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Fatigue behavior of innovative alloys at elevated temperature

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Abstract

The present paper summarizes the results from uniaxial-tension stress-controlled fatigue tests performed at different temperatures up to 650°C on Cu-Be and 40CrMoV13.9 specimens. Two geometries are considered: hourglass shaped (both materials), plates weakened by a central hole (Cu-Be alloy). The motivation of the present work is that, at the best of authors' knowledge, only a limited number of works on these alloys under high-temperature fatigue are available in the literature and no results deal with notched components.
In the present contribution, after a brief review of the recent papers, material properties and experimental procedure are described. The new data from un-notched and notched specimens are summarized in the corresponding fatigue curves. The Cu-Be specimens fatigue data are re-analysed in terms of the mean value of the Strain Energy Density (SED). The approach, successfully used by the same authors to summarise fatigue data from notched specimens made of different materials tested at room temperature, is extended here for the first time to high-temperature fatigue. In the plates with central holes the SED is evaluated over a finite size control volume surrounding the highly stressed zone at the hole edge. A value of the radius equal to 0.6 mm seems to be appropriate to summarize all fatigue data in a quite narrow scatter-band. Thanks to the SED approach it is possible to summarise in a single scatter-band all the fatigue data, independent of the specimen geometry.

Keywords: high-temperature fatigue; copper-cobalt-beryllium alloy; fatigue strength; notched specimens; 40CrMoV.

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1. Introduction

In recent years, the interest on fatigue assessment of steels and different alloys at high temperature has increased continuously. In fact, high-temperature applications have become ever more important in different engineering fields, e.g. turbine blades of jet engine, nuclear power plant, molds for the continuous casting of steel, hot rolling of metals. Among the traditional alloys available for this kind of applications, Cu-Be alloys surely stand out and fall within the most interesting materials suitable not only for high-temperature applications, thanks to their excellent compromise between thermal conductivity and mechanical properties over a wide range of temperatures (Lu et al. 2006, Caron 2001, Davis 2001).

At the current state of the art, relatively few papers are available in the literature dealing with the fatigue strength of copper alloys (both at room and high-temperature). Worth mentioning is a contribution by Li et al. (2004), who reviewed some expressions able to quantify the thermal creep and fatigue life time of various copper alloys, including Cu-Ni-Be alloy. In another newsworthy paper by Kwofie (2006), the cyclic creep behavior of copper, which usually accompanies low cycle fatigue under tensile mean stress, was investigated. While the fatigue strength problem at high temperature has been investigated in a number of papers and books such as Prasad et al. (2013), Ko and Kim (2012), Liu et al. (2013), no papers discuss the fatigue behavior at elevated temperature of notched specimens made of Cu-Be alloys. Only a recent work by Berto et al. (2013) presents a complete characterization of this alloy at high temperature, considering smooth and notched specimens.

Another material which is commonly employed for hot-rolling of metals is 40CrMoV13.9 steel. It is usually subjected to a combination of mechanical and thermal loadings. High temperature fatigue strength of different steels has been studied in the literature. In Krukemyer et al. (1994) an experimental investigation was conducted on 22Cr-20Ni-18Co-Fe alloy at 871 °C using un-notched specimens. Cyclic deformation properties of the tested material were obtained from the data, and three fatigue models were applied. Dealing with the 1.25Cr0.5Mo steel, high-temperature stress controlled tests were carried out at by Fan et al. (2007) at different loading conditions to investigate the fatigue–creep interaction. Fully reversed axial fatigue tests have been performed by Uematsu et al. (2008) by testing smooth specimens of 18Cr–2Mo ferritic stainless steel (type 444) at room temperature, 673 K and 773 K in laboratory air, with the aim to investigate the effect of temperature on high cycle fatigue behavior.

At the best of authors knowledge the recent and past literature lacks of data from plain and notched specimens made of 40CrMoV13.9 and Cu-Be at high temperature. To fill this gap, the present paper investigates the behavior of these alloys at temperatures ranging from room temperature up to 650°C. Two geometries are considered: hourglass shaped (both materials), plates weakened by a central hole (Cu-Be alloy).

The paper describes the experimental procedure adopted during the tests. The obtained fatigue curves are discussed with emphasis on the reduction of stress concentration effects. Finally, the fatigue data of Cu-Be alloy are re-analyzed in terms of the averaged Strain Energy Density approach, applied to a control volume surrounding the most stressed region at the notch edge.

2. Experimental details

2.1. Material

The Cu-Be alloy under investigation belongs to high conductivity class usually used for production of shells for hot rolling. The spark emission spectroscopy analysis gave the composition reported in Table 1. In the same table a comparison between the present alloy and the copper alloy UNS Number C17410 is carried out. This is a specific alloy belonging to the above mentioned high conductivity class but characterized by a very low concentration of alloying elements. However it is the most close to the material under investigation in the present paper. The tensile properties of the material at 650°C, obtained through tensile tests on un-notched specimens, are listed in Table 2.

The 40CrMoV13.9 has the chemical composition shown in Table 3 (mass %). The data-sheet reports the following mechanical properties at room temperature (25°C): elastic modulus E equal to 206 GPa, tensile strength equal to 1158 MPa and a yield strength of 1034 MPa with a percent of elongation of 15%.