FATIGUE BEHAVIOUR OF A HIGH STRENGTH LOW ALLOY STEEL AT DIFFERENT CONDITIONS

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ABSTRACT

The effects of prestraining and strain ageing on fatigue properties and dislocation structure of a hot rolled dual-phase steel have been studied. The obtained results showed that, the fatigue life of prestrained steel is slightly higher than that of the as-received one. However, prestraining plus ageing gave rise to a decrease in fatigue life at higher stress amplitude as compared with as-received condition. Also, the results are explained in term of changes in dislocation configurations and residual stresses on the specimen surface.

INTRODUCTION

Dual-phase steels are a new class of high strength low alloy steels consisting of martensite and ferrite phases, which have a good combination of strength, ductility and formability that makes them attractive for weight saving applications in automobile industry [1]. A dual-phase steel can be used to manufacture automotive components which are more difficult to form because its stamped performance is better than that of a conventional high strength low alloy steel. However, the formability is closely related to the yield strength of the material. The yield strength can be increased due to production, transportation, stamping and artificial ageing. The change in yield behaviour causes important influence on the service life of automobile components. Davies [2], has studied the effects of strain ageing on mechanical properties of dual - phase steels such as yielding behaviour. It is found that, the life in service of many

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components is strongly dependent on the material fatigue properties, service history and design factors. However, little attention has been paid to fatigue behaviour of dual - phase steel. Sherman et al. [3], and Chai et al. [4], studied, respectively, the influences of the volume fraction of martensite and microstructure on fatigue properties of the dual - phase steels. Sherman et al. [5], have preliminarily studied the effects of strain ageing on the fatigue behaviour of a vanadium containing dual-phase steel and high purity iron.

In the present work, fatigue properties of a hot rolled dual - phase steel under conditions of as - received, prestrained and strain aged have been investigated.

MATERIALS AND EXPERIMENTAL PROCEDURE

The steel used in this work was in the rolled condition and supplied in a sheet of 3 mm thickness. The material has a composition (in wt%) of 0.06 C, 0.55 Si, 1.5 Mn, 0.02 S, 0.031 P, 0.52 Cr, 0.046 Al, 0.46 Mo and Fe balance.

Fatigue specimens were tested with gauge section of 12x7x3 mm^3 in size and cut from the as - received plate. The longest axis of each specimen was parallel to the rolling direction of the plate.Some specimens were subjected to a tensile prestraining of 10% or tempered at 175 °c for 30 minutes after prestraining in order to determine the effects of strain ageing on fatigue properties. Also, tensile tests were carried out and the residual stresses were measured by the X-ray diffraction technique with both as - received and treated specimens.

Fatigue tests under constant load control were conducted at room temperature on a ±200 KN push-pull fatigue testing machine. A sinusoidal waveform was the controlling signal. In order to investigate the relationship between fatigue properties and microstructures, dislocation configurations of failed specimens were observed by transmission electron microscope, TEM. The metallographic examination using an optical microscope was also carried out.

RESULTS AND DISCUSSION

Microstructure:

The microstructure of the investigated steel in the as-received condition is shown in Fig. (1). It is clear that, the microstructure consisting of fine grained ferrite and dispersed patches of martensite on fine grained ferrite. The volume fraction of martensite was determined to be 20% by using quantitative metallography.

Tensile and Fatigue Behaviour:

The tensile properties and residual stresses of the investigated steel in the as-received, prestrained and strain aged conditions are shown in Table (1). It is found that, prestraining and strain ageing lead to about 220 MPa and 252 MPa increases in the yield stresses. As expected, prestraining results in an overlap of the compressive residual stress with that induced by hot-rolling. However, ageing at 175 °c for 30 minutes caused a significant release in the existing residual stresses on the specimen surface.

Figure (2), illustrates the stress-life behaviour of the specimens in the three conditions tested. From this figure,it can be seen that, there is a fatigue limit of about 270 MPa for the as-received steel. As shown in Fig. (2), the fatigue strength in the prestrained condition is only slightly higher than that in the as-received one. Similarly, in comparison with as-received condition, ageing after prestraining produces almost no change in fatigue strength at low stress amplitude but a slight decrease at high stress amplitude. A general explanation for this is based on the wavy slip character of dual-phase steel which is not a strong function of prestraining [5]. As summarized by Laird [6], wavy-slip materials, whatever their structures before strain cycling, develop cell structures if they are cycled at high strains.

