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Editorial

Fracture, Fatigue, and Structural Integrity of Metallic Materials and Components Undergoing Random or Variable Amplitude Loadings

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1. Introduction and Scope

When quickly reviewing engineering and industrial fields, one often discovers that a large number of metallic components and structures are subjected, in service, to random or variable amplitude loadings. The examples are many: vehicles subjected to loadings and vibrations caused by road irregularity and engine, structures exposed to wind, off-shore platforms undergoing wave-loadings, and so on.

Just like constant amplitude loadings, random and variable amplitude loadings can make fatigue cracks initiate and propagate, even up to catastrophic failures. Engineers faced with the problem of estimating the structural integrity and the fatigue strength of metallic structures, or their propensity to fracture, usually make use of theoretical or experimental approaches, or both. Counting methods (e.g., rainflow) provide information on the fatigue cycles in the load, whereas damage accumulation laws (as the celebrated Palmgren–Miner linear rule) establish how to sum up the damage of each counted cycle. In structural integrity, this is named as the "time-domain" approach. Over recent years, the "frequency-domain" approach has also received increasing and widespread use, especially with random loadings; this approach estimates fatigue life based on load statistical properties represented, in the frequency domain, by a power spectral density. Neither of the previous approaches, however, can do without the support of experimental laboratory testing, which provides a means to collect material strength data under specific loading conditions, or to verify preliminary estimations.

The purpose of this Special Issue is to collect articles aimed at providing an up-to-date overview of approaches and case studies—theoretical, numerical or experimental—on several topics in the field of fracture, fatigue strength, and the structural integrity of metallic components subjected to random or variable amplitude loadings.

2. Contributions

The Special Issue counts a total of ten articles on a variety of topics, including fracture mechanics, experimental measurement and testing, and structural integrity assessment.

Šmíd et al. [1] investigate the role of microstructure on the high-temperature fatigue strength of a polycrystalline Ni-based superalloy used for manufacturing gas turbine blades by investment casting. Alloys made by three different casting setups, with or without the application of hot hydrostatic pressing (HIP), are examined to identify the inter-relationship between the casting process, microstructure, and fatigue life. The experimental findings suggest that the fatigue life of the tested superalloy is mainly related to the porosity retained after casting and to the effect of HIP treatment, with a prominent role of porosity size; by contrast, grain size and texture have a minor effect and contribute mostly to fatigue life scatter.

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Uzun and Korsunsky [2] apply the height digital image correlation (hDIC) technique for determining the discontinuous displacement field associated with cracks on the specimen or component surface. Their paper implements graphics processing unit (GPU) parallel computing to improve the computational performance of the hDIC technique when it is applied to high-density topography data necessary to determine discontinuous displacements. The proposed hDIC technique with GPU parallel computation method is successful in identifying discontinuous edges in a 6082/HE30 aluminum alloy specimen subjected to tensile testing until failure.

Three papers [3–5] focus on fracture mechanics analysis under spectrum loadings. Jones et al. [3] present a fracture mechanics approach in the context of damage tolerant design and economic service life assessment of military helicopters—where "economic life" indicates the period during which repairing a component is more cost-effective than replacing it. The results of a computational study reveal that the Hartman–Schijve variant of the NASGRO crack growth equation—extensively validated against long crack growth data—can also model the small crack growth in the AA7075-T7351 alloy under a simplified or reduced helicopter spectrum. The role of statistical variability in crack growth histories is also pointed out.

Related to small-crack growth under spectrum loading is also the article by Newman [4], which deals with the "rainflow-on-the-fly" subroutine implemented in FASTRAN, an advanced nonlinear crack closure-based numerical code for fatigue life prediction. Laboratory fatigue tests conducted on compact and single-edge-notch-bend specimens made of a 9310 steel are used to validate the "rainflow-on-the-fly" subroutine under several specially designed variable-amplitude loading sequences. Results indicate that the damage is a function of load history and that the usual rainflow counting method would not be able to capture the crack-growth damage correctly, unless the method is updated during crack-growth history.

