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Uniaxial Ratcheting of Mild Steel under Cyclic Tension

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***Abstract*- Uniaxial ratcheting characteristics of mild steel at room temperature are studied experimentally. Cyclic tension tests, in which maximum strain increases every cycle by prescribed amounts, are conducted systematically in addition to conventional monotonic, cyclic and ratcheting tests. Thus the effects of mean stress and stress amplitude on the ratcheting behavior of mild steel are discussed. The cyclic tension tests reveal that at the same stress amplitude (mean stress), the ratcheting strain increase as mean stress (stress amplitude) increased.**

I. INTRODUCTION

Strain accumulation induced by cyclic loading, i.e., ratcheting, is important in designing structural components. Ratcheting taking place under uniaxial cyclic loading with nonzero mean stress is referred to as uniaxial ratcheting, which is most fundamental and has been studied in many works [1]. For 304 and 316 stainless steels, uniaxial ratchetting experiments have been reported by Yoshida et al. [2], Chaboche and Nouailhas [3,4], Ruggles and Krempl [5], Sasaki and Ishikawa [6], Delobelle [7], Haupt and Schinke [8], and so on.

Many engineering components often endure tension cyclic loading during their service. The component will be subject to cyclic creep under asymmetrical load. The accumulation of cyclic deformation is also called ratcheting. On the other hand, the ratcheting phenomenon is defined as a cycle-by-cycle accumulation of plastic strain with the application of cyclic load characterized by constant stress amplitude with a nonzero mean stress. After a sufficient number of cycles, the total strain (displacement) become so large that the original shape of the structure is altered, thereby making the structure unserviceable. The typical repetitive loading for ratcheting and shakedown is shown in Fig.1 [9].

Ratcheting, namely cyclic plastic strain accumulation is a phenomenon that can occur in a structure subjected to a primary load with a secondary cyclic load. Severe ratcheting may lead o failure due to either excessive deformation or ratcheting and fatigue interaction.

Shakedown occurs if the behavior of the mechanical structure always cease to develop further and the accumulated dissipated energy in the whole body remains bounded such that the body responds purely elastically to the applied variable loads. Except for the first loading cycle during which plastic strains may occur, the strain just increase for the first cycle and the second cycle. No further deformation increment occurs on the application of a loading cycle. Shakedown will occur when the ratcheting fails to occur [9].

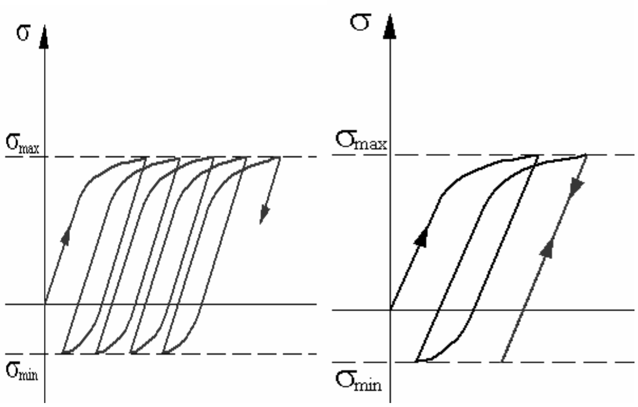


Fig. 1: a) Ratcheting phenomenon, and b) Shakedown phenomenon.

Under the asymmetrical load, the component may fail because of its unacceptable ratcheting deformation. To establish an accurate constitutive model to evaluate the accumulated deformation of a structure, it is essential to study ratcheting behavior farther for the materials. Recently, a considerable number of ratcheting experiments, including uniaxial and multiaxial ratcheting, has been conducted on various materials. The effects of different loading paths on the cyclic behavior and ratcheting mechanism were also carefully observed. Factors, such as mean stress, stress (strain) amplitude and their histories were revealed to relate to the ratcheting strain.

In the present work, therefore, the uniaxial ratcheting characteristics of mild steel in cyclic tension at room temperature are studied. The effects of loading rate, mean stress and stress amplitude on the ratcheting behavior of mild steel are discussed.

II. MATERIAL AND EXPERIMENT PROGRAM

The specimens tested had gauge sections 8 mm in diameter and 30 mm in axial length. They were machined from mild steel rolled sheet 50 mm in thickness, so that they had the axis oriented in the rolling direction of the sheet. The sheet had the chemical composition shown in Table 1.

TABLE I
CHEMICAL COMPOSITION OF MILD STEEL (%)

C	Si	Mn	P	S	Ni	Cr	Mo	Cu
0.05	0.12	0.15	0.044	0.011	0.11	0.035	0.005	0.24

In the ratcheting test, the controlled variable was axial load (which implied controlling the stress of the specimen when the deformation of the specimen was not so large, e.g less than 2%). In a simplified way, Fig. 2 shows the diagram of input stress against time during the uniaxial ratcheting test. The specimen was subjected to cyclic loading with $\sigma_m + \sigma_a$, where σ_m is mean stress and σ_a is amplitude stress.

