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an experimental study on the ratcheting behavior and fatigue life prediction of polyacetal under uniaxial cyclic loading

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Abstract

To study of effects of some parameters on the ratcheting strain and fatigue life of polyacetal, some experimental tests have been done applied by using Instron 8802 servohydrolic machine under uniaxial cyclic loading. All tests carried out in the stress-controlled mode and stress-strain data for each cycle recorded. Loading conditions are different as mean stress, amplitude stress so result different fatigue life. To show effect of stress on polyacetal fatigue life, stress function and damage parameters has introduced. Results showed the function predict fatigue life so good.

Keywords: Ratcheting, Fatigue, Life prediction, Polyacetal, Experimental test.

1. Introduction

The start of birth strength of material returns to second mid of 19th century and with showed of a relationship from Leve. To pay attention to experience of fracture and failure of structures even in loads less than yield limit, a branch with the name of fatigue in second mid of 20th century be came. So fatigue is a very important discuss to design structural engineering. Till now a lot of researches has been done for different materials and loading geometry. Finally in the end of 20th century or in another clause in 80's decade, researches in ratcheting behaviors started and continue [1]. A very important worry of facilities such as atomic power, plants, chemical industries, sea structural, parts of machine, metallic buildings and bridges structures under low cycle fatigue is unexpect and unforecastable failure.The cracks in machines' components can be created when were under cyclic loading such as an earthquake, bad weather or in situation with thermal stress. Engineering structures are usually under cycle loading. The loading can be in stress-control or strain-control mode. Fatigue phenomena is sensitive to tensile stress either in low cycle fatigue and high cycle fatigue. Positive mean stress grows up and increases cracks and lead to failure [2]. Ratcheting is a phenomena in which accumulation of deformation occurred while the loading is in stress-control mode with non-zero mean stress [3].
Nowadays supposing world without polymer is difficult. These materials create a large part of our lives and they use in many different thing in our life, industry, science and so on. Polyacetal, because of specific fatigue characteristic is in use as an engineering polymer. Thus, it is necessary to investigate it's behavior such as ratcheting behavior.

1. 2. HISTORY

The effect of average tensile stress, with and without ratcheting strain, on fatigue life had been investigated by Xia et al. in 1996 [4].In 2007, Tao and Xia [3] ran a experiment in order to study the ratcheting behavior of a epoxy resin, and its effects on the fatigue life. They recognized that the ratcheting strain and its accumulation rate were sensitive to stress amplitude and the average stress, and ratcheting strain also did not have any considerable influence on the epoxy fatigue life. In Hui and Chen’s article (2005) [5] the relation between loading rate and stress-strain response and also the ratcheting behavior of PTEE were studied. They founded that PTEE influenced by the rate of loading, only below 40 N/s. They also noticed that loading rate slightly influence on the ratcheting strain rate and at a certain stress amplitude (constant mean stress), a decrease in the mean stress (stress amplitude) leads to an increase in ratcheting strain and its rate of changes. In 2009 Zhang and Chen performed an experiment on cylinders with cyclic shear strain under axial stress at the ambient temperature. The effects of axial stress with the variation of shear strain and its rate were investigated and its history effect on the PTEE behavior was also studied. They founded that ratcheting strain and shear strain range related to shear strain rate. Furthermore, in constant axial stresses, ratcheting strain increased when shear strain range increased or shear strain rate decreased. In 2011 Shariati et al. [6] experimentally studied the behavior of polyacetal under uniaxial cyclic loading. They showed that the ratcheting strain and its rate were sensitive to imposed average stress and the stress amplitude. They also founded that the material showed a softening behavior in this condition. In order to apply the effect of average stress on the fatigue life of polyacetal, an average stress function was defined in terms of equivalent damage parameter, and all of the material constants were calibrated in regard to stress, strain and energy. They concluded that the stress and energy approaches better predicted the fatigue life of the polyacetal. In 2011, Shariati et al. conducted an experimental and numerical investigation on the softening behavior of the polyacetal under cyclic loading. The numerical solution was implemented by ABAQUS software, by use of advanced plasticity models, including isotropic hardening, linear kinematic hardening and nonlinear kinematic and isotropic hardening models [7].

