Materials Science & Engineering A 679 (2017) 66–74

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Ratcheting fatigue behaviour of 42CrMo4 steel under different heat treatment conditions

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ARTICLE INFO

Keywords:
Ratcheting
Heat treatment
Grain size
TEM
Dislocation density

ABSTRACT

In the present investigation uniaxial ratcheting behaviour of the 42CrMo4 steel has been investigated at ambient temperature using different combinations of mean stresses (σ_m) and stress amplitudes (σ_a) in two different heat treatment conditions. The results indicate that the ratcheting strain increases with increase in number of cycles for all combinations of σ_m and σ_a in both annealed and normalized conditions. Further, the value is less in the normalized condition and is attributed to the rapid attainment of stable dislocation configuration with fine grained structure accompanying it. The specimens subjected to ratcheting exhibit smaller grain size than the undeformed one and it decreases with increase in stress parameter. TEM results indicate that the dislocation substructure varies from thin stripes to walls and then to cells, as the cyclic load continuously increases. The tensile strength of the ratcheted samples reduces compared to the unratcheted one owing to cyclic softening associated with the steel in both annealed and normalized conditions.

1. Introduction

The 42CrMo4 steel is widely used as a structural material for the purpose of designing automotive components which are frequently subjected to various kinds of static as well as cyclic loadings. In practical application a component may be subjected to varying magnitudes of cyclic loading in particular, or a combinations of cyclic and static loadings. It is therefore necessary to assess the influence of unusual cyclic loading and associated effects on mechanical properties of the steel for ensuring safety during applications. The conventional cyclic fatigue experiments are generally low or high cycle fatigue. However, the recent advancement in the field is ratcheting, wherein effect of mean stress on the accumulation of plastic strain are analysed. It is reported in literature that accumulation of ratcheting strain is strongly dependent on the magnitude of mean stress during cyclic loading. The strain accumulation becomes positive/negative when the applied mean stress is positive/negative [1,2]. In fatigue, damage accumulation by ratcheting is significant because the accumulated ratcheting strain might cause additional damage, resulting in shorter fatigue life [1].

Thus, ratcheting may be inferred as one of the important deformation mechanisms in engineering components. It is manifested by changes in the internal structure of the material and modification of the stress–strain response. Microstructures, grain size variation, and increment in dislocation density are figured as mechanism of fatigue [2,3]. The steel under investigation has very extensive use in engineering practice and therefore, few researchers studied various mechanical behaviour properties of it. However, the ratcheting behaviour of the steel is still not clear with respect to structural alterations. Severe changes of substructure and accompanying variation of mechanical properties of bcc materials are usually limited [4]. Researchers [5–16] carried out experimental investigations as well as simulations on the 42CrMo4 steel. However, the studies were only based on mechanistic approaches. The influence of varying microstructure, grain size and substructural features on ratcheting behaviour of the steel is not existing in literature.

Therefore, in this work, ratcheting behaviour of the annealed and normalized 42CrMo4 steel has been investigated by uniaxial stress controlled cyclic loading with non-zero mean stress. The characteristics variation in cyclic stress–strain response and microstructural features such as alteration of grain size, substructural change in terms of dislocation density has been studied. Strain accumulation with varying stress parameters has been correlated with induced dislocation densities, by using transmission electron microscopy (TEM).

2. Experimental procedure

The 42CrMo4 steel used in this investigation was in the form of 16 mm diameter rod. Chemical composition of the steel is C-0.384, Cr-0.926, Mo-0.225, Mn-0.678, Si-0.210, S-0.020, Al- 0.035, and Fe-

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http://dx.doi.org/10.1016/j.msea.2016.10.019
Received 25 May 2016; Received in revised form 28 September 2016; Accepted 5 October 2016
Available online 06 October 2016
0921-5093/

balance (wt%). Specimens cut from the as-received steel were annealed and normalized for achieving different grain sizes. This was done by heating the specimen at 900 °C for 1 h followed by furnace cooling for annealing and air cooling for normalizing. Microstructures of the steel under annealed and normalized conditions were observed by an optical microscopy, (Model: Olympus BX61) after usual metallographic polishing followed by etching with 2% nital. Specimens were fabricated from the heat treated steel rods according to ASTM standards E8M for tensile and E606 for fatigue tests.

Tensile tests were conducted at ambient temperature by employing a servo-hydraulic universal testing machine (Model: BISS-100 kN) at a crosshead speed of 1 mm/min. The cross head speed corresponds to a nominal strain rate of 6.66×10^{-4}/s. Ratcheting tests were carried out using different combinations of mean stress (σ_m) and strain amplitude (σ_a), at a stress rate of 50 MPa/s. The values of σ_{max} were 60%, 70% and 80% of the ultimate tensile strength (UTS) of both the annealed and normalized samples. The various combinations of the σ_m and σ_a adopted for different tests are shown in Table 1. For brevity, in the current report combinations of mean stress and stress amplitude are represented as MxAy; where ‘M′ stands for mean stress, ‘A′ stands for stress amplitude and ‘x′, ‘y′ are the corresponding stress values. For example, M40A360 stands for the test done with σ_m=40 MPa and σ_a=360 MPa. The total numbers of loading cycles during each fatigue test were 200 and the specimens were then subjected to post-fatigue tensile tests. About 250 data points per cycle were collected for constructing the stress–strain hysteresis loops. The strain measurements during all the ratcheting tests were carried out using a 12.5 mm dynamic extensometer (Model: BISS, AC-07–1110). Fractographic studies of the broken tensile samples were carried out by using scanning electron microscope (Model: JEOL JSM-6480L). In order to observe the substructural variations using transmission electron microscope (Model: JEM 2100, Tokyo, Japan) thin slices of the specimens were prepared sequentially by manual polishing on emery paper, dimpling and ion milling.