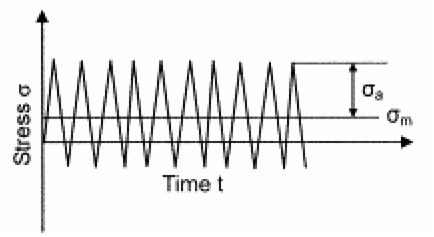


Fig. 2: The diagrams of input stress against time under the stress cycling.

Due to the unclosed hysteresis loops of the asymmetrical stress-controlled cycling, the ratcheting strain, ε is defined the average of maximum strain and minimum strain, the formula is given as :

$$\varepsilon = \frac{1}{2}(\varepsilon_{\max} + \varepsilon_{\min})$$

where $\varepsilon_{\max}$ is the maximum of axial strain in each cycle, $\varepsilon_{\min}$ is the minimum. The rate of ratcheting strain is defined as dε, where the increment of ratcheting strain, ε in each cycle.

In order to determine the cyclic load, the mean stress was set as $0.67\sigma_y$, where σ_y is yield stress. Thus, according to the monotonic tensile test result, the uniaxial ratcheting testing can be conducted with a multi-step loading of stress.

Ratcheting experiment was conducted in a universal testing machine, under load control. The loading waveform was triangular. The displacement was measured by strain gauges during the test as shown in Fig. 3. Fig. 4 shows the schematic diagram of experimental setup for the ratcheting test. All specimens were subjected to cyclic loading with $\sigma_m + \sigma_a$. Loading conditions are shown in Fig. 5.

(a) Universal testing machine (b) specimen with strain gauges

Fig. 3: Specimen and machine

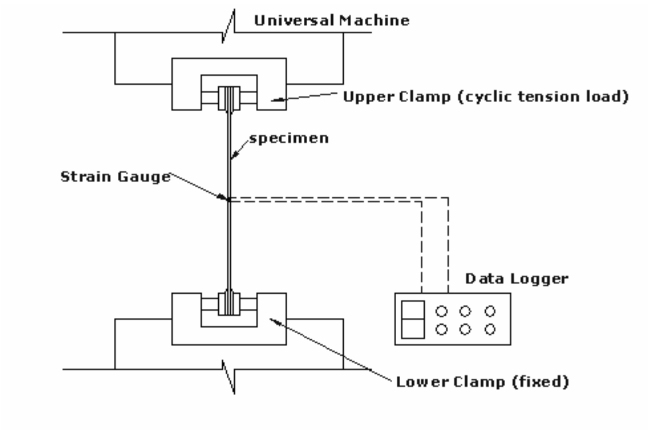
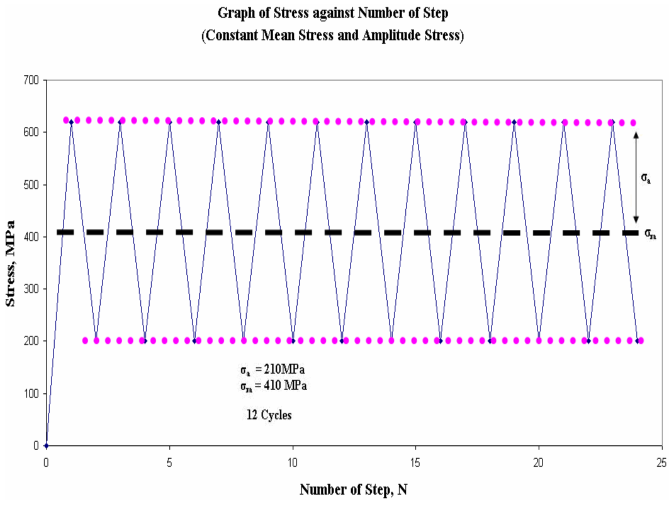
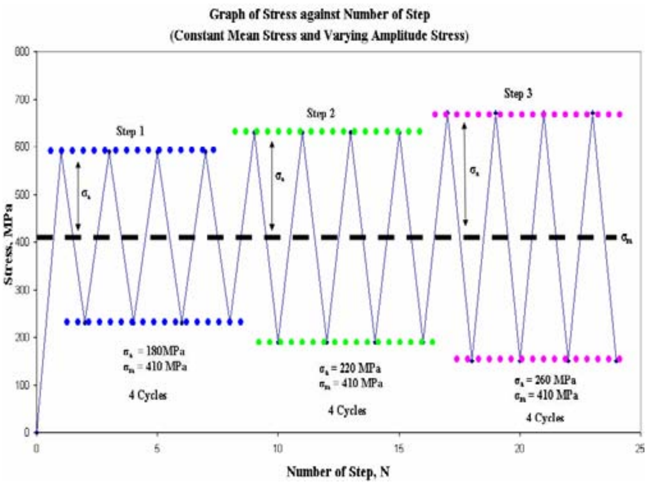


