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ON ESTIMATION OF BASQUIN-COFFIN-MANSON FATIGUE PARAMETERS OF LOW-ALLOY STEEL AISI4140

Robert Basan
Marina Franulović
Božidar Križan
Faculty of Engineering, University of Rijeka
Vukovarska 58, HR-51000 Rijeka
Croatia

ABSTRACT
Strain life approach and methodology is widely used in product development for calculation of number of load reversals $2N_f$ to crack initiation. Since in early design phases experimentally determined material parameters necessary for performing lifetime calculations are rarely available, methods for their estimation from monotonic material properties are usually implemented. Most of the existing methods for the prediction of strain life parameters are based on direct and independent correlation of experimentally determined strain life parameters with one or more monotonic properties of the material. Certain methods even suggest use of constant values for these fatigue parameters. In strain life approach the fatigue durability of the material is defined by $\Delta\varepsilon/2$ - $2N_f$ relationship. As an alternative to the existing approach and methods, it is suggested that estimation of strain life fatigue parameters should be based on analysis of actual strain life data. Instead of individual fatigue parameters, $\Delta\varepsilon/2$ - $2N_f$ relations are correlated with chosen monotonic property so that, unlike in existing methods, fatigue parameters are not treated independently. New Basquin-Coffin-Manson parameters determined in such a manner can then be correlated with and estimated from chosen monotonic property. Values of strain life fatigue parameters have been estimated for typical high-strength low-alloy steels AISI4140 using both proposed approach and hardness method proposed in literature. Evaluation and comparison of fatigue lives calculated for different values of strain amplitude confirmed validity and good predictive capabilities of method based on new approach.
Keywords: strain life approach, fatigue parameters, estimation, monotonic properties

1. INTRODUCTION

In order to shorten product development time and cut down expenses, simulations and analyses of product CAD/CAE numerical models are increasingly being performed during early stages of product development. In this process, for the calculation of parts' and products' fatigue lifetime, strain life approach and methodology associated with it are often implemented due to their practicality and existence of extensive knowledge base [1]. Although most accurate, experiment-based determination of required Basquin-Coffin-Manson fatigue parameters [2] is rarely used in these early stages of product design, because of long duration and high costs of necessary cyclic experiments. Since monotonic experiments are simple and inexpensive, number of methods for estimation of strain life fatigue parameters from readily available monotonic material properties are proposed in the literature. They are usually implemented in early stages of product development and it can be presumed that enhancing accuracy of these estimation methods could contribute to product improvement already at the beginning of its development.

2. EXISTING AND PROPOSED METHODOLOGY OF FATIGUE PARAMETERS ESTIMATION

In strain life approach, one of the basic premises is correlation of strain amplitude $\Delta\varepsilon/2$ and number of load reversals to crack initiation or failure, $2N_f$ [1]. This relation itself is defined with well-known Basquin-Coffin-Manson's expression:

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c \qquad \text{... (1)}$$

Number of methods for estimation of strain life fatigue parameters from various monotonic material properties are proposed in literature [3,4,5,6,7,8,9]. After performing extensive literature review and analysis of existing estimation methods, it was reported that to a different extent, following features seem to be common to all existing methods [10,11]:

- establishment of a direct and independent relationship between the chosen monotonic property (or properties) and experimentally obtained fatigue parameters (this is mostly true for fatigue strength coefficient σ_f' and fatigue ductility coefficient ε_f'),
- assignment of constant values to certain fatigue parameters, mostly due to the lack of satisfactory correlation among them and chosen monotonic properties (this especially applies to fatigue strength exponent b and fatigue ductility exponent c),
- disregard of the differences in strain life behavior of certain groups of materials (Uniform material law [6] and Medians method [9]) seem to be exceptions).

Establishing these shortcomings in existing methods and in the approach to the estimation of strain-life fatigue parameters on which they are based, pointed to the possibility of their improvement. Hence, in [10,11] a novel approach to the estimation of strain life parameters from monotonic properties was proposed. The principle and the main point of this new approach is that instead of directly and independently correlating individual fatigue and monotonic parameters, estimation of fatigue parameters should be based on the analysis of actual, strain life data i.e. $\Delta\varepsilon/2$-$2N_f$ relationships (1) and their relations with the selected monotonic property of the material.

The estimation procedure development itself can be summarized as follows: based on experimentally obtained fatigue parameters, relationships between the chosen monotonic parameter i.e. Brinell hardness HB and $\Delta\varepsilon/2$–$2N_f$ relations have been identified and established. From these relationships, new values of fatigue parameters σ_f', b, ε_f' and c were determined for each of the Brinell hardness values. Subsequently, functions based on which values of fatigue parameters can be calculated from hardness, $\sigma_f'/E = \sigma_f'/E\ (HB)$, $b = b\ (HB)$, $\varepsilon_f' = \varepsilon_f'\ (HB)$ and $c = c\ (HB)$ have been developed. One of the key advantages of this new approach is that the fatigue parameters are not estimated individually, i.e. independently from one another.

3. COMPARISON OF PROPOSED AND REPRESENTATIVE EXISTING METHOD

Described methodology proposed in [10,11] was applied for estimation of Basquin-Coffin-Manson fatigue parameters for total of 32 normalized and quenched and tempered high-strength low-alloy steels AISI4140 (42CrMo4) for which experimental data was obtained from literature [12,13,14,15,16]. Sole monotonic parameter used in estimation procedure was Brinell hardness HB – a common and easily obtainable material parameter. In [10], fatigue parameters of these materials were also estimated using hardness method [8] which for estimation requires only Brinell hardness of the material HB and its modulus of elasticity E.

