 9, the crack area was observed visually during the 0.3 hr of EC prior to failure, with the aid of a magnifying glass and a strong light. No gas bubbles were observed

coming from the crack until it had opened quite widely, 5-10 sec before final failure. At this time, a few fine gas bubbles (presumably hydrogen) were released from the crack.

The methods used did not permit measurement of the EC crack propagation velocity as a function of K. However, because the fracture faces of the specimens showed EC fringes about 0.2 in. (5 mm) deep for propagation times such as those shown in Figure 9, a rough approximation would be about 2×10^{-4} in./sec (5×10^{-3} mm/sec). This corresponds reasonably well with the results of other workers.

DISCUSSION

When alloyed with titanium, palladium acts as a β stabilizer of the eutectoid forming type^(14,15,16). Its solubility in titanium is low, Rudnitskii and Birun⁽¹⁴⁾ quoting a figure of less than 8% (4 at.%) and Rosenberg and Hunter⁽¹⁵⁾ probably less than 1%. Because there are no data on the effect of aluminum on the solubility of palladium in titanium, it cannot be said with certainty that Ti_2Pd precipitation does not play a part in the strengthening and ageing effects in the present alloys. However, since the ageing effect is present even in the absence of palladium, it is more likely due to the precipitation of α_2 (Ti_3Al).

Likewise, the general tendency toward increases in yield strength and ultimate tensile strength is probably due mostly to the solid solution of palladium in the α titanium. Parelleling this, the dry K^* values indicated a progressive increase in fracture toughness with palladium content for alloys having 0.38 to 1.56% Pd. At the 1.56% Pd level, the maximum increase was shown, amounting to about 20% as compared with the base Ti-721, the desensitized and sensitized alloys behaving similarly. This, again, suggested that the mechanism was solid-solution of palladium rather than compound formation.

In the tests on unstressed coupons, results were equivalent for the sensitized and desensitized conditions. In both cases, an alloying addition of 0.26% Pd was sufficient to passivate Ti-721 alloy even in NaCl solutions which were more acid than might be expected to develop at crack tips^(3,4,5). In the EC tests, the alloy containing 0.26% Pd showed anomolous behaviour and will be discussed later. The alloy containing 0.38% Pd showed significantly increased wet K^* values, as compared with palladium-free Ti-721. A further slight increase of K^* was observed for the alloy containing 0.75%, which behaved in most respects like the alloy containing 1.56% Pd.

For the desensitized alloys, wet K^* values were in all cases relatively high and more or less paralleled the increases in tensile strength and fracture strength imparted by palladium. For the sensitized alloys, the wet K^* values were generally much lower (presumably because of the presence of α_2 (Ti_3Al)) but the increases in resistance to EC imparted by palladium were proportionately much greater, roughly amounting to a doubling of the breaking load. The sensitized alloys, therefore, warrant further discussion.

Results such as those of Figure 9 provided no indication that palladium was retarding the rather rapid crack propagation rates shown by Ti-721. Presumably, the EC process outpaced the ability of palladium to repassivate the crack tip by selective dissolution and surface enrichment in palladium. It appeared, therefore, that its principal beneficial effects must be in lengthening the induction period, or increasing the value of K_{ISCC} , the critical stress intensity for EC. In the rising-load measurements it was not possible to disentangle the two parameters, but the change to Type I fracture for sensitized Ti-721-1.56% Pd is convincing evidence of increased K_{ISCC} for at least this alloy. To the extent that K_{ISCC} is increased, it appears possible, though highly speculative, that this might be due to some preferential association of palladium with the α_2 (Ti_3Al) such that its effect on EC sensitivity is reduced. However, confirmation of this would be difficult.

An addition of 0.26% Pd was observed to be detrimental in so far as EC resistance was concerned. In other systems in which a noble metal has

been alloyed with a passivable metal, an insufficient addition of the noble metal has been occasionally observed to cause increased active corrosion rates, whereas the same addition at a higher level has brought about passivity and low corrosion rates^(17,18). A similar effect may be operative in the present work.

SUMMARY AND CONCLUSIONS

Heats of Ti-721 titanium alloy were prepared with palladium alloying additions in the range 0.26 to 1.56%. Mechanical properties were measured, corrosion tests were done on unstressed specimens in acidified 3.5% NaCl solutions, and rising-load cantilever EC tests were done on notched, precracked specimens in nearly neutral 3.5% NaCl. Principal findings were as follows:

1. For Ti-721 alloys containing 0.75 to 1.56% Pd, ultimate tensile strength and 0.2% offset yield strength showed slightly increased values proportional to the palladium content. The sensitizing heat treatment, designed to produce α_2 (Ti_3Al), caused an increase of about 10% in yield strength that was independent of palladium content.
2. In dry cantilever tests, Ti-721 alloys containing 0.38 to 1.56% Pd showed increases in fracture toughness proportional to the Pd content. Both sensitized and desensitized alloys showed similar behaviour, with Ti-721-1.56% Pd showing the highest dry K^* values, 20% higher than the base alloy.
3. For unstressed coupons, an addition of 0.26% Pd to Ti-721 was sufficient to bring about passivation in strongly acidified 3.5% solution.
4. In the EC tests in 3.5% NaCl solution, an addition of 0.26% Pd was definitely deleterious for desensitized alloys and probably deleterious for sensitized alloys. However, for both heat-treatment conditions, 0.38% Pd caused an increase in EC resistance relative to ordinary Ti-721 and 0.75% Pd caused a further increase. Ti-721-1.56% Pd was, generally, similar to Ti-721-0.75% Pd, these two alloys

showing the highest EC resistance of those tested. General resistance to EC was much greater for the desensitized alloys. Although palladium brought about proportionately greater improvements in the sensitized alloys, they remained unacceptably susceptible to EC.

