THE PERFORMANCE OF T-PAD BEARING PADS, AS A REMEDY AGAINST PRESSURE TUBE CREVICE CORROSION, ON BUNDLES IRRADIATED AT BRUCE AND POINT LEPREAU

by

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ABSTRACT

Crevice corrosion in CANDU reactors can occur between the standard design fuel bundle bearing pads and the pressure tube when the element operates at a sufficiently high power to create the crevice boiling condition necessary for the concentration of lithium hydroxide leading to enhanced oxidation of the bearing pad and pressure tube. Since crevice corrosion was discovered in Pickering pressure tubes, a concerted effort has been made on design changes to the standard bearing pads in order to minimize/eliminate crevice corrosion. This development program led to the T-Pad bearing pad design. Recent demonstration irradiations of prototype bundles, fitted with T-Pad bearing pads, were conducted in Bruce and Point Lepreau Nuclear Generating Stations. The subsequent post-irradiation examinations indicated, that except for increased hydrogen and deuterium pickup in the T-Pads, the performance of the T-Pads and bundles is consistent with standard bearing pad bundles.

INTRODUCTION

Crevice corrosion in CANDU reactors can occur between the standard design fuel bundle bearing pads and the pressure tube when the element operates at a sufficiently high power (>40 kW/m) to create the crevice boiling condition necessary for the concentration of lithium hydroxide leading to enhanced oxidation of the bearing pad and pressure tube [1].

The bearing pad/pressure tube corrosion phenomenon was discovered in some pressure tubes removed from the Pickering Nuclear Generating Station in the mid-seventies. The corrosion observed in these pressure tubes occurred in the interface area of the fuel element bearing pad and the pressure tube. Very small gaps or crevices between the bearing pads and the pressure tube is believed to cause reduction in the coolant flow rate around these regions to the extent that superheating and/or boiling can occur, see Figure 1. This boiling tendency causes a local increase in the concentration on the ph control agent lithium hydroxide, sufficient to generate the critical concentration required for accelerated corrosion of the zirconium alloys. The key to preventing this type of corrosion is to prevent the concentration of the lithium hydroxide in these very small gaps or to vent the gaps to allow coolant access [2].

Since crevice corrosion was discovered in Pickering pressure tubes, a concerted effort has been made on design changes to the standard bearing pads in order to minimize/eliminate crevice corrosion. Various designs of advanced bearing pads (standoff, axial groove and trapezoid) were extensively tested. This development program led to the T-Pad bearing pad design [3]. This design combined all the functional characteristics of the former three configurations. It had three regions of full bearing pad width in contact with the sheath and which are of reduced height to prevent direct heat transfer from the sheath to the bearing pad/pressure tube interface. The bearing surfaces are supported by thick webs and transition regions exposed to coolant flow which tends to reduce the heat flux from the sheath to the bearing surfaces thus reducing the potential for crevice corrosion.

A test program funded by CANDEV, was set up to verify the performance of the T-Pad through (1) analysis of temperature distributions, (2) prototype fabrication of T-Pad bearing pad specimens, (3) testing of the bearing pads and joints [4]. The positive conclusion of this work led to the current T-Pad design and the manufacture of prototype bundles for irradiation, first in the Nuclear Power Demonstration (NPD) reactor and more recently in Bruce [5] and Point Lepreau nuclear generating stations [6]. A schematic drawing of the T-Pad design and a photograph of a bundle fitted with T-Pad bearing pads are shown in Figures 2 and 3 respectively.

Forty fuel bundles manufactured by Zircatec, were modified with T-Pads for irradiation in the Bruce Nuclear Generating Station (BNGS) and in the Point Lepreau Nuclear Generating Station (PLNGS). Half of the bundles had T-Pads on all outer-ring elements and half were manufactured with T-Pads and standard bearing-pads on alternate outer elements [7]. The standard production-type bearing pads acted as a control for the test irradiations. The T-Pads were manufactured from standard bearing-pad spacers by special machining. Zircatec product specifications applied to all phases of manufacture and inspection.

