Cyclic Deformation and Stress-Strain Characteristics of 38XH3MΦA Steel

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Abstract

In this paper, the cyclic plastic behaviors such as cyclic hardening and cyclic creep of special steel garde 38XH3MΦA are studied. Tensile test (uniaxial monotonic test) has been conducted to get mechanical properties of the materials. Cyclic deformation tests were carried out for specimens bearing uniaxial load over materials yield limit in cyclic tension-compression with both strain – controlled and stress – controlled methods. The obtained stress – strain loops were used to identify the cyclic hardening parameters, the Bauschinger effect and cyclic creep characteristics of the steel. The experiment results show the good mechanical properties of 38XH3MΦA steel and its capabilty to endure cyclic deformation.

Keywords: Hardening rule, cyclic hardening, 38XH3MΦA steel, Bauschinger effect.

1. Introduction

38XH3MΦA steel (GOST 4543-71) belongs to a group of special steels that are used for heavy duty or high impact components such as high pressure vessels, gun tube, artillery barrel [1-3]. Normally, with these important components numerical simulation of their mechanical behaviour must be conducted during designing phase. Therefore the hardening rule and hardening parameters need to be provided into the simulation programme [4].

Moreover, these components often work under cyclic loads, therefore shakedown character of workpieces made of 38XH3MΦA steel must be considered during designing component from this steel, because component's service life is nominally characterized as a function of the strain range and shakedown character [6]. When the steel is subjected to cyclic loading i.e loading followed by unloading and subsequent reloading, the response changes cycle by cycle until its gets saturated. The ratcheting (cyclic creep) can be defined as accumulation of steel with increasing number of cycles and can influence the fatigue life of mechanical parts due to the exhaustion of plastic ability of material earlier than the initiation of fatigue crack caused by low-cycle fatigue [5].

The hardening rule and cyclic behavior of 38XH3MΦA steel are not provided by foreign suppliers or shown in academic documents due to the involving of this steel in weapon manufacturing. These informations also must be clarified when we produce this type of steel. This work presents tests on 38XH3MΦA steel and shows various cyclic plastic behavior of the materials that are Bauschinger effect, cyclic hardening and ratcheting or shakedown.

2. Experiments

Sample for experiment is a rounded bar Φ200 mm x 300 mm, provided by factory Z27, Thai Nguyen City. The heat treatment of sample to obtain high strength with good ductility is as follows: quenching from 860 ^{0}C in oil plus tempering at 680 ^{0}C for 4 hours. From this, spiecemens were cut for mechnical and chemical composition testings. The test on chemical composition was done by DOS method in Military Technical Academy: C ≈ 0,385; Si ≈ 0,22; Mn ≈ 0,39; P ≈ 0,017; S ≈ 0,008; Cr ≈ 1,45; Ni ≈ 3,3; Mo ≈ 0,45; Fe - balace. According to standard GOST 4543-71, the sample has chemical composition equivalent to 38XH3MΦA steel (GOST 4543-71). This is an alloyed steel of high quality with very low concentration of impurities P, S.

Cylindrical specimens with diameter of 10 mm and gauge length of 100 mm (Fig. 1) were machined from the provided sample. These specimens were used for all three tests: tensile test, cyclic plastic test and ratcheting test on servo hydraulic universal testing machine MTS-350 at Ho Chi Minh city University of Technology. The testing process is controlled with a specialized computer software that can give test results in different fromat ready for further processing. The constant strain rate of the test with equipmet MTS350 was controlled by providing a constant movement speed of the machine's crosshead, and this strain rate was kept to be small in all cases.

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Fig. 1. Rounded specimens for tensile test

The monotonic tensile test has been performed in displacement-controlled mode in accord-ance with ISO 6892:1998 standard with displacement rate of 0.2 mm/min. The obtained stress – strain curve is used for calculating the strength coefficient and hardening exponent beside showing the strength and ductile of the materials.

To characterize the hardening properties of the materials, completely reversed strain controlled cyclic plastic tests were performed. The strain-controlled tests were performed on the specimens with symmetric tension-compression strain cycles at different strain limits: $\Delta\varepsilon = \pm 0.50\%$, $\pm 0.60\%$, $\pm$ 0.80%, $\pm$1.00% (Fig. 2). During tests, a sinusoidal wave shape was used to control a constant strain rate of 10^{-2}/s and the stress – strain curves were recorded.

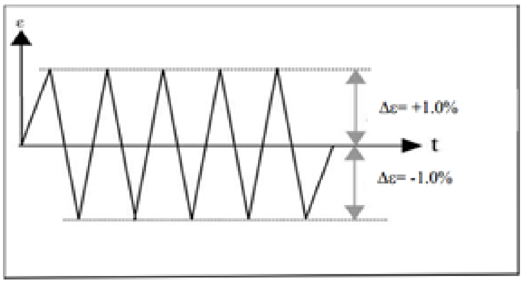

Fig.2.Loading history during strain controlled test.

