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Experimental Investigation of Fatigue Damage Development Using Microhardness and Chord Modulus Variation Methods in Stainless Steel 316L

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ABSTRACT: In this research, an experimental study of the fatigue damage growth process has been investigated for 316L stainless steel. For this purpose, using ASTM E466 fatigue special standard, testing samples with rectangular cross-section, has been drawn and prepared. The mechanical properties of the material were extracted through the test. Uniaxial low cycle fatigue has been performed at similar stress amplitudes, similar frequency, and various loading cycles. After carrying out fatigue tests, in order to derivation damage development process, microhardness and loading-unloading tests –deriving relation of microhardness and chord modulus with strain- has been performed too. Experimental tests have been carried out under environmental conditions. The Damage development process was achieved, using results of fatigue, loading-unloading, and microhardness tests. A method for estimating damage is proposed in this research. In the end, the results of the methods of the chord modulus, microhardness and purposed are compared with each other. The damage growth process of the purposed method has a good fit with the method of chord modulus. The obtained critical damage was 0.38 by using the chord modulus method and 0.41, by microhardness.

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1- Introduction

The growth of microcracks and cavities, called mechanical damage in the material, leads to a weakening of the mechanical properties of the material. Fatigue is a type of damage that can lead to sudden fracturing of the parts and cause irreparable harm. Each structure may be damaged due to the use of repetitive loads, or the damage to the previous one may grow. If the growth rate of damage in a piece is estimated at different loading, the design will be more accurate and more efficient. In 1958, Kachanov [1] founded the basis of the mechanism of damage mechanics. Lemaitre [2] showed that the modulus of elasticity decreases with damage growth. Accordingly, he provided a model for assessing damage growth. In collaboration with Dufaily [3], he introduced the evaluation of the microhardness during plastic deformation as a suitable method for assessing the damage growth. Tai [4] introduced the evaluation of the microhardness during plastic deformation as a suitable method for assessing the damage growth. Ye and Wang [5] provided a method for evaluating fatigue damage using hardness. Mkaddem et al. [6] evaluated the growth of damage under axial loading in different materials. They used the hardness method to assess the damage. Guelorget et al. [7] examined the hardening process in the tensile sample. Ganjiani [8] used microhardness test to assess damage in aluminum in 2024. Between the results of the simulation and the experimental results, an appropriate match was observed. Cai and Ma [9] used variations in the chord modulus to extract the damage. The purpose of this study was to investigate damage growth in low-carbon stainless steel 316 under low cycle fatigue loading. For this purpose, the micro hardness and chord modulus methods and a proposed method have been used.

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2- Experimental Test Procedure

Test specimens should be loaded in such a way that they are very similar to the actual conditions of the material being loaded in the industrial equipment. Apart from this, these steps should be selected in such a way that the initial stage of the measurement of damage can be easily accomplished. At first, fatigue tests are performed. Specimens of fatigue loading are prepared in a number of different cycles. By using microhardness, chord modulus and the proposed method, the growth of fatigue damage is extracted based on the number of loading cycles.

2- 1- Fatigue Test

The specimens were cut in accordance with the dimensions of the standard fatigue test and cut off by lasers with carbon dioxide gas. Grading of specimens was performed to determine the deformation rate at different points of the specimens. Grading was done by creating circles 2.5 mm in diameter on the surface. In order to determine the fatigue life, 5 specimens were subjected to cyclic loading to fracture. Fatigue test with a constant frequency of 3 Hz and according to ASTM E466 standard using Instron 8502. Fatigue tests were performed under stress control. Fatigue loading is defined as stretch-stretching, with a range of 0 to 600 MPa. The fatigue life of 5815 cycles was achieved. specimens of fatigue testing are provided in different cycles. The relationship between plastic deformation and the number of fatigue load cycles is derived from image processing.

