Materials and Design 32 (2011) 1101–1107

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Effect of mean stress on fatigue properties of 1800 MPa-class spring steels

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ARTICLE INFO

Article history:
Received 5 July 2010
Accepted 4 November 2010
Available online 11 November 2010

Keywords:
A. Ferrous metals and alloys
E. Fatigue
F. Defects

ABSTRACT

Fatigue tests were conducted for 1800 MPa-class spring steels at various stress ratios. For comparison, similar fatigue tests were conducted for conventional steels whose tensile strength was lower than 1200 MPa. The spring steels exhibited fish-eye fractures, and the origins of these fractures were oxide, TiN and the matrix itself. In contrast, the conventional steels never exhibited fish-eye fractures. The fatigue strength of these steels decreased monotonously as the stress ratio increased, when the fatigue strength was evaluated in terms of stress amplitude. However, the fatigue strength degradation was less than that expected from a modified-Goodman line, and the best fit line was obtained by connecting the fatigue limit at zero mean stress to true fracture strength instead of tensile strength. This research also reviewed application of a power low to the stress ratio effect evaluation. In these results, the difference between the spring and conventional steels was negligible.

1. Introduction

The demand for high-strength steels is growing along with the development of lighter and faster vehicles. When the steel strength is enhanced, a major problem arises, namely fish-eye fractures (internal fractures) caused by an inclusion [1,2]. When a fish-eye fracture occurs, the conventional fatigue limit disappears, and the fatigue strength in the long life region decreases [3,4]. Consequently, fatigue strength is not so improved as to be expected from enhanced steel strength in this case. This type of fish-eye fracture problem has been actively studied in recent years [5–8]. As the results of these researches, it is well known today that following factors influence the fatigue strength in case of fish-eye fracture: (1) inclusion distribution, (2) residual stress and loading type, (3) specimen size and dimensions and (4) number of specimen.

Our research group has also been working on the problem of fish-eye fracture, and for example, already pointed out that high-strength steels whose tensile strength exceeds 1200 MPa begin to exhibit fish-eye fractures [9]. Our past researches investigated the effects of inclusion size and type on the fish-eye fracture properties [10–12]. The origin of fish-eye fractures is oxide inclusions such as Al_2O_3 in most cases. However, when steels are super-cleaned or subject to inclusion control, TiN inclusions and the matrix itself (matrix cracking) [10] also cause fish-eye fracture. Through these researches, it was found that the inclusion size is a primary factor influencing the fish-eye fracture properties, while the inclusion type also has a secondary effect. Concerning the loading type, several types of fatigue testing were used to conduct fatigue tests up to gigacycle regions, i.e., rotating bending, axial loading and ultrasonic fatigue testings. As the results, ultrasonic fatigue testing showed good agreements with other types of fatigue testings on condition where fish-eye fracture occurred [4,13]. In comparison between rotating bending and axial loading fatigue testings, these two types of fatigue testings showed good agreements when risk volume conditions were equalized [4]. The risk volume is a measure of the size of the region in which high stress acts in the fatigue test specimen, so it corresponds to an effective size of the specimen [1]. When the specimen sizes are equal between rotating bending and axial loading fatigue testings, the risk volume of rotating bending is smaller due to stress gradient, leading to higher fatigue strength. The risk volume effect was more clearly demonstrated in a later research [14]. This later research conducted ultrasonic fatigue testing using different sizes of specimens, and demonstrated the large size effect. Moreover, it was found that the size effect closely related to distribution of Al_2O_3 inclusions.

On the other hand, such research on fish-eye fractures is often conducted with the typical mean stress set at zero (stress ratio $R = -1$) since there are abundant data for comparison, and this condition allows us to perform an evaluation with a simple rotating bending test. However, the stress actually imposed on mechanical parts is greater when $R \neq -1$ than when $R = -1$. Although the effect of the stress ratio (mean stress) is practically important as described above, little research has yet been reported on fish-eye fractures [15–17].

The effect of the stress ratio is generally evaluated with a modified Goodman diagram or a Gerber diagram [18]. Of these, the modified Goodman diagram is simple to use, produces a safe-side evaluation, and is therefore very often used in practice. One of the

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doi:10.1016/j.matdes.2010.11.011