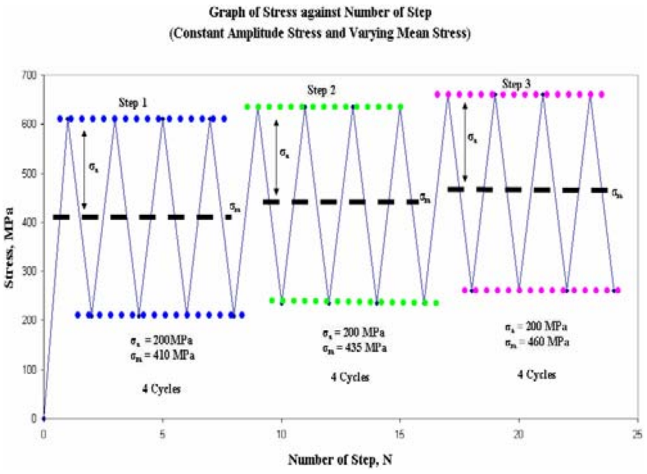
Fig. 4: Schematic diagram for ratcheting test.



(a) Constant mean stress and amplitude stress.



(b) Constant mean stress and varying amplitude stress.



(c) Varying mean stress and constant amplitude stress.

Fig. 5: Loading conditions

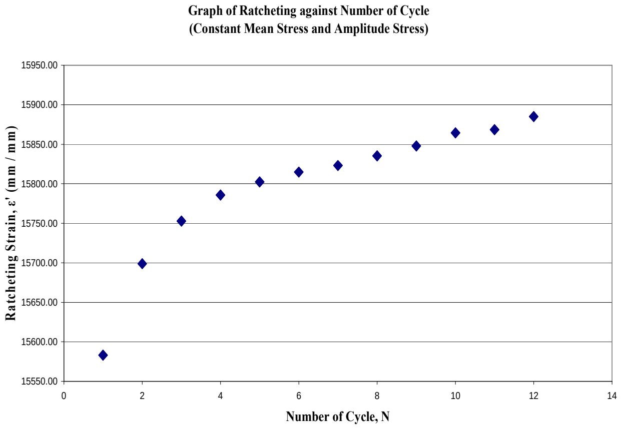
III. RESULT AND DISCUSSION

The main interest in this study is to examine how factors such as the mean stress, the amplitude stress, and ratcheting rate influence the ratcheting behavior of mild steel bar. A series of ratcheting tests were conducted with stepwise variation of control variables. These test comprising of loading steps with alternating tensile and compressive mean stresses and constant stress amplitude.

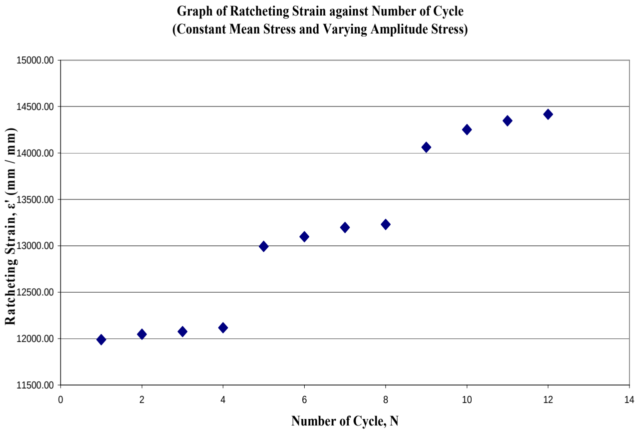
Fig.6 (a) shows the graph of ratcheting strain against number of cycle. It is shown that the ratcheting strain increases when the number of cycle is increased. During the initial stage, the graph shows clear that ratcheting strain increases rapidly. Then, the ratcheting strain become constant and the ratcheting rate decrease as compare to initial stage. The average ratcheting rate in steady state condition was found as 12.41μ. It is about 58% decrease if compared to initial stage where the true ratcheting rate is about 50.7μ. For the following cycles, the increasing of ratcheting strain is almost constant.

Fig. 6(b) shows the results of ratcheting test at the same mean stress and different stress amplitudes. It is shown that ratcheting strain increases with increased stress amplitude, and the cyclic saturation value of ratcheting strain increases also. The average ratcheting rate for each increment of stress amplitude was found increases as 42.7μ, 78.6μ and $118.6\ \mu$.