Of the bundles irradiated: two bundles J81172Z (100% T-Pads) and J81192Z (50% T-Pads and 50% standard bearing pads) from Bruce-A, Unit 4; and two bundles Y00005Z (50% T-Pads and 50% standard bearing pads) and Y00015Z (100% T-Pads) from PLNGS, were shipped to Whiteshell Laboratories (WL) for post-irradiation examination (PIE). All bundles were visually inspected underwater at the stations prior to shipment.

IRRADIATION HISTORY

BNGS bundles J81172Z & J81192Z resided in channel 024, bundle J81172Z was in position 7 throughout its irradiation history, and bundle J81192Z remained in position 8. Both bundles were in-core a total of 247 days, followed by a cooling period of 710 days. Bundle J81172Z achieved a burnup of 141 MWh/kgU, while bundle J81192Z achieved a burnup of 137 MWh/kgU. Peak outer element burnups for both bundles were 159 and 154 MWh/kgU respectively. Bundle J81172Z operated at a peak bundle and outer element linear power of 575 and 36 kW/m respectively. Bundle J81192Z operated at a peak bundle and outer element linear power of 557 and 35 kW/m respectively. The average outer element surface heat flux for bundle J81172Z was 88 W/cm^2, for bundle J81192Z it was 86 W/cm^2.

PLNGS bundle Y00005Z resided in channel P14E, positions 4/12 for 256 days and achieved a calculated bundle average burnup and peak outer element linear power rating of 187 MWh/kgU and 46 kW/m respectively. Bundle Y00015Z resided in channel P20E, positions 4/12 for 169 days and achieved a calculated bundle average burnup and peak outer element linear power rating of 166 MWh/kgU and 35 kW/m respectively. The maximum surface heat flux for bundles Y00005Z and Y00015Z was 111 and 85 W/cm^2 respectively. The bundle irradiation histories are displayed in Table 1.

POST-IRRADIATION EXAMINATION

The in-cell PIE consisted of the following:

1) Detailed visual examination and photography: to record the as-received condition of the bundles and to look for any unusual characteristics associated with the T-Pad design.

2) Bearing pad wear mapping: to determine the existence and severity of any wear on the bearing pads.

3) Bundle profile measurements: to determine the effect of T-Pads on bundle geometry.

4) Hydrogen and deuterium (H/D) analysis of sheath and bearing pad sections: to determine any differences in H/D pickup as a result of the T-Pads.

5) Metallographic examination of the sheath and bearing pads: to investigate braze bonding, H/D distribution, corrosion, cracking etc.

OBSERVATIONS AND RESULTS

1. All wear was within the normal range observed in previously examined BNGS bundles.

2. There was no buildup of crud or any foreign material in any of the cut-out sections of the T-Pads.

3. There was very little evidence of fretting on either bundle. The majority of the marks observed were longitudinal scratches caused by fuel loading/unloading in the reactor, and out-reactor handling and transportation.

4. Profilometer measurements of the profiles of the outer ring elements of both bundles did not indicate anything unusual about the performance of these elements or the bearing pads. The outer-ring elements were predominantly bowed away from the pressure-tube (towards the centre of the bundle).

5. The condition of the T-Pad bearing pads compared very closely to the standard bearing pads. There was no indication of braze failure or other features that would indicate that the performance of the T-Pads was less satisfactory than that of the standard bearing pads.

6. Averaged hydrogen values were in the range of 18-58 µg/g for all samples analyzed. The greatest amount of hydrogen was found in the T-Pad sections with up to 100 µg/g analyzed in a few of the samples. The T-Pad sections picked up more hydrogen than did the standard bearing pads.

   Deuterium values were higher in all samples, averaging from 45-300 µg/g with the greatest amount also in the T-Pad sections with up to 600 µg/g analyzed in a few of the samples. Again the T-Pad sections generally picked up more deuterium than did the standard bearing pad sections. Hydrogen/deuterium analysis results are displayed in Table 2. Figure 4 is a comparison of photographs of a T-Pad and a standard bearing pad etched to reveal hydrides/deuterides. Figure 5 is a photograph of the T-Pad with the greatest concentration of hydride/deuterides observed.