It appears, on the whole, that further investigation of the EC behaviour of Ti-721 Pd alloys is not warranted at this time. The concept of improving EC resistance through the use of a noble alloying addition appears, however, to have some validity. The investigation of the effect of other noble additions, preferably of lower cost than palladium appears justified. Such work should include static-load tests in addition to the more demanding rising-load tests.

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TABLE 1

Titanium Alloy Analyses

Ti-721 + Palladium and Others

Heat No.	Ingot or Button	Nominal Composition (wt %)				Initial Analysis (wt %)				Check A1 Analysis (wt %)
		Al	Nb	Ta	Pd	Al	Nb	Ta	Pd	
2097	Ingot	7.0	2.0	1.0	0	7.03	2.14	1.13	-	-
2053	Ingot	7.0	2.0	1.0	0	7.17	2.37	1.04	-	-
2226	Ingot	7.0	2.0	1.0	0.25	7.76	1.93	1.25	0.26	7.29
2245	Ingot	7.0	2.0	1.0	0.75	7.37	1.98	1.23	0.75	-
2257	Ingot	7.0	2.0	1.0	0.40	7.36	1.95	1.22	0.38	6.85
2306	Ingot	7.0	2.0	1.0	1.50	6.23	2.01	0.97	1.56	6.51
2320	Ingot	7.0	2.0	1.0	1.15	6.36	2.07	0.97	1.09	6.61
S2142	Button	7.0	0	0	0	6.88	-	-	-	-
S2143	Button	7.0	0	0	1.50	7.40	-	-	-	6.79
S2144	Button	7.0	2.0	1.0	0	7.14	-	-	-	-
S2149	Button	7.0	2.0	1.0	0	7.36	-	-	-	-
S2148	Button	7.0	2.0	1.0	0.50	6.76	-	-	-	6.80
S2145	Button	7.0	2.0	1.0	1.50	7.06	-	-	-	6.80

TABLE 2

Tensile Properties

Alloy Ti-721 + Palladium

Heat No.	Pd Level (wt %)	Condition	UTS* (ksi)	0.2%* Yield (ksi)	E1 (%)	R A (%)	Details
2097	Nil	Desensitized (D)	119.4	101.5	19.0	42.9	D-900°C-1hr, WO
"	Nil	Sensitized (S)	119.4	107.1	20.0	41.2	S-900°C-1hr, WO 650°C-8hr, AC
2226	0.26	D	118.0	100.6	20.5	40.8	
"	"	S	122.1	113.6	19.5	37.5	
2257	0.38	D	116.8	100.9	17.0	39.8	
"	"	S	117.0	107.0	20.0	42.8	
2245	0.75	D	120.0	101.9	17.5	40.0	
"	"	S	122.4	110.4	18.8	38.0	
2320	1.09	D	123.9	106.9	18.0	36.0	
"	"	S	124.8	115.0	20.0	37.1	
2306	1.56	D	-	-	-		not tested
"	"	S	126.9	116.0	18.0	32.7	

*For conversion from ksi to MPa, multiply by 6.89.

TABLE 3

Behaviour of Palladium-Modified Ti-721 in
Rising-Load Cantilever Tests

Heat No.	% Pd	Stress Intensity at Fracture K^* , ksi $\sqrt{\text{in.}}$ ††			
		Sensitized (900°C for 1 hr WQ, then 650°C for 8 hr, AC)		Desensitized (900°C for 1 hr, WQ)	
		Dry	Freely Corroding in 3.5% NaCl	Dry	Freely Corroding in 3.5% NaCl
2053	--	75.5 73.7	29.2 (2) † 24.9 (2)	--	
2097	--	--	28.0 (2)	74	64.5 (1) † 61.0 (1)
2226	0.26	74.5 70.3	23.5 (2) 24.9 (2)	81.3 71.3	46.5 (2) 42.4 (2)
2257	0.38	83.0 79.5	39.0 (2) 40.8 (2)	82.7 82.5	68.2 (1) 68.8 (1)
2245	0.75	85.0 85.0	53.0 (2) 53.5 (2) 43.0 (2) 46.2 (2)	84.9	72.1 (1) 71.8 (1)
2306	1.5	92.8 86.0	47.9 (1) 54.0 (1)	92.0 95.6	72.2 (1) 75.7 (1)

† Numbers in brackets signify fracture type as follows:

Type 1: EC predominantly in the plane of the fatigue precrack.

Type 2: EC (usually branching) inclined at an acute angle to the
plane of the fatigue precrack.

†† For conversion from ksi $\sqrt{\text{in.}}$ to MPa·m^{1/2}, multiply by 1.10.

