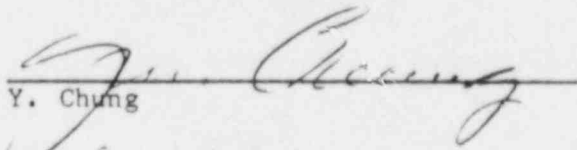


FAILURE ANALYSIS OF DIESEL CYLINDER
LINER EXPANSION BELLOWS


Report for
South Texas Project

Prepared for R. L. Randels

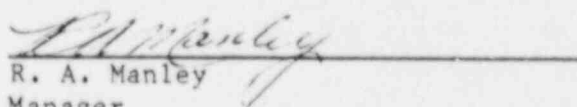
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ABSTRACT

Two 18-inch Type 321 stainless steel bellows removed from diesel liner expansion seals were examined to determine the cause of the failure. One of the bellows showed corrosion perforation and cracking in the convolutions and the seam weld. The results of visual examination, metallographic examination, and microbiological analysis are presented. The corroded areas showed signs of iron bacteria (*Gallionella*) which influenced the corrosion and cracking the stainless steel bellows.

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1.0 INTRODUCTION

Two 18-inch expansion bellows for diesel engine cylinder liner expansion lower seal were received for a failure analysis at the Bechtel M&QS Laboratory. These two bellows, shown in Figure 1 in the as-received condition, had the following identification.

<u>Bellows No. 1</u>	<u>Bellows No. 2</u>
C-B PN 2-01S 118-001	C-B PN 2-01S 118-001
DATE OF MFR 1-78	DATE OF MFR 1-78
8B7155	8B2160

We performed visual examination, metallographic examination, and microbiological analysis.

2.0 CONCLUSIONS AND RECOMMENDATIONS

- (1) One of the two bellows examined failed due to pitting corrosion and cracking which perforated the Type 321 stainless steel convolution. The other bellows showed no pitting or cracking.
- (2) Both bellows were exposed to fluids containing iron bacteria, which influenced the corrosion and cracking in the bellows elements and the end pieces.
- (3) The cooling fluids entering the bellows should be treated with biocide.

3.0 MATERIAL

The bellows material is Type 321 stainless steel according to the memorandum* referenced below. This is confirmed by titanium carbonitride particles in the microstructure, which are a characteristic of this grade.

4.0 VISUAL EXAMINATION

Bellows No. 1 showed holes in the convolutions of the bellows element; Bellows No. 2 appeared to be free from corrosion pits or cracking. Therefore, visual examination focused on Bellows No. 1.

The two bellows have a drain hole near the bottom (Figure 1). Using the drain hole as a reference point (6 o'clock looking down), Figures 2, 3, and 4 show the inside surface of Bellows No. 1. Perforation in the convolution can be seen above the drain hole in Figure 2(a). Brown corrosion products, sometimes with nodules, were found throughout the inside surface. One prominent example of corrosion nodules is shown in Figure 3. The edges of the end pieces which were welded to the bellows element showed numerous cracks (Figure 4).

A closeup view of the perforation in the convolution of Bellows No. 1 is shown in Figure 5(a). In addition to a hole, about 1/2 inch diameter, the seam weld in the convolution was preferentially attacked. Much of the weld metal

*Memorandum from T. T. Phillips to R. A. White, 2/12/88.

fell off during saw cutting of a section containing the seam weld. Figures 5(b) and (c) show this area surrounding the seam weld after flattening the convolution. The outside surface around the perforated hole and the corroded seam weld showed colonies of brown rust. The metal with rust cracked when the convolution was flattened (Figure 6). The same phenomena occurred on the outside surface of the corrosion nodule shown in Figure 3. The holes in Figure 7(a) and (b) are the perforation caused by pitting corrosion in the two black areas marked by the arrows in Figure 3(a). The rusted areas cracked when flattened (Figure 7).

Figure 8(a) shows an example of corrosion pits in the weld metal and cracking in the top end piece of the bellows. Figure 8(b) is the area where the corrosion perforated the convolution wall. Numerous cracks can also be seen in the corroded area.

As mentioned before, Bellows No. 2 showed no corrosion pits or cracking. Only a few scattered brown rust spots and some brown film along the bottom inside corner were observed.

5.0 METALLOGRAPHIC EXAMINATION

Figure 5(a) shows preferential corrosion attack to the seam weld in the Bellows No. 1 convolution. The bottom area of the seam weld was saw cut for metallographic examination. During saw cutting, the corroded weld metal fell off as can be seen in Figure 10(a). This specimen was flattened, mounted in a molding material, polished and etched on a plane parallel to the inside surface. Figure 10(c) is a micrograph showing the seam weld with its top and bottom portions consumed by corrosion. Figure 11 presents micrographs of selected areas from Figure 10(c). These micrographs show that the corrosion preferentially attacked the weld metal, following the interdendritic solidification pattern, and that numerous transgranular cracks developed. Figure 12 shows examples of transgranular cracks in and around corrosion pits in the base metal near the seam weld. Figure 13 shows extensive branching in one of the cracks along the edges of the end pieces which were welded to the bellows convolution.

6.0 MICROBIOLOGICAL ANALYSIS

Corrosion products and surface deposit were collected from the following locations and analyzed for iron bacteria. The results are as follows:

<u>Specimen No.</u>	<u>Location</u>	<u>Findings</u>
1-1*	Corrosion products with nodules (Figure 3b)	Short Gallionella filaments
1-2	"Dirt" at the bottom corner directly below the drain hole (Figure 2a)	Gallionella filaments
1-3	Corrosion products near the seam weld (Figure 2a)	No positive identification of iron bacteria

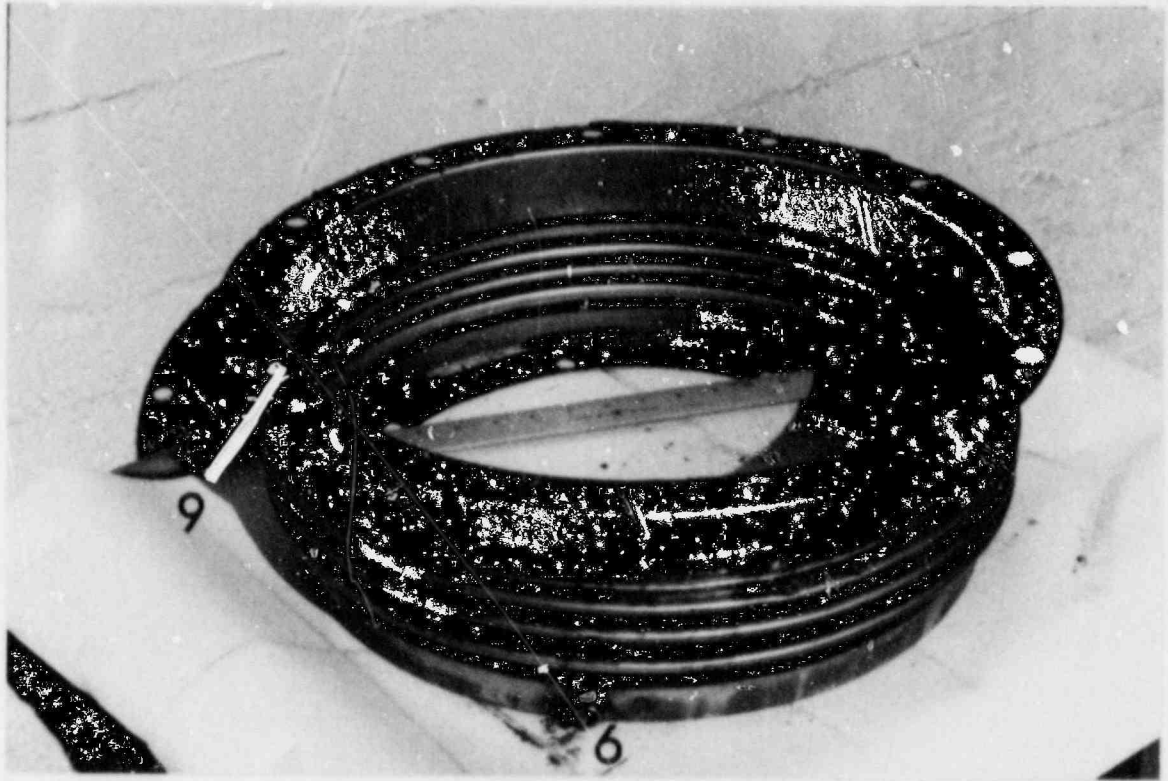
<u>Specimen No.</u>	<u>Location</u>	<u>Findings</u>
2-1	Brown film at the bottom corner below the drain hole (Figure 9a)	Short Gallionella filaments

*1-1, 1-2, 1-3 from Bellows No. 1; 2-1 from Bellows No. 2

7.0 DISCUSSION

The results of the foregoing examination and analysis clearly indicate that the corrosion and cracking found in Bellows No. 1 was influenced by iron bacteria (Gallionella). The following features support this conclusion.

