W.C. PEI, J.W. DONG, H.C. JI, H.Y. LONG, S.F. YANG

ISSN 0543-5846
METABK 58(3-4) 219-222 (2018)
UDC – UDK 669.15.26.28:539.388.1:620.178.3-539.375:620.16:539.26-620.18=111

STUDY ON CRACK PROPAGATION OF 42CrMo

Received – Primljeno: 2019-01-17
Accepted – Prihvaćeno: 2019-03-20
Original Scientific Paper – Izvorni znanstveni rad

For the fatigue failure of 42CrMo, the tensile test was performed on the CT specimen at different load ratios using a fatigue tensile tester. Data on the fatigue crack growth rate of the material and the crack tip factor were obtained. Scanning electron microscopy (SEM) was used to observe the microstructure and crack initiation and propagation of fractures. The crack initiation and propagation path law during fatigue crack propagation were obtained. The fatigue crack life was calculated by Paris formula, and the fatigue crack growth test and microscopic observation were compared. The propagation law and fatigue crack life of different stages of crack propagation were analyzed. The results show that the stable propagation stage of fatigue crack propagation is the key stage to determine fatigue fracture, the rate of growth is related to the stress ratio.

Key words: 42CrMo; fatigue crack life; fatigue crack propagation; stress; microstructure.

INTRODUCTION

In the past two decades, fatigue cracks have been studied extensively. Because more than 70 – 80 % of the total fatigue life may be used in the crack initiation and small crack development stages [1]. Previous studies have shown that cracks and small cracks that occur at the beginning of fatigue life are affected significantly by the intrinsic microstructure, resulting in anomalous propagation behavior compared to long crack behavior [2]. Therefore, accurate measurement of small crack growth rate and understanding of small crack propagation mechanisms are very important for reliable prediction of material fatigue life. Wang [3] carried out fatigue crack growth tests of SiCp/Al composites with different stress ratios, and found that the fatigue crack growth rate of the material decreases with the increase of stress ratio. The initiation of fatigue short cracks is obviously affected by the mesostructure of the material. Due to the different mesostructures, the initiation mode of fatigue short cracks is also different [4]. Kim and Laird [5] believe that the orientation of the grains on both sides of the interface is quite different. The direction of motion of the intragranular slip zone intersects with the grain boundary, causing a large stress concentration at the grain boundary, which eventually leads to cracking of the grain boundary and formation of grain boundary microcracks. Each microcrack merges to form a short crack. Fatigue cracking is sensitive to stress concentrations. If the stress exceeds the strength limit of the interface, it will easily lead to the occurrence of short fatigue cracks. Moreover, the second phase structure or inclusions are generally relatively brittle or hard, which tends to cause cleavage fracture.

In this paper, CT specimens were stretched on an MTS 810 electro-hydraulic servo material test system. The metal fracture was then observed under a focused ion beam scanning electron microscope. The effects of crack initiation and propagation in different extension zones and the influence of grain on the extension path during the expansion process were studied.

FATIGUE CRACK INITIATION AND PROPAGATION TEST OF 42CrMo

In order to study the fatigue fracture problem of 42CrMo, the crack growth rate test is needed to obtain the da/dN curve of the material 42CrMo at room temperature. Further, the fatigue crack life of the material can be calculated. The raw materials of the test sample are rolled and formed sheets. Prior to the test, specimen were taken on 42CrMo plates in accordance with national standards. In this test, a CT specimen having a crack growth rate parallel to the rolling direction was prepared by sampling at about 1/4 of the thickness of the sheet. The specimen size is: width W = 40 mm, thickness B = 6 mm.

The crack growth rate test required for this test was carried out on the MTS 810 electro-hydraulic servo material test system of the Mechanical Testing Center of the State Key Laboratory of New Metal Materials of University of Science and Technology Beijing.

The test was carried out in accordance with GB/T 6398-2000 Test Method for Fatigue Crack Growth Rate of Metallic Materials. Prior to the start of the test, the CT specimen was pre-cracked by the compliance method, and the pre-crack length was 1 mm. After the pre-crack-

W.C. Pei, J.W. Dong, H.C. Ji, H.Y. Long, S.F. Yang. College of Mechanical Engineering, North China University of Science and Technology, Hebei, Tangshan, China; H. C. Ji (E-mail: jihongchao@ncst.edu.cn), College of Mechanical Engineering, North China University of Science and Technology, Hebei, Tangshan, China; National Center for Materials Service Safety, University of Science and Technology Beijing, China;

