

# A Study of Fatigue Property for FV520B-I at Different Loading Frequencies

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**Abstract.** Fatigue property of FV520B-I can be affected by the changing of the loading frequency. However, few theories about fatigue property for metal at different loading frequencies has ever been proposed. Experimental data are obtained from the conducted traditional experiment (140 Hz) and ultrasonic experiment (20 kHz). Fatigue property of high strength steel FV520B-I obtained by ultrasonic high-frequency fatigue testing method is higher than that by traditional low frequency testing. FV520B-I fatigue strength conversion model are established with comprehensive use of a fitting algorithm based on the combination of experimental data and classic three-parameter-model. The fatigue strength conversion coefficient  $C_0$  for FV520B-I is proposed. A clear understand of the effect of loading frequency on the fatigue property of FV520B-I is novel and has an important significance in guaranteeing the accuracy of the actual fatigue analysis of FV520B-I.

## 1. Introduction

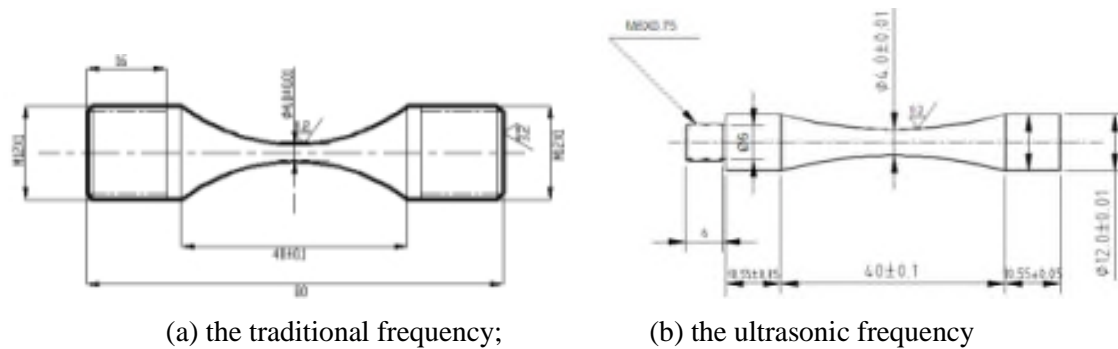
High strength metal FV520B-I has numerous good mechanical properties including high strength, high corrosion resistance, high abrasive resistance and good welding characteristics [1]. These properties make FV520B-I widely adopted in the manufacturing of centrifugal compressor vanes. The manufactured vanes are generally used under cyclic loading condition. So, the fatigue life of the used FV520B-I should be over  $10^7$  cycles and even reaches  $10^9$  or  $10^{10}$  cycles, a “giga-cycle” fatigue level [2-4]. Fatigue failure can cause serious accidents easily [5-7], which will lead to tremendous economic loss, significant impact on the mechanical system and even can threaten human life.

Traditional fatigue test system frequency is usually tens of hertz to several hundred hertz, which makes it hard to study fatigue properties in ultra-high cycle range [8, 9]. The emergence of ultrasonic fatigue test system makes the fatigue test loading frequency directly increased to 20KHz, the efficiency increased by 200 times, so that for various types of metal materials, ultra-high cycle fatigue research can be carried out. However, it was found that [10, 11] the fatigue properties of the materials obtained by the ultrasonic fatigue test method were higher than those under the traditional low-frequency fatigue conditions, and the fatigue failure mechanism under different loading frequencies was different. So the fatigue properties of the materials obtained under ultra-high frequency loading cannot be directly applied to the actual fatigue analysis. In this paper, ultrasonic fatigue test (20kHz) and traditional fatigue test (140Hz) were carried out for high strength steel FV520B-I respectively. A fatigue strength conversional model for FV520B-I at different loading frequencies was established. Using this model, the fatigue strength of the material obtained under the ultra-high frequency loading condition can be converted into the fatigue strength of the material under the conversional condition. So it is an important work which has important engineering significance in practical fatigue analysis.



## 2. Experiment

The ultrasonic fatigue experiment is carried out in USF-2000 ultrasonic fatigue test system with an operating frequency of 20 kHz, and the traditional fatigue experiment is carried out in PLG-100 with an operating frequency of 140Hz. The experiments are generally carried out under room temperature (20°C) and the mean-stress was zero which presented that the stress ratio  $r = -1$ , the stress amplitude interval is 25MPa. Standard fatigue test specimen must be used in two experiments, the geometrical shape of the specimen used in the test are shown in figure 1 (a) and figure 1 (b).



