Failure under complex strains and stresses: fracture and fatigue in advanced materials

Professor Filippo Berto, at the Norwegian University of Science and Technology (NTNU), has been investigating a novel method of obtaining fatigue data from advanced engineering materials. Using complex techniques which allow for examination of multiaxial loading and high temperatures, his data show promising advances in the analysis of stress testing data which will have significant impact on component design and industrial applications.

Within materials science, as is true of anything, it is important to push the limits. This is especially important when researching material fatigue. In simple terms, this focuses on understanding how much stress a material can withstand before fracturing, through repeated stress cycles under controlled levels of intensity.

THE NAME OF THE GAME
Professor Filippo Berto is an experienced researcher within the field of materials science. Having achieved the highest honour possible in his first degree from the University of Padua, Italy (one of the oldest universities in the world and consistently highly ranked), he moved to Florence to complete his PhD in mechanical design. His return to Padua was inevitable, however, as was his rapid rise from researcher to assistant professor of mechanical design and then associate professor of mechanics. Clearly a rising star in mechanical engineering, he was most recently offered the Chair of Mechanics and Materials at NTNU’s Department of Engineering Design and Materials, in recognition of his academic achievements and prolific publication portfolio.

Following exhaustive searches of the literature, Prof Berto identified key areas where fatigue data was lacking for modern engineering materials. When considering high-performance materials, high strength in high-temperature conditions is of paramount importance. Most researchers studying this area have focused on creep and low-cycle fatigue (deformation of a material and relatively low number of straining events respectively). However, because of the nature of the applications, high-cycle fatigue is a more likely real-world scenario.

APPLYING THE STRESS
To address this dearth of data on high-cycle, high-temperature fatigue in advanced engineering materials, some researchers have suggested extrapolating current room temperature data where this is shown to be experimentally possible. This led Prof Berto to examine whether Strain Energy Density (SED), an assessment which has previously
been shown to be applicable to room temperature data, could be extended to high temperature material fatigue.

The concept is that strain data for a material can be expressed as a function of volume to give values which hold true irrespective of the specimen’s geometry. Using samples of advanced engineering materials called superalloys (such as OZ125 and Inconel 718) which are designed to be used in high temperature environments such as turbine engines, as well as high grade carbon steel and advanced titanium alloys, the team tested their fatigue at high temperature to confirm that the SED data held true. Using a combination of hourglass-shaped specimens and those which had either blunt or v-shaped notches to simulate machined specimens and those which had either blunt or v-shaped notches to simulate machined

CRACKING OPEN THE DATA

The fatigue data was analysed using standard models and specific mechanical loading equations to compare how the different samples responded to the stresses applied. This allowed for the calculation of the SED which can then be plotted against the number of load cycles. This clearly demonstrates the power of the SED approach as all data points fall within a narrow band on the scatter plot. From these data, the failure energy of each material can be calculated independently of its geometry.

It also clearly showed that the approach is extendable across the range of operating temperatures for which the material is designed. Linear relationships at room temperature can also be applied to high temperature situations, as long as certain conditions are met. Examples of these conditions include remaining within elastic (returns to original shape) or plastic (bends without breaking) deformation.

STRETCHING THE REACH

The same holds true, to some extent, for Prof Berto’s work with titanium alloys. By applying different control volumes to the data, the results can be algebraically manipulated to provide comparable values for SED under conditions for torsional, tensile and multiaxial loading. This makes it possible for these varied conditions, for both notched and un-notched samples, to be simply evaluated. This synthesis of all the fatigue strength data, regardless of loading mode or specimen geometry, displays the unifying nature of the SED approach.

FROM MAN TO MACHINING

It is this ability to collapse the data into a narrow band curve that makes the SED approach preferable over current methods. The more common practice of presenting the data in terms of the stress range is unable to collapse the data into such a convenient format.

For industrial applications, this is an important advance over current methodologies. As many components are continuously refined and redesigned, having a parameter for mechanical resistance which is not dependent on the geometrical shape means that testing the component every time is no longer necessary. This will save considerable time and money, and also offer great potential within the advanced engineering materials sector.

When considering the sectors in which these materials are applied, such as the manufacture of turbine engines for aerospace and marine markets, or the further processing of metals in hot rolling and machining procedures, it is no wonder that advances such as these are required. Superalloys in turbine engines are used at 90% of their melting temperature, as the thermodynamic efficiency of these engines increase with increasing engine inlet temperature. Therefore, being able to accurately predict how these materials will behave is of paramount importance.

As these technologies progress, the tools required to design and manufacture them also need to progress at a similar rate. Prof Berto and his team are leading the way in improving the understanding of materials science, as well as providing advantageous solutions applicable to those working within the industry.

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