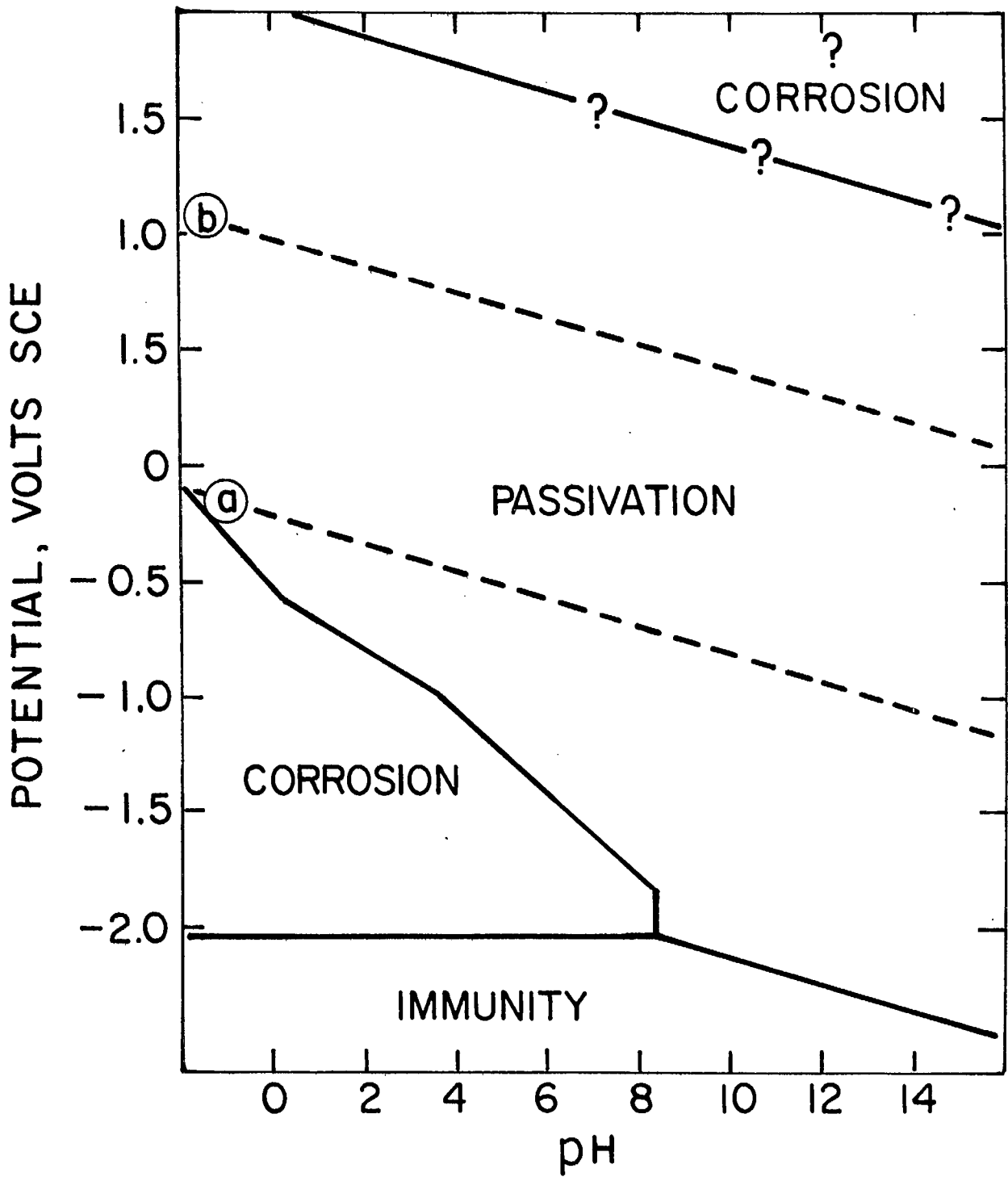
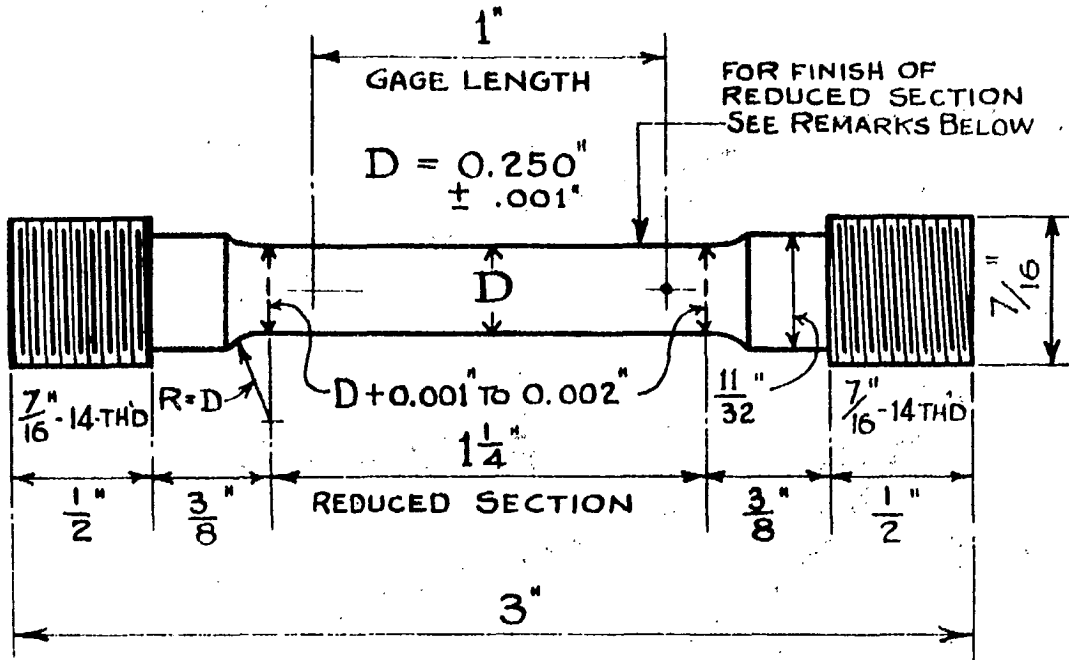


Figure 1. Simplified Pourbaix Diagram for Titanium.

PM.R.L
 BOOTH ST.
 OTTAWA



NOT TO SCALE

$\frac{1}{4}$ " TENSILE SAMPLE

REMARKS

FINISH REQUIRED ON REDUCED SECTION
 TO BE AS SPECIFIED ON WORK ORDER
 IF NOT SPECIFIED FINISH IS TO BE ∇

FILE IA

AMERICAN SOCIETY FOR METALS

DRAWN BY W.A.E.