- (a) Preferential crystallographic corrosion attack to the weld metal (Figures 10 and 11).
- (b) Brown and black corrosion products with nodule formation (Figure 3).
- (c) Corrosion and cracking in colonies on the outside surfaces where perforation occurred (Figures 6 and 7).
- (d) Concentration of corrosion pits in the welds.



(a)

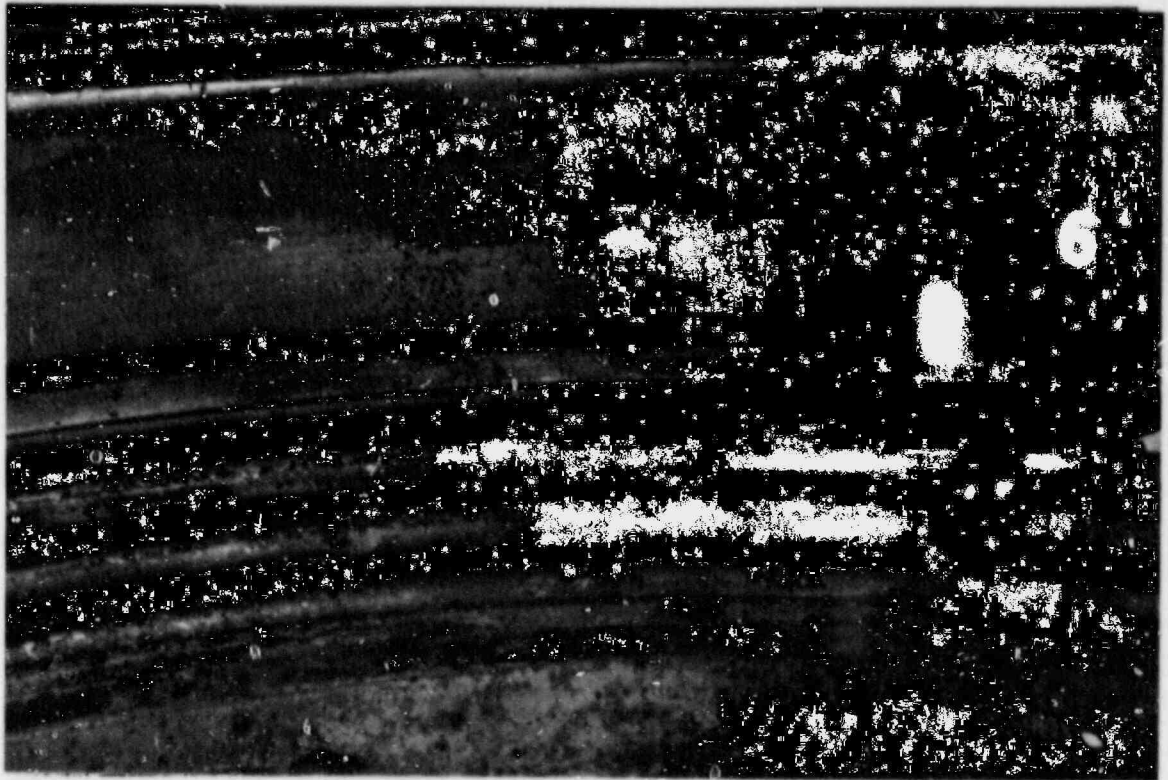
Bellows No. 2



(b)

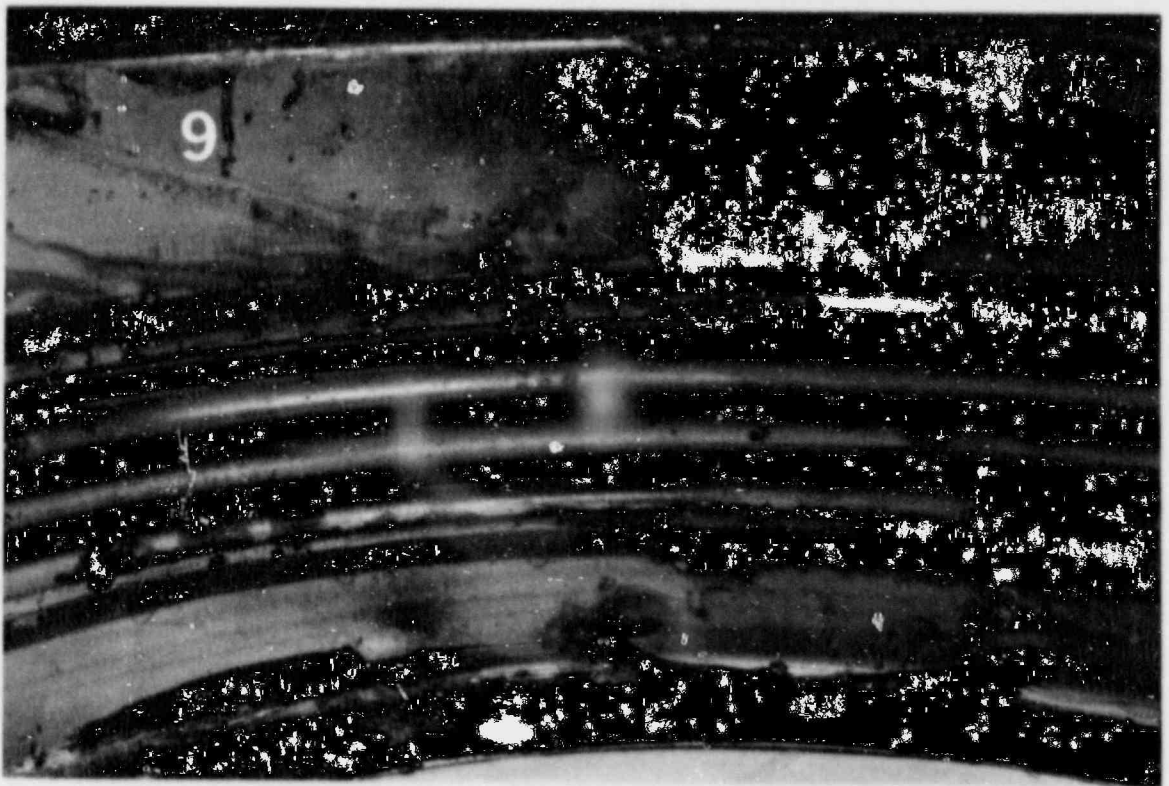
Bellows No. 1

Figure 1 Two bellows in the as-received condition, from the cylinder head liner expandable lower seal.