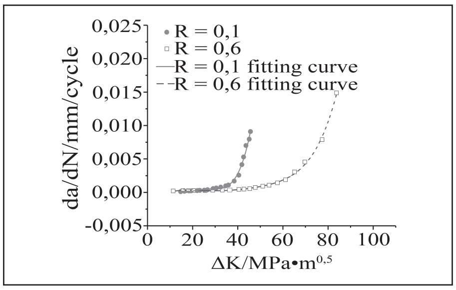

Figure 1 da/dN-ΔK curve

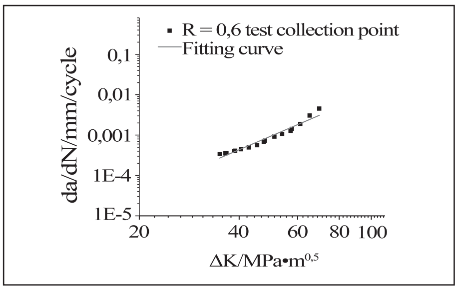

Figure 3 da/dN-ΔK curve at R = 0,6

ing was completed, the specimen was loaded with a sine wave and the loading frequency is 10 Hz. The experiment was carried out at two load ratios of 0,1 and 0,6. In order to ensure the accuracy and completeness of the test, three specimens were stretched at each load ratio.

The crack growth rate da/dN and the stress intensity factor ΔK obtained by the experiment were plotted and fitted directly, as shown in Figure 1. The symbols "○" and "□" in the figure indicate test data measured at a stress ratio R of 0,1 and 0,6, respectively.

The Paris formula was proposed below to perform regression analysis on the fatigue crack growth rate test data under different stress ratios. Among them, the Paris formula is as Equation 1:

$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

Where, a-crack length
N-fatigue week
Da/dN-the amount of crack propagation per unit cycle, ie. the rate of crack propagation
ΔK-the range of stress intensity factors
C, m-material constant

Therefore, if both sides of Equation 1 take the logarithm at the same time, then there is Equation 2.

$$\lg\frac{da}{dN} = \lg C + m\lg(\Delta K) \tag{2}$$

Therefore, for the test data of stress ratio R = 0,1 da/dN and ΔK were plotted in logarithmic coordinates, and it can be found that the crack growth rate da/dN and the stress intensity factor ΔK have a linear relationship in logarithmic coordinates. The slope is m, the intercept is lgC, and they were drawn and linearly fitted to obtain Figure 2.

When the linear regression fitting of the experimental data can obtain R = 0,1, the crack propagation equation are Equation 3 and Equation 4. At this time, the correlation coefficient r = 0,96484.

$$\lg\frac{da}{dN} = -7{,}00299 + 2\ 5850\lg(\Delta K) \tag{3}$$

$$\frac{da}{dN} = 9{,}9314\times10^{-8}\cdot(\Delta K)^{2{,}5849} \tag{4}$$

For test data with a stress ratio of R = 0,6, da/dN and ΔK were plotted in logarithmic coordinates and fitted linearly to obtain Figure 3.

When the linear regression fitting of the experimental data can obtain R = 0,6, the crack propagation equation are Equation 5 and Equation 6. At this time, the correlation coefficient r = 0,97729.

$$\lg\frac{da}{dN} = -8{,}58996 + 3\ 2670\lg(\Delta K) \tag{5}$$

$$\frac{da}{dN} = 2{,}57063\times10^{-9}\cdot(\Delta K)^{3{,}2670} \tag{6}$$

When the stress ratio R are 0,1 and 0,6, the linear correlation coefficients are 0,96484 and 0,97729 respectively, and the linear correlation coefficients are all above 0,96. The relationship between the crack growth rate da/dN and ΔK at different stress ratios were simultaneously plotted in logarithmic coordinates and fitted with the Paris formula, as shown in Figure 4.

Among them, when ΔK = 40MPa·$m^{0,5}$ and R = 0,1, the fatigue crack growth rate da/dN is 1,3756×10^{-7} mm/cycle. Under the same ΔK value, when R = 0,6, the fatigue crack growth rate da/dN is 1,7136×10^{-8} mm/cycle. When ΔK = 42 MPa·$m^{0,5}$ and R = 0,1, the fatigue crack growth rate da/dN is 1,5593×10^{-7} mm/cycle. Under the same ΔK value, when R = 0,6, the fatigue crack growth rate is 5,1663×10^{-8}mm/cycle. When the stress ratio R is increased from 0,1 to 0,6, the crack growth rate da/dN decreases as the stress ratio R increases, therefore, the fatigue life is longer.