CHECKED BY N.B.B.

MATERIAL :-

AS STATED ON WORK ORDER

DWG. NO. 12

Figure 2. Tensile Sample.

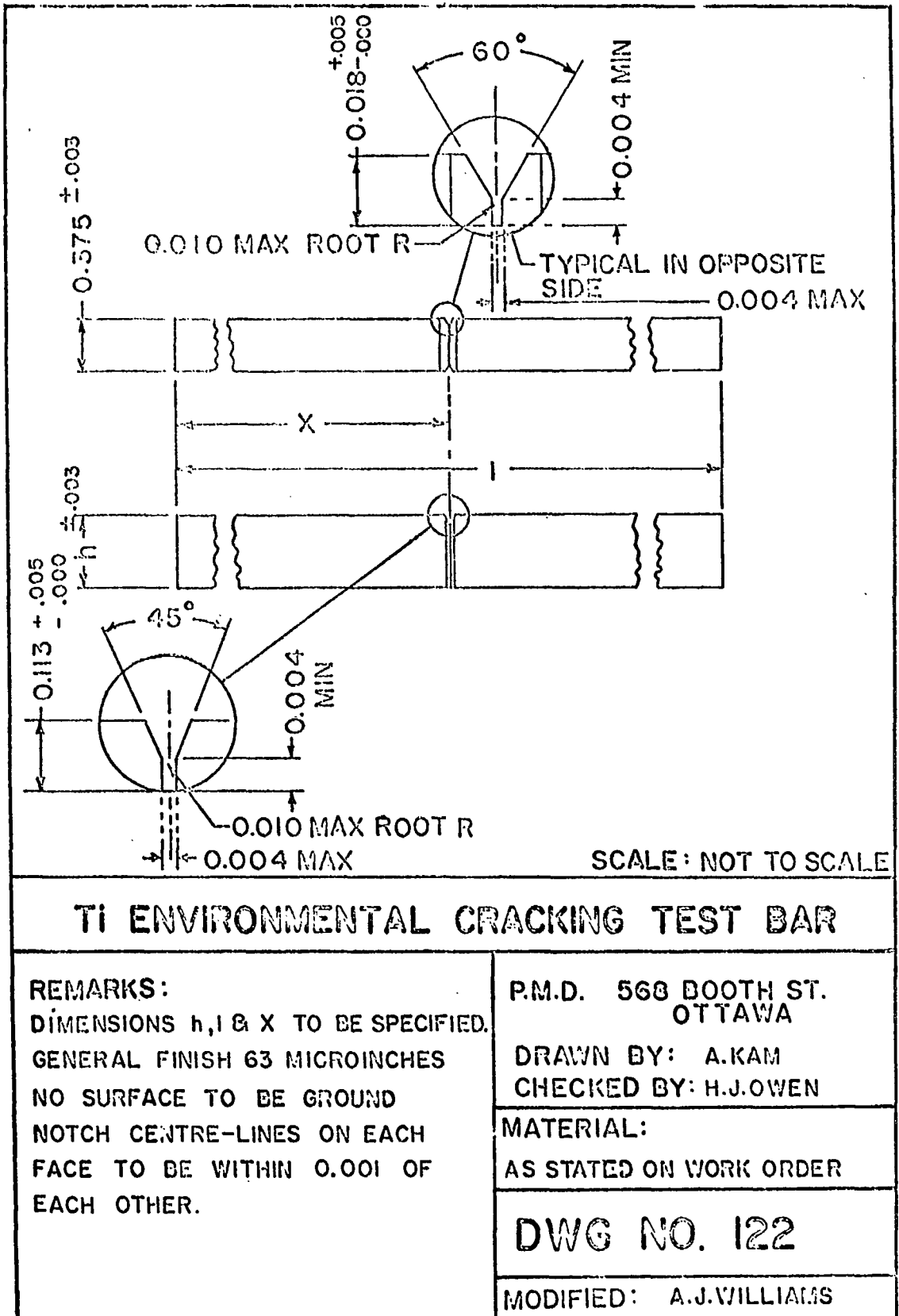


Figure 3. Environmental Cracking Test Bar.