(a)

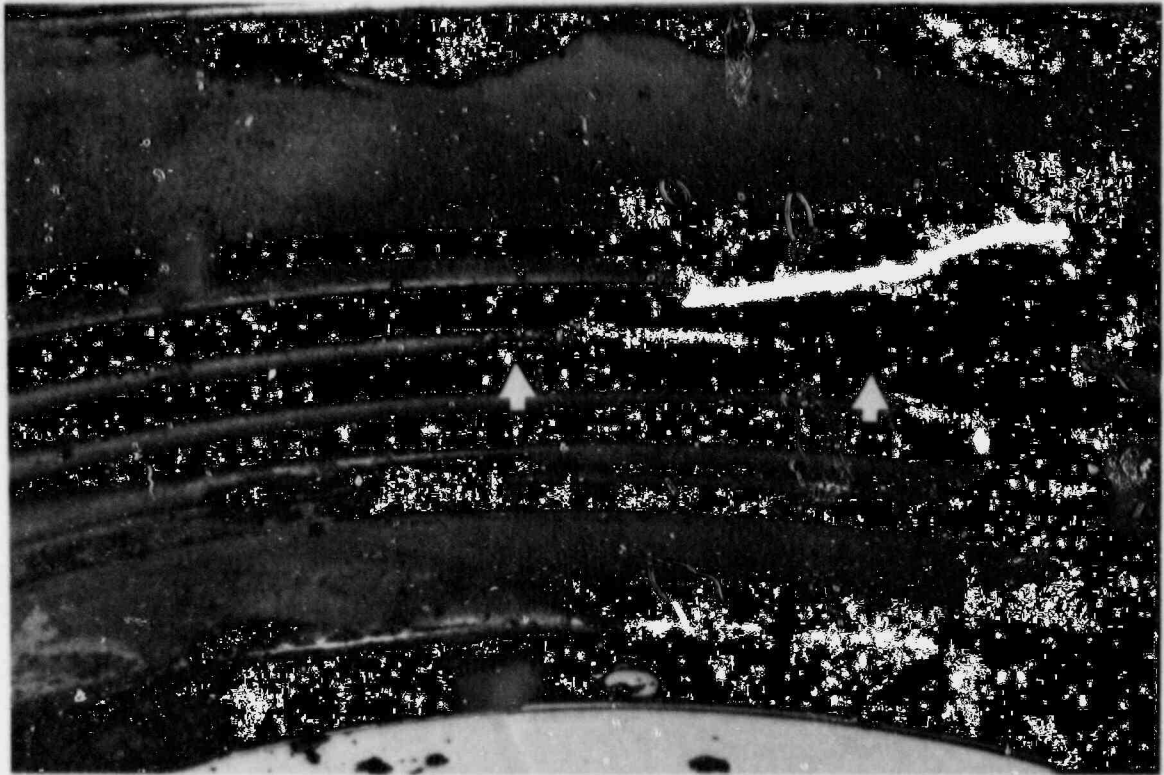
6 O'clock



(b)

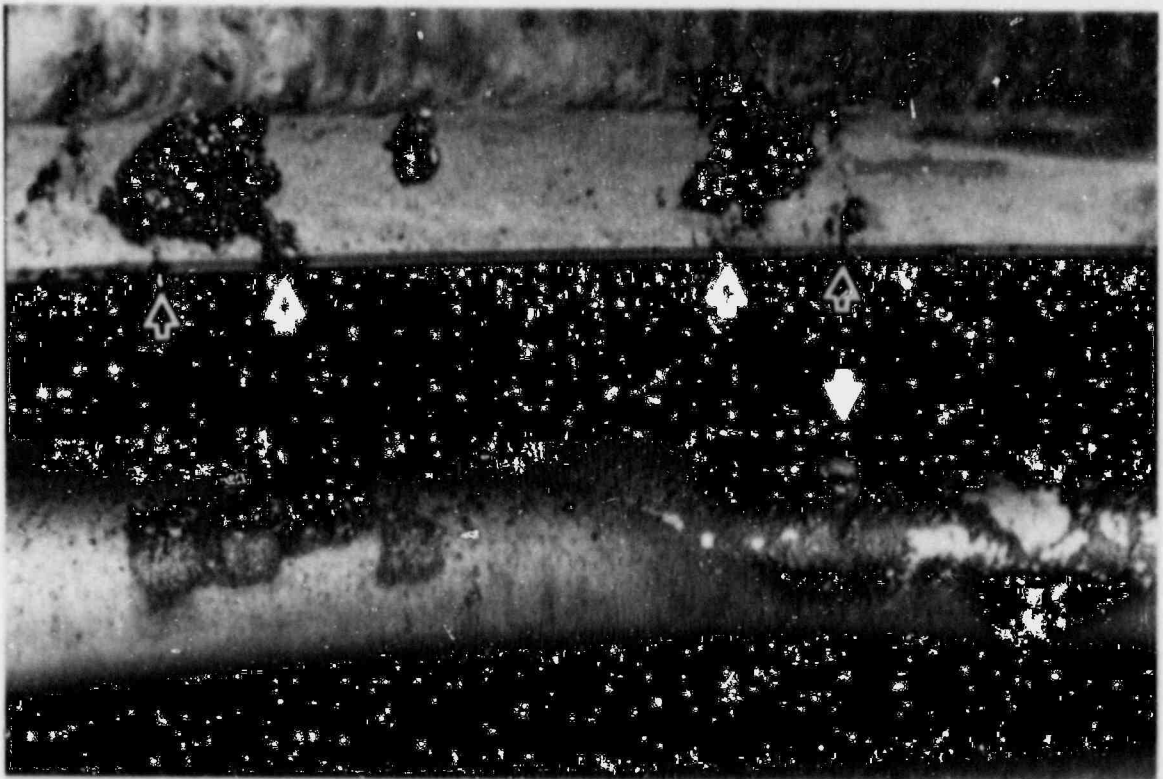
9 O'clock

Figure 2 Corrosion on the inside of Bellows No. 1 with holes in the bellows convolution above a drain hole in (a).



(a)

7 O'clock



(b)

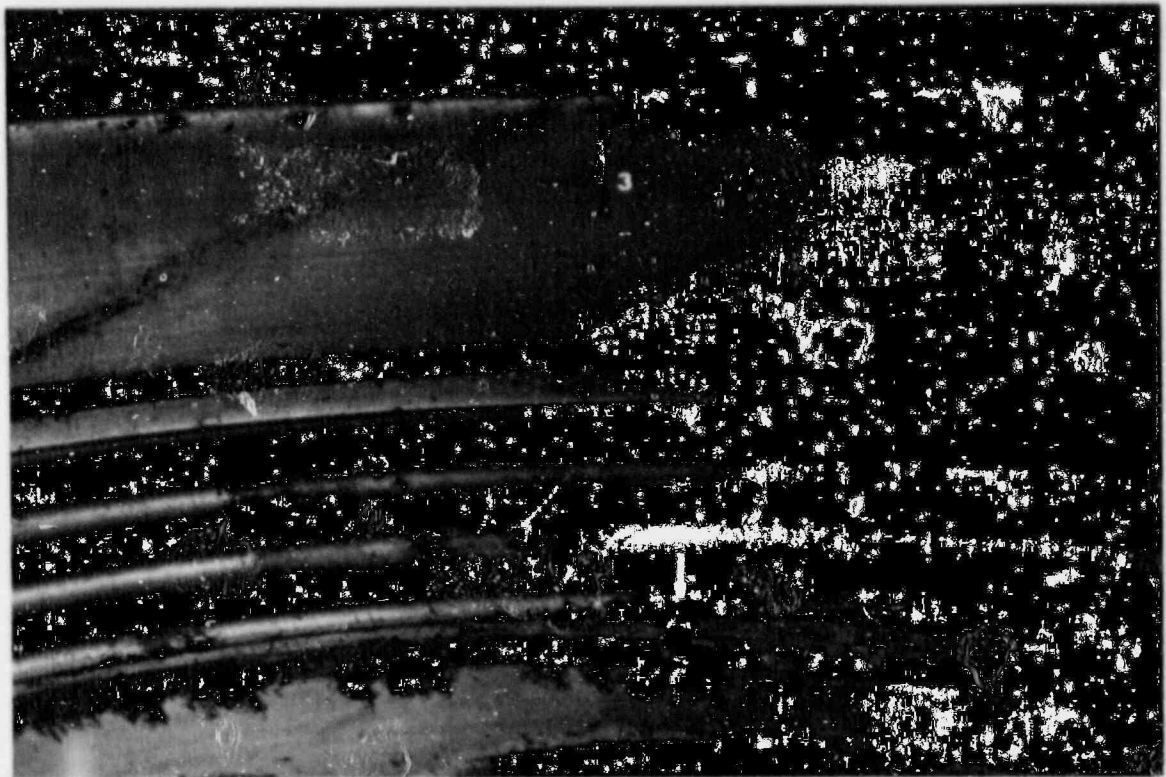
7 O'clock

Figure 3 Corrosion on the inside of Bellows No. 1. The solid arrow points to a nodule and the hollow arrows to cracks. (b) is a closeup view of an area in (a).



