Very High Cycle Fatigue Behavior of Carbon Manganese Steels

Xue Hongqian, Danièle Wagner

Very high cycle fatigue behavior of carbon manganese steels

Hongqian Xue[1,a], D. Wagner[2,b]

[1.] School of Mechatronics, Northwestern Polytechnical University, Xi'an 710072 China,

[2.] LEEE, Paris X University, 50, Rue de Sevres 92410 Ville D'avray France

[a] xuedang@nwpu.edu.cn, [b] daniele.wagner@u-paris10.fr

Keywords: VHCF, 20kHz, C-Mn steel, high temperature

Abstract. An ultrasonic fatigue testing system capable of operating at temperatures at 250℃ has been introduce to study the fatigue behavior of carbon manganese steels (A42 and A48) and loading frequency of approximately 20 kHz. Endurance limit results were comparable to those generated at room temperature to determine the effect of temperature. Scanning electron microscopy was then used to determine the initiation sites and the failure mechanisms. Initial results indicate that fatigue strength decrease a little at 250℃, interior inclusions were the major microstructural feature responsible for crack initiation in the alloy.

Introduction

In order to obtain the highest performance of any components operating in a pressurized water reactor system in nuclear power plant, it requires the accurate assessment of fatigue life under the complicated cyclic loading. The assessment procedure must therefore account for the typical service duty likely to be encountered in order to obtain accurate data.

The C-Mn steel as a kind of typical material was used as pipe components in nuclear power plant, although the pipe components mission loading is very complicated, it can be modeled as a combination of low frequency high-strain cycles and high-frequency low-amplitude cycles. The former represents low-cycle fatigue (LCF) loading resulting from pressurized water, continuous vapor impact vibrating, while the latter represents. The combined cyclic stresses are associated with high temperature condition developed during the operation of the engine. So the fatigue behavior in high temperature condition should be concerned. So, there is a need for understanding the fatigue behavior of these alloys in gigacycle regime with low-amplitude.

In general, fatigue tests in the very long lifetime regime (>10^8 cycles) are prohibitively time consuming with conventional servo-hydraulic testing equipment. For this reason, few studies of high cycle fatigue behavior of C-Mn steels at very long lifetimes using conventional instrumentation have been performed [1]. While high temperature fatigue studies of these materials at very high frequencies in the range of 15–21 kHz have not been reported, a number of studies at temperatures up to 500 ◦C have been recently completed on a wide range of structural alloys, including aluminum [2,3], steel [4] and titanium alloy. Thus, ultrasonic fatigue techniques offer a potentially attractive approach for investigation of the high cycle fatigue behavior of carbon steel at very high vibratory loading frequencies. In this paper, fatigue tests of two kinds of alloys up to 10^9 cycles at 250℃ and room temperature are conducted to examine the fatigue behavior of the alloys.

Experiments

- Experimental material

Two kinds of C-Mn steels have been used in the investigation. The chemical compositions of the steels A42 and A48 are given in table1. The specimens were manufactured from a 40mm thick plate, prior to manufacturing the specimens, the plates were heat treated, the details of heat treatment are as follows: the furnace was heated to a temperature of 870℃, followed by air cooling, thus leading to a microstructure composed of banded ferrite and pearlite. The center of the plate resulting from the solidification of the initial ingot appears a major segregation constructed a rich zone of solutes. This zone shows mechanical characteristics higher than the metal at the quarter thickness as filiations of hardness. The zones close to surface show some degrading characteristics due to oxidation and surface decarburizing. Static strength properties measured after normalizing are listed in table2.

Tab.1 Chemical composition of steels (wt%)

Materials	**C**	**N**	**S**	**P**	**Si**	**Mn**	**Al**	**Cr**	**Mo**	**Cu**	**Sn**
A48	0.198	0.0082	0.012	0.0104	0.207	0.769	0.004	0.021	0.002	0.027	0.003
A42	0.14	0.0082	0.0057	0.016	0.225	0.989	0.045	0.095	0.025	0.273	0.023

Tab.2 Properties of the steels

Steel	E(GPa)	Density (kg/m3)	UTS (20℃)	$R_{0.002}$	Poisson ratio
A42	209	7850	460MPa	282MPa	0.3
A48	209	7850	510MPa	313MPa	0.3

- Ultrasonic fatigue test system

An ultrasonic fatigue test system was used to determine the fatigue limit of the C-Mn steels up to 10^9 cycles. The ultrasonic fatigue systems and their applications have been reviewed in some papers[5-6].

