Eling and Analysis of Torsion Shaft Fatigue Life of Armored Vehicles

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Abstract: This paper studies the fatigue life modeling of key parts of armored vehicle suspension system. The life modeling was carried out for the surface crack initiation and expansion of the torsion shaft, and the mathematical model of fatigue crack growth life was established based on Paris formula, and the numerical calculation and simulation under different torsion stresses were completed. The two-stage mathematical model can provide theoretical support for the life analysis of the torsion shaft.

1. Introduction

The torsion shaft is a key part of the armored vehicle suspension system. Due to its small size, large energy storage and harsh working conditions, it often breaks, which is one of the important reasons for the fault of the armored vehicle [1].

The torsion shaft bears large stress and torsion load at work. After the torsional axis is subjected to enough disturbance loads, a crack is formed from the local area of high stress or high strain, which is called crack initiation. After that, under the action of disturbance load, the crack expands further until it reaches the critical size and completely breaks. Therefore, the fatigue failure of the torsion shaft goes through three stages: crack initiation, crack stable growth and crack instability fracture. Since the crack propagation is rapid and has little effect on the life, it is not considered when calculating the life. Therefore, the total life should be the sum of crack initiation life and crack growth life [2].

2. Mathematical Model of Torsion Shaft Fatigue Crack Initiation Life

45CrNiMoVA material is commonly used in the torsion shaft of armored vehicles in China. Due to the small size of the sample itself, the fracture will occur soon after the initial crack exists. Therefore, the fatigue life of the torsional axis fatigue crack initiation can be determined by the fatigue life under the specified survival rate. The relationship between fatigue life and tensile stress is shown in equation (1) [3].

$$\log N_i = a_p + b_p \cdot \log\sigma \tag{1}$$

The torsion shaft is subjected to shear stress while working, and the relation between shear stress and tensile stress transformation can be determined by equation (2), namely:

$$\tau = k\sigma \tag{2}$$

Therefore, the mathematical model of fatigue crack initiation life is:

$$\log N_i = a_p + b_p \cdot \log(\tau / k) \tag{3}$$

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3. Mathematical Model of Torsion Shaft Fatigue Crack Growth Life

3.1. Crack Propagation Life Modeling based on Paris Formula.

According to the Paris theory, there is the following exponential relationship between the fatigue crack growth rate of the torsion axis da/dn and the stress intensity factor amplitude ΔK :

$$da/dN = C(\Delta K)^m \tag{4}$$

Where, the crack growth rate influence parameter C 、 m is the basic parameter to describe the fatigue crack growth performance of the material.

When a member has an initial crack of length a_0 , is subjected to the stress ratio R and maximum load $\sigma_{\max}$, the calculation formula is as follows [5]:

Stress intensity factor:

$$K = f\sigma\sqrt{\pi a_0} \tag{5}$$

Amplitude of stress intensity factor:

$$\Delta K = K_{\max} - K_{\min} = f(\sigma_{\max} - \sigma_{\min})\sqrt{\pi a_0} = f\Delta\sigma\sqrt{\pi a_0} \tag{6}$$

After judging the crack growth, calculate the critical crack length:

$$a_c = \frac{1}{\pi}\left(\frac{K_C}{1.12\sigma_{\max}}\right)^2 \tag{7}$$

Crack growth life:

$$N_c = \begin{cases} \dfrac{1}{C(f\Delta\sqrt{\pi})^m(0.5m-1)}\left(\dfrac{1}{a_0^{0.5m-1}} - \dfrac{1}{a_c^{0.5m-1}}\right), m \neq 2 \\ \dfrac{1}{C(f\Delta\sqrt{\pi})^m}\ln\left(\dfrac{a_c}{a_0}\right), m = 2 \end{cases} \tag{8}$$

Where,, f 、 ΔK_{th} and K_C are the stress intensity factor coefficient, threshold stress intensity factor amplitude and fracture toughness of the material respectively.

