Abstract

The difficulties encountered in mechanical testing of brittle materials create the need of developing new procedures to improve the characterization and complement the experimental information on them, which is necessary to increase components design efficiency and reliability. To meet this need, the ultrasonic tensile test was developed, widening the application of the ultrasonic testing machine employed in very high cycle fatigue tests, adapting the experimental control and data acquisition system to cause material failure in less than $200\ cycles$, allowing the acquisition of tensile strength data on brittle materials while avoiding fatigue damage.

The ultrasonic tensile test was shown to be capable of estimating the obtained ultimate strength values to those of a quasi-static test, while eliminating issues caused by mechanical fixtures and tensile testing machine alignment, also allowing a considerable increase in material risk-volume when compared to traditional test methods. Evidence that fatigue failure was indeed avoided was collected through experimental procedures that allow the analysis of facture surfaces and internal defects. The internal defect analysis, through micro-computed tomography, also allowed the definition of criteria to identify the critical defect size in each specimen, as well as general characterization of the defects population.

The ultrasonic tensile test was numerically modeled, with the specimen geometry, test parameters, and the measured displacements being applied to find the optimum material model and properties that best describe its behavior. The optimized numerical model allowed the calculation of the specimen failure strength, which could then be correlated to its critical defect size in the form of empirically formulated stress intensity factors.

The described methodology was successfully implemented through two brittle materials: alumina 99.5% and graphite R4550. Alumina specimens all failed in at most $100\ cycles$, showing a large scatter of fracture strengths, ranging from $79.5\ MPa$ to $322.6\ MPa$, as calculated from an optimized linear-elastic material model, whose elastic modulus was $371.2\ GPa$. The strengths being associated with a wider variety of imperfection types and sizes, broadly classified into pores, cracks and inclusions, with critical sizes ranging from $92\ \mu m$ to $3443\ \mu m$, consequently generating a rather complex empirical formulation for stress intensity factors.

Meanwhile, graphite specimens, having withstood at most $140\ cycles$, showed only pores as defects, with critical sizes ranging from $82\ \mu m$ to $112\ \mu m$, and fracture strengths from

$45.3\ MPa$ to $59.6\ MPa$, generating a simpler empirical formulation for stress intensity factors than that of alumina. However, graphite experimental behavior required a nonlinear material model for optimization, with slightly different elastic moduli in tension and compression, being $11.31\ GPa$ and $11.42\ GPa$, respectively, and added viscoelastic behavior, with shear relaxation modulus of $1.83\ GPa$ and decay constant of $31.38\ ms^{-1}$. The methodology application to alumina and graphite, which present pronounced differences in behavior and results, allowed its validation as a new experimental-based procedure to collect additional data on brittle materials.