(a)

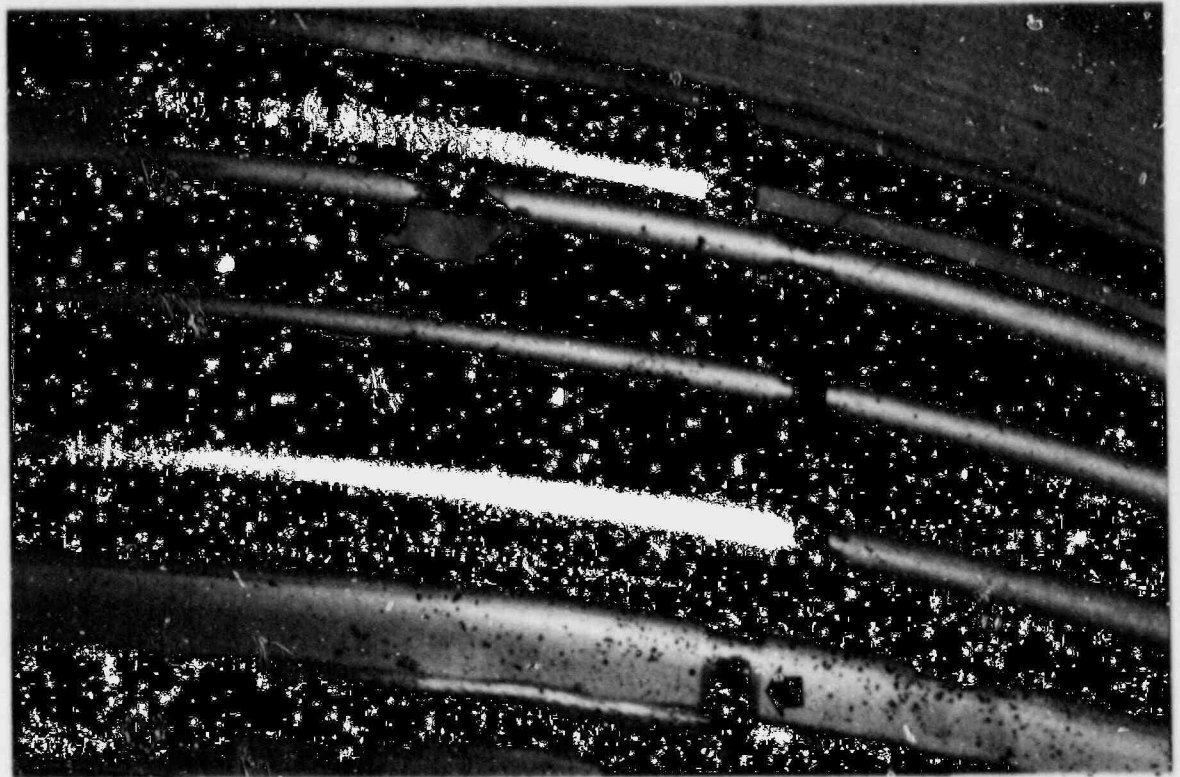
12 O'clock



(b)

3 O'clock

Figure 4 Corrosion on the inside of Bellows No. 1. The arrows point to cracks.



(a)



(b)



(c)

Inside

Figure 5 The holes in Bellows No. 1. (a) As received. (b) and (c) after cutting and cleaning.



(a)

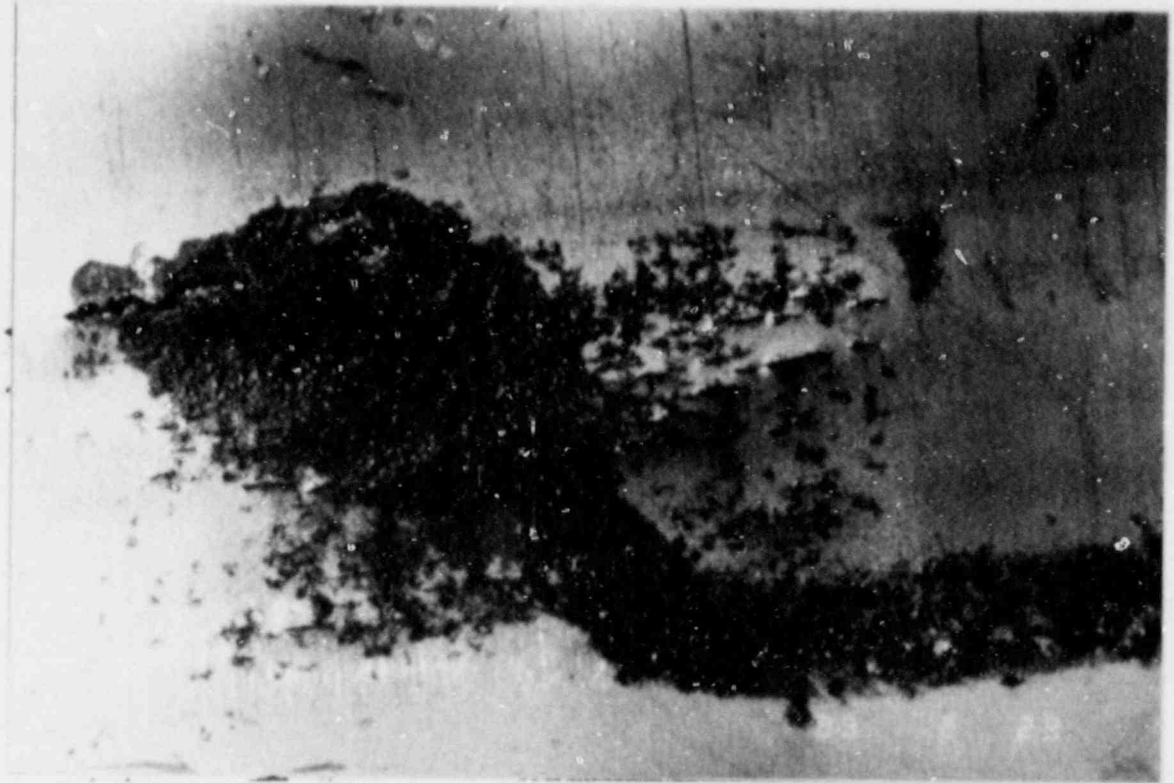
Figure 6

Closeup view of the area marked by the arrow in Figure 5(b).