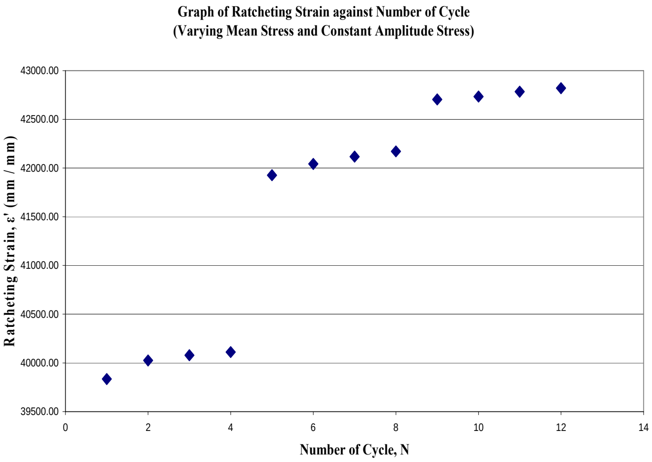
Fig. 6(c) shows the results of ratcheting tests at the same stress amplitude and different mean stress. At the same stress amplitude, ratcheting strain increases with increased mean stress, and the cyclic saturation value of ratcheting strain increases also. However, mean stress has more effect on ratcheting strain than stress amplitude. The ratcheting strain of the first cycle is the greatest and the average increment of ratcheting strain for each subsequent cycle became smaller with 92.4μ, 81.3μ and $38.6\ \mu$.



(a) constant mean stress and constant amplitude stress.



(b) constant mean stress and varying amplitude stress.



(c) constant amplitude stress and varying mean stress.

Fig. 4: Uniaxial ratcheting strain

IV. CONCLUSION

Based on the current investigation, the following conclusions can be drawn:

1. At the same stress amplitude, ratcheting strain increased with increasing mean stress. The higher the mean stress, the faster the ratcheting strain develops. The ratcheting rate increases with the number of cycle increased.

2. Meanwhile, at the same mean stress, ratcheting strain increased with increasing stress amplitude. However, mean stress has more effect on ratcheting strain than stress amplitude. The increment of ratcheting strain decreased when the stress amplitude increased.

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REFERENCES

[1] M. Mizuno, Y. Mima, A.B. Karim, N. Ohno, "Uniaxial ratchetting of 316FR steel at room temperature, Journal *of Engineering Materials and Technology*, vol. 122, pp.29-34, 2000.

[2] Yoshida, F., "Uniaxial and biaxial creep-ratchetting behavior of SUS304 Stainless Steel at Room Temperature," *International Journal of Pressure Vessels and Piping,* vol. 44, pp. 207–223, 1990.

[3] J.L. Chaboche, D. Nouailhas, Constitutive modeling of ratcheting effects, part†: experimental facts and properties of the classical models, *ASME Journal of Engineering Material and Technology*, vol. 3, pp. 384–392, 1989.

[4] J.L. Chaboche, D. Nouailhas, Constitutive modeling of ratcheting effects-part II: possibilities of some additional kinematical rules, *ASME Journal of Engineering Material and Technology*, vol. 111, pp. 409–416, 1989.

[5] Ruggles, M. B., and Krempl, E.,"The Interaction of Cyclic Hardening and Ratchetting for AISI Type 304 Stainless Steel at Room Temperature—I: Experiments," *Journal of the Mechanics and Physics of Solids,* Vol. 38, No. 4, pp. 575–585, 1990.

[6] Sasaki, K., and Ishikawa, H., "Experimental Observation on Viscoplastic Behavior of SUS304 (Creep and Ratchetting Behavior)," *Transactions of the Japan Society of Mechanical Engineers,* Series A, Vol. 59, No. 562, pp. 39–45, 1993.

[7] Delobelle, P., Robinet, P., and Bocher, L., "Experimental Study and Phenomenological Modelization of Ratchet under Uniaxial and Biaxial Loading on an Austenitic Stainless Steel," *International Journal of Plasticity,* Vol. 11, No. 4, pp. 295–330, 1995.

[8] Haupt, A., and Schinke, B., "Experiments on the Ratchetting Behavior of AISI 316L(N) Austenitic Steel at Room Temperature," *ASME Journal of Engineering Material and Technology*, Vol. 118, No. 3, pp. 281–284, 1996.

S.C.Kulkarni, Y.M Desai,T.Kant, G.R.Reddy, P.Prased, K.K.Vaze, and C.Gupta, J., "Uniaxial and Biaxial Ratcheting in Piping Material-Experiments and Analysis", *Journal of Pressure Vessels and*