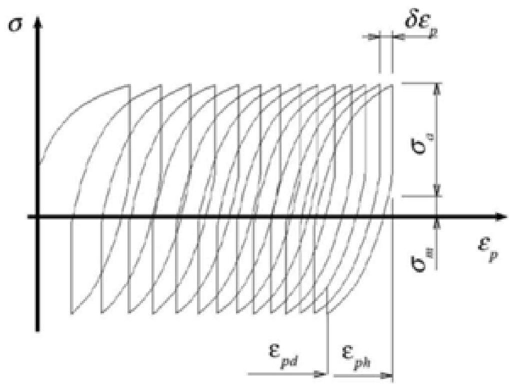

Fig. 3. Loading scheme for ratchetting test

Beside the tests with symmetry load, a test with assymmetry load was also conducted. This is an uniaxial test under load controll with non-zero mean stress σ_m, therefore the accumulation of axial plastic strain can occur cycle by cycle. This effect is called cyclic creep or ratcheting, see Fig.3. The uniaxial ratcheting is characterized by an open hysteresis loop and it is a result of different nonlinear behaviours of the materials in tension and compression. In the test with 38XH3MΦA steel, a cyclic asymmetry load scheme was applied with maximal peak of 910 MPa and minimal peak of stress of -900 MPa.

3. Results and discussion

Stress and plastic strain data obtained between the yield point and the ultimate point are used to find the strength coefficient “K” and hardening exponent “n” in the stress – strain relation: $\sigma = K.\varepsilon^n$. To do this, strain and stress data is transformed into the logarithmic scales and the exponential function is mapped onto a straight line: $\log \sigma = \log K + n \log \varepsilon$. The strain hardening exponent (n) and the strength coefficient (K) are calculated from the log σ – log ε data by the least square method. The tesile test results and related materials parameters are displaed in Table 1.

Table 1. Materials parameters from tensile test

E, GPa	σ_y, MPa	σ_B, MPa	δ, %	$\sigma = K\,\varepsilon^n$	
				K	n
210	805	1100	22	2665	0.3

Fig. 4a to Fig. 4e are hysteresis stress – strain loops for different strain amplitudes in a uniaxial cyclic test of 38XH3MΦA steel at strain rate of 10-2/s at room temperature. In these tests, materials are applied initially with a tension stress higher than tension yield stress, then the load is reversed to compress the materials through the yielding state and the cycle is repeated. Data from these tests shows a Bauschinger effect that yielding in compression starts at stress lower than tension yield stress. For example, in Fig. 4d, the yielding in the initial tension corresponds to point 1 (805 MPa), but in subsequent compression yielding point is point 2 (780 MPa) and in the following tenssion falls at point 3 (784 MPa). Therefore, the hardening rule of this steel can be characterized by kinematic hardening rule. To the first approximation from these test data, the bilinear kinematic hardening parameters for this steel are as follows: Young module – 210 GPa, yield limit – 805 MPa and secant tangent – 30 GPa. These figures show that hysteresis loops become symmetry and stable after about 40 cycles and the materials comes to an equilibrium condition for the imposed strain amplitude. These are evidences about the presence of Bauschinger effect in both compression and tension uniaxial tests [6]. The results shown that, with strain amplitudes from 0.5% to 0.8% materials have an initial hardening and then softening before failure. Meanwhile with strain amplitude of 1.0% materials shows secondary hardening before failure. Also, it can be observed that cyclic hardening rate increase with strain amplitude [7].

The stress-strain response of 38XH3MΦA steel during cycle asymmetry soft loading is shown in Figure 5. The calculated mean stress and stress amplitude in this case are 5 MPa and 905 MPa respectively. This result is an evidence of a non-linear behavior of tested steel when subjected to cyclic load. Therefore, to fully simulate the cyclic behavior of this steel, more complicated materials models should be used. This will be investigated in our further studies.

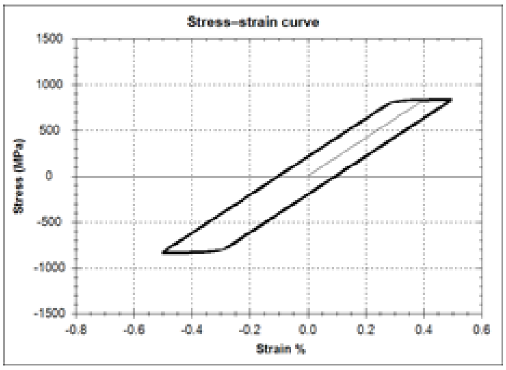

Fig.4a. Stress – strain loop for strain aplitude ε=0.5%.