The specimens used in this study were cylindrical dog bones with a gage section diameter of 6 mm. The specimens were designed so that the maximum strain is located in the gage section. The specimen dimensions are shown in Fig. 1. The threaded end of the specimen is attached to the horn. The other end of the specimen is a free surface for ultrasonic testing under fully reversed loading conditions. A thorough review of the ultrasonic testing technique for fatigue and fracture applications can be found in [6–8].

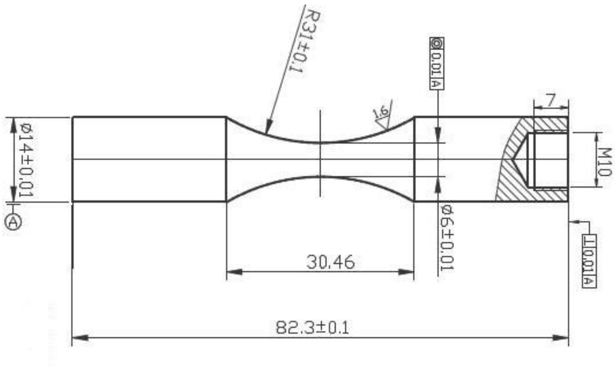

Fig. 1. Ultrasonic fatigue specimen

- Calibration

In order to make the ultrasonic fatigue machines work correctly, prior to each test, the displacement at the free end of the specimen is calibrated at room temperature with a strain gage bonded to the gage section, because the strain gages cannot be used at temperatures of 250℃. Under the nominally elastic conditions used for loading to very high cycles, there is a linear relationship between the displacement at the end of the specimen and the strain in the gage section.

- Experimental method

Ultrasonic fatigue tests were conducted under fully reversed loading condition (load ratio R =-1), at room temperature and 250 ℃. An induction coil is employed for specimen heating in fatigue test with high temperature, Careful design and placement of the copper coil allows the entire specimen to reach a uniform temperature and prevents elastic modulus gradients.

The temperature in the specimen gage section is monitored by an infrared pyrometer, and temperature calibration is performed using a blackbody prior to fatigue test. Besides, an important consideration in ultrasonic testing is the heat that can be generated internally due to internal friction and damping. For some materials, this internal damping can lead to large temperature increases, so it should pay more attention to minimize the effects of the damping.

The length of tested specimen is adjusted to vibrate in resonance to obtain specific load amplitudes. In resonance, the length of specimen is an integral number of the acoustic wavelength, λ, the length of specimen is determined by the dynamic Young's module and density of the material. Due to the dynamic young's module of material changes with the increase of temperature, so the length of specimen used in ultrasonic fatigue test at 250℃ should be kept in 20kHz resonance frequency, so as to keeping the system running well.

Results

The S–N data generated by ultrasonic fatigue testing for the carbon manganese steels are shown in Fig. 2. Run outs at N=10^9 were observed at room temperature for six samples of A42 and A48, respectively. Due to the effect of high temperature, run outs at N=10^8 were observed for two samples of A48 at 250℃. For A48, stress amplitudes between approximately 240 and 270MPa, fatigue life varied from 10^6 to10^9 cycles, at very high numbers of cycles, fatigue data are approximated with a line parallel to the abscissa, which indicates the mean endurance limit at 10^9 cycles of 245 ± 3 MPa for A48. However, most specimens for A42 steel failed in range of 10^6-10^7 cycles, fatigue lives increases significantly with a little decreasing stress amplitude.

Increasing the test temperature resulted in a decrease in fatigue resistance at ultrasonic frequencies. The endurance limit at 10^9 cycles was decreased by about 30 MPa from 20 to 250℃. The dependence of endurance limit, is related to yield strength or tensile strength, while, the yield strength of A48 is pronounced depended of temperature.

