LONG LIFE MATERIALS FOR AGGRESSIVE SULFURIC ACID ENVIRONMENTS.

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Introduction: Venus' atmosphere presents a very difficult materials problem to mitigate. While materials are available for specific concentration or temperature ranges such as found in industrial plants, Venus presents variable environments with altitude. Ranges of sulfuric acid and other corrosive agents, combined with variations in pressure and temperature requires a material which can protect itself over this entire environmental envelop, and perhaps including even some unknown hazards.

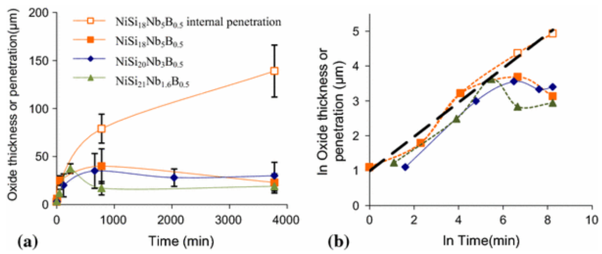
An alloy was developed specifically for the most aggressive ranges of sulfuric acid concentrations for commercial purposes [1]. This alloy was based on a ductile Ni-Si intermetallic, Ni3Si, rather than more conventional metal alloys which typically depend on chromium additions to provide protection. The alloy forms amorphous SiO2 in the presence of strong oxidizing environments, rather than Cr2O3, like traditional corrosion resistant alloys.

It is proposed that this alloy system, or a modification of it, could be used for spacecraft protection, particularly in the descent phase of the mission. The exceptional corrosion resistance of this alloy could enable much longer residence times on the surface of Venus than were previously thought possible.

Description of Developed Alloy: This new alloy contains Ni, Si, Nb, and B [2]. The Nb is able to impart extra ductility to the alloy. The high concentration of Si is exceptional for any other known alloy, and enables the production of an amorphous silica (glass) reaction layer, which has excellent adherence and physical match with the underlying alloy, producing an almost zero rate of corrosion. If the coating is damaged, the oxidizing environment will promote new formation of the glass, and repassivates the material.

The alloy was developed for a casting application, and is therefore highly castable, as well as weldable [3]. Given the fabricability of this alloy, it should be easy to 3D print it as well. A later project to develop this material for hydrogen production, as well as heat exchanger applications, resulted in a sort term project to develop a wrought analog, which could be formed into sheet or tubes. In addition, there was interest in using the alloy as a coating material, which was successfully applied by plasma spraying [4].

Alloy Performance: The alloy has been tested in a number of environments for extensive periods of time. The figure shows some test results from the development project for different compositions of the basic elements. The commercialized alloy has a composition of NiSi20Nb3B0.5, and it can be seen that it passivates and then basically stops corroding. The sulfuric acid concentration is 70% and the tests were conducted at the boiling temperature. The natural log graph shows the parabolic film formation followed by the corrosion arrest.



Additional testing has been carried out at high atmospheric pressures and temperatures and performed equally well [5]. The alloy is also capable of good strengths at elevated temperatures and is very erosion resistant. All of these attributes would be useful in a descent stage.

References:

[1] Newkirk, J. W. and Zhang, S. Zhang, US Patent #6,342,181, 1/2902.

[2] Hsu, J.H., Larson, C.M. Newkirk, J.W., Brow, R.K., and Zhang, S.H., (2016) *J. of Materials Engineering & Performance*, Vol 25, 2, 510-517.

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[4] McNelis, K., Newkirk, J.W., and Van Aken, D.C., (2004) " Proc. of the 3rd International Surface Engineering Congress, ASM-Intl, 18-27.

[5] Newkirk, J.W., Hsu, J.H., Brow, R.K., and Lillo, T., (2011) *International J. of Hydrogen Energy*, Vol. 36, Issue 7, 4588-4594.