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Fatigue shape optimization of notched machine parts made of metallic or two-phase composite materials

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ABSTRACT

Advanced composite materials can be classified into three main categories depending on the configurations of the embedding materials: (1) continuous fiber-reinforced composites, which consist of reinforcing continuous fibers in a matrix at certain orientations, or randomly oriented, (2) discontinuously reinforced composites, which are formed by reinforcing discontinuous fibers or inclusions in a matrix, and (3) molecular composites. Discontinuously reinforced composites include: (1) particulate fiber-reinforced composites, (2) chopped fiber-reinforced composites, and (3) whiskers- reinforced composites.

Particulate metal matrix composites (PMMC) are increasingly finding applications in the aerospace, automotive, sports equipment, and electronic industries. In contract to the their long fiber counterparts, PMMC generally have isotropic properties and are much easier to produce and machine by standard methods.

When machine parts are subjected to cyclic loadings, cracks and therefore failures generally initiate at notches or at reinforcement-matrix interfaces. Although it can be assumed that the bulk of a PMMC component remain elastic, the stresses in the metallic matrix in the vicinity of these concentrations may exceed the yield stress of the material.

There are many mechanical failure modes of materials (metals or composites). Excessive deformation or yielding and progressive damage are probably the most commonly studied failure modes. The mechanical components are usually subjected to time variable and in particular to cyclically varying stresses. The fracture and fatigue phenomena are induced by these stresses and are observed at geometrical discontinuities, which are called notches.

There are three stages in a fatigue failure of notched machine or structural elements: fatigue crack initiation, fatigue crack propagation and final fracture. Hence, a closely related problem is that of rational design of notch shape in order to maximize the critical number of cycles corresponding to crack initiation (life to the formation of a crack on the order 0.25-0.5 mm) and the crack propagation (life from this existing crack to fracture). The elastic stress concentration factor and elastic-plastic notch root strain are often required for crack initiation analysis. On other hand, in the prediction of notch crack growth, the stress intensity factor plays very important role. The crack growth per cycle (Paris's or Wheeler laws, for instance) is proportional to the range of the stress intensity factor. There are different ways to increase a

number of cycles to failure, among others, by varying the shape of a boundary of the machine component.

The shape optimization of notched machine parts with respect to low cycle fatigue is discussed in this paper. The optimization task is: for specified boundary conditions, external loading and material properties find a such shape of notched part for which the minimal number of cycles to failure reaches the maximum value at some critical BEM points (points where number of cycles in initiation stage is evaluated). This is the well known max-min approach with discontinuous objective function. Using the bound formulation the problem is converted to the simple max problem, with linear objective function [3].

The low cycle fatigue analysis (the local strain approach) needs some plasticity models for describing cyclic material properties: a stress-strain relation, which describes the uniaxial loading behaviour of material, a yield criterion, which distinguishes between multiaxial elastic and elastic-plastic behaviour, a flow rule relating the stresses to the corresponding strain increments, and a hardening rule describing the changes of the yield criterion during the deformation process. The multisurface Mróz fatigue plasticity model and Neuberlike corrections rules to compute the actual strain-stress field in the notch zone are the main components of the fatigue analysis module. It was shown in literature [2] that Mróz model can be adopted for instance to particulate metal matrix composites using the modified generalized multiaxial Neuber and the modified generalized multiaxial equivalent strain energy density (Molski-Glinka or ESED method) [1]. It is assumed for particulate metal matrix composites that for an increment in load on the composite system, the corresponding increment in the constituents-weighted total strain energy (specific strain energy in ESED method) around the notch contour in an elastic-plastic body can be specified in terms of the corresponding elastic stress and strain components. [2]. For homogeneous (metallic) materials this relation reduces to the incremental homogeneous form of Neuber or ESED method [1].

To solve so stated optimization problem we use (after constraints linearization) the Sequential Linear Programming method with ‘move limits’ enhanced by the CAGD method (Bezier curves, superellipses) for shape definition of components to be optimized, the fatigue analysis module and the linear BEM used in Neuberlike methods.

Numerical examples showing different possibilities of a significant enhancement of fatigue life are presented.

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