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An influence of cyclic loading on the form of constitutive relationship for DP500 steel

W. Moćko [a,b], P. Grzywna [b,*], Z.L. Kowalewski [b], J. Radziejewska [c]

[a] Motor Transport Institute, Jagiellońska 80, 03-301 Warsaw, Poland
[b] Institute of Fundamental Technological Research, Pawińskiego 5B, 02-106 Warsaw, Poland
[c] Warsaw University of Technology, Narbutta 85, 02-524 Warsaw, Poland

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ABSTRACT

Fatigue loading induces a microstructure evolution leading to the change of macroscopically observed mechanical behavior of a dual phase DP500 steel. It was assumed that stress–strain characteristic of a pre-fatigued material may be determined using constitutive equation taking into account damage parameter. To estimate development of the fatigue damage in specimen a variation of the inelastic strain component was applied.
The flat "dog-bone" specimens were initially loaded using stress controlled cycles. When the strain reached a given value the fatigue process was stopped. Subsequently, the specimens with introduced fatigue damage were subjected to tensile tests. Next, the Johnson-Cook's constitutive equation was calibrated separately for each pre-fatigue case. Finally, a new constitutive relationship, based on the Johnson-Cook's model was proposed. It reflects the hardening and softening effects by taking into account both a change in the dislocation structure and development of fatigue microdamage. Proposed model shows a very good agreement with experimental data.

1. Introduction

From engineering point of view, an influence of fatigue cyclic loading on the change of mechanical properties of material and construction is a crucial issue still requiring intensive investigations. The most modern constructions (including energy-absorbing elements for the automotive industry applications) are designed with the lowest weight in mind, that is caused by an intention of fuel consumption decrease and improve of the broadly understood performance of the designed vehicles. Such an approach leads to constructions that are imposing to the loads variations of high magnitude.

The contemporary fatigue study still constitutes a current issue and is the subject of analysis being conducted at numerous global research centers [1]. The basic objective of these studies is to determine the number of cycles leading to failure [2,3]. In addition, the research dealing with determination of the microstructural mechanisms leading to fatigue degradation of the material is being conducted [4]. Furthermore, the study objective is to determine an influence of cyclic loadings on the mechanical properties [5] and elaborate an efficient measurement methodology of fatigue damage [6–10].

Among many existing methods for fatigue degradation level assessment [9] one can indicate the measurement of strain components constituting a response of the material into the given elastic loading [11]. Depending on the stress amplitude and microstructure of the material, the fatigue damage process may occur due to adequate mechanisms. It might be ratcheting on the one hand, that determines a level of mean strain change in the subsequent cycles, and cyclic plasticity on the other, which dominates at high magnitudes of stress amplitude and reflects an increase of the inelastic strain as well as variation of the hysteresis loop width. It may be assumed, that for elastic-plastic material in the absence of any structural defect no plastic deformation occurs if the material is loaded in the elastic range. In fact, all structural steels exhibit small inelastic deformation even if they work in the elastic range. This can be attributed to the internal friction that takes place during the elastic deformation of most metallic alloys. If a microcrack forms, stress concentration around the crack tip occurs, leading to plastic zone formation. This phenomenon can be observed in the macroscopic scale as a change of the stress–strain hysteresis loop width and its position [10,12].

A width change of the hysteresis loop as a function of the cycle number for the A336GR5 steel is presented in Fig. 1 [13]. This feature was identified for five specimens tested under different stress amplitudes, what is highlighted by different shape and color of the testing points. Two additional, oblique broken lines divide the area of the graph into three ranges. In the first range on the left side, no development of damage under the effect of cyclic loadings is observed. The second range in the middle represents an initiation and stable development of fatigue damage in which the value of damage parameter calculated on the basis of inelastic strain components of subsequent hysteresis loops gradually increases. The third range on the right side of the second

* Corresponding author.
E-mail address: pgrzywna@ippt.pan.pl (P. Grzywna).

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