**Figure 1.** Specimen dimensions.

The chemical compositions and mechanical property of the FV520B-I specimens are displayed in table 1 and table 2 as below:

**Table 1.** Chemical compositions of the specimen.

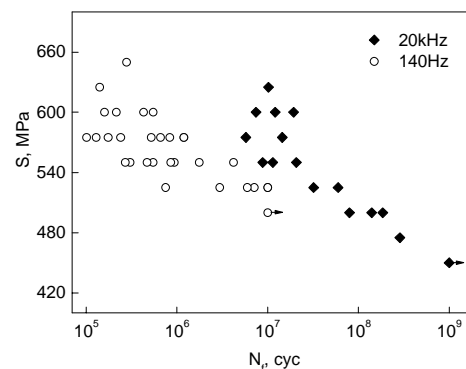
Chemical Elements	Si	C	Ni	Cu	Mn	S	Cr	Mo	Nb
Weight Percent/%	0.15-0.7	0.02-0.07	5-6	1.3-1.8	0.3-1	<0.025	13-14.5	1.3-1.8	0.25-0.45

**Table 2.** Mechanical property of FV520B-I.

Mechanical property	E/GPa	Rm/MPa	Rp0.2/MPa	HV/kgf.mm-2	A/%	$\rho$ /kg.m-3
Value	194	1180	1029	380	16.07	7.82x10 <sup>3</sup>

Note: E—elastic modulus, Rm—tensile strength, Rp0.2—yield strength, HV—Vickers hardness, A—shrinkage ratio,  $\rho$ —density.

## 3. Result and observation

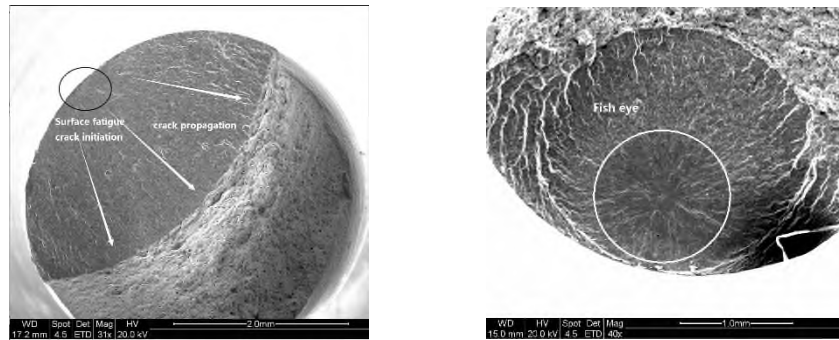


**Figure 2.** Experimental data.

The experimental data obtained from the traditional fatigue test (140 Hz) and the ultrasonic fatigue test (20 kHz) are shown in figure 2. It shows that when the fatigue life is at the same level, the

ultrasonic fatigue experiment will obtain the higher fatigue strength than the traditional one. The observations can be captured as shown in figure 3(a) and figure 3(b).

Figure 3 shows that the fatigue life is about  $7 \times 10^6$  cycles but the corresponding stress amplitudes are 525MPa (140 Hz) and 600MPa (20 KHz). GBF region and “fish-eye” can be observed clearly in the figure 3(b), which means that the fatigue failure was caused by internal inclusion. However, no such observations can be obtained from the traditional experimental fracture section, and the primary factor result in the surface fatigue failure is the surface defect, especially the surface roughness [12].



(a) The traditional observation (525MPa, 7.12e6); (b) the ultrasonic observation (600MPa, 7.44e6)

**Figure 3.** Specimen observation.

The observations and the experimental data show that the primary factors leading to the fatigue failure under 140 Hz and 20 KHz loading frequencies are different that imply that the FV520B-I fatigue properties under different loading frequencies are also different [13]. Therefore, the obtained fatigue properties data must be corrected under the impact of loading frequency before it can be applied to the fatigue analysis under the traditional condition.

#### 4. The influence of loading frequency on FV520B-I fatigue property

In the study of high-cycle and even very-high cycle fatigue problems, the three-parameter model [14] is widely used in the fitting of fatigue life S-N curve by virtue of the form flexibility and the ability of fitting data. The three-parameter model at the loading frequency of 20KHz and 140Hz can be expressed as follow:

$$\begin{cases} (S_H - S_{0H})^{\alpha_H} N_{fH} = C_H & \text{--- 20KHz} \\ (S_L - S_{0L})^{\alpha_L} N_{fL} = C_L & \text{--- 140Hz} \end{cases} \quad (1)$$

where  $S_{0H}$  and  $S_{0L}$  are the theoretical fatigue strength for 20KHz and 140Hz;  $\alpha_H$ ,  $C_H$ ,  $\alpha_L$ ,  $C_L$  are the undetermined coefficients for 20KHz and 140Hz;  $S_H$  and  $S_L$  are loading stress amplitudes (or fatigue strengths) for 20KHz and 140Hz;  $N_{fH}$  and  $N_{fL}$  are fatigue life for 20KHz and 140Hz. Six model parameters ( $S_{0H}$ ,  $\alpha_H$ ,  $C_H$ ,  $S_{0L}$ ,  $\alpha_L$ ,  $C_L$ ) for the material FV520B-I at 20KHz and 140Hz are obtained according to the experimental data in figure 2 and the equation (1) with the use of MATLAB curve fitting tool. The fitting results are shown in table 3.