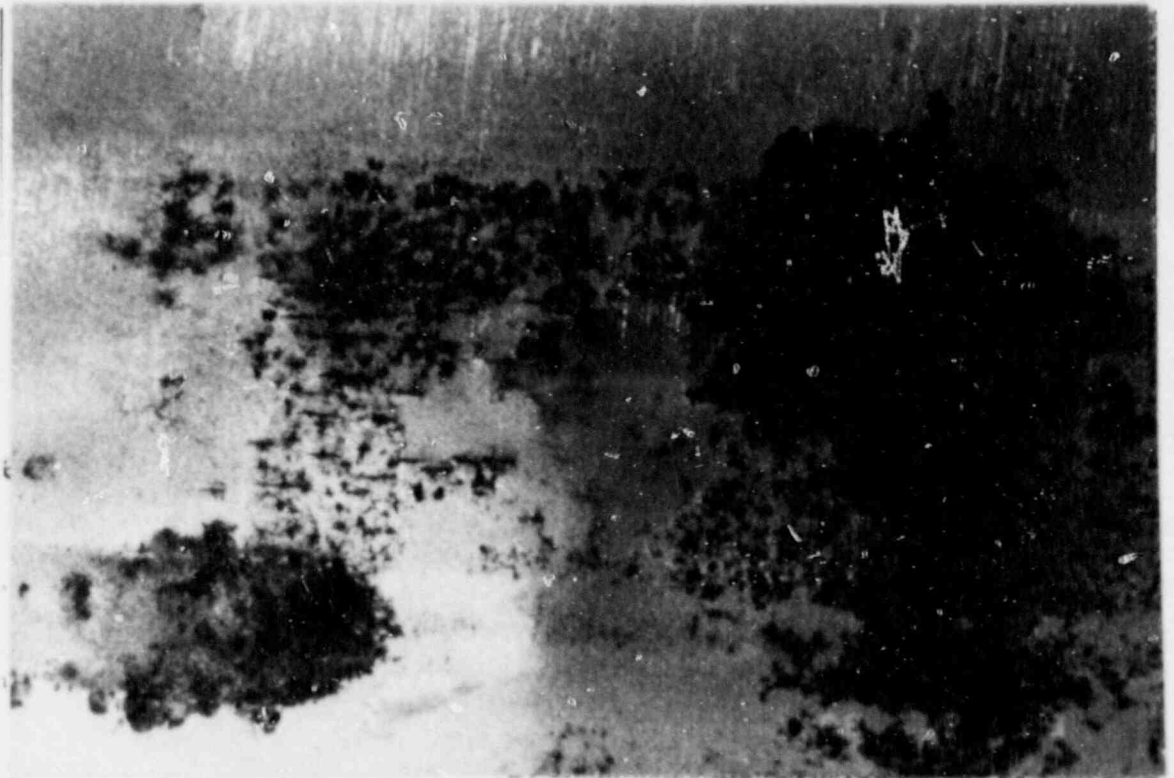
The white arrows in (b) point to cracks in corroded areas.



(b)

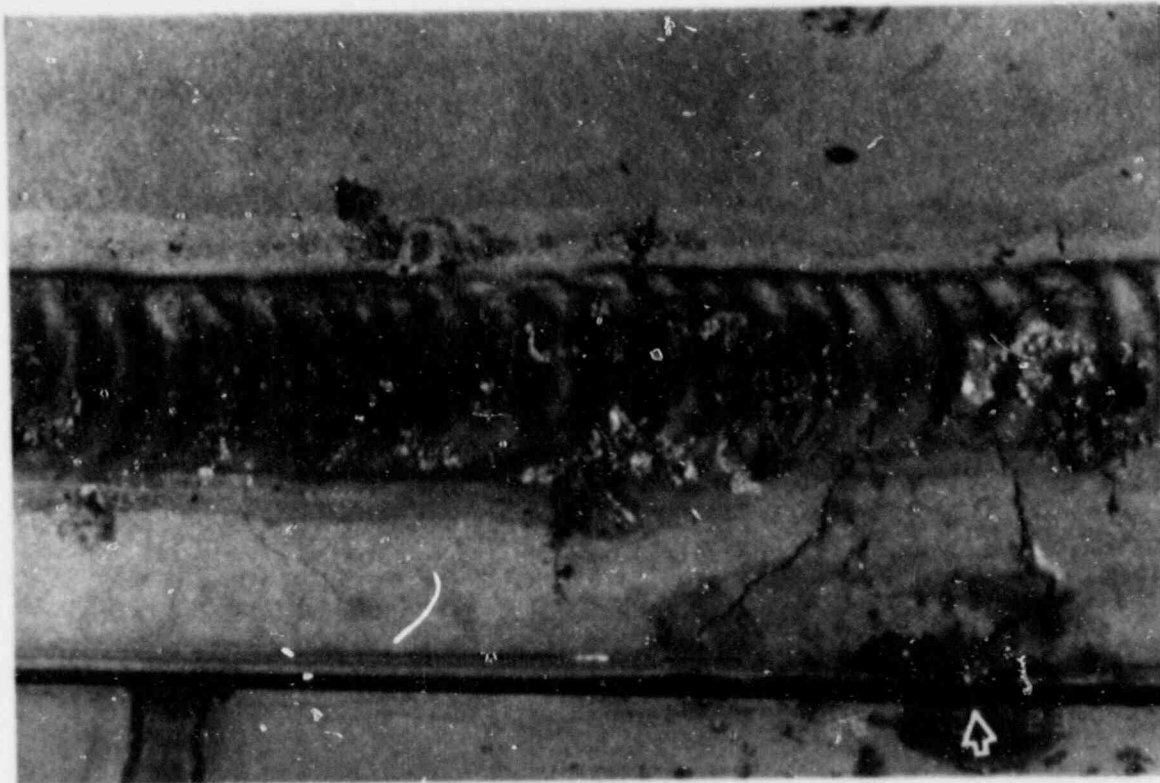


(a)

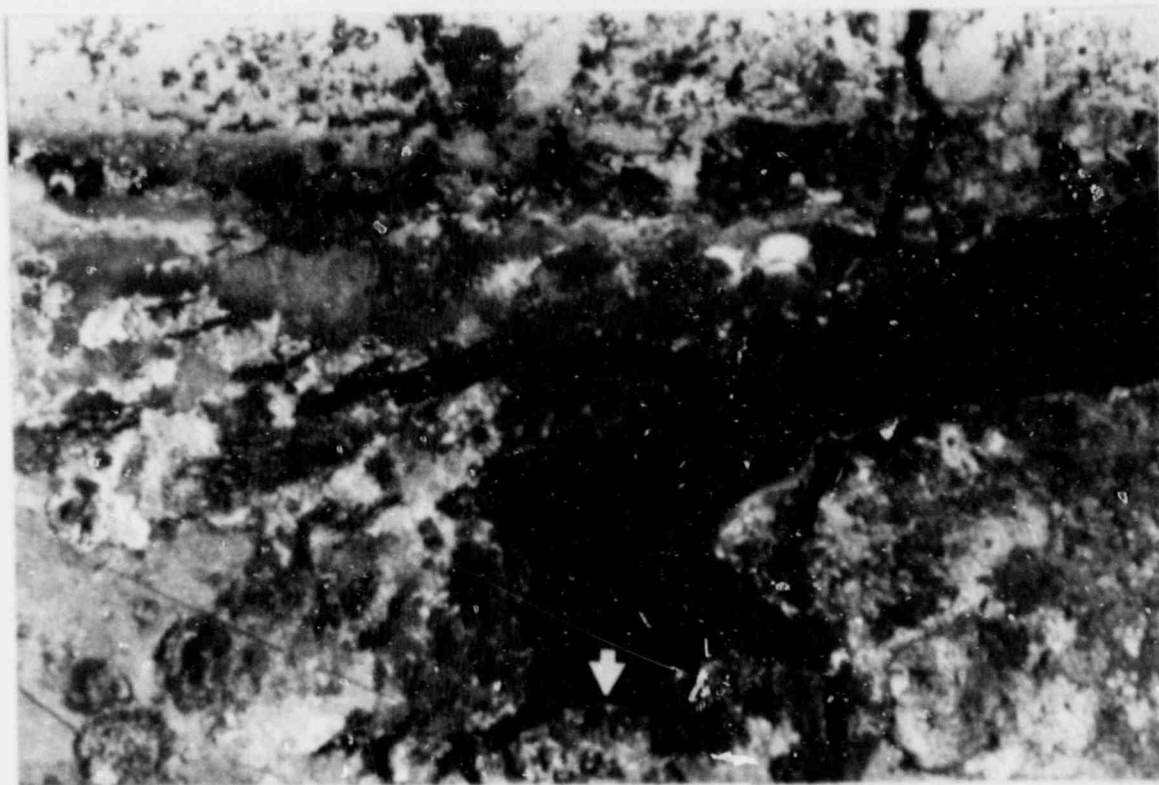


(b)

Figure 7 The corrosion and cracks on the outside surface of the convolution with the corrosion nodule shown in Figure 3(b).

