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CYCLIC PLASTICITY UNDER MACROSCOPICALLY ELASTIC STRESS CONDITION

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ABSTRACT

The extended elastoplastic constitutive equation is formulated by introducing both the elastic boundary and the damage concepts for cyclic plasticity phenomena under the macroscopically elastic stress condition. These concepts are introduced to describe a pure elastic responses and a progressive degradation of stiffness of materials. The extended model is applied for metals obeying not only isotropic but also kinematic hardening law, and the mechanical responses under cyclic loading condition are examined in detail.

KEY WORDS: Fatigue; Cyclic Plasticity; Ratcheting; Cyclic Creep; Persistent Slip Band.

INTRODUCTION

The lifetime prediction of structures is one of a dominant factor to achieve an optimum design. Also, it is well known that cyclic loads produce failure of structural parts for values of stress lower than those obtained in monotonic tests. This phenomenon is so-called fatigue and is the main cause of failure of machine parts in service. Classical approaches to study these phenomena involve the characterization of total fatigue life to failure by using the stress amplitude-life (S-N) curves, while some studies are based on the fracture mechanics (c.f. Suresh, 1998; Toyosada et al., 2003). On the other hand, continuum description of cyclic plasticity deformation during the fatigue phenomena is also useful for its understanding.

In order to simulate these mechanical fatigue phenomena represented by cyclic plasticity such as ratcheting the plastic stretching within a yield surface has to be described, whilst the plastic strain is induced remarkably as the stress approaches the yield stress. The traditional plastic constitutive equation, however, is capable of describing deformation behavior for the stress path only near the monotonic/proportional loading, since its inside of the yield surface is assumed to be an elastic state. Therefore, various constitutive models, which are categorized in the framework of unconventional plasticity (Drucker, 1988) premising that an interior of the yield surface is not the elastic domain, have been proposed up to the present. Among them (Mroz, 1967; Iwan, 1967; Dafalias and Herrmann, 1980; Dafalias and Popov, 1975; Hashiguchi, 1980, 1989) the subloading surface model (Hashiguchi, 1989) describing a smooth elastic-plastic transition has a mathematical structure applicable to the description of deformation behavior in an arbitrary loading (including unloading and reloading) process of materials with an arbitrary smooth yield surface. The model fulfills the basic mechanical requirements (Hashiguchi, 1983a, b), i.e. the continuity condition, the smoothness condition, the work rate-stiffness relaxation and the Masing effect. Furthermore, in order to describe the vertex (tangent) effect, causing the dependence of not only the magnitude but also the direction of the inelastic stretching on the stress rate, the extended vertex type of constitutive model has been proposed (Hashiguchi and Tsutsumi, 2001; Tsutsumi et al., 2002; Tsutsumi and Hashiguchi, 2005). It has been verified that a smooth elastic-plastic transition can be well described for many kinds of soils (Hashiguchi and Chen, 1998; Hashiguchi et al., 2002; Hashiguchi and Tsutsumi, 2003; Tsutsumi and Hashiguchi, 2005). The validity of these models was also verified for monotonic and low cycle deformation behavior of metals (Hashiguchi and Yoshimaru, 1995; Hashiguchi and Protasov, 2001; Tsutsumi et al., 2005, 2006).

On the other hand, it is well known for many metallic materials that a purely elastic response, such as Hooke's type, would be observed under a particular lower state of stress, so-called proportional or elastic limit, whilst they also exhibit a smooth elastic-plastic transition with increase of stress to the dominant yielding state. Also it should be noted the experimental evidence that fretting fatigue failure could occur in the case of variable amplitude loading condition even when every stress amplitudes was kept below the fretting fatigue limit diagram (Endo et al., 2005). To describe these fatigue phenomena, appropriate description of deformation behavior for cyclic stresses lower than a yield stress is required.

In this study, to propose the unconventional plasticity model describing the cyclic loading behavior for the stress cycles lower than the yield stress and the damage effect caused by accumulation of plastic strain, the subloading surface model is extended by incorporating the concepts of the elastic boundary and the damage together with the consistent material functions. The proposed model exhibits a purely elastic response under the particular state of stress and a smooth elastic-plastic transition keeping the mechanical features of the subloading surface model. The mechanical responses of the model are examined to the cyclic loading condition.