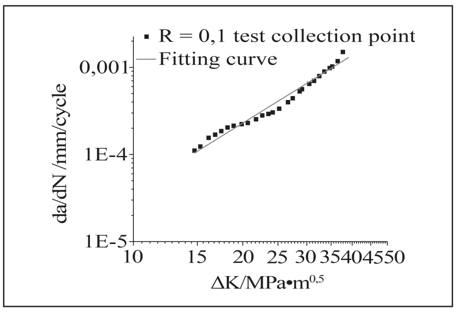

Figure 2 da/dN-ΔK curve for R = 0,1

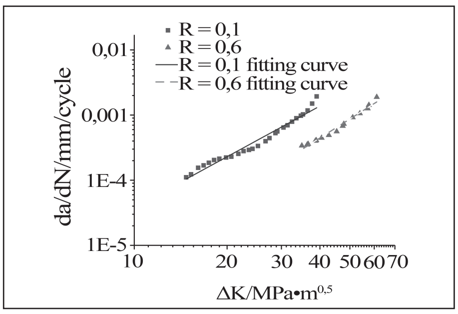

Figure 4 da/dN-ΔK curve in logarithmic coordinates

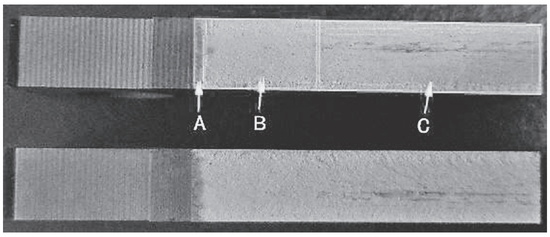

Figure 5 Fatigue fracture

FATIGUE SECTION ANALYSIS OF TENSILE SPECIMENS

In practical engineering, the form of cracked members can be divided into three basic types roughly: Crack open type (I-type), crack staggered type (II-type) and crack slip type (III-type). Among the three crack forms, the "I-type" loading mode of the crack-opening type is the most common and the most dangerous form that is most susceptible to brittle failure. Therefore, the "I-type" crack loading situation, the force situation and the crack propagation form have attracted the attention of many researchers [6].

MACRO ANALYSIS

As shown in Figure 5, the fatigue fracture morphology can be divided into three distinct regions, namely: A, crack source region; B, crack stable expansion region and C, instantaneous fracture region. The three regions constitute the cross-sectional features of the entire fatigue fracture. The crack source region accounts for a small proportion of the entire fracture, and the main crack starts from this position. The crack source is located at the far left of the fracture and slowly expands to the right from this position. The bright region of the crack source was formed when the crack length was less than 1 mm and the crack slowly expands. At this stage, the crack opening displacement was small and the expansion was slow. Repeated opening and closing caused the fracture surfaces to be squeezed on each other to form the most smooth area on the fracture. The macroscopic section of the crack stable expansion region is fine and flat, and the expanded area occupies about one-third of the entire section, and is the most important feature area on the fatigue fracture. Since the fracture surface of the specimen was compressed repeatedly by friction and rubbed, the region became smooth and fine-grained. After the crack stable expansion regions is instantaneous fracture region, the instantaneous fracture region is the region formed by the instability expansion after the fatigue crack propagates to the critical dimension under the fatigue load. In this area, it is apparent that the fracture becomes rough, exhibits an unstable state, there are gullies and bulges that are torn, the direction of cracking points in the direction of crack propagation, perpendicular to the direction of the load.

FRACTURE MICROSCOPIC ANALYSIS

In order to have a further understanding of the fracture morphology. The specimen was first ultrasonically cleaned in an ultrasonic cleaner. The fracture was then observed by focused ion beam field emission scanning electron microscope model Scios 03040702.

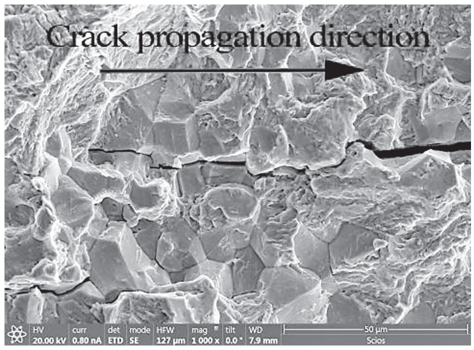

Figure 6 Extended path of small cracks in the fracture

As shown in Figure 6, once the crack is initiated, according to the principle of the minimum energy consumption of the fracture [7], the propagation path of the crack always proceeds along the surface with the weakest atomic bonding force. It will expand along the plane of maximum shear stress (about 45°). The crack originates at the grain boundary, which is precisely because the newly initiated crack has lower energy. The polyhedral morphology of each grain can be clearly seen under the scanning electron microscope observation, similar to the accumulation of rock candy pieces. In the same region, there are multiple cracks that extend in the same or different directions. During the crack propagation process, as the crack tip factor K increases and new fatigue cracks are initiated and aggregated, the energy of the crack increases. The expansion path will change from the original intergranular expansion to the transgranular expansion, while consuming more energy. With the obstruction of the grains and the consumption of more energy required. A crack will continue to increase due to the addition of small cracks, and the crack energy will continue to increase, eventually leading to fatigue failure of the specimen. A crack consumes more energy when it encounters an obstacle due to transgranular expansion. It cannot accommodate the expansion direction of the initial crack and there is no new small crack incorporation. It has less energy and ends up in the grain barrier.