7. Metallographic examination indicated good braze bonding on all bearing pads examined. Hydrides/deuterides were concentrated in the extremities of the T-Pads, particularly in the PLNGS bundle T-Pads.

8. There was little evidence of corrosion or pitting on either bearing pad type on any of the bundles. Most of the corrosion pits observed were minor, the largest measuring 38 µm in depth by ~0.5 mm in diameter. Figures 6 is photographs of this feature. The corrosion pits observed were from elements believed to have been at the six o'clock position of the bundle while in the reactor channel.

CONCLUSIONS

These PIEs indicated that the performance of T-Pad bearing pads was consistent with that of the standard bearing-pad design. There was no indication of unusual wear, fretting, corrosion, erosion, scratching, pitting, chipping, discoloration, or crud buildup that could be attributed to the design or performance of the T-Pads. Deuterium pickup is greater in the T-Pads than the standard bearing pads due partly to the lower operating temperature of the T-Pads. This creates the thermal gradient which drives the hydrogen/deuterium to the coolest region of the T-Pad. The increased surface area of the T-Pads and differences in surface finish, as a result of the T-Pad manufacturing, may also contribute to the increased pickup of deuterium. Overall the performance of the T-Pad bearing pads, under the operating conditions experienced, is very similar to that of the standard bearing-pad design. There was little crevice corrosion observed in connection with either the T-Pads or standard bearing pads. Therefore, it cannot be unequivocally determined at this time that the T-Pads are more effective in preventing crevice corrosion in pressure tubes. Additional bundles irradiated to higher burnups and operated at higher power should be examined. Additionally, it may be necessary to conduct examinations of pressure tubes to be able to absolutely determine the effectiveness of the T-Pad bearing pads as a remedy against crevice corrosion.

REFERENCES

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2) D. Lim, V. L. Williams, "Bearing Pad/Pressure Tube Crevice Corrosion Development Work at W-CAN", CWAPD-427, 1984 March .

3) R. Sejnoha, Memo to A. A. Posanrm, "Bearing Pad/Pressure Tube Crevice Corrosion Modified Bearing Pad Design", 1992 November 29.

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6) M. A. Ryz, "Post-Irradiation Examination of T-Pad Bundles Y00005Z and Y00015Z Irradiated in Point Lepreau", COG-94-529 (in preparation).

7) A. E. McCorry, "Manufacture of Twenty Bruce Fuel Bundles with "T" Bearing Pads", COG-89-93, 1993 April.

TABLE 1

IRRADIATION HISTORY

Reactor	**Bruce-A Unit 4**		**Point Lepreau**	
Bundle	**J81172Z**	**J81192Z**	**Y00005Z**	**Y00015Z**
Channel	O24	O24	P14E	P20E
Position	7	8	4/12	4/12
Duration (Days)	247	247	256	169
Burnup (MWh/kgU)	141	137	187	166
OE Burnup (MWh/kgU)	159	154	212	188
Bundle Power (kW/m)	575	557	741	568
Peak OELP (kW/m)	36	35	46	35
OE Heat Flux (W/cm^2)	88	86	111	85

TABLE 2

COMPARISON OF AVERAGED H/D RESULTS (μg/g)

Element Type/Sample/Analysis		Point Lepreau NGS		BNGS-A4
		Y00005Z	Y00015Z	J81192Z
T-Pad/ BP Only/	H	58	44	36
T-Pad/ BP Only/	D	119	196	297
STD/ BP Only/	H	40	-	33
STD/ BP Only/	D	120	-	198
T-Pad/ Sheath HAZ/	H	38	29	22
T-Pad/ Sheath HAZ/	D	110	128	122
STD/ Sheath HAZ/	H	34	-	30
STD/ Sheath HAZ/	D	104	-	147
T-Pad/ Sheath ARZ/	H	20	28	18
T-Pad/ Sheath ARZ/	D	60	71	53
STD/ Sheath ARZ/	H	28	-	19
STD/ Sheath ARZ/	D	78	-	45

