APPLICATION OF ANISOTROPIC ELASTICITY TO CENTRIFUGALLY CAST PIPING*

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SUMMARY

Austenitic stainless steel piping of the CPF8 (composition similar to AISI type 304) and CPF8M (similar to AISI type 316) designation finds application in numerous coolant and process transport stream applications. Centrifugally cast pipe has radially elongated grains and subgrains, and probably preferred crystallographic orientations as a result of the preferred growth direction. These factors can cause mechanical anisotropy. We have determined anisotropic elastic constants and demonstrated the importance of considering anisotropy in stress analyses for these materials.

Our principal method of determining the anisotropic stiffness matrix was by the use of ultrasonic velocity measurements and the Christoffel relations. A cylindrical specimen configuration gave nearly continuous data for velocity as a function of orientation in three orthogonal planes and verified the texture of the material. One cube and a set of three cylinders, one each oriented in the radial ($r-$), tangential ($t-$), and longitudinal ($z-$) directions, were made for CPF8 and CPF8M having both high and low ferrite content — a total of four materials. The 25 mm (1 in.) dia. and 51 mm (2 in.) long cylinders were evaluated with an ultrasonic immersion method where relative velocities of 2.25 MHz longitudinal waves transmitted through the diameter were measured for each 5° of rotation. Contact measurements were made on a 25 mm (1 in.) cube for shear as well as longitudinal waves in the r—, t—, and z—directions. From these contact measurements, the relative velocities in the cylinders were converted to absolute velocities. The data were plotted and smoothed and the elastic stiffness matrices were determined.

A number of tensile specimens were prepared with a 32 mm (1.25-in.) reduction section and a nominal 6.4 mm (0.25 in.) diameter. These specimens were instrumented with a clip-type extensometer to measure the modulus of elasticity with a universal testing machine. Examination of the microstructures of the alloys showed the elongated grains had a short dimension of approximately 2.5 mm (0.1 in.). Hence, specimens used for ultrasonic as well as static modulus measurements should be large enough to approach a continuum.

The principal result of this work is the set of elastic stiffness matrices. We have found the stiffnesses fit the "specially" orthotropic model reasonably well. The stiffness matrices may be routinely transformed to give the engineering constants. The moduli of elasticity (E_r, E_t, E_z) range from 120.7 to 155.1 GPa (17,500 to 22,500 ksi), the strain ratios (ν_{rt}, ν_{rz}, ν_{tz}) range from 0.28 to 0.40, and the shear moduli (G_{rt}, G_{rz}, G_{tz}) range from 39.3 to 64.8 GPa (5700 to 9400 ksi).

As an example, a pressurized pipe has been analyzed by use of these engineering constants in the SAP-IV finite-element stress analysis program. Results for stress and displacement analysis show significant differences from those derived from the use of the usual isotropic material constants. Typically, the radial component of displacement is from 26 to 53% larger than that predicted with isotropic elastic constants. depending on geometry and the particular alloy.

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