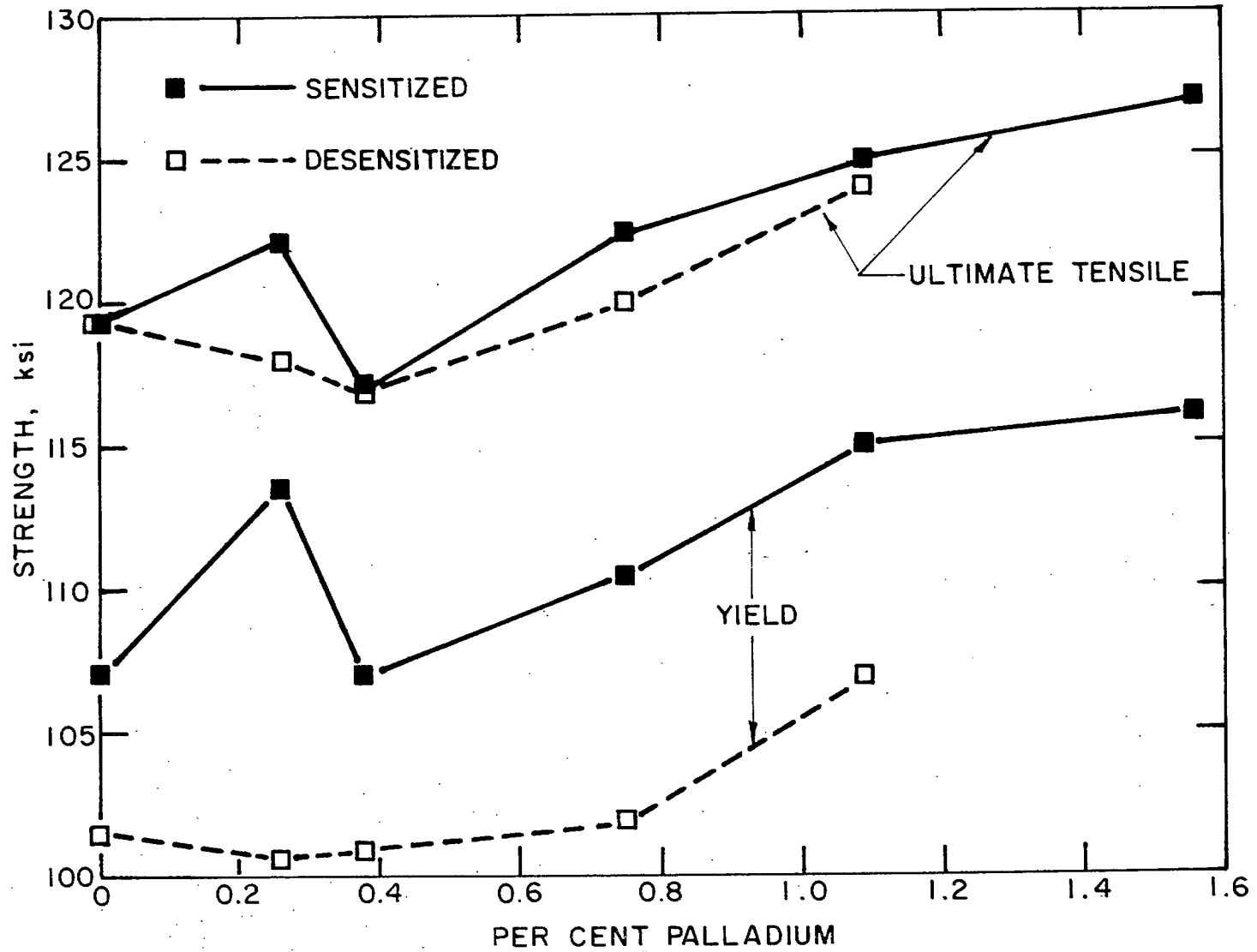


Figure 4. Ultimate Tensile and Yield Strengths of the Ti-721 Pd Alloys.

