The Erosion-Corrosion Behaviour of Copper-Nickel Alloys.

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Chapter 10

Conclusions and Further Work.

10.1. Conclusions.

A detailed study of the behaviour of the two Cu-Ni-base alloys under jet impingement conditions has demonstrated the extreme complexity of the erosion-corrosion process. The experimental arrangements resulted in behaviour which, apart from the most-severe conditions of 86m/s impingement on Cu-10%Ni, did not exhibit major differences between the various hydrodynamic zones, laminar, high turbulent and wall jet, of the specimen. The velocity-dependencies and the time-dependencies of erosion-corrosion damage were extremely complex and there were substantial differences in the behaviour of the two alloys studied. The main separate conclusions are listed below.

- Over long periods, (7 months), the static corrosion resistance of Marinel appeared to be inferior to that of Cu-10%Ni at 19°C.

- Over the entire range of conditions studied, the erosion-corrosion resistance of Marinel was substantially superior to that of Cu-10%Ni.

- At 86m/s on Cu-10%Ni, the erosion-corrosion damage showed intense pitting attack on the central directly impinged zone and in a narrow region at a radial distance of about 4.5 mm, which undoubtedly corresponds to the maximum turbulence region associated with an impinging jet.

- Apart from the above case, the erosion-corrosion damage was found to be generally similar in type over the entire surface and comprised general attack, manifested by etching of the surface, plus film formation.

- In the first few hours of exposure to impingement over the velocity range of 2.38m/s-86m/s, (R_e=4500-86000), the direct corrosion resistance of Marinel was inferior to that of Cu-10%Ni.

- Over longer exposure periods at 17m/s, the direct corrosion rates of Marinel were lower than for Cu-10%Ni.

- In most of the conditions studied it was found that the direct corrosion accounts for only a proportion of the total material loss with significant amounts of pure erosion and often substantial proportions of corrosion-assisted erosive damage ("synergy").

- The hydrodynamic conditions stimulated film formation on the surface of Marinel and to a lesser extent on Cu-10%Ni, but the films became unstable in some circumstances. The complex patterns of film formation and destabilisation appear to account for the complex effects of impinging-velocity and time on the erosion-corrosion damage rates.

- The effect of increasing the impinging velocity on erosion-corrosion after 30 minutes and 4 hours exposure was observed to lead to a general increase in total material loss but with some indications of a step in the weight loss/velocity relationship at intermediate velocities/R_e. The direct corrosion rate was clearly seen to increase with velocity up to a range of velocities, at which the corrosion rates stabilised, followed by a subsequent increase in corrosion rate at higher velocities.

- The direct corrosion mechanism corresponding to the above trends, was rationalised in terms of mixed charge transfer/diffusion control of the anodic reaction at low velocities, corrosion rate stabilisation due to film formation at intermediate velocities and film breakdown, (leading to anodic rate control), at high velocities.

- At the impinging velocity of 17m/s the rate of the pure erosion declined with increasing time, but the corrosion rate/time relationships appeared to be cycling between high and low values. It is postulated that the initial phase of increasing corrosion rate with time is associated with increasing diffusion rates of anodic products across a diffusion boundary layer. Later, film formation introduces a period of decreasing corrosion rate. The subsequent period of increasing corrosion rate is thought to be associated with film breakdown possibly due to surface

roughness and mass transfer effects. It is thought that the above mentioned phases may be repeated to produce continued cycling behaviour.

- ❖ The erosion contributions were found to be significant on Cu-10%Ni, but only on Marinel at very high velocities. Microscopical observations indicated that the erosion damage was due to impact events, for instance from air bubbles.

- ❖ Synergy mechanisms have been proposed but it is recognised that in some respects (particularly for Marinel), these need to be clarified by further experiments.

- ❖ Experiments with concentric specimens revealed a higher corrosion rate on the specimen, which encompassed the directly impinged and highly turbulence zones, than on the specimen comprising the wall jet regions. However, extremely low galvanic currents flowing between the two components of a concentric specimen, further demonstrated the absence of substantial differences in erosion-corrosion behaviour between the various zones of the specimens employed in this study. Thus the hydrodynamic conditions, performing in the experiments conducted in the present work, did not simulate active/passive cells.

- ❖ The damage mechanisms for both alloys at different impingement angles were very complex, emphasising the futility to simply transfer angular relationships obtained from dry erosion, through to aqueous erosion-corrosion.

- ❖ For Cu-10%Ni salinity variations did not appear to affect the direct corrosion rate.

- ❖ Although the erosion-corrosion rates for Cu-10%Ni were higher at 35°C than at 19°C, the opposite was the case for Marinel. This interesting and potentially important finding for Marinel was correlated with a great attendance for the formation of more protective surface films at the higher temperature.