The slight effects of prestraining and strain ageing on the fatigue life behaviour of dual - phase steels might be caused through several specific factors, such as mechanical properties, residual stresses etc. As indicated in Table (1), strain ageing caused a significant reduction in elongation which is considered responsible for the decrease in fatigue life at high stress amplitude, because low cyclic fatigue depends mainly on the ductility rather than on the strength of the material. The residual stress which was enhanced by prestraining or released by further ageing (see Table1), is another important factor affecting the fatigue life. In associating the residual stress in Table (1) with the fatigue life shown in Fig. (2), it is evident that, the variation of residual stress is quite consistent with that in fatigue life, especially at high stress amplitude. The higher the residual stresses, the longer the fatigue life.

Dislocation Configuration:

The microstructure of specimens in three conditions either or after fatigue failure were examined by TEM. Some typical results are shown in Figs. (3-5). As indicated in Fig. (3-a), the martensite in as-received condition consisted of block lath's, a typical, structure of low-carbon martensite [7 & 8]. Moreover, the ferrite contained dense tangles of extrinsic transformation accommodation dislocations in the regions adjacent to martensite (Fig. 3-a) , but much low density in more remote locations (Fig. 3-b). It can be seen from Fig. (3-c) that, the martensite changed from the block lath's to twinning type after 10% tensile prestraining. The dislocations are distributed uniformaly throughout the ferrite matrix with much higher density than that before prestraining, as seen in Fig (3-d). Dense tangles of dislocations can be seen in ferrite grains. The examination by TEM also indicates that, ageing caused no change in dislocation configurations.

Figure (4), illustrates the dislocation structure in the specimens which were cycled to failure at a stress amplitude of 300 MPa. In comparison with the dislocation arrangements prior to fatiguing (Fig.3), fatigue loading produces modifications in dislocations characteristics to some extent in all three conditions. As compared with Fig. (3-b), it is noted from Fig. (4-a), that dislocations with high density were induced and characterized by tangles. The dislocations configuration in the prestrained specimen was rearranged into more regular bands which tend to form incomplete cell structures as shown in Fig. (4-b). Fig. (4-c), shows the dislocation arrangements in the strain aged specimen after fatigue failure. It is evident that, rearrangement of dislocation was not as that in the prestrained specimen. The small particles of carbides as a result of ageing could be found in the ferrite matrix. Some evidences of interaction between dislocation and precipitates could also be seen in Fig. (4-c). The morphology and substructure of the martensite phase were often found to be modified by cyclic deformation. One example is shown in Fig. (4-d), where the martensite lost its original lath's structure and consisted of high dislocation accumulation.

Figure (5), shows the appearance of dislocations in prestrained and strain aged specimens cycled to failure at 370 MPa and 360 MPa, respectively. Obviously, dislocation cells were well developed and became the dominant structures when high stress amplitudes were applied. A similar and well defined cell structure was also found in as - received specimens cycled at high stress amplitude.

However, the intrinsic behaviour of dual - phase steels and its associated dislocation structure still play the main role in controlling the fatigue life, although some additive factors mentioned before may cause slight deviations. As demonstrated in Figs. (3-5), no matter how different the dislocation structures are prior to fatiguing. The cyclic loading eventually results in a more or less unique dislocation structure corresponds to a certain stress amplitude.

Macroscopically, much or all of the strength which increase gained by prestraining or strain ageing, is lost under cyclic loading due to softening [5 & 6]. Prestraining or strain ageing produces almost no change in fatigue life of dual - phase steels as observed. As revealed by TEM obsevations, cyclic loading could cause modifications of martensite morophologies and substructure.

CONCLUSIONS

From this study, the following conclusions may be drawn:-

1. Prestraining cause a slight improvement in fatigue life of dual-phase steel. Ageing has no appreciable effect on fatigue properties, except in the high stress amplitude region.
2. Cyclic loading produces dislocation tangles at low stress amplitude and dislocation cell structures occur at high stress amplitude in spite of the original conditions of the specimen.
3. The morphology and substructure of martensite in dual - phase steel could be modified by cyclic loading.

4. The effct of prestraining and strain ageing on fatigue behaviour can be assesement in term of dislocation structure, surface residual stresses and work hardening characteristics.