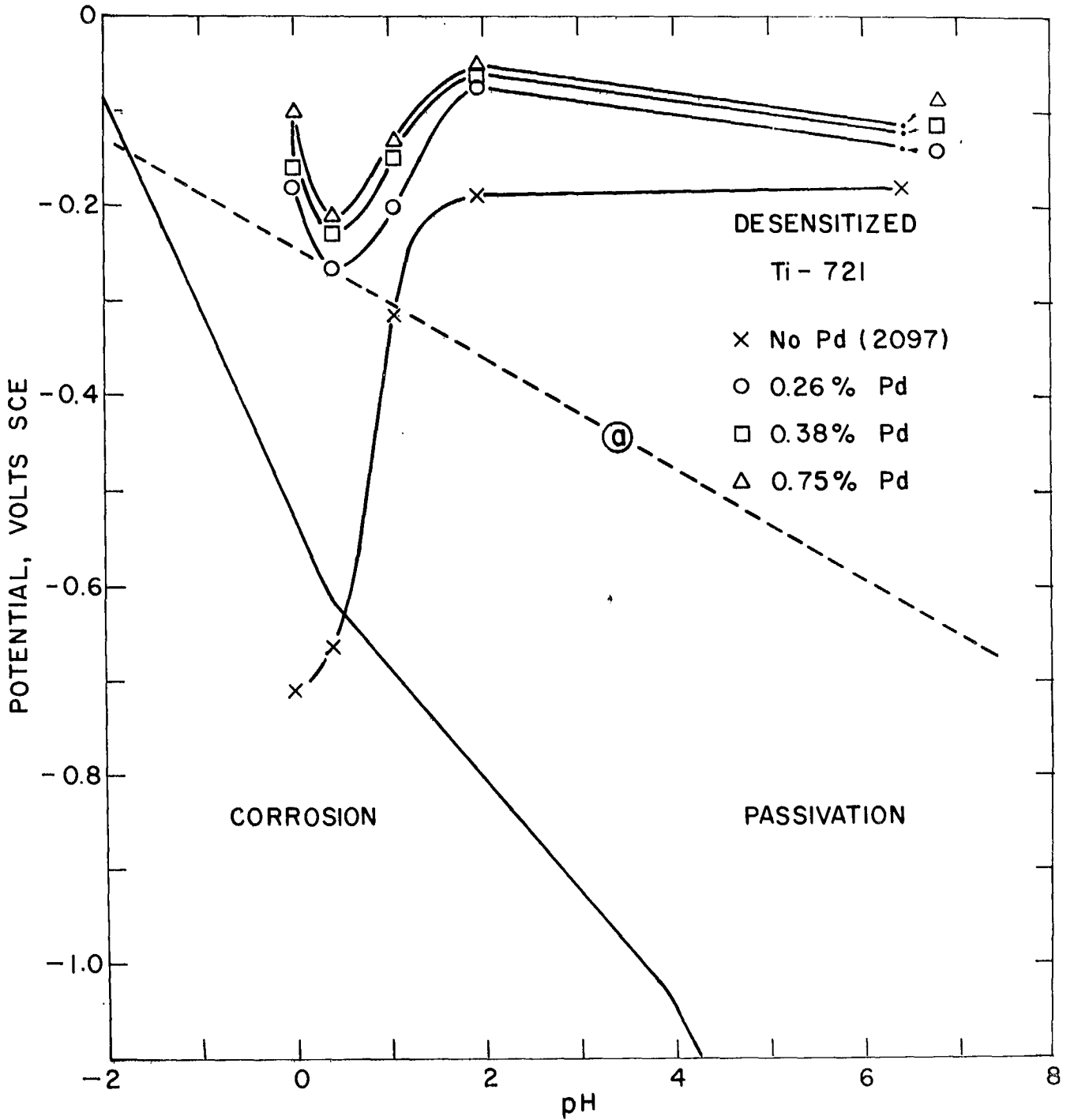


Figure 5. Steady-State Potentials of Desensitized Ti-721 Pd Alloys in 3.5% NaCl Solutions at Different pH Values.

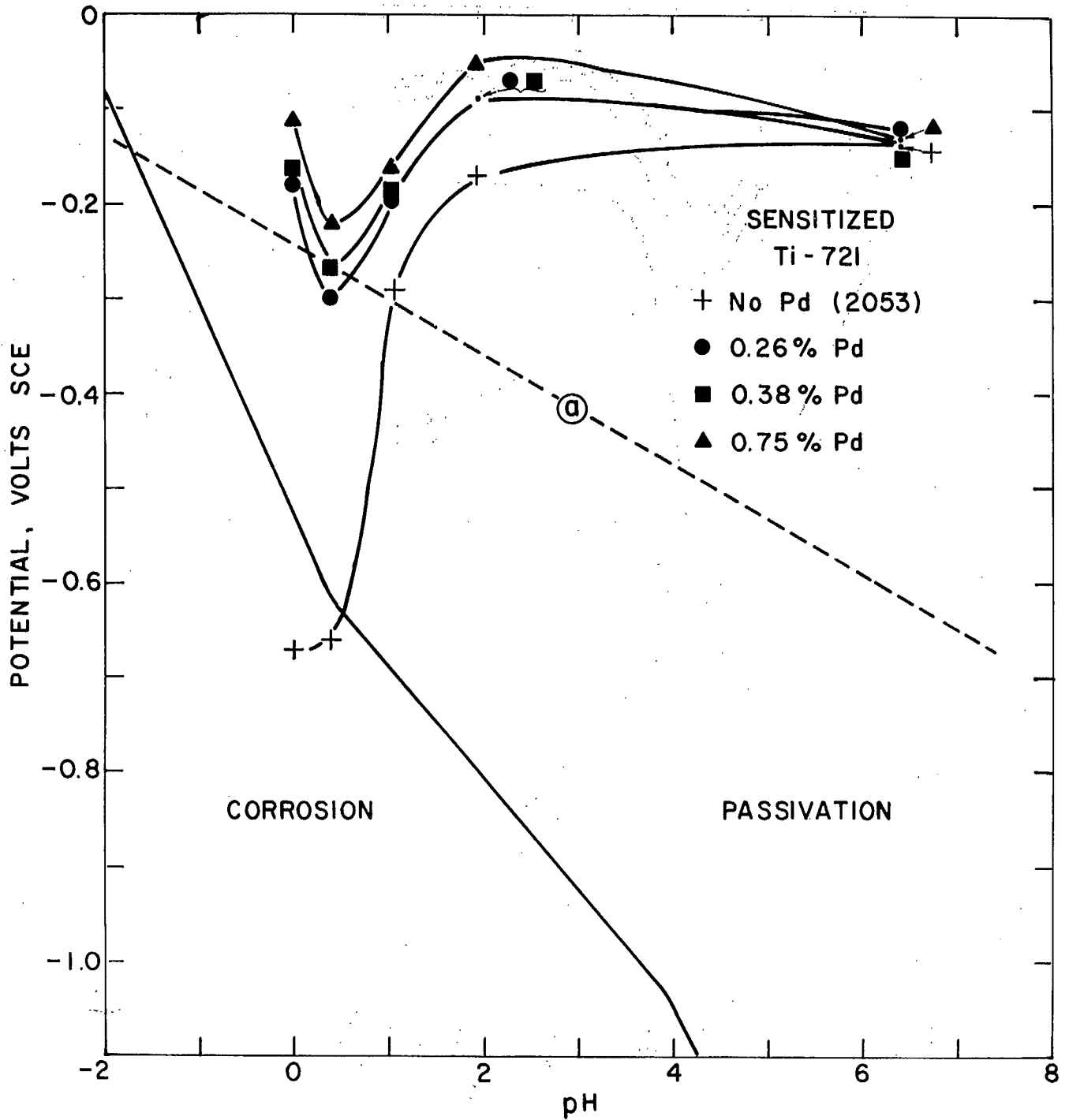


Figure 6. Steady-State Potentials of Sensitized Ti-721 Pd Alloys in 3.5% NaCl Solutions at Different pH Values.

