Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(4) (2018) 1-3
DOI:

Study the Fatigue Behavior of AISI 1045 Steel Using Ultrasonic Fatigue Test Machine

S.Amini*, M.Aghaei

Mechanical Engineering Department, University of Kashan, Kashan, Iran

ABSTRACT: Nowadays, industrial developments and applying more dynamic loads on metals made the issue of fatigue as an important problem which approximately causes 90% failure of the metal components. Some examples of such failures found in aircrafts, automotive and high-speed trains and turbines. In the last two decades, a new field called very high cycle fatigue in fatigue life has attracted a lot of attention. Access to the number of 10^7 cycles and above by using existed common testing devices is time-consuming and costly, due to the low frequency. For a lot of material, fatigue failure after 10^7 cycles have been reported, i.e. in the range of very high cycle fatigue. Very high cycle fatigue properties are significant issues for ensuring long life and reliability machines and structural components due to the growing demands regarding industries. Accordingly, an ultrasonic fatigue test machine in frequency about 20,000 Hz was used to reach the mentioned number of fatigue cycles causing time reduction. Therefore, this article for the first time in the country describes the design and construction of an ultrasonic fatigue test method, in which its operating frequency is 20 kHz. Furthermore, this device was implemented to analyze the fatigue behavior of AISI 1045 steel.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Fatigue
Very high cycle
Piezoelectric
Ultrasonic
AISI 1045 steel

1- Introduction

Many structural components endure more than 10^7 cycles, but predicting fatigue properties is typically limited to between 10^6 and 10^7cycles. The life-cycle of turbine engine components is close to 1010 cycle. The phenomenon of very high cycle fatigue failure in many alloys is widely considered [1, 2]. Due to these conditions, the researchers tried to develop more accelerated tests that operate at high frequency [3]. Mason's activities in 1950 [4] have important effects on the development of the ultrasonic fatigue test. According to a study conducted to the very high cycle fatigue abroad and the need for very high cycle fatigue testing devices inside the country. In this study, after producing ultrasonic generator, amplifiers instrument and other components, an operating frequency of 20 kHz ultrasonic fatigue test machine was designed and built. Finally, S-N diagram for AISI 1045 steel was established.

2- Methodology

In the ultrasonic fatigue test, external frequencies generated by the test machine should be one of the natural frequencies of the sample. In other words, the natural frequency of the device must be equal to applied frequency, so the geometry of the machine including transducers, horn and specimen need to be designed to achieve the natural frequency equal to the applied frequency of about 20 kHz. Ultrasonic fatigue testing method has some advantages and limitations. Its advantages are Time saving, energy saving, possible testing procedures, and specimen fixture. Its limitations are resonance loading condition, material temperature, load control and low cyclic loads [5].

Up to now, no standard testing methods for ultrasonic fatigue test has been developed. For this reason, laboratories should develop their devices and offer practical design for test methodology but all of them have three part: a power generator that transforms 50 or 60 Hz voltage signal into ultrasonic 20 kHz electrical sinusoidal signals, a piezoelectric transducer excited by the power generator, which transforms the electrical signal into longitudinal ultrasonic waves and mechanical vibration of the same frequency and an ultrasonic horn that amplifies the vibration coming from the transducer in order to obtain the required strain amplitude in the middle section of the specimen. Therefore, these components come together to build a fatigue testing machine and by applying a control condition ability to create ultrasonic fatigue test. As shown schematically in Fig. 1, displacement differs in different parts and design to be done in a way that at the middle of the specimen vibration node to be created and at both end of it anti node to occur thus in its middle, maximum of stress occurs.

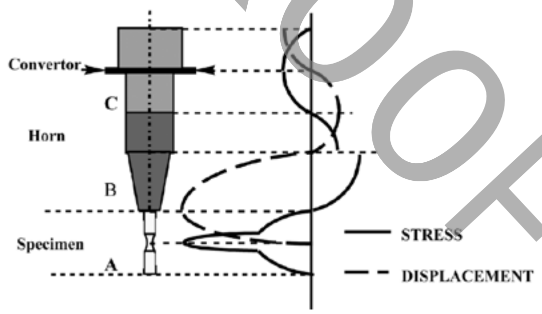

Fig. 1. Displacement and stress distribution [1]

*Corresponding author E-mail: amini.s@kashanu.ac.ir

Measurement of stress in the middle of the specimen is done by numerical but if the geometry to be power analytical solution can also be presented. Longitudinal wave equation for a specimen with a variable area can be written as follows [2]:

$$\rho S(x)\frac{\partial^2 u}{\partial^2 t}=\frac{\partial f}{\partial x} \quad (1)$$