NOTES: HAZ = Heat-Affected Zone
ARZ = As-Received Zone
STD = Standard Bearing Pad
T-Pad = T-Pad Bearing Pad
BP = Bearing Pad
H = Hydrogen Value
D = Deuterium Value

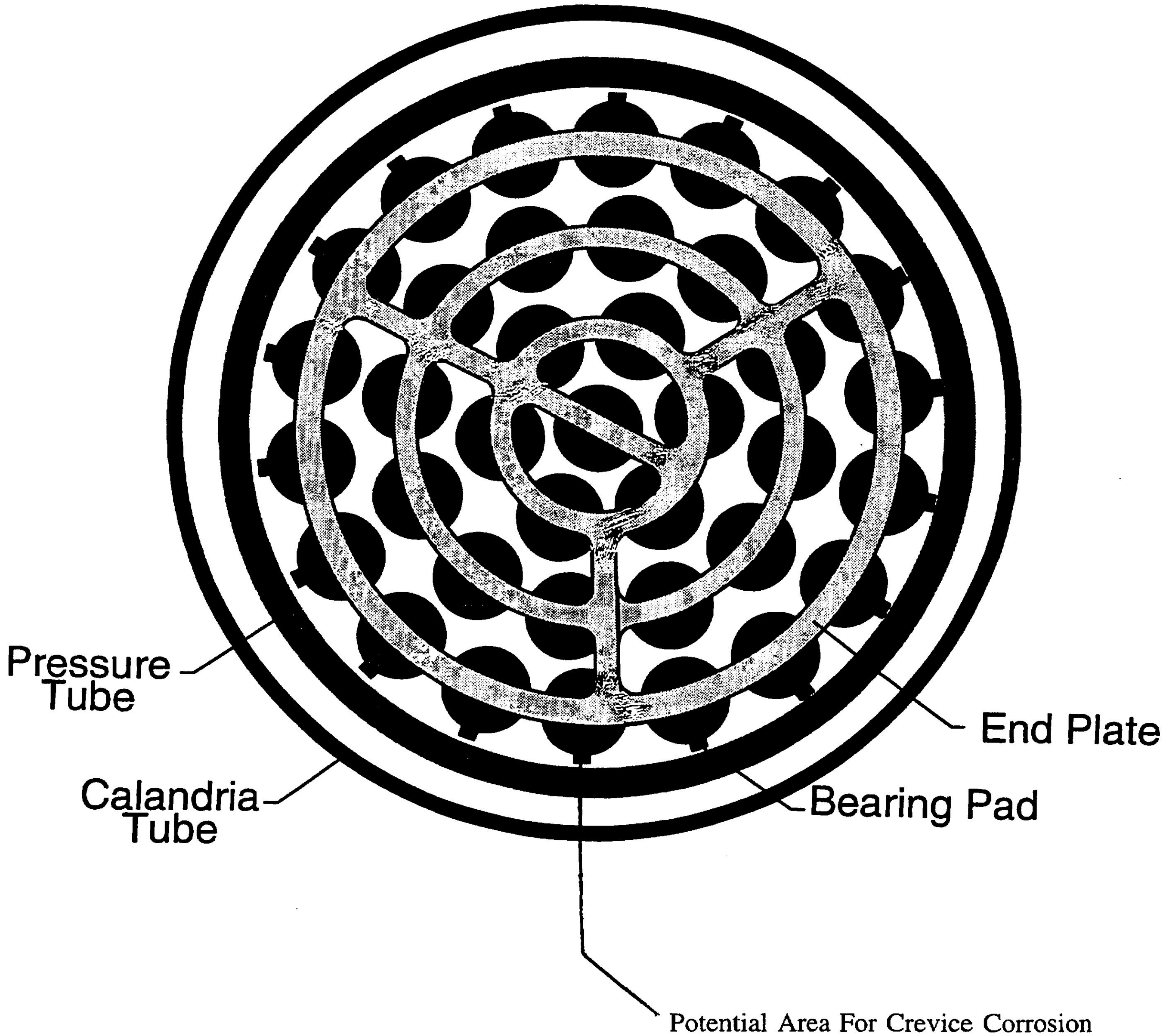