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Table 1. Parameters that obtained directly from experiments and used in the relationships of this research

Parameter	Value
Ultimate Tensile Strength	669 MPa
Micro Hardness Vickers	135 Kg/mm^2
Chord Modulus	38.25 GPa
Fatigue Life	5815 Cycle

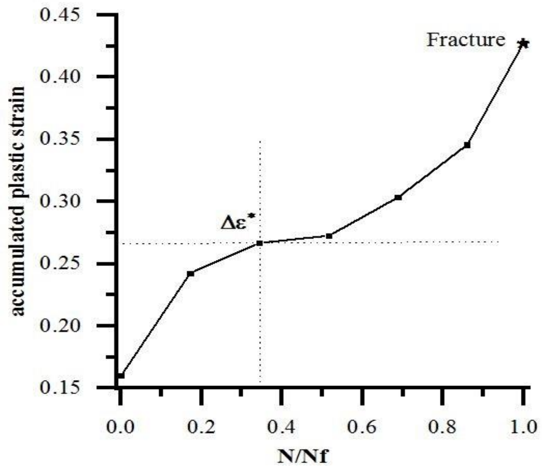

Fig. 1. Plastic strain changes with increasing fatigue loading cycle

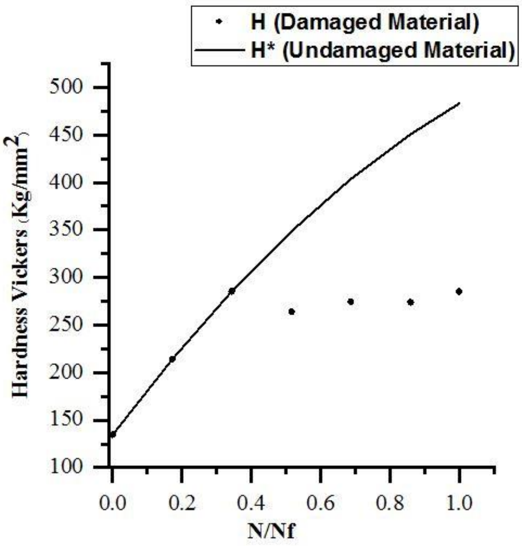

Fig. 2. Microhardness changes with increasing fatigue loading cycle

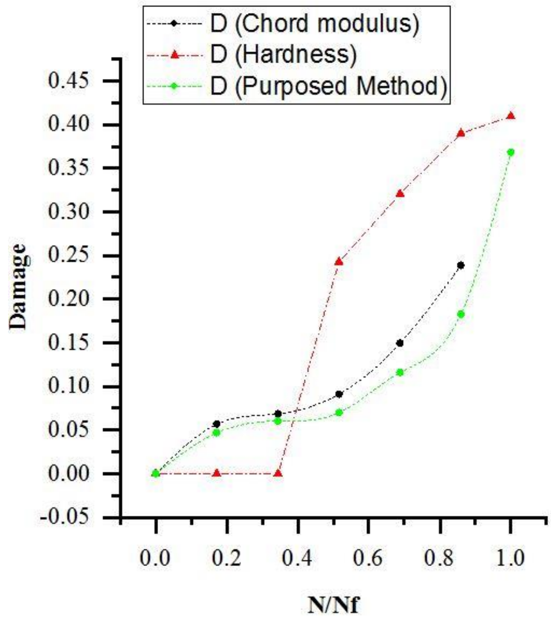

Fig. 3. Growth of damage in the methods of chord modulus, microhardness and suggested in this research with increasing fatigue loading cycle

2- 2- Micro Hardness Method

For microscopic measurements, the force is applied to 0.1 kg for 10 seconds. The microhardness test is performed on specimens. The microhardness change process is extracted from the application of loading from the beginning of the load to the moment of failure Which is a H-N graph, which is the amount of microhardness of the damaged material in terms of number of cycles. The amount of H* in the number of cycles-no damage-is the same as the H value obtained from the test. Sustainability occurs after a number of cycles, and the onset of damage occurs within the range of cyclic stability. As shown in Fig. 1, accumulated plastic strain in the cyclic stability range is introduced with Δε*. According to this point, The H*-N chart shows the amount of microhardness in terms of the number of fatigue loading units for the non-damaging material extracted from the extraction of points before the cyclic stability range.