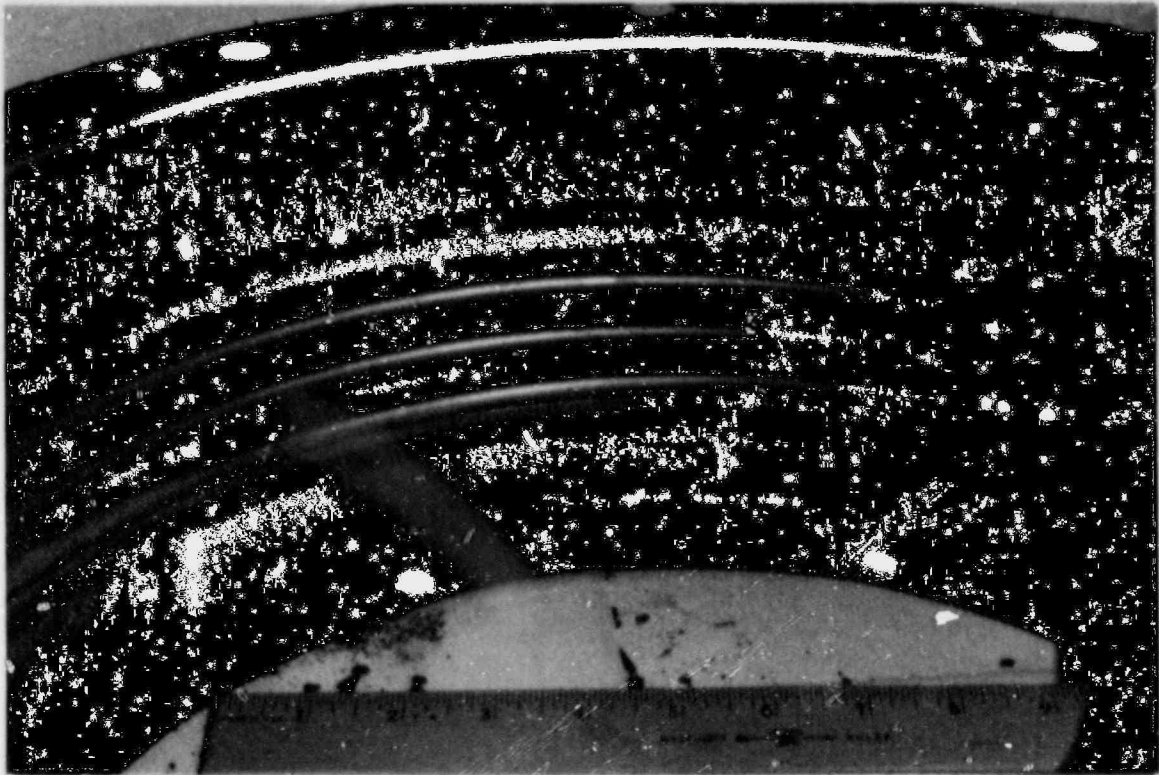


(a)

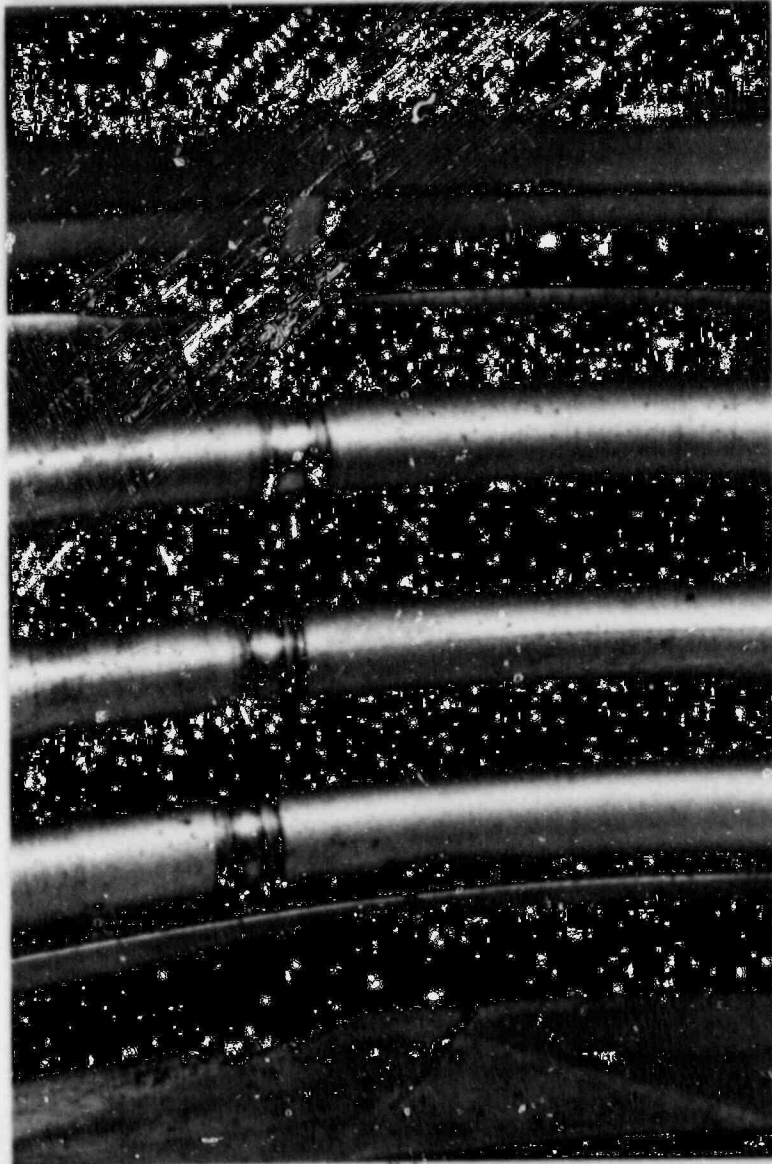


(b)

Figure 8 Corrosion pits and cracks in the area marked by the arrows in Figure 5(c).



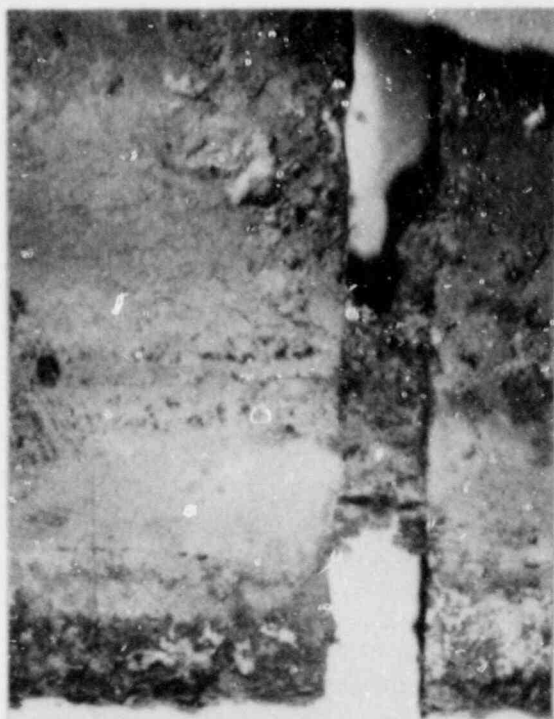
(a)



(b)