Table1
Various combinations of σ_a and σ_m for ratcheting tests.

Material	Serial no.	Mean stress (σ_m)/ MPa	Stress amplitude (σ_a)/ MPa
Annealed	1	40	360,390,420
	2	70	360,390,420
	3	100	360,390,420
Normalized	1	55	480,533,587
	2	90	480,533,587
	3	125	480,533,587

3. Results and discussion

3.1. Microstructure and tensile properties

Typical microstructures of the annealed and normalized samples are illustrated in Fig. 1(a) and (b), respectively. Microstructures in both

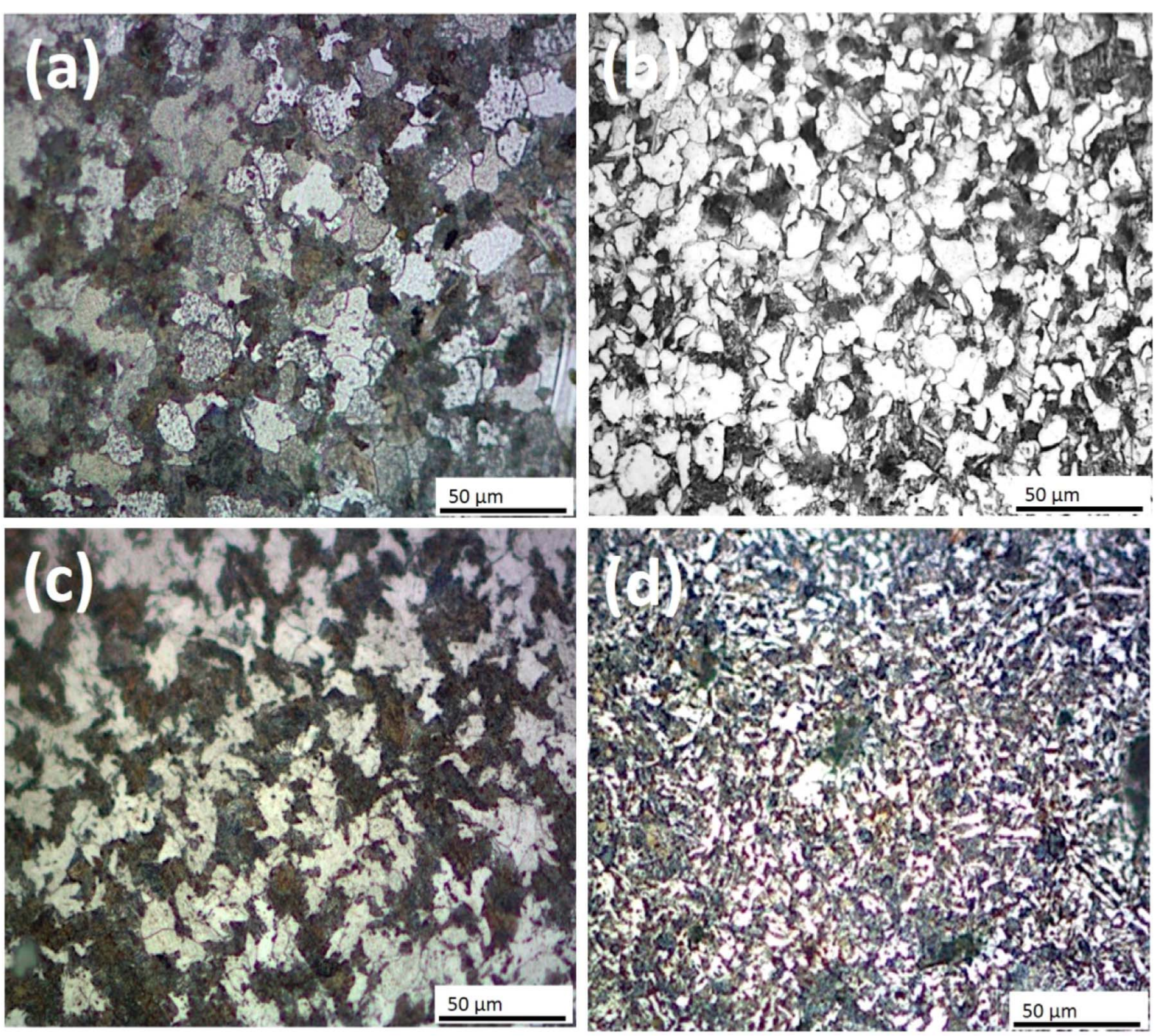

Fig. 1. Microstructures of the undeformed (a) annealed, (b) normalized and deformed (c) annealed, (d) normalized specimens.