For experimental and estimated sets of fatigue parameters of all materials, numbers of load reversals to crack initiation $2N_f$ were calculated for 10 different values of total strain amplitude ($\Delta\varepsilon/2$ = 0,15 %, 0,2 %, 0,25 %, 0,35 %, 0,5 %, 0,7 %, 0,9 %, 1,2 %, 1,5 % and 2,0 %. Number of criteria were proposed in [17] to facilitate validation of individual estimation method as well as its comparison with others. These criteria, conventional error criterion $E_f(s = 3)$, goodness of fit criterion for individual materials $(E_a)_i$, goodness of fit criterion for all materials $(E_a)_{tot}$ and average value of all criteria $\bar{E}$ have been extensively used in different comparisons and verifications of estimation methods reported in literature. Values of these criteria calculated for determined numbers of load reversals, $2N_{f,exp}$ and $2N_{f,est}$ are given in diagrams in Figures 1 and 2.

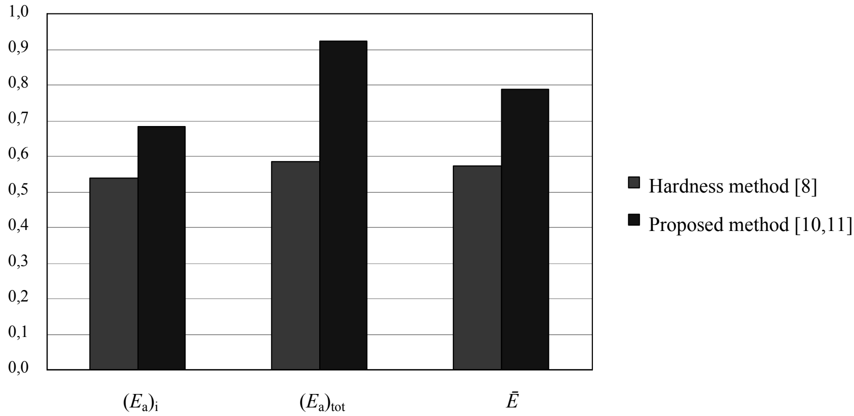

Figure 1. Values of criteria $(E_a)_i$, $(E_a)_{tot}$ and $\bar{E}$ calculated for Hardness and proposed method.

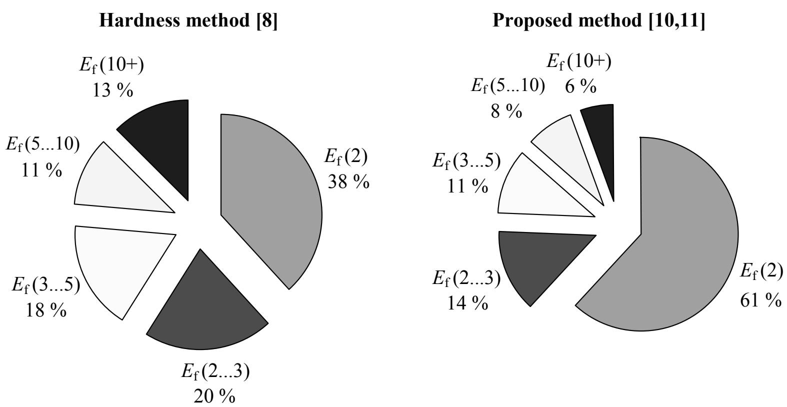

Figure 2. Values of criteria $E_f(s = 2, 2..3, 3..5, 5..10, 10+)$ calculated for Hardness and proposed method.

Values of all criteria calculated based on the numbers $2N_f$ obtained with proposed method are noticeably higher than values determined for the results of hardness method. The fact that particularly needs to be pointed out is the value of $E_f(s = 2)$ which amounts to 0,38 (38 %) for the hardness method and 0,61 (61 %) for the proposed method. This means that almost twice as much lifetime data falls within scatterband with factor of 2 which is quite a significant improvement.

Although obtained results seem to be quite promising, it must be noted that they were obtained for the relatively limited material dataset and that dataset which served for method development is the same as the one used for its validation. Further analyses must be performed on extended datasets and comparisons with more estimations must be performed before any definitive conclusion regarding fitness of the newly proposed approach and estimation method can be made.

4. CONCLUSION

In this paper, newly proposed approach to estimation of Basquin-Coffin-Manson fatigue parameters from hardness was further analysed and in a preliminary manner compared to already established hardness method. Based on analysis of strain life behavior of 32 differently heat treated steels AISI4140 and almost identical AISI 4142, apparently good correlation was ascertained between the logarithm of number of load reversals $\log(2N_f)$ and Brinell hardness HB over a wide range of total strain amplitudes $\Delta\varepsilon/2$. This served as a basis for estimation of fatigue parameters from Brinell hardness both using proposed approach and existing hardness method. Fatigue lives which were calculated using experimental and estimated values of fatigue parameters served as a basis for calculation of values of already established evaluation and comparison criteria.

Fatigue lives calculated using estimated values of fatigue parameters are found to be in very good agreement with those calculated using experimentally obtained fatigue parameters. Furthermore, determined values of comparison criteria are significantly higher for proposed method than those calculated for the hardness method. Dataset used in the development and analysis is rather limited and will be expanded in further work so that further verifications can be done using independent data. However, inspite of these limitations, obtained results seem to confirm general validity of the proposed approach and that its predictive capabilities seem to be potentially very good and quite promising.

5. CONCLUSION

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