Figure 9

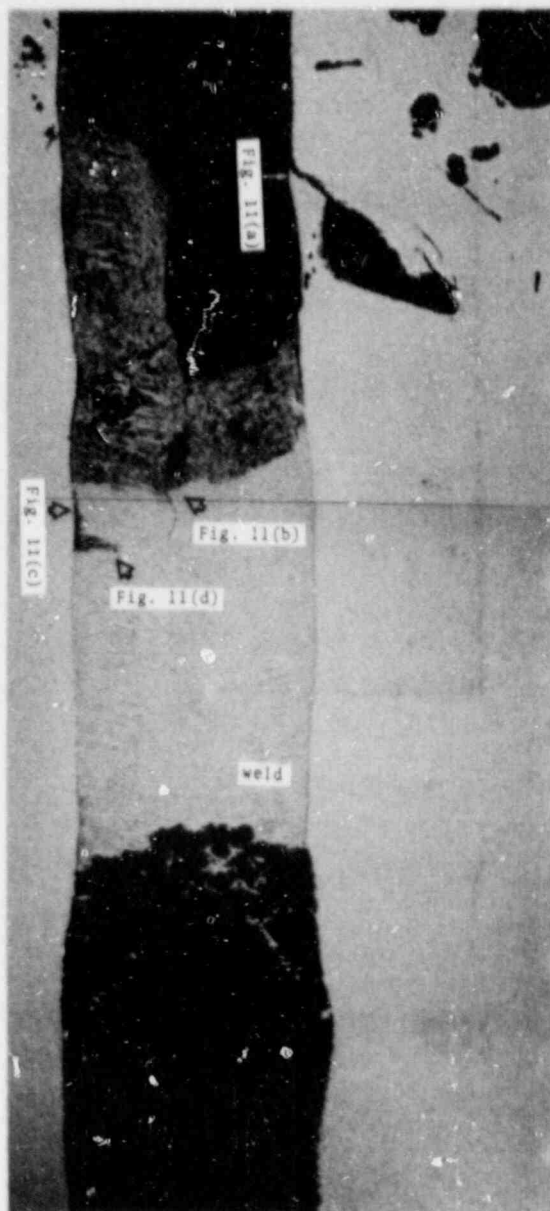
The inside of Bellows No. 2.
(b) shows a closeup view of the
weld.



(a) Inside 4X



(b) Outside 5X



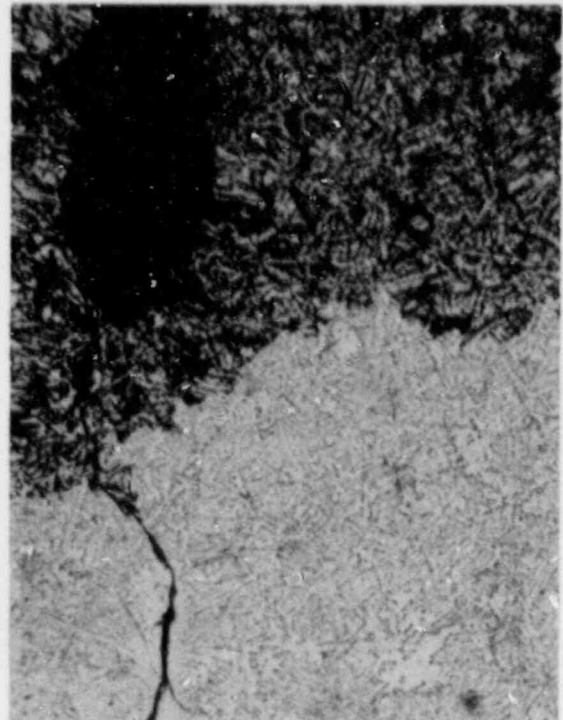
(c) 25X

Figure 10 The lower end of the convolution weld marked by the arrow in Figure 5(a). (c) is a mirror image of (a) after polishing and etching.



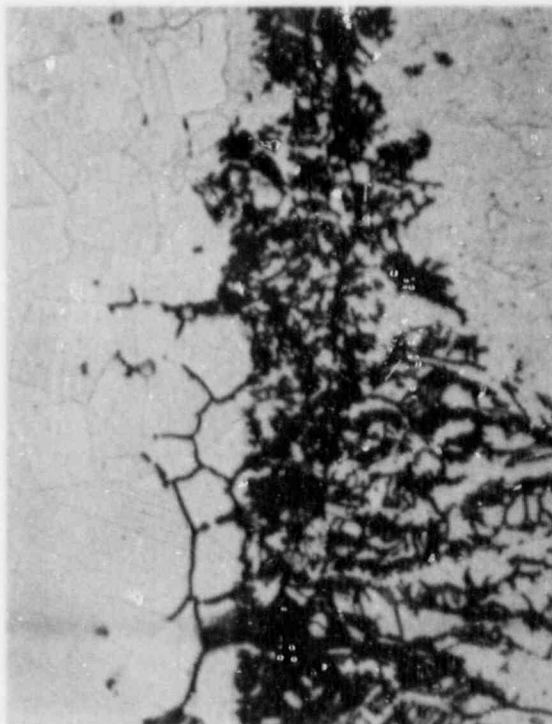
(a)

200X



(b)

100X



(c)

400X



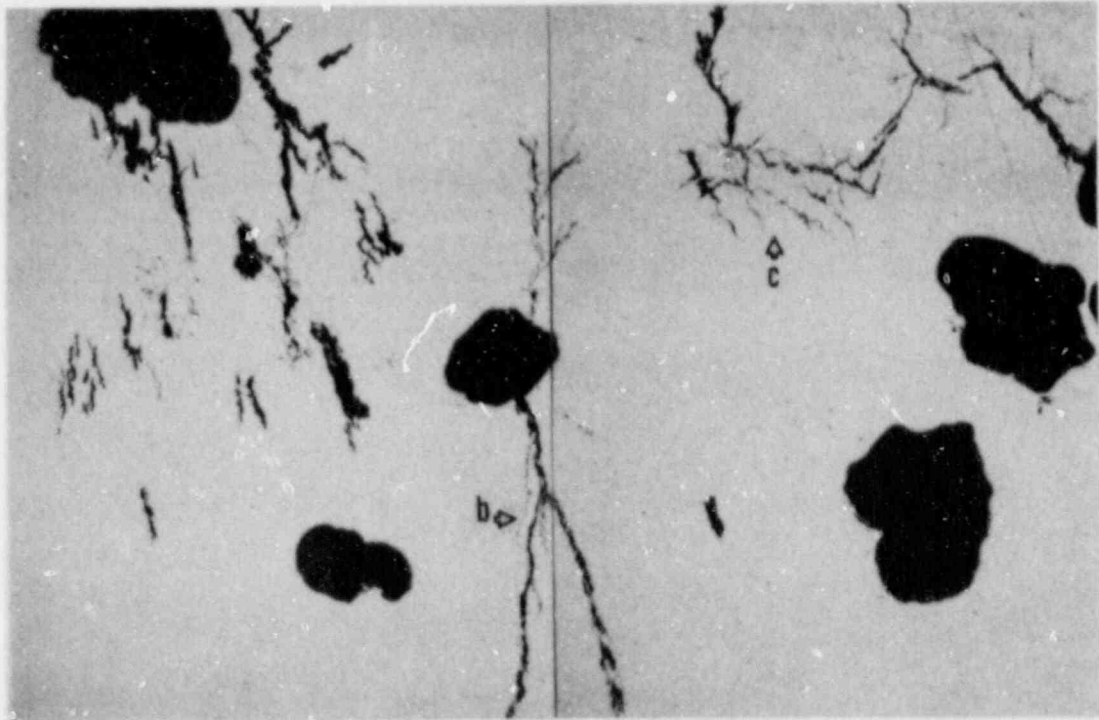
(d)

400X

Figure 11 Micrographs showing the areas marked in Figure 10(c).