FIGURE 1: CROSS-SECTION OF BUNDLE, PRESSURE TUBE & CALANDRIA TUBE

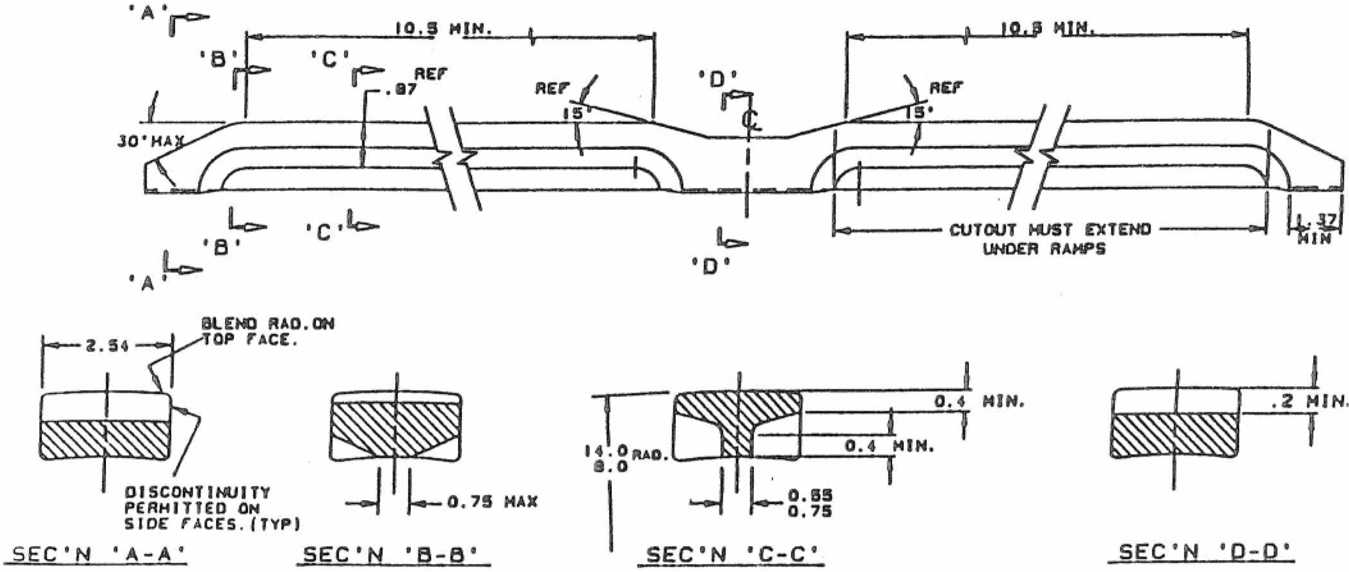

FIGURE 2: T-PAD BEARING PAD DESIGN

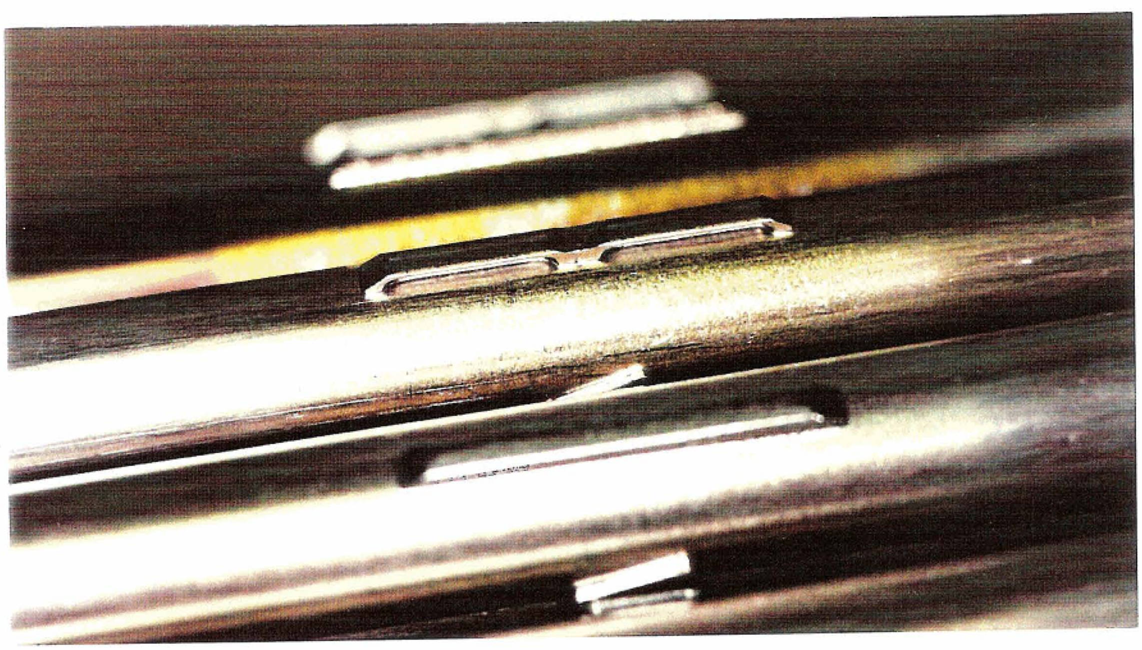