2. Experimental Tests

2. 1. Specimens and test setup

To perform tests, specimen made according to ASTM E606-92 Standard. Specimen is made from 40 mm diameter polyacetal shaft. To have more accuracy and toughness, specimen manufactured by CNC lathe. The specimen geometry is shown in fig. 1. All tests carried out by using a servo hydraulic Instron 8802 machine, as shown in fig 2.

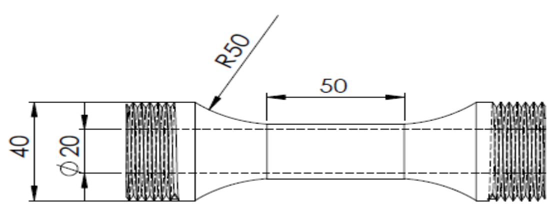

Figure 1: Specimen geometry (dimensions in mm)

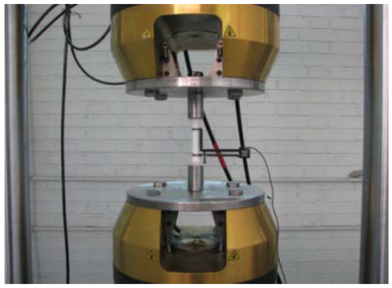
Figure 2: Servo hydraulic INTSRON 8802 machine

2. 2. Tensile Test

After performing tensile test, according to ASTM E 8-03 standard, Young modulus and yield stress of polyacetal calculated. These values are shown in table 1.

Table 1: Mechanical properties of polyacetal

Young modulus	$3100MPa$
Yield Stress	38.19 MPa
Yield Strain	1.57 %

2. 3. Test Setup

All test are in stress-control mode and ambient labratovary temperature. Because of sensitivity of ratcheting behavior to loading rate [8] and on the other hand, high rates increase the temperature and changes mechanical properties. So the loading rate has adjusted equal 8 KN/sec to have good situation. Ta apply loading rate it's necessary to obtain frequency. Frequency can be expressed as follows:

$$\Omega = \frac{\dot{\sigma}}{4F_{amp}} \tag{1}$$

Where Ω is frequency, $\dot{\sigma}$ is stress rates and F_{amp} is stress amplitude. In the table 2 loading condition is shown:

Table 2: Applied loading conditions

Force amplitude (kN)	Mean force (kN)	Test
5.95	5.95	T1
5.6	5.95	T2
5.95	5.6	T3
5.6	5.6	T4
5.25	5.6	T5
5.95	5.25	T6
5.6	5.25	T7
4.9	4.9	T8

Ratcheting strain can be expressed as equation (2):

$$\varepsilon_r = \frac{\varepsilon_{\max} + \varepsilon_{\min}}{2} \tag{2}$$

3. Results and Discussion

In this essay, two approaches for fatigue, stress and strain, introduced. In each one, by a relation like eq. (3) fatigue life relates to damage parameters [8].

$$\psi = \kappa.(N_f)^{\gamma} + \psi_0 \qquad (3)$$

Wher ψ is the damage parameter, N_f is the fatigue life, ψ_0 is fatigue limit and , γ are material constants.
As the damage parameter selected, which could be a function of the stress or strain.igue analysys can be analysezd with either the stress or strain.

3.1. Fatigue based on the stress approach

From refrence [26] a simple power law function for mean stress function can be introduced as equation (4)

$$f\left(\frac{\sigma_m}{\sigma_a}\right) = (1 + \eta\frac{\sigma_m}{\sigma_a})^n \qquad (4)$$

Where n and η are material constants.
By substituting $\sigma_m = 0$ in the relation (4), resulted $\sigma_{eq} = \sigma_{-1}$ that means in fully revesed tests, it's possible to use stress amplitude instead of effective stress. It's essential to say that in equation (4) just for n=1, the relation has physical meaning.
For fully reversed tests the relation is such as equation (5).

$$\sigma_{eq} = (1 + \eta\frac{\sigma_m}{\sigma_a})\sigma_a \qquad (5)$$

By fitting a curve from data to $\frac{\sigma_a}{\sigma_{-1}}$ vs. $\frac{\sigma_m}{\sigma_{-1}}$, η was determined.