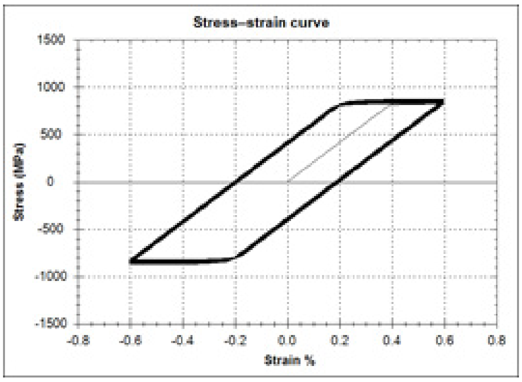

Fig.4b. Stress – strain loop for strain aplitude ε=0.6%.

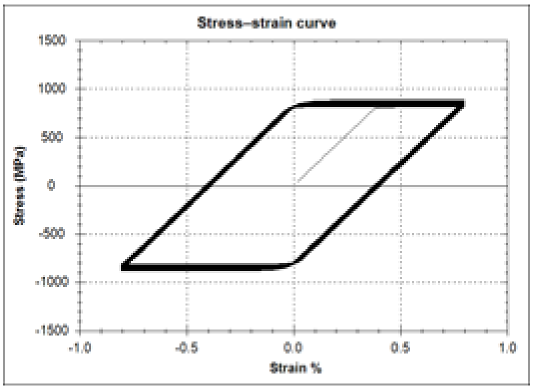

Fig.4c. Stress – strain loop for strain aplitude ε=0.8%.

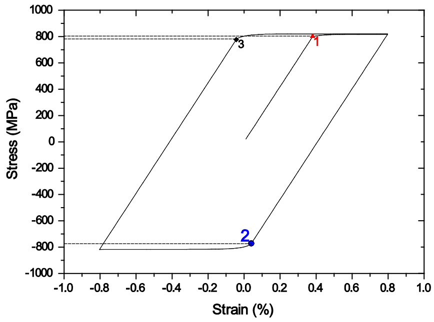

Fig.4d. Stress – strain loop for strain aplitude ε=0.8% (only the first cycle is plotted and yield points are marked).

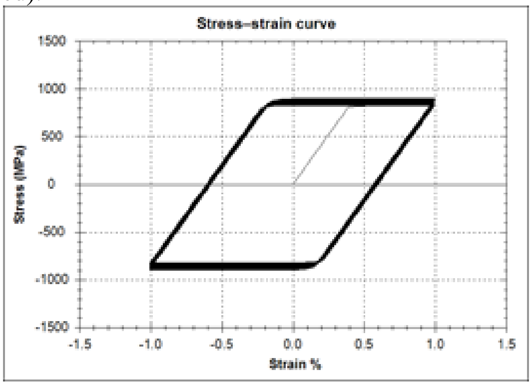

Fig.4e. Stress – strain loop for strain aplitude ε=1%.

Moreover, the stress – strain curves under this asymmetry cyclic load tend to come to stabilization after about 80 cycles. This shows the shakedown ability of the materials under asymmetry loading, even under stress amplitude higher than its yield stress for this case. This means that even at this high level loading, dimensions of work piece from this steel can be stabilized after a certain number of load cycles [8].

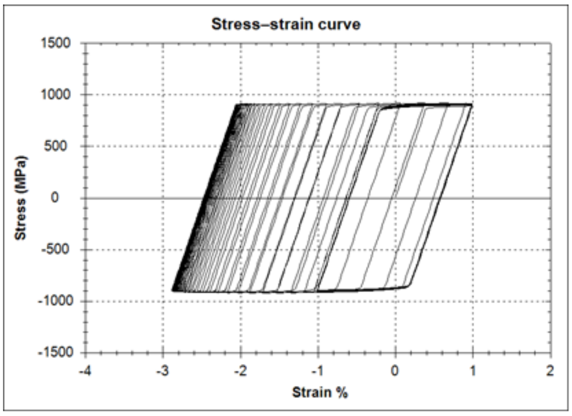

Fig. 5. The stress-strain response of 38XH3MΦA steel during cyclic asymmetry soft loading.

4. Conclusion

Characteristics of cyclic plastic behavior of 38ХН3МФА steel have been evaluated by experiment observation. Those are Bauschinger effect and cyclic hardening and also ratcheting behaviour. Static strength characteristics and cyclic hardening perameters were calcalated from test results. The obtained data can be used in numerical simulation of components made from 38ХН3МФА steel under cyclic load by the finite element method.

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