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MASTER

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FAILURE ANALYSIS OF A HASTELLOY C-276 GEOTHERMAL INJECTION PUMP SHAFT

G. E. Tardiff[†] and E. O. Snell

Summary

A metallurgical analysis of a fractured Hastelloy C-276^{*} brine injection pump shaft was carried out to determine the cause of failure. Loss of load carrying cross section due to intergranular corrosion by molten bronze bearing alloy followed by torsional overload of the remaining section was the cause of failure. Lack of evidence for brine induced corrosion or stress corrosion of the Hastelloy C-276 alloy is consistent with prior successful experience with this material in contact with high temperature, high salinity Salton Sea Geothermal Field brines.

Discussion

The pump in question is a vertical, nine stage, centrifugal type as described in reference 1. The 12 foot long x 2-1/4 inch diameter Hastelloy C-276 pump shaft failed after 59 hours service in 100°C, 30% dissolved salt Salton Sea Geothermal Field brine at San Diego Gas and Electric's Geothermal Loop Experimental Facility (GLEF). A metallurgical failure analysis was carried out to determine if a material limitation due to corrosion or stress corrosion susceptibility in the geothermal brine contributed to the failure and to establish the mechanism of failure.

[†] Formerly with LLL, now a private consultant.

^{*} Nickel base alloy containing 2.5 Co[†], 16 Cr, 16 Mo, 4 W, 5 Fe, 1 Mn[†], .35 V[†]. ([†] maximums)

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Metallurgical Analysis - The fracture surfaces of the shaft were severely scored and deformed by a rubbing action which occurred after the shaft had fractured. Thus, it was not possible to carry out a fractographic analysis. Figure 1 shows a longitudinal cross section through the fractured end of the shaft showing a conical fracture with multiple, branching secondary cracks of the type normally associated with a stress corrosion cracking mechanism. Figure 2 shows a higher magnification view of area A in Figure 1. A deposit is observed on the fractured surface (top of Figure 2) and close inspection reveals that a second phase is present in many of the failed grain boundaries of the Hastelloy C-276. A higher magnification view of the deposit on the fracture surface in Figure 3 shows it to consist of equiaxed grains surrounding incompletely dissolved remnants of the Hastelloy. Figure 4 shows a high magnification view of a deep secondary crack, filled with foreign phases. Electron beam microprobe analyses showed that both the surface deposit and the intergranular phases consisted of elemental Cu, Sn, and Pb.

Failure Analysis - Both the surface deposits and the intergranular phases originated from melting of the type SAE 660 bronze bearing (83 Cu, 7 Sn, 7 Pb, 3 Zn). Intergranular corrosion by the liquid metal reduced the effective cross sectional area of the shaft and finally a torsional overload caused complete separation. It is of interest to note that a complete torsional overload of a ductile material such as Hastelloy would be expected to cause failure in shear with the fracture surfaces normal to the shaft axis. The conical fracture which was observed (Fig. 1) illustrates the strong embrittling effect of liquid metal corrosion. The poor resistance of nickel base alloys to molten metals is well documented.² It is concluded that bearing failure and/or deposition of scale in the bearing/shaft gap caused frictional heating sufficient to melt the bronze bearing alloy. Intergranular liquid metal corrosion then reduced the effective cross sectional area of the shaft and final separation occurred by torsional overload.

Figure 1. Photomicrograph of Polished Section Through Fractured End of Shaft (2.9X)

Figure 2. Photomicrograph of Area A of Pump Shaft Fracture Shown in Fig. 1 (15X)

Figure 3. Photomicrograph of Section Through
Reddish Deposit on Fracture Surface
Major Constituent Identified as Cu.
(200X)

Figure 4. Photomicrograph of Section Through
Separated Grain Boundary Region.
Constituents in Boundries Identified
as Elemental Cu, Sn, and Pb. (500X)

Suitability of Hastelloy C-276 for Service in Salton Sea Geothermal Brine - A review of experience with Hastelloy C-276 in Salton Sea Geothermal Field brine service shows that no instances of corrosion or stress corrosion have yet been found which would pose any limitation on the use of this material for critical brine applications. This experience includes a 2 month exposure of Hastelloy tubing at a depth of 3800 ft. in the Magmamax No. 2 well (250°C) and a one month exposure of welded U-bend stress corrosion specimens in reduced pH brine (125 & 150°C at pH 4).³ This successful experience to date does not preclude the necessity of qualification testing any previously untested metallurgical conditions of the alloy.

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