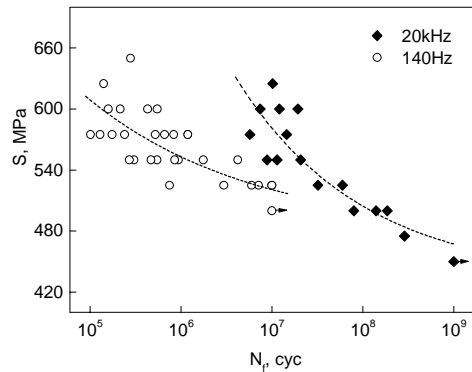
**Table 3.** Model parameters for FV520B-I.

Coefficient	$S_{0H}$	$\alpha_H$	$C_H$	$S_{0L}$	$\alpha_L$	$C_L$
Fitted Value	432.1	3.182	$8.3 \times 10^{13}$	476.7	4.187	$7.65 \times 10^{13}$

By substituting the parameters into the equation (1), the empirical three-parameter model formulas for FV520B-I with 20 KHz and 140 Hz can be written as:

$$\begin{cases} (S_H - 432.1)^{3.182} N_{fH} = 8.3 \times 10^{13} & \text{--- 20KHz} \\ (S_L - 476.7)^{4.187} N_{fL} = 7.65 \times 10^{13} & \text{--- 140Hz} \end{cases} \quad (2)$$

As shown in figure 4, the S-N curve of the FV520B-I ultrasonic fatigue test and the traditional fatigue test are obtained by the equation (2) after the results of the parameter fitting in table 3.



**Figure 4.** S-N curve from three-parameter model.

As the fatigue life for 20kHz is similar to the fatigue life for 140Hz, that is  $N_{fL} \approx N_{fH}$ , according to equation (1), the relationship between the corresponding fatigue strength ( $S_H$  and  $S_L$ ) can be expressed as:

$$(S_L - S_{0L})^{\alpha_L} = \frac{C_L}{C_H} (S_H - S_{0H})^{\alpha_H} \quad (3)$$

The ratio between the determined coefficients ( $C_L$  and  $C_H$ ) is the fatigue strength conversion factor, which can be expressed as:

$$C_0 = \frac{C_L}{C_H} = 0.922 \quad (4)$$

The final fatigue strength conversion model can be expressed as:

$$(S_L - 476.7)^{4.187} = 0.922(S_H - 432.1)^{3.182} \quad (5)$$

So the converted  $S_L$  can be calculated by substituting the ultrahigh loading frequency experimental data ( $S_H$ ) into equation (5), the results and the errors between their related fatigue life ( $N_{fH}$  and  $N'_{fL}$ ) are shown in the table 4.

**Table 4.** Fatigue strength conversion and the errors.

$N_{fH}/\text{cyc}$	3.21e7	2.07e7	1.45e7	7.44e6
$S_H$	525	550	575	600
$S_L$	507.4	513.5	519.3	524.8
$N'_{fL}$	4.54e7	2.13e7	1.15e7	6.90e6
Errors	41.43%	2.90%	20.69%	7.26%

Note:  $N_{fH}$ —Fatigue life experimental data for 20 kHz,  $S_H$ —Fatigue strength for 20 kHz,  $S_L$ —converted fatigue strength from 20 kHz to 140 Hz, —Fatigue life for 140 Hz related to  $S_L$  according to equation (2).

It can be seen from the data in table 4 that the errors between the fatigue life ( $N_{fH}$  and  $N'_{fL}$ ) obtained from three-parameter model in the low-frequency and the experimental fatigue life in the ultrahigh loading frequency are within the acceptable range, which satisfied the assumption that the fatigue life for 20kHz is similar to the fatigue life for 140Hz. Thus the fatigue strength conversion model (equation (3)) is established which can be used to convert the fatigue strength with different loading frequencies.

## 5. Conclusion

(1) The fatigue performance of FV520B-I obtained under ultrasonic fatigue test is better than that under the low frequency fatigue condition when the fatigue life is at the same range.

(2) Changes in loading frequency causes changes in cause of fatigue failure. Fatigue failure in ultrahigh loading frequency (20KHz) is mainly originated in the internal non-metallic inclusions, and in traditional loading frequency (140Hz) is mainly caused by surface roughness defects.

(3) Six model parameters ( $S_{0H}$ ,  $\alpha_H$ ,  $C_H$ ,  $S_{0L}$ ,  $\alpha_L$ ,  $C_L$ ) for FV520B-I are obtained which can be used in the fatigue analysis for the material FV520B-I.

(4) The fatigue strength conversion model of metal material at different loading frequencies is established (equation (3)), and the fatigue strength conversion coefficient  $C_0$  is proposed.

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