Preliminary Design: Steel Ring and Plug Specimen for Residual Stress Round Robin

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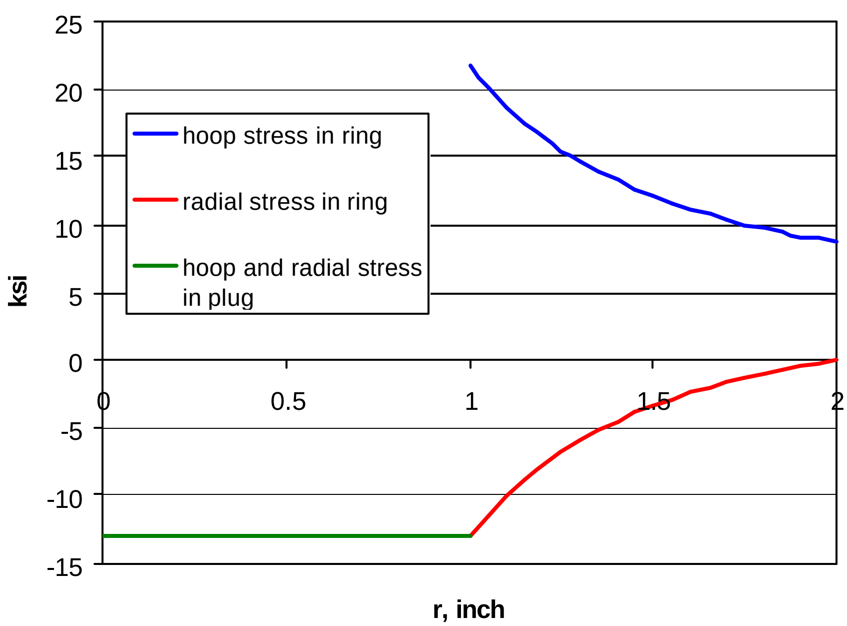
Summary:

This is a preliminary design for a 4-inch diameter steel known-stress shrink-fit ring and plug, where a slightly oversized plug is fit into the slightly smaller hole in a ring. Because the steel properties are not yet finalized, the design should be revisited after final material selection. The main design considerations were to (1) maximize the stresses in the specimen in order to allow for reasonable measurements while (2) making the specimen reasonably easy to fabricate and (3) avoid any yielding of the specimen during assembly.

Design:

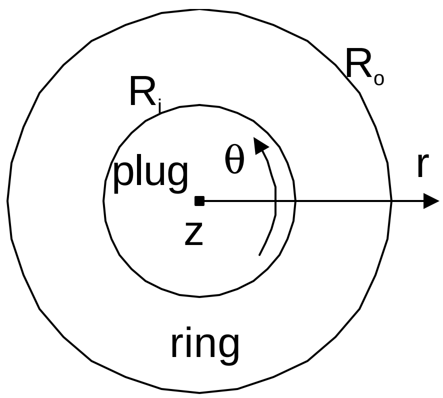
Nominal plug radius, ring inner radius	1 inch
Nominal ring outer radius	2 inch
Thickness	0.5 inch
Radial interference at room temp.	0.0012 inch
Radial clearance with plug at –320F (liq. N_2)	0.0023 inch
Assumed steel yield strength after relief	38 ksi
Max $\bar{s}/S_y$ as assembled	0.8
Assumed Elastic Modulus	28.5×10^6 psi
Assumed Poisson's ratio	0.28



Designed residual stress distribution in steel ring and plug

Specimen Configuration and Formulae

A shrink-fit ring and plug, where a slightly oversized plug is fit into the slightly smaller hole in a ring, is a convenient known residual stress specimen for several reasons. (See Figure for a sketch of this specimen and a definition of coordinates.) First, this specimen has a closed form solution for the residual stresses, so long as the stresses do not cause yielding. The stress distribution is simple: the stresses are constant in the plug and a function of only *r* in the ring. Second, this specimen provides the full range of biaxial stress states for testing. Some measurement methods are sensitive to the difference between the in-plane principal stresses, $|\sigma_1 - \sigma_2|$. For the ring and plug specimen the principal stresses are σ_r and σ_θ. In the ring near the interface, σ_θ is positive and σ_r is negative. Near the outer edge the stress state is nearly uniaxial since σ_r goes to zero. In the plug, the stress state is equi-biaxial, $\sigma_\theta = \sigma_r$. Therefore, with one specimen it is possible to have all of these stress states. The ring and plug specimen has been used routinely in the literature as a known stress specimen, e.g., [1,2,3].



Sketch of ring and plug and coordinates. *Z*-direction is out-of-plane.

For the shrink fit the pressure between the ring and plug can be calculated in terms of the *radial* interference ***d*** as [4]:

$$p = \frac{Ed}{2R_i}\frac{\left(R_o^2 - R_i^2\right)}{R_o^2} \qquad (1)$$

Where *p* is taken as positive. Now the stresses in the ring and plug can be calculated using standard pressure vessel formulae:

$$
\begin{aligned}
&\text{throughout the plug :} \\
&s_r = s_q = -p \\
&\text{in ring :} \qquad\qquad (2) \\
&s_r = \frac{pR_i^2}{R_o^2 - R_i^2}\left(1 - \frac{R_o^2}{r^2}\right) \\
&s_q = \frac{pR_i^2}{R_o^2 - R_i^2}\left(1 + \frac{R_o^2}{r^2}\right)
\end{aligned}
$$

From which the strains can be calculated as

$$
\begin{aligned}
e_r &= \frac{1}{E}\left(s_r - n s_q\right) \\
e_q &= \frac{1}{E}\left(s_q - n s_r\right)
\end{aligned}
\qquad (3)
$$

The radial displacement in the ring can also be calculated as [5]:

$$
\begin{aligned}
u_r &= \frac{pR_i^2}{Er\left(R_o^2 - R_i^2\right)}\left[(1+n)R_o^2 + (1-n)r^2\right] \\
&= \frac{2pR_i^2R_o}{E\left(R_o^2 - R_i^2\right)} \text{ at } r = R_o
\end{aligned}
\qquad (4)
$$

where u_r at $R=R_o$ gives the change in outer radius of the ring after assembly, which can serve as an experimental check of the actual interference in the fit [6].

Assembly

Hytec is familiar and experienced with assembly issues. Because of the small interference and radial displacements of the parts, strain gages will have to be used to accurately determine the actual interference pressure and, thus, the stresses.

References

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2. Blessing, G. V., et al., "Ultrasonic-Shear-Wave Measurement Of Known Residual-Stress In Aluminum," *Experimental Mechanics*, **24**, 218-222, 1984.
3. P. C. Brand et al., "Possible Standard Specimens for Neutron Diffraction Residual Stress Measurements," *Neutron Scattering in Materials Science II*, ed.: D. A. Neumann et al., 1996.
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5. J. W. Dally and W. F. Riley, *Experimental Stress Analysis*, 2nd Edition, McGraw-Hill, 1978, pp. 73-75.

6. P. C. Brand et al., "Possible Standard Specimens for Neutron Diffraction Residual Stress Measurements," *Neutron Scattering in Materials Science II*, ed.: D. A. Neumann et al., 1996.