FIGURE 3: T-PAD BEARING PADS AS INSTALLED ON A CANDU BUNDLE

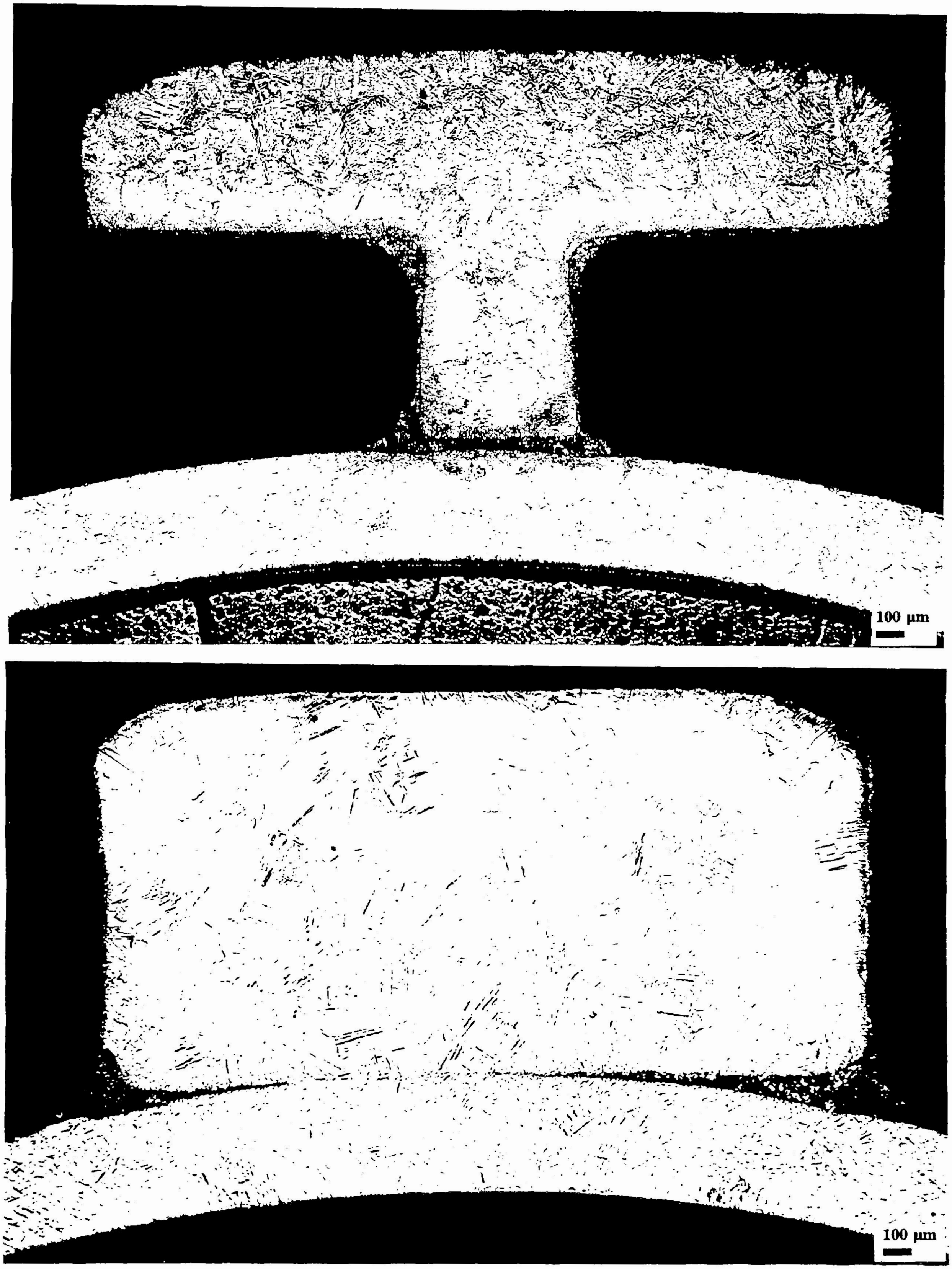

FIGURE 4: COMPARISON OF A T-PAD AND A STANDARD BEARING PAD, ETCHED TO REVEAL HYDRIDE/DEUTERIDE DISTRIBUTION (50X).