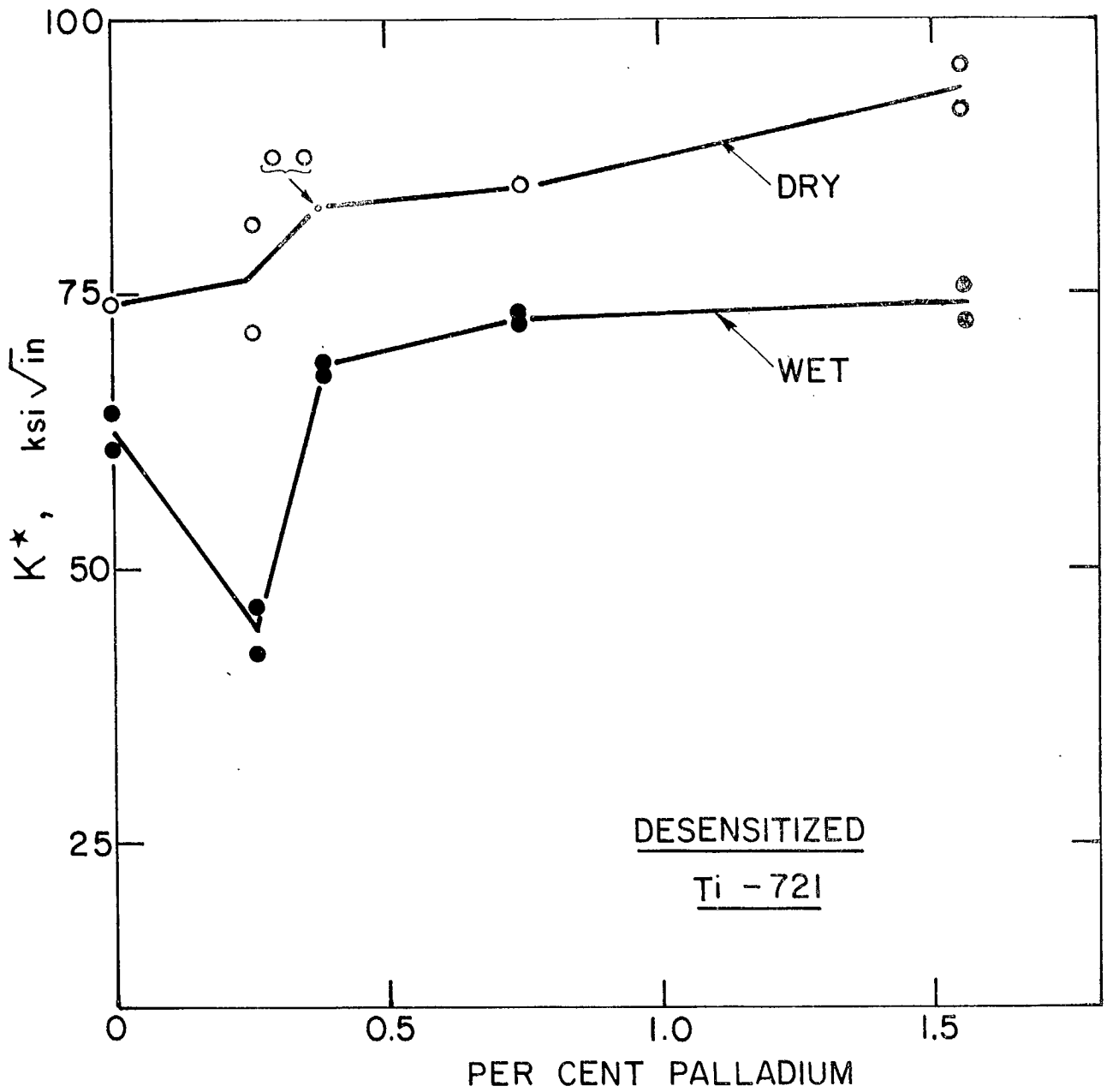


Figure 7. Results of Environmental Cracking Tests in 3.5% NaCl Solution on Desensitized Ti-721 Pd Alloys.