Boljanović and Carpinteri [5] develop a novel computation framework to investigate the effect of overloads (e.g., retardation effect) on the crack growth and fatigue life of cracked plates. The study considers the Huang–Moan crack growth model to account for R-ratio effect, and includes crack retardation through Wheeler's model. As a case study, the paper analyzes a 6061-T6 aluminum plate with edge crack subjected to several types of constant amplitude loading characterized by different R and overload ratios; besides axial loading, inclined loading corresponding to mixed I+II mode loading is also considered. The paper concludes that a higher overload ratio induces more pronounced retardation effects, with an increase in fatigue life. Other conclusions are that retardation effects due to overloading also depend upon overload crack length and loading direction.

Another study related to fracture mechanics is that by Yang et al. [6]. It applies an elastoplastic fracture analysis by the extended finite element method (XFEM) to study how thermal shock in repair welding affects the cracking behavior in the heat affected zone (HAZ) of a welded joint. A two-dimensional model with initial crack is used for simulating the thermo-mechanical shock during repair welding of a butt weld in P91 steel. In XFEM simulation, the nonlinear damage evolution (elastoplastic fracture) is represented by a cohesive crack model. This model allows for a comprehensive understanding of the evolution of both thermo-mechanical stress and damage in repair welding, and how they relate to crack propagation.

The topic of structural integrity assessment of engineering components is discussed in four papers [7–10]. Among them, the literature review of Marques et al. [7] surveys the various systems for high-cycle fatigue testing with uniaxial and multiaxial random loadings. Testing systems are compared in terms of several characteristics, as for example type of machine (servo-hydraulic, shakers), specimen geometry, relationship between the number of loading inputs applied to the specimen and the resulting local state of stress. A classification is proposed to allow the analogies, differences, advantages and possible limitations of every testing system to be emphasized.

Another review article is the work by Dirlik and Benasciutti [8]. Not only does it provide a general introduction to the frequency domain approach (spectral methods) used for assessing fatigue life directly from the power spectral density of the random loading, but it also scrutinizes in more detail two methods—Dirlik method and TB method–that are considered the most accurate by many scholars. Other than explaining the historical background that led to the development of these two methods, the paper also emphasizes their better performance by summarizing the outcomes of numerical and experimental comparative studies from the literature. It finally concludes with some recommendations for the use of spectral methods.

The paper by Marques et al. [9] is, instead, focused on evaluating the sampling variability of the fatigue damage computed in one single nonstationary time history. Damage variability is tackled by means of confidence intervals, which are constructed from the damage values of disjoint segments and blocks into which the nonstationary time history is subdivided. As a case study, the paper analyzes the strain records measured in a wheel of a telescopic handler industrial vehicle. Interesting is also a preliminary screening in which strain records are examined by two methods (short-time Fourier transform, run test) to verify whether they fulfill the hypotheses of the proposed confidence interval.

The interesting study of Pisani et al. [10] deals with the structural integrity and fatigue life estimation of two types of lattice structures in AlSi10Mg alloy (namely, face-centered cubic and diamond lattice-based), fabricated by laser powder bed fusion (L-PBF) and tested under random fatigue loadings. The structural integrity of lattice structures is estimated by a finite element model, validated on sweep dynamic tests and employed to determine the stress levels within the lattice structures when subjected to the input accelerations applied in experiments. Fatigue failure is identified by acceleration change or frequency drop in the structure. Predicted and experimental results are shown to agree quite well.

3. Conclusions and Outlook

With its ten published papers, this Special Issue covers various topics related to the fatigue strength and structural integrity assessment of engineering components subjected to variable amplitude or random loadings. Theoretical, numerical, and experimental approaches are presented, both as more methodological analyses and as case studies. We believe, as Guest Editors, that the quality and variety of the collected articles can contribute to the advancement of future research in this highly challenging research field.

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