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Table (1): **Tensile Properties and Residual Stresses Under Three Conditions:**

Condition	Tensile strength σ_u, MPa	Yield strength $\sigma_{y\,0.2}$, MPa	Elongation Δ%	Residual stresses σ_r, MPa
as - received	596	405	29.2%	-219
10% Prestrained	447	625	22.7%	-317
10% Prestrained + aged at 175°c for 30 min.	660	657	14.6%	-132

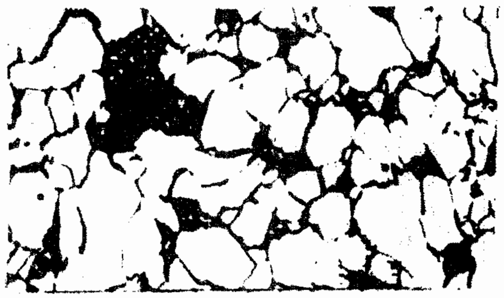


Fig. (1) Microstructure of the investigated steel. 350X

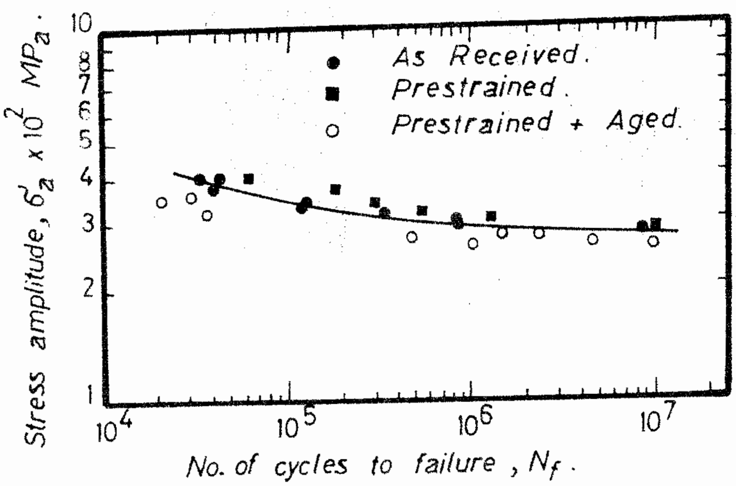
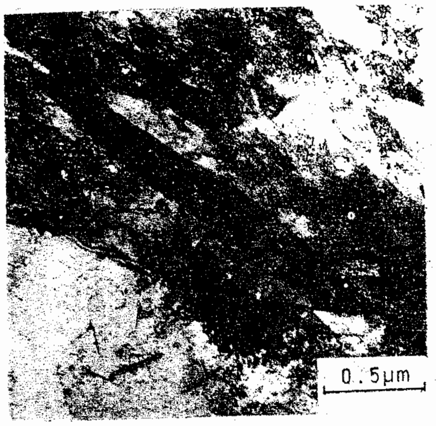
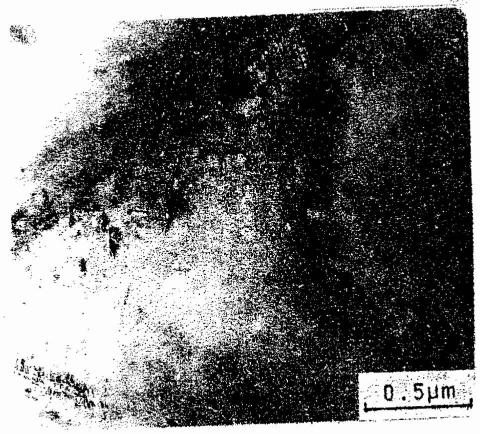


Fig.(2) Stress-life curves for three conditions.



(a)



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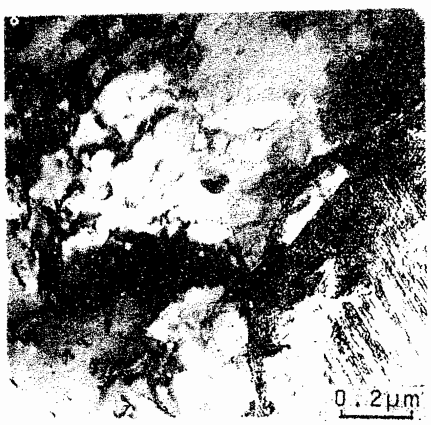
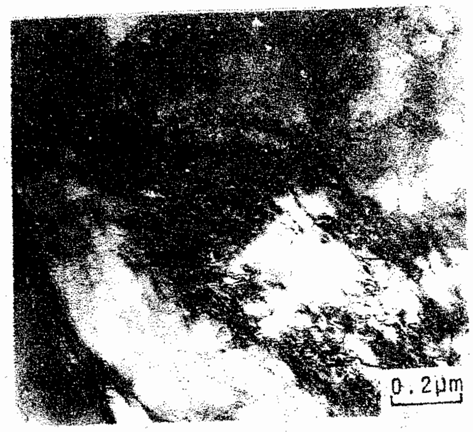


(c)