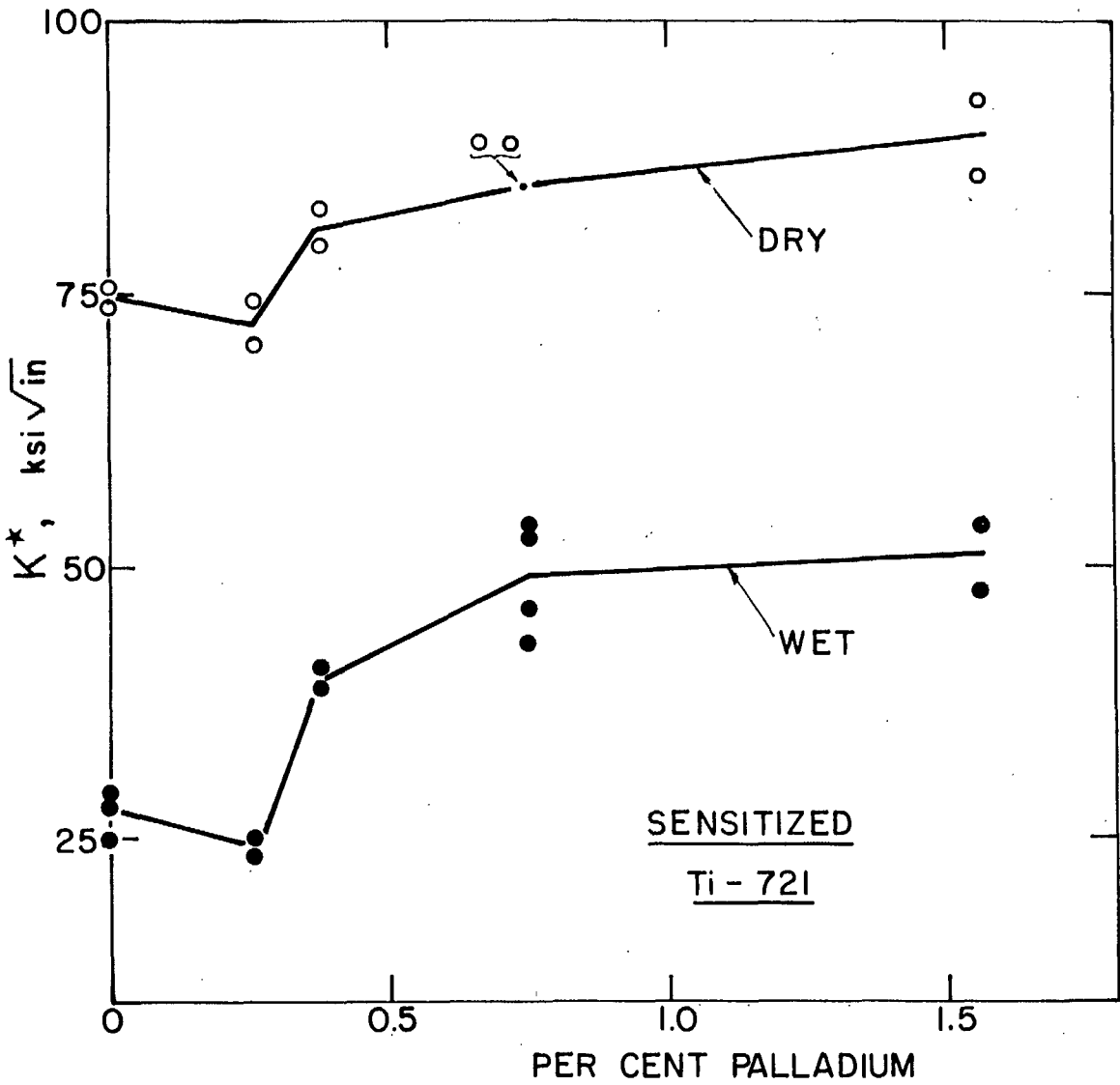


Figure 8. Results of Environmental Cracking Tests in 3.5% NaCl on Sensitized Ti-721 Pd Alloys.

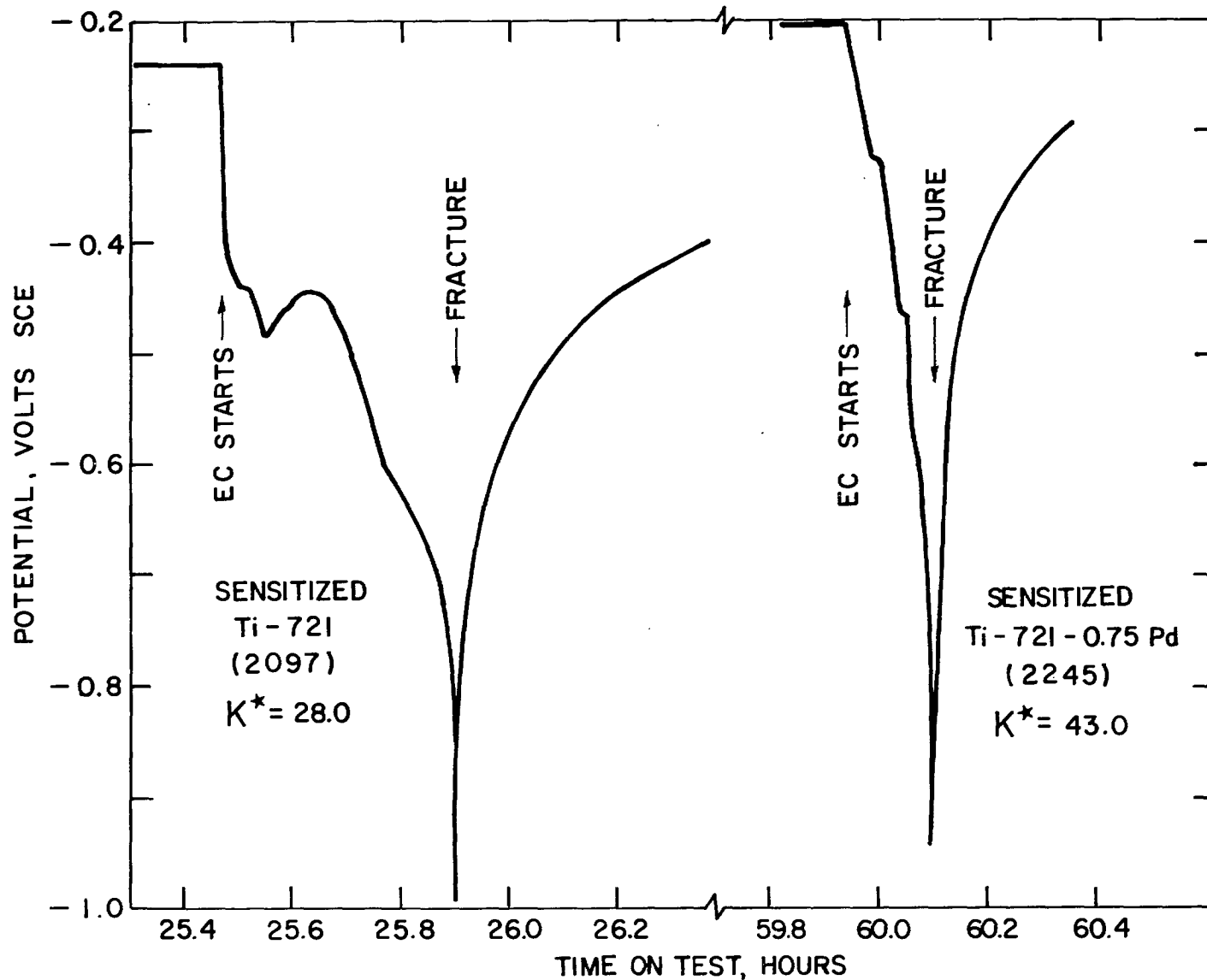


Figure 9. Potentials Shown in Environmental Cracking Tests in 3.5% NaCl Solution During Specimen Failures.

