Effect of Porosity on Ductility Variation in Investment Cast 17-4PH[1]

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The stainless steel alloy 17-4PH contains a martensitic microstructure and second phase delta (δ) ferrite. Strengthening of 17-4PH is attributed to Cu-rich precipitates produced during age hardening treatments at 900-1150°F (H900-H1150). For wrought 17-4PH, the effects of heat treatment and microstructure on mechanical properties are well-documented [for example, Ref. 1]. Fewer studies are available on *cast* 17-4PH, although it has been a popular casting alloy for high strength applications where moderate corrosion resistance is needed. Microstructural features and defects particular to castings may have adverse effects on properties, especially when the alloy is heat treated to high strength. The objective of this work was to outline the effects of microstructural features specific to castings, such as shrinkage/solidification porosity, on the mechanical behavior of investment cast 17-4PH.

Besides heat treatment effects, the results of metallography and SEM studies showed that the largest effect on mechanical properties is from shrinkage/solidification porosity. Figure 1a shows stress-strain curves obtained from samples machined from castings in the H925 condition. The strength levels were fairly similar but the ductility varied significantly. Figure 1b shows an example of porosity on a fracture surface from a room-temperature, quasi-static tensile test. The rounded features represent the surfaces of dendrites which did not fuse or only partially fused together during solidification. Some evidence of local areas of fracture is found on some dendrite surfaces. The shrinkage pores are due to inadequate backfilling of liquid metal and simultaneous solidification shrinkage during casting.

A summary of percent elongation results is displayed in Figure 2a. It was found that higher amounts of porosity generally result in lower ductility. Note that the porosity content was measured *on the fracture surfaces*. The results are qualitatively similar to those found by Gokhale et al. and Surappa et al. in cast A356 Al and by Gokhale et al. for a cast Mg alloys [2-5]. The quantitative fractography and metallography work by Gokhale et al. illustrated the strong preference for fracture in regions of porosity in cast material. That is, the fracture process is not correlated to the *average* microstructure in the material but is related to the *extremes* in microstructure (local regions of high void content). In the present study, image analysis on random cross-sections of several heats indicated an overall porosity content of 0.03%. In contrast, the area % porosity was as high as 16% when measured on fracture surfaces of tensile specimens using stereology techniques. The results confirm that the fracture properties of cast 17-4PH cannot be predicted based on the overall "average" porosity content in the castings.

Following the approach of Gokhale et al. [2,3], the correlation between tensile elongation and the area fraction of defects on the fracture surface can be represented by the expression:

$$e = e_0 \left[1 - f\right]^n$$

where e is ductility (% elong.) and f is area fraction defects on the fracture surface. The parameter e_0 can be thought of as the ductility of a *defect-free* casting and the exponent n may be interpreted as the index of defect susceptibility of the alloy. A fit of the data (Figure 2b) shows that the susceptibility parameter is 11.4 for investment castings of 17-4PH in the high-strength condition.

References

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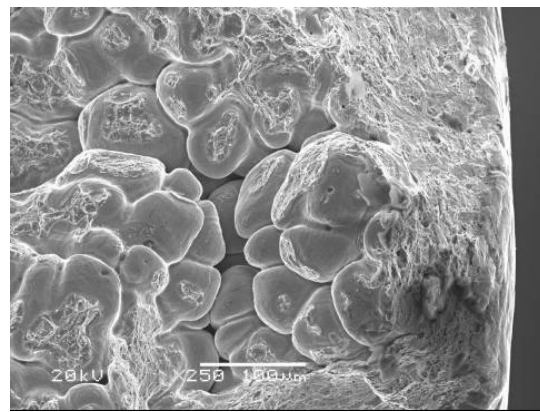[5] M.K. Surappa, E. Blank, and J.C. Jaquet, *Scripta Met.*, (1986), 20, 1281-1286.
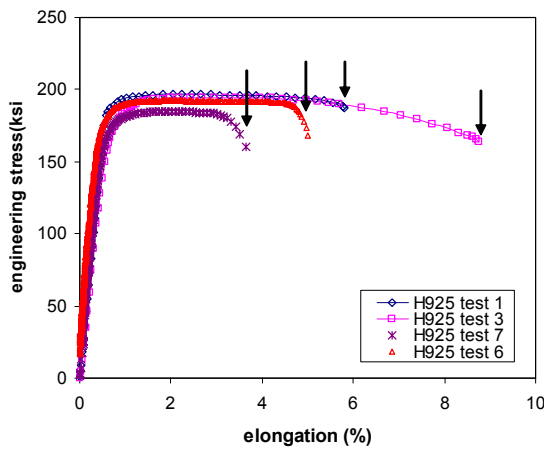

Fig. 1a. Stress-strain curves for 17-4PH castings in the H925 condition. Arrows indicate the large variation in strain to fracture in three different tensile tests.
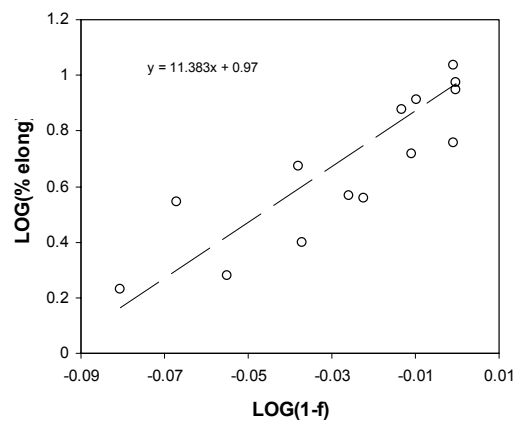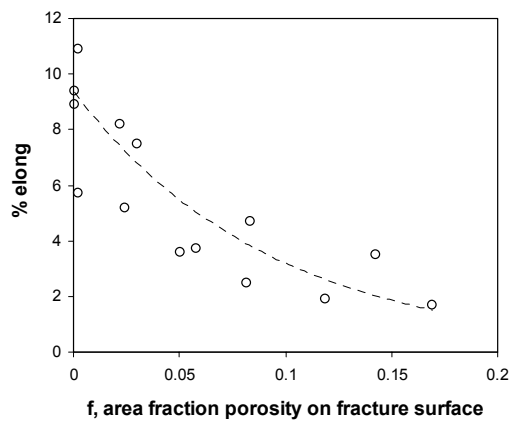Fig. 1b. SEM photomicrograph of casting porosity on a tensile bar fracture surface.

Fig. 2a. Plot of tensile ductility vs. area fraction porosity on the fracture surfaces.
Fig. 2b. Plot of log(e) vs. log(1-f) for the data in Fig. 2a. The data are from three casting lots.