The crack stable expansion region is the region where the specimen fracture is more obvious. It occupies most of the area of the fracture from which the step of slow crack propagation can be seen. Due to the constant stress or constant strain test in the laboratory, the load spectrum is relatively stable, and the fracture is generally free of embossing characteristics. At this time, the surface of the fatigue fracture surface was rubbed by repeated compression, so that the area becomes smooth and fine-grained.

The third region is the instantaneous fracture region of the crack. Since the specimen was subjected to tearing stress, tearing dimple was produced in the instantaneous fracture region. The tearing dimple is also an elongated dimple, in the shape of a parabola. When the

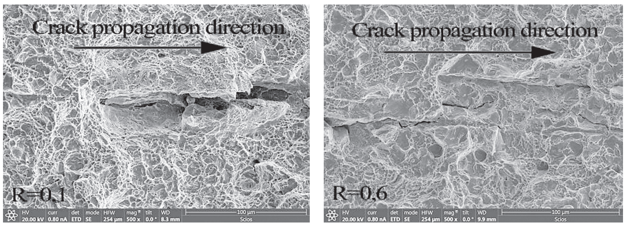

Figure 7 Dimple state diagram for stress ratios of 0,1 and 0,6

tear was applied, the specimen was subjected to a moment, and the stress of each part of the microscopic cavity was different, and the dimple was elongated along the direction of the larger force. Under the fatigue load, the fatigue crack grows and expands. When the crack expands to the critical dimension, the crack will expand rapidly until the final fracture. This period of time is shorter, and the fracture morphology is similar to that of the static load fracture. Both of them exhibit a dimple-like shape, that is, a tear of internal fibers.

It can be seen from Figure 7 that the instantaneous fracture region of the fracture has a distinct equiaxed dimple morphology, and these equiaxed dimples of varying sizes are apparently produced by tensile stress. The shape of the dimple mainly depends on the stress state. The dimple is a microscopic cavity created by plastic deformation of the material in the micro-region, which is nucleated, grown, gathered, and finally connected to each other to cause traces left on the fracture surface after the material breaks.

Figure 7 shows the fracture morphology of the fatigue crack during the rapid expansion phase. There is a secondary crack in the fracture of the instantaneous fracture region. The dimple break is the main form of crack propagation at this stage. The dimple fracture is a high energy absorption process. Because the energy accumulated by the cracks in the stable expansion region needs to be instantaneously released in the rapid expansion region, the secondary crack state in the instantaneous fracture region is a coarse gully. As shown in Figure 7, the dimple is parabolic, and the opening direction is directed to the direction in which the crack propagates. At a stress ratio of 0,1, the state in which the dimples appear is larger and the number of dimples per unit area is larger. The large dimples also contain small dimples, which also contain secondary cracks in the dimple region during the propagation of the main crack. The secondary crack in the same direction as the main crack propagation is obviously caused by tearing. The state of the crack is relatively large and deep, but the extended length is limited. During the tearing process, the crack propagates along the grain boundary or propagates through the crystal. Compared with the latter, the latter consumes more energy for crack propagation, and the energy of the crack itself is greatly reduced. The final crack will stop at the grain barrier. The secondary crack perpendicular to the direction in which the main crack propagates has a width, a length and a depth that are far less than the secondary crack in the same direction as the main crack. But the similarities between the two are that they are all in the place where the dimples gather, and they end up in the grain barrier. When the stress ratio is 0,6, the state in which the dimples appear is large and relatively dispersed, and there are secondary cracks extending in two directions. One is the same as the main crack propagation direction, and the other is perpendicular to the main crack propagation direction. The expansion is similar to the secondary crack when the stress ratio is 0,1.

CONCLUSION

(1) The fatigue crack growth rate da/dN of 42CrMo is related to the stress ratio R, and da/dN decreases with the increase of the stress ratio R.

(2) Increasing the fatigue strength of a material can be achieved by introducing a large number of microscopic obstacles, such as a grain refining method. In the first stage of crack propagation, the grain barrier must be overcome and passed through the grain boundaries. Therefore, surface mechanical treatments such as shot peening and surface rolling also introduce some microscopic obstacles.

(3) Reducing tissue defects in the material can effectively avoid the generation of fatigue cracks.

Acknowledgments

This research was funded by China Postdoctoral Science Foundation (NO. 2018M641186); Major Projects of Hebei Education Department (NO. 2018101002792); Supported by the Graduate Student Innovation Fund of North China University of Science and Technology (NO. 2019S28)

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Note: The responsible translator for English language is J W Dong-North China University of Science and Technology, China