Due to having H and H* values, each damage loading is obtained according to the relation D=1-H / H*.

2- 3- Chord Modulus Method

In order to obtain the chord modulus, tensile load-loading should be performed on individual specimens. For this purpose, the encoded specimens-the specimens are only different in the number of loading cycles-were subjected to a tensile test. Loading and tensile loading were carried out in the elastic range of 50% and delivered at a speed of 2 mm/min using the Santam stm-20 machine and the results for each piece were extracted. Elastic zone changes were used to elucidate the growth trend of damage. In each loading and unloading step, two loading and loading curves with a straight line were interconnected. The slope of this line represents the chord modulus [9]. After extraction of the chord modulus for all specimens loaded in different cycles, the trend of changes in the amount of chord modulus was extracted with the increasing number of fatigue loading cycles. From the comparison of the chord modulus of the loaded parts in different cycles with the damaged specimen as the reference value, the fatigue damage trend was obtained by measuring the changes in the chord modulus. Depending on the relationship D=1-(E/E0), the amount of fatigue damage is extracted in different loading. The value of the reference chord modulus with E0 and the value of the chord modulus in each load is showed with E. The value of E0=38.25GPa has extracted from the experimental test.

2- 4- Proposed Method

This method is derived from the classical definition of the damage variable. The damage measurement criterion is the change in specimen cross-sectional area per loading. In this method, the cross-section of specimens was measured before loading. After loading, the minimum cross-sectional area of the specimens was measured. This was done for all uploaded specimens. By passing the nearest curve from the points obtained, the cross-sectional diagram was extracted from the number of loading cycles. Dimensions were measured by micrometer and caliper with a precision of 0.01 mm. Broken cross-sectional area was measured by image processing. The difference between the proposed method and the method of classical damage development is to determine the cross-sectional area affected. In the proposed method, the cross-sectional variation of the plastic deformation determines the size of the damage, but in the classical method, the effective surface is measured using a microscope. The damage variable in this method is defined by relation D=1- (A/A0). A is cross-section after loading and A0 is cross-section before loading (without damage).

3- Results and Discussion

The results obtained from all three methods were compared. The proposed method is based on the apparent cross-sectional variation of the loading. The amount of damage in this method is a good approximation of the method of chord modulus. This method is very simple and can be done at a very low cost. In the range of damage start, the strain of plastic is about 45% of the strain of plastic at the moment of fracture. The microhardness method can be used for a range of different conditions. For example, a portable hardness test device can be used to measure hardness on a variety of equipment. But in the method of chord modulus, it must be sampled and loaded-unloading in the tensile testing machine and the same may result in restrictions in some workshop conditions or expensive equipment that cannot be sampled. In the method of measuring the changes in the chord modulus, the damage variable only grows in plastic deformations. For this reason, this method is not recommended for the investigation of high cycle fatigue damage. Because of the fact that in the high cycle fatigue, the damage is very local. On the other hand, load-unloading is done to extract the chord modulus in the range of 50% of the material's delivery limit and this method has a mistake in predicting high cycle fatigue damage. In the method of chord modulus, the critical damaging value was Dc=0.38 and in the microhardness method, the critical damage value was Dc=0.41 and in the proposed method was Dc=0.37. It is clear that 38% damage in the chord modulus method represents the final damage to the substance. The same amount of damage occurs in the microhardness method when the sample has passed approximately 85% of its fatigue life. With these results, it would seem reasonable and appropriate that the critical damage value for SS316L should be Dc=0.38.

4- Conclusions

The amount of critical damage is close to each other in two ways and this reflects the proper matching of two different methods, which can be exploited in each situation under different conditions. The proposed method for low carbon stainless steel 316 can estimate the growth of low cycle fatigue damage. The error percentage of the proposed method is directly related to the difference in effective surface and apparent surface that can be obtained through micrography. The onset of damage in the loading of low cycle fatigue can be considered at the point of the material cyclic stability. This is achieved by measuring the accumulated plastic strain for most materials.

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