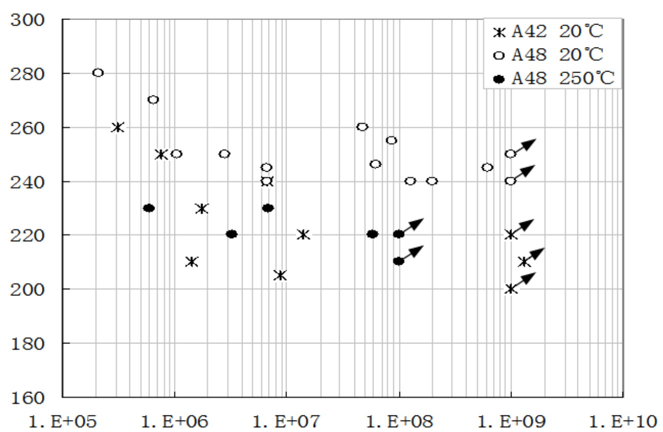

Fig.2 Ultrasonic fatigue test results for specimens tested at 20 and 250℃

Fig.2. S–N curves characterized by comparing two kinds of steel in different loading condition, Fig. 3 shows a typical fracture surface for fracture surface for A48 from ultrasonic fatigue test, the

crack initiation was from interior inclusion. This is consistent with the results of other steel reported in many papers, fatigue crack initiated from interior inclusion of the steels in very high cycle regime, no matter what the testing condition is. In contrast, for the specimens with lower fatigue life, fatigue crack mainly initiated from specimen surface.

Some evidence suggests that crack propagation occurs depends on the combined shear and normal stresses, with the former responsible for damage accumulation from irreversible cyclic deformation and the latter required to cause crack propagation in the damaged regions. Due to the yield strength of the steels decrease significant with increasing of temperature, in the ultrasonic fatigue test, interior fraction of material at 20kHz frequency results in increasing of temperature, and leads to increasing of the irreversible cyclic deformation when fatigue small crack propagate.

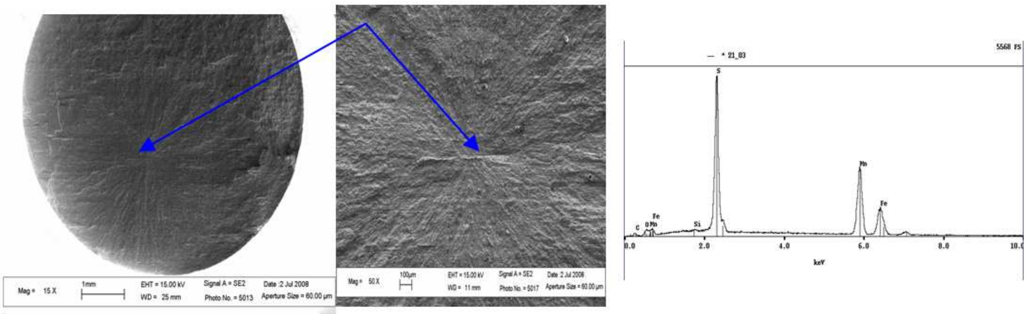

Fig.3 Fatigue crack initiate from interior inclusion (MnS) of A48 steel

(σ_{max}=220MPa, N_f=5.97x10^7 cycles,T=250℃)

Conclusion

The fatigue tests on two kinds of C-Mn steels were carried out at room temperature and 250 ℃ in air and the following conclusions were drawn:

1. A stronger effect of temperature on cyclic life was observed for the C-Mn steels, pronounced cyclic softening occurred, and cyclic softening behavior depends strongly on test temperature and stain amplitude.
2. Increasing test temperature results in a decrease in fatigue resistance at ultrasonic frequencies. It is related to yield strength, which decrease significantly with increasing of temperature.
3. Interior fatigue crack initiation results in high numbers of fatigue life, however, interior fractures are not the only reason that the fatigue limit disappears. The difference in the fatigue life is not clear between surface and interior fractures.

References:

[1] H.Mayer,M. Papakyriacou, R. Pippan, S. Stanzl-Tschegg, Mater. Sci. Eng. A 314 (2001) 48–54.

[2] X. Zhu, A. Shayam, J.W. Jones, et al, Int. J. Fatigue 28 (2006) 1566–1571.

[3] R. Morrissey, T. Nicholas in: T. Sakai, Y. Ochi (Eds.), Very High Cycle Fatigue, Soc. Mater. Sci., Japan, Kusatsu, Japan, 2004, pp. 156–162.

[4] Bathias C, Pairs PC. Gigacycle fatigue in mechanical practice. Marcel Dekker; 2005.

[5] Marines I, Dominguez G, et al. Int J Fatigue 2003;25:1037–46.

[6] Meyer H. Int Mater Rev 1999;44(1).

[7] Stanzl-Tschegg SE. Ultrasonic fatigue. Fatigue 1996;96:1887–98.

Acknowledgements

The project Sponsored by the Nation Nature Science Foundation of China(50775182) and Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry.