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ABSTRACT

Examinations of three Inconel pump impellers were made to establish the extent of cavitation damage and degree of carburization sustained during pump endurance tests. The pumps, two of which circulated fluoride salt and one sodium, had operated for the bulk of the test programs in the temperature range 1000-1250°F. Cavitation damage was manifested in each of the impellers by the formation of deep pits (in excess of 1/4-inch), the location of damaged areas varying with impeller geometry. Pit formation appeared to have occurred by uniform rather than preferential removal of metal components. Each of the impellers exhibited heavily carburized zones along exposed surfaces. The cause of carburization may have been associated with the type of gas purge utilized for these pumps.

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Introduction

During the past two years impellers from three Inconel pump endurance tests have been submitted to the Corrosion Engineering Group with the request that they be metallographically examined for evidences of wear and corrosion. This report summarizes the results of these examinations.

During operation, each of the impellers had been intentionally subjected to cavitation conditions, and each bore characteristic evidences of cavitation damage. In addition, a thin carbon deposit over upper regions of the pumps (associated with oil leakage) suggested the probability of carburization during testing of these components. Accordingly, metallographic examinations of the impellers were aimed primarily at evaluating the extent of cavitation and carburization phenomena.

Description of Experiments

Experiments from which the three impellers were derived were as follows:

1. Sodium Hot Pot (Pump Type - MN)

The Inconel impeller received from this test operated for 2500 hr in sodium at temperatures in the range from 1000°F to 1250°F. Sodium flow was confined to the pump bowl.

2. Fluoride Salt Hot Pot (Pump Type - MF)

This experiment was similar in design to that described above but with Salt No. 30 substituted for sodium. The impeller operated for 3550 hr between temperatures of 1100°F and 1400°F.

3. MFF Performance Test

The impeller from this test, like the one above, was exposed to Salt No. 30; however, the pump was operated in an isothermal test loop rather than a pot. The operating temperature of the system was 1200°F and the accumulated operating time of the impeller was 25,500 hr. The impeller was subjected to cavitation conditions for the latter 24,700 hr.

Test Results

1. Sodium Hot Pot

a. Sections examined - A quadrant of the impeller was removed, as shown in Figure 1, and was submitted to the Y-12 Metallography Laboratory for further sectioning. One section was taken directly across a cavitation area, which is clearly visible in Figure 1, and a second section was taken near the edge of the cavitation zone.

b. Cavitation damage - The appearance of the section taken directly through the cavitation zone is shown in Figure 2 at a magnification of 8X. (This section was copper-plated prior to polishing, which accounts for the thin coating visible over most of the exposed edges in the photograph.) In cross-section, the cavitated areas appear as a series of pits and holes to a depth of approximately 0.340 in. There is no doubt that the holes visible in this cross-section are in reality pits which in third dimension connect to the surface, since the copper plate is seen to have coated all holes of significant dimensions.

It is apparent that the edges surrounding the holes and pits in Figure 2 are heavily stained. The sample is in the unetched condition, so that staining would be unexpected; however, it is likely that it is in some way associated with seepage of sodium or plating solution from the pitted areas below the polished surface. In the etched condition, as illustrated in Figure 3, holes are seen to be surrounded by a light etching envelope, which in turn is surrounded by darkly etched field corresponding to the stained areas in Figure 2. (The holes shown were so small that they were not reached by the plating solution, and the light-etching envelope must be explained by something other than a copper plate.)

Figure 4 illustrates the appearance of a longitudinal cross section of the impeller adjoining the zone of pronounced cavitation damage. The sample was taken approximately 1/2 in. from the area of deepest penetration. The surfaces of this sample are heavily pitted and suggest that metal attrition due to cavitation has occurred for a sizeable distance (at least 1/2 in.) around the obviously damaged area in Figure 1.

The sample in Figure 4 (which was not copper plated) shows a light etching layer along the surface similar to the envelope surrounding the pitted areas in Figure 3. The layer appears to have been deposited rather than formed in place and closely resembles mass transfer deposits found in sodium forced convection tests.

c. Carburization - Below the surface layer in Figure 4, a zone of carburization is apparent to a depth of 3 mils. The absence of visible carburization in the surface layer can be explained by the thesis that this layer was deposited from the working fluid. Mass transfer deposits in Inconel-sodium systems have been found to be composed principally of nickel. In contrast to Inconel, nickel is not subject to carbide precipitation in the presence of carbon.

2. Fluoride Hot Pot

a. Specimens examined - The Inconel impeller utilized in conjunction with the fluoride hot pot is pictured prior to examination in Figure 5. A comparison of this impeller with that from the sodium experiment (Figure 1) indicates that the two impellers are similar but for the addition of webs at the base of the pump. Areas of cavitation in the fluoride hot pot impeller were found where the webs joined the inner ring support (arrow B in Figure 5). A single metallographic

sample was taken from the cavitated area (marked B) in Figure 5 and a second sample from the area marked A. It should be noted that this pump impeller was cleaned in nitric acid to remove fluoride deposits prior to examination. Because of poor pickling procedures, the impeller sustained was negligible in the cavitation area (arrow B).

b. Cavitation damage - Figure 6 is a cross-section of the area of deep cavitation (arrow B) pictured in Figure 5. The section was cut parallel to the longitudinal axis of the impeller and directly through the area where penetration appeared deepest. Pitting in this section, which is shown at 11X magnification, is not so confined as in the case of the sodium impeller (Figure 2) and penetrates the metal at a relatively wide angle. The depth of pitting could not be determined in this sample, because the rather complex shape made it impossible to gauge the original edge.

c. Carburization - A photomicrograph of the base of the cavitated area is shown in Figure 7. The larger pores apparent in this figure were undoubtedly caused by cavitation, while the smaller subsurface voids must be attributed to fluoride corrosion. Carburization was extremely heavy in this region and penetrated the entire specimen thickness ($3/16$ in.). A similar amount of carburization was apparent in sample A removed from the other side of the web.

3. MFF Pump Loop

a. Specimens examined - Two quadrants of the MFF Pump Loop Impeller were removed as shown in Figures 8 and 9. Cavitation in the first of these quadrants (Figure 8) was apparent near the leading edge and on the concave side of the impeller blades. If Figure 8 is examined closely, it will be noted that cavitation in this area caused complete penetration of the blade, as indicated by the light spot in the center of a particularly heavy pit. In the second quadrant, pictured in Figure 9, cavitation was evident on the convex side at the root of the blade.

The first of the quadrants (Figure 8) was sectioned across the blade and directly through the area completely pierced by cavitation. In the second quadrant, a section was taken through the weld area which joined the blade to the impeller driving hub (the area encircled in Figure 9).

b. Cavitation damage - The cross-section of the blade near the area of complete penetration is shown in Figure 10. (The blade in this photograph is magnified approximately 10 times). The roughened surfaces outlining the area of cavitation are shown at higher magnification in Figure 11.

c. Carburization - Surface carburization, which is evident in Figure 11, occurred along all exposed surfaces of the impeller to depths in excess of 20 mils.

d. Weld cracking - Cracks were visually detected at the weld junction between one of the impeller blades and the impeller driving hub (Figure 9). A macrograph of the weld area in which cracking occurred is shown in Figure 12. The cracks are seen to be confined to the weld bead with the exception of one area near the bottom of the photograph, which appears to be the result of incomplete weld penetration. Cracks in all cases were intergranular, as shown in Figure 13.

Discussion and Conclusions

1. Cavitation Damage

Metallographic examinations of impeller sections which sustained cavitation damage provided little information in addition to that which was apparent from external examinations of the impellers - namely, that the damaged areas were comprised of a series of deep pits, each connecting to the surface. The surfaces lining these pits, although extremely rough, exhibited no significant changes in microstructure compared to underlying areas. Thus, it can be concluded that surface disturbances associated with cavitation did not produce melting (at least on a macroscopic scale). Likewise, the removal of metal components seems to have occurred uniformly rather than preferentially, based on the fact that carbide precipitation took place out to the edge of the pits. This is indicative that chromium, which has the highest vapor pressure among the components of Inconel and is the principal carbide former in Inconel, was not depleted ahead of the other metal components.