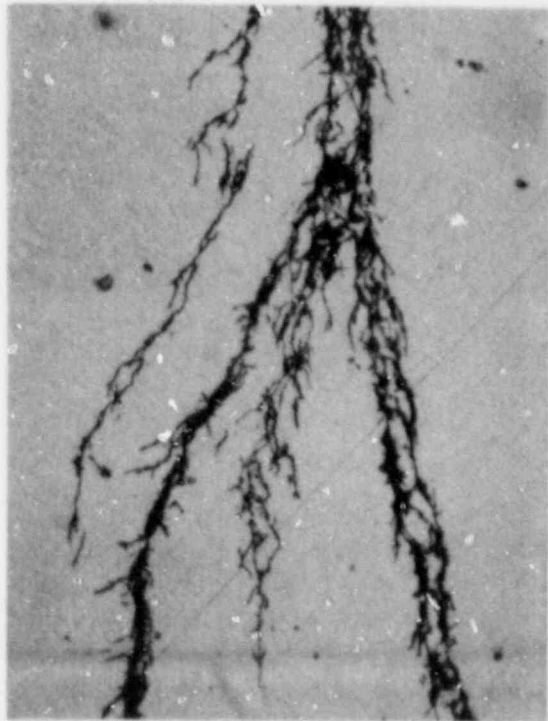
(a) transgranular cracks

(b), (c), & (d) interdendritic corrosion attack in the weld



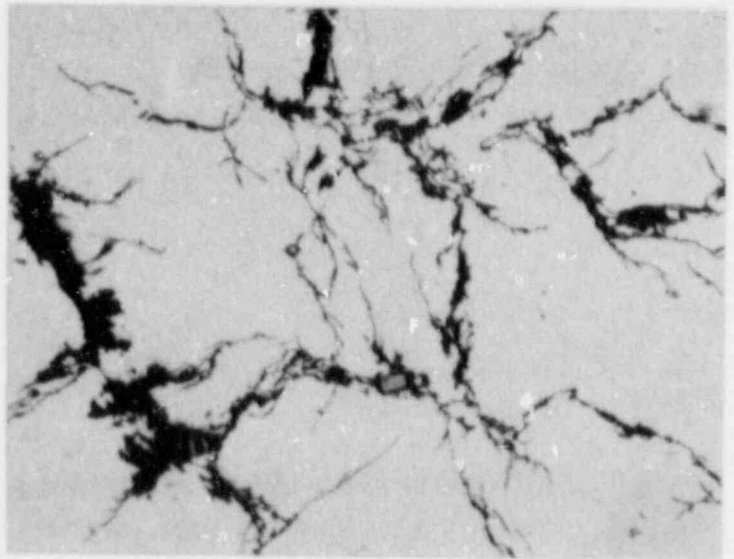
(a)

25X



(b)

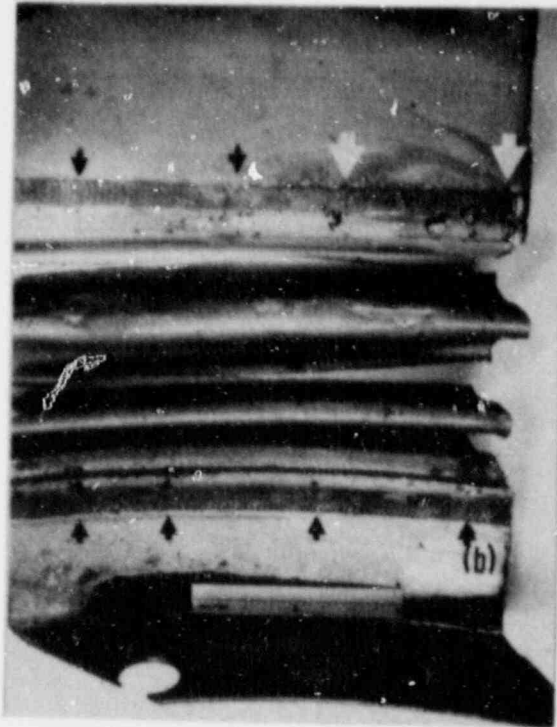
200X



(c)

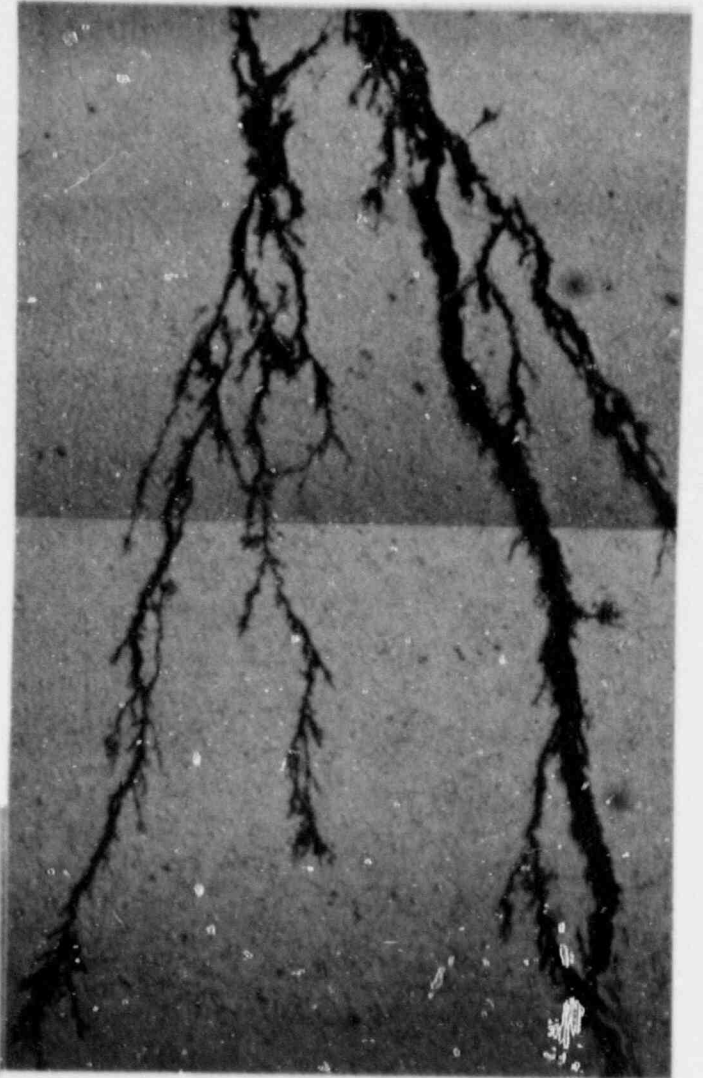
200X

Figure 12 Corrosion pits and transgranular cracks in the bellows element as seen on a plane parallel to the inside surface.



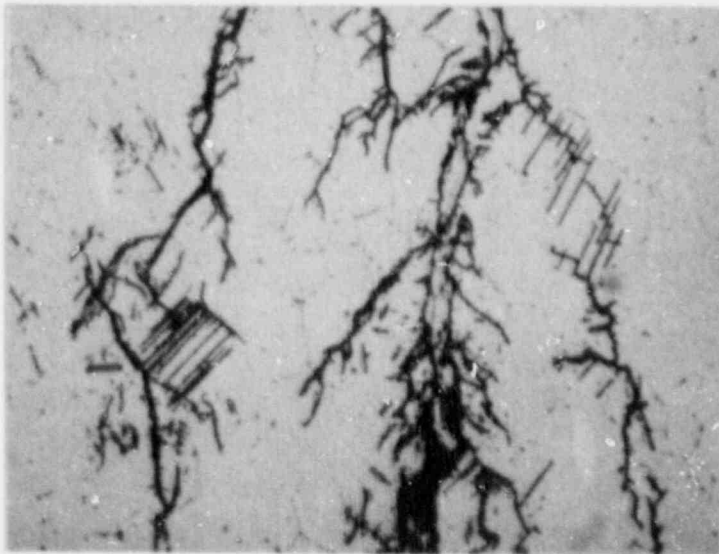
(a)

0.5X



(b)

50X



(c)

500X

Figure 13 (a) The section of the bellows shown in Figure 3. The arrows mark cracks in the end pieces.
(b) Micrograph showing transgranular cracks
(c) Micrograph showing the area marked in (b).