3.2. Determination of Parameters.

1) Stress intensity factor

Under the torsion load, the elastic stress distribution surface of the torsion shaft is the largest, and the surface crack is the main cause of fatigue fracture. The surface crack of torsion shaft is a three-dimensional crack problem and its shape is usually described by semi-ellipse. Since the crack size is small relative to the surface of the torsion shaft, it can be considered that the crack is located on the front surface of a semi-infinite plate. If the length is $2a$, the depth is b , and Irwin conditions are met, then the semi-ellipse surface stress intensity factor can be obtained as:

$$K = M_1\frac{\sigma\sqrt{\pi a}}{E(k)} \tag{9}$$

Where, M_1 is the correction coefficient of the front surface; $E(k)$ is the second kind of complete ellipse integral. Since the correction coefficient M_1 is difficult to be accurately determined, it can be further simplified [5]:

$$K = 1.03\frac{2\sigma\sqrt{a}}{\sqrt{\pi}} = (2.06/\pi)\tau\sqrt{\pi a} \tag{10}$$

2) Initial crack size at depth

The initial crack size can be determined by judging whether the torque axis expands under the given stress level, that is:

$$\Delta K \geq \Delta K_{th} \tag{11}$$

$$2.06(\sigma_{\max} - \sigma_{\min})\sqrt{a/\pi} \geq \Delta K_{th} \tag{12}$$

According to equation (12), it can be seen that:

$$a \geq (\Delta K_{th})^2 \cdot \pi / [2.06(\tau_{\max} - \tau_{\min})]^2,$$

Namely, the initial crack size is: $a_0 = (\Delta K_{th})^2 \cdot \pi / [2.06(\sigma_{\max} - \sigma_{\min})]^2$

4. Numerical Calculation and Simulation

The values of 45CrNiMoVA samples under the 99.9% survival rate were 20.2774 and -5.5723, respectively. The values of each parameter in the extended life mathematical model are:

$C = 5.63 \times 10^{-12} m/cycle$、 $n = 3.12$、 $\Delta K_{th} = 4.22$、 $K_C = 102.8\left(MPa\sqrt{m}\right)$.

The difference between torsional shear stress and residual stress is determined. The numerical calculation and simulation results of fatigue life are shown in table 1 and figure 1 respectively.

Table 1 numerical calculation results of torsion shaft fatigue life

Shear stress MPa	*800*	*850*	*900*	*950*	*1000*	*1050*	*1100*	*1150*	*1200*
Initiation life	3635	2593	1886	1395	1048	799	616	481	380
Extended life	71099	62980	56177	50419	45503	41273	37606	34407	31599
Total fatigue life	74734	65573	58063	51814	46551	42072	38222	34888	31979

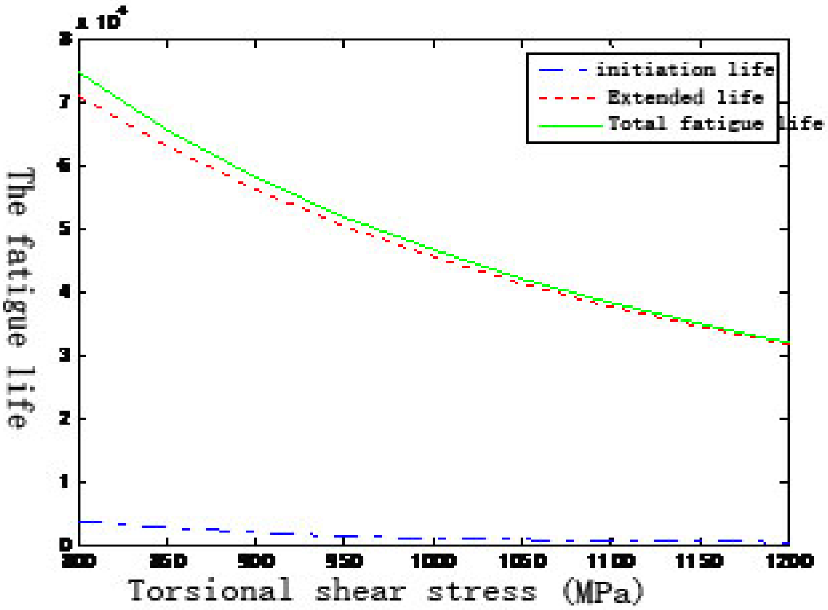

Figure 1. simulation results of torsion shaft fatigue life

5. Conclusion

According to the simulation results, it can be found that:

The percentage of torsion shaft crack initiation life in the total life is very small, that is, the life in the expansion stage accounts for the majority of the total life.

The torsional shear stress has a great impact on the fatigue life, with a life difference of more than 40,000 times within the span from 800 to 1200MPa. Therefore, the residual stress should be increased within an appropriate range to offset the reverse stress produced by the applied load and thereby reduce the total shear stress.

The calculation of torsion shaft fatigue life based on the mathematical model in this paper is in line with the actual test data of the fatigue testing machine. This model can provide theoretical support for the life analysis in the development process of torsion shaft.

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