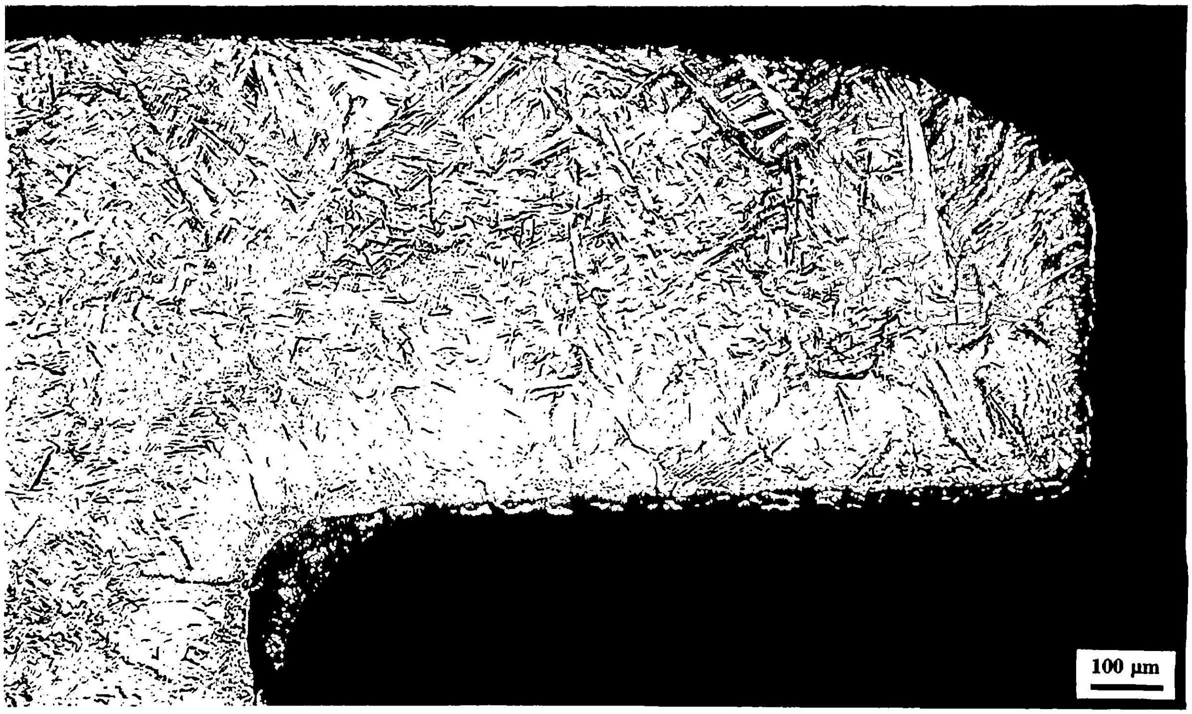

FIGURE 5: THE T-PAD DISPLAYING THE GREATEST AMOUNT OF HYDRIDE/DEUTERIDE OBSERVED (100X).

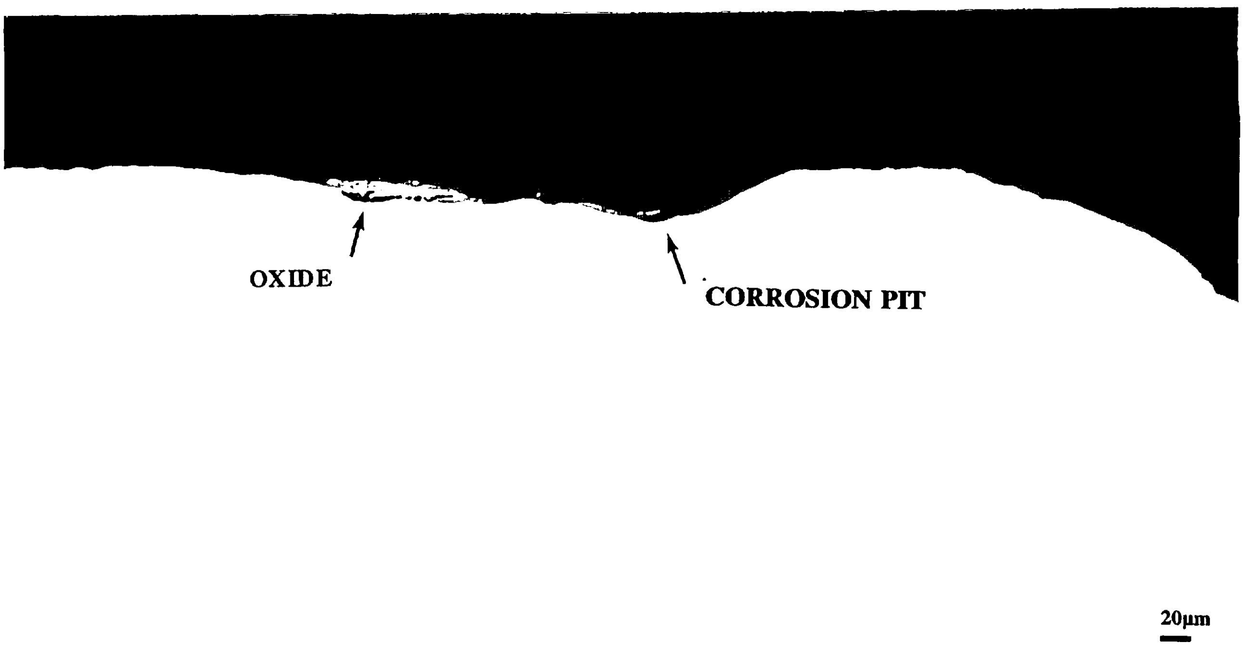

FIGURE 6: THE LARGEST CORROSION PIT OBSERVED (~0.5 mm IN DIAMETER x 38 µm DEEP) ON THE CONTACT SURFACE OF A T-PAD. NOTE THE PATCH OF OXIDE IN THE PIT REGION (200X).