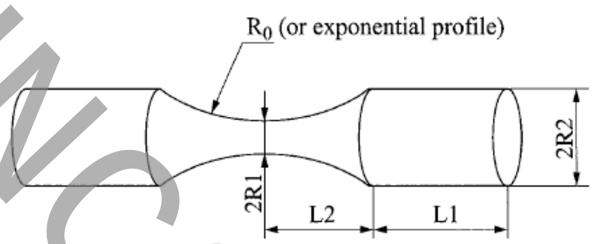

Fig. 2. A schematic of the specimen [1]

The middle section geometry is defined by Eq. (2):

$$\begin{aligned} y(x) &= R_2 \quad L_2<|x|\le L \\ y(x) &= R_1\cosh(\alpha x) \quad |x|\le L_2 \end{aligned} \quad (2)$$

By applying boundary conditions, the following equations show the displacement, stress, and strain of the specimen.

$$\begin{aligned} U(x) &= A_0\frac{\cos(L_1 k)\cosh(\alpha L_2)}{\sinh(\beta L_2)}\frac{\sinh(\beta x)}{\cosh(\alpha x)}, \quad |x|\le L_2 \\ U(x) &= A_0\cos(k(L-x)), \quad L_2<|x|<L \end{aligned} \quad (3)$$

$$\begin{aligned} \varepsilon(x,t) &= \frac{\partial u(x,t)}{\partial x} \\ \sigma(x,t) &= E_d\,\varepsilon(x,t) \end{aligned} \quad (4)$$

$$\begin{aligned} \varepsilon(x) &= A_0\varnothing(L_1,L_2)\frac{\beta\cosh(\beta x)\cosh(\alpha x)-\alpha\sinh(\beta x)\sinh(\alpha x)}{cosh^2(\alpha x)} \\ \sigma(x) &= E_d A_0\varnothing(L_1,L_2)\frac{\left[\beta\cosh(\beta x)\cosh(\alpha x)-\alpha\sinh(\beta x)\sinh(\alpha x)\right]}{cosh^2(\alpha x)} \end{aligned} \quad (5)$$

After testing the assembled machine and initial tests, it showed some desirable performance. Specimens made of AISI 1045 steel were produced and their dimensions were achieved using software and modal analysis.

3- Results and Discussion

To achieve the S-N diagram staircase method was used that in case of failure stress amplitude decreases and if the sample does not break the amplitude increases. Finally in Fig. 3 the S-N diagram related to this steel has been shown through ultrasonic fatigue test. Samples were loaded up to 10^8 cycles and were considered as out of the test sample, if the samples in this range do not break.

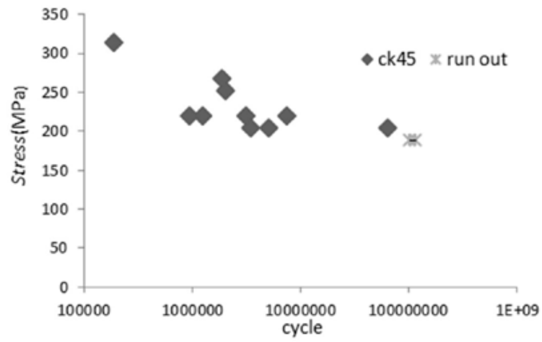

Fig. 3. S-N diagram

Fig. 4 shows a middle section of the specimen view that magnified by VMM. There is a point that by crack initiation and its growth, resonant frequency changes.

Fig. 4. Cracks grown in a sample that has been photographed with VMM

At Fig. 5, an example of Fish-eye effect can be seen at the cross section of the specimen

Fig. 5. An example of the failure started from the surface and its fish-eye

4- Conclusion

In this research, ultrasonic fatigue test machine was introduced, by analyzing the relationship and doing the relevant tests the following results have been obtained:

- The use of ultrasonic fatigue test reduces the time, due to its high frequency
- Due to time-reduction requirement in order to achieve a number of specific cycles reaching over 10^7 cycles at the time much less than the past is possible.
- Reducing the diameter of the middle part causes larger applied stress.
- Increasing curvature in the middle part causes larger applied stress.
- Fatigue strength of AISI 1045 reduced to 204 MPa.

References

[1] Bathias, C., Paris, P.C., 2004. Gigacycle Fatigue in Mechanical Practice. Section 7, Marcel Dekker.

[2] Bathias, C., Pineau, A., 2010. Fatigue of materials and structures. in Great Britain and the United States: ISTE Ltd and John Wiley & Sons, Inc.

[3] Nicholas, T.,2006.high cycle fatigue a mechanics of material respective,section 2&3, Elsevier Ltd.

[4] Manson, W.P., 1956. Piezoelectric Crystals and their Application in Ultrasonics. New York: Van Nostrand,

[5] Mayer, H., 1999. “Fatigue crack growth and threshold measurements at very high frequencies”. International Materials Reviews, Vol. 44, No. 1, pp. 1-34,