$$\sigma_{eq} = \kappa.N_f^{\gamma} + \sigma_0 \qquad (6)$$

In the next step, by using the relation for stress, constants could be obtained. So the value of effective stress for all test calculated, then by using equation (5), a curve from data $\frac{\sigma_{eq}}{\sigma_a}$ vs $\frac{\sigma_m}{\sigma_a}$ fitted and η determined.
In the thereth step, by compositing constants eq. (5) completed and it shows fatigue life.
In this investigation, because fully reversed tests have not carried out, to present a relation for prediction fatigue life, the relation introduced by Shariati and et. All [5] used and tests in which amplitude stress and mean stress are the same are the base for the first step.

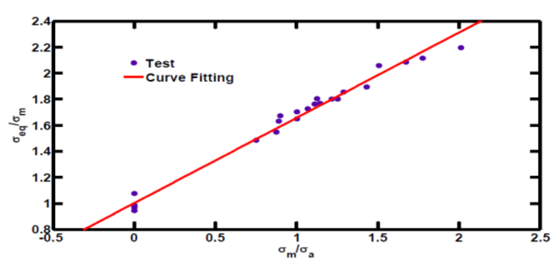

Figure 3:Function of mean stress based on the stress approach

By notice to fig 3 for data which $\frac{\sigma_m}{\sigma_a} = 1$, the value of $\frac{\sigma_{eq}}{\sigma_m}$ is equal 1.6 so by fitting effective stress vs fatigue life for the three tests is drawn and shown in fig 3.

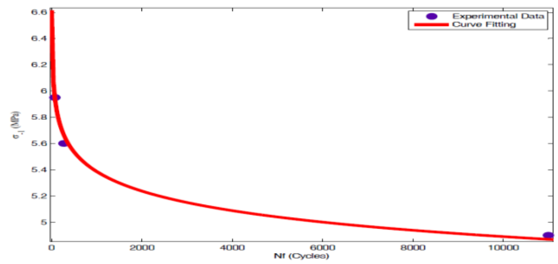

Figure 3: Interpolating power curve from equivalent stress vs. fatigue life

By interpolating with Matlab 7.1 constants like equation (7) calculated in which σ_0, γ and κ are equal 62.17, 0.003774 and -55.32 respectively.
Now it could be use equation (7) to changing tests' stress data to effective stress, the equation follows as:

$$\sigma_{eq} = -55.32 {N_f}^{0.003774} + 62.17 \tag{7}$$

By fitting a curve from the data to $\frac{\sigma_{eq}}{\sigma_a}$ vs. $\frac{\sigma_m}{\sigma_a}$, η was determined to be 0.002165.

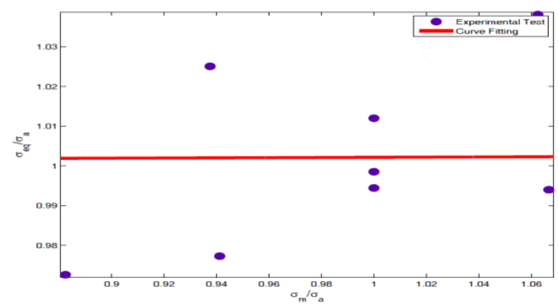

Figure 4:Function of mean stress based on the stress approach

Thus, to predict fatigue life base on the stress approach, the relation (8) introduced as follows:

$$(1 + 0.002165\frac{\sigma_m}{\sigma_a})\sigma_a = -55.32 {N_f}^{0.003774} + 62.17 \tag{8}$$

Experimental test and equation (8) is shown in fig. 5, that shows successful in prediction fatigue life.