As was noted in a preceding section, a thin surface film was found on surfaces of the sodium impeller, which appeared to be formed by deposition rather than by reaction in place. At least two causes of such a layer are immediately obvious. First, the layer was similar in appearance to deposits formed as a consequence of mass transport in sodium pumped loops, and it is conceivable that temperature fluctuations may have produced conditions leading to metal dissolution and deposition. Secondly, the layer may represent the redeposition of metal removed by cavitation.

2. Carburization

A surface zone of heavy precipitation, characteristic of carburization, was observed in metallographic specimens of each of the Inconel impellers. The likelihood that the precipitates represent carbides is strengthened by the fact the non-wetted surfaces of the pumps were coated by a thin carbon deposit, as noted in the introduction.

There are at least two plausible hypotheses by which to account for carburization in these tests. The simplest is to assume that a small amount of oil leaked into the test fluid. The breakdown of oil under the temperature and environmental conditions achieved in these pump tests

is known to produce a number of potentially carburizing compounds.¹

A second carburization mechanism, which definitely bears consideration, concerns the method of gas purge used in these particular pump endurance tests. Each pump incorporated what is termed a "down-shaft" purge; under this concept the helium purge gas flows past the seal oil leakage before entering the pump bowl. It is quite possible that the purge gas became sufficiently laden with oil vapors before coming in contact with the working fluid to itself serve as the carburizing medium. One piece of indirect evidence which supports this contention is the fact in over 450,000 hr of testing of fused salts and sodium, systems incorporating the Model LFB centrifugal pump have not exhibited even a minor degree of carburization. This pump utilizes a stagnant rather than dynamic purge. Pump endurance tests currently in progress with still other forms of gas purging should shed further light on the relationship of pump purge and carburization problems.

¹ G. Goldberg, Compatibility of Pump Lubricants With Alkali Metals and Molten Fluoride Salts, ORNL-2168, Dec. 28, 1956.

Fig. 1 (T-17758) Sector of Impeller Removed From Sodium Hot Pot (Type MN Pump). Area of Cavitation is Evident at Center of Photograph.

Fig. 2 (T-17936) Cross-Section of Cavitation Zone Visible in Figure 1. Specimen was Copper-Plated prior to Polishing. Mag: 8X. As Polished.

Fig. 3 (T-17937) Photomicrograph Showing Detail of Small Pores Formed by Cavitation. Mag: 250X. Etch: Modified Aqua Regia.

Fig. 4 (T-17939) Appearance of Impeller Surface Approximately 1/2 in. From Zone of Heavy Cavitation in Figure 1. Mag: 250X; Etch: Modified Aqua Regia.

Fig. 5 (T-18118) Photograph Showing Areas of Cavitation (Arrow B) in Impeller Operated in Fluoride Hot Pot.

Fig. 6 (T-18718) Cross-Section of Cavitation Zone Shown by Arrow B in Figure 5. Mag: 11X. As Polished.

Fig. 7 (T-18719) Photomicrograph of Area at the Base of the Pit Shown in Figure 6. Heavy precipitation in this area is attributed to carburization. Mag: 250X. Etch: Modified Aqua Regia.

Fig. 8 (T-19372) Quadrant of MFF Pump Loop Impeller Which Sustained Complete Penetration of Impeller Blade by Cavitation.

Fig. 9 (T-19373) Sector of MFF Impeller Which Exhibited Weld Cracking (Encircled Area) and Cavitation (Lower Left Hand Corner).

Fig. 10 (T-19375) Cross-Section of Heavily Cavitiated Impeller Blade Shown in Figure 8. Mag: 10X. As Polished.

Fig. 11 (T-19376) Appearance of Metal Outlining Pit Shown in Figure 10.
Mag: 100X. Etch: Modified Aqua Regia.

Fig. 12 (T-19378) Area of Cracking Found in Weld Bead Joining Impeller
Blade to Pump Driving Hub. Mag: 10X. As Polished.

Fig. 13 (T-19379) Photomicrograph of Weld Bead Cracks Visible in Figure 12. Mag: 250X. Etch: Modified Aqua Regia.

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