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Measurement of residual stresses in thick-walled composite pipes

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Abstract

The Sachs method of residual stress measurement allows for the determination of the residual stresses that exist through the thickness of a pipe or disk. Compared to other methods of residual stress measurement, this method is advantageous since the full state of stress can be determined in a single experiment. Additionally, these residual stresses can be determined analytically, with no need for time-consuming finite element (FE) modelling. Although the Sachs method has seen extension to pipes of cylindrical orthotropy, no solution exists for application of this technique to layered anisotropic pipes.

This work presents an extension of the Sachs method to layered anisotropic pipes, of any wall thickness. Under the assumption of linear elasticity, the response of a pipe to removal of material from the outer surface is utilised to determine the released residual loads. These loads are used to evaluate the state of stress that existed prior to any material removal. It is demonstrated that not only is this method accurate for layered anisotropic pipes, but also superior to previous extensions of Sachs' method when thick-walled orthotropic pipes are considered.

Using the current method, the residual stress state within three thick-walled filament wound glass fibre reinforced plastic (GFRP) pipes is experimentally measured. The first of these pipes is wound entirely at the industry-standard winding angle of $\pm 55^{\circ}$. The remaining two pipes each comprise layers of two separate winding angles. The first of these is wound at $\pm 65^{\circ}$ within the inner layer, and $\pm 47^{\circ}$ within the outer layer. The second layered pipe is wound at $\pm 75^{\circ}$ and $\pm 36^{\circ}$, respectively. Layers of approximately 0.3 mm thickness were incrementally ground from the outer surface of the pipes, and the corresponding strain responses measured using strain gauges bonded to the inner surfaces. The resulting residual axial, hoop and in-plane shear stress distributions all satisfy the requirement of self-equilibrium, and the radial stress distributions all vanish to zero at the inner and outer surfaces.

Using the measured data of each pipe configuration, the effect of removal of thicker layers is investigated. It is shown that for relatively simple stress states, little or no loss in the resolution of the residual stress distributions occurs. It is also demonstrated that error

analysis, based upon the standard linearised differential relationships, is highly dependant on the removed layer thickness, and thus not suited for this method of residual stress measurement. An improved method of error analysis is consequently presented, based upon a sensitivity analysis of the residual stress distributions to the level of experimental scatter in the measured strain responses. This method is used to determine the true bounds in error of the measured stress distributions of each pipe configuration.