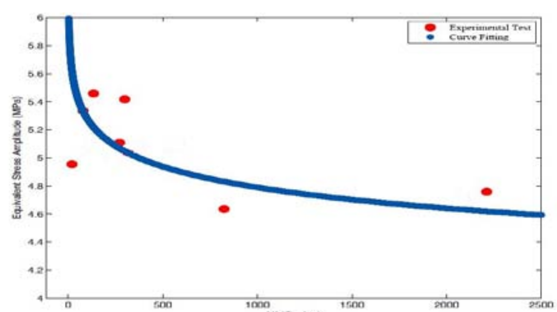

Figure 5:Equivalent stress amplitude vs. fatigue life

3.2. Fatigue based on the strain approach

Analyzing fatigue life based on the strain is another approach that, in continue explained. In this approach, like stress approach, a relation introduced and equivalent strain like equation (9) defined.

$$\varepsilon_{eq} = (1 + \eta \frac{\varepsilon_m}{\varepsilon_a})\varepsilon_a \tag{9}$$

During the stress- controlled test, the amplitude strain and mean strain are not constant. So the average values of mean stress and strain amplitude are in use.
The process is like previous section, stress approach, so it is not necessary to repeat again. Thus, in this section just relation and calculated values presented.
By interpolating the data, the equation (10) calculated.

$$\varepsilon_{eq} = \kappa . N_f^{\gamma} + \varepsilon_0 \tag{10}$$

Thus, ε_0 , γ and k values are 192.1, 0.0008329 and -189.6 respectively.

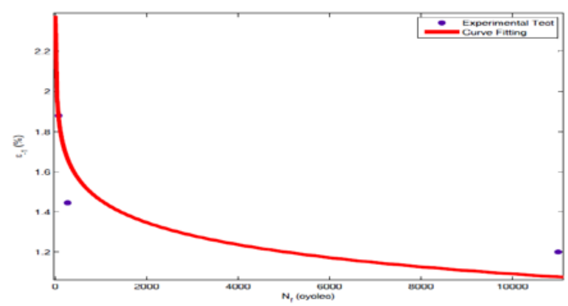

Figure 6: Interpolating power curve from mean strian vs. fatigue life

Now, by using equation (10), a relation to calculate effective strain obtained, so strain values for each test could be known.

$$f\left(\frac{\varepsilon_m}{\varepsilon_a}\right) = 1 + \eta \frac{\varepsilon_m}{\varepsilon_a} \tag{11}$$

By fitting a curve to the data $\frac{\varepsilon_{eq}}{\varepsilon_a}$ vs $\frac{\varepsilon_m}{\varepsilon_a}$ and interpolating by equation (11), η would be 0.08371.

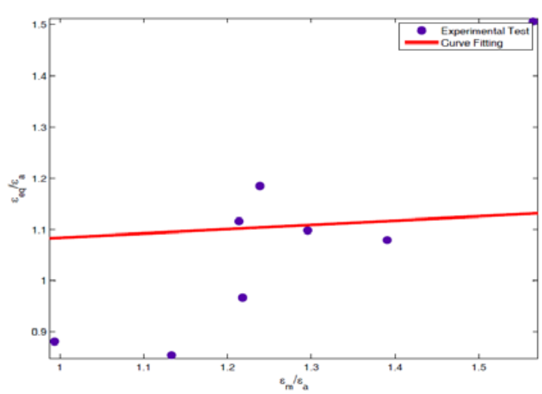

Figure 7: Function of mean strain based on the strain approach

At the end by composing equation (7) and equation (9) a relation to estimate and prediction of fatigue life like equation (12) obtained.

$$-189.6.N_{\mathrm{f}}^{0.0008329} + 192.1 = (1 + 0.08371\frac{\varepsilon_m}{\varepsilon_a})\varepsilon_a \quad (12)$$

Diagram of equation (12) in fig. 8 is drawn.

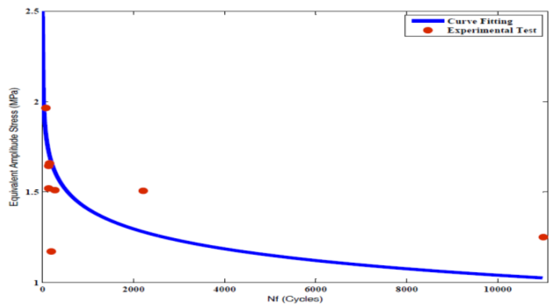

Figure 8: Equivalent strain amplitude vs. fatigue life

4. Conclusion

By comparing two diagram 6 and 9 results the two approaches can predict fatigue life. It's obvious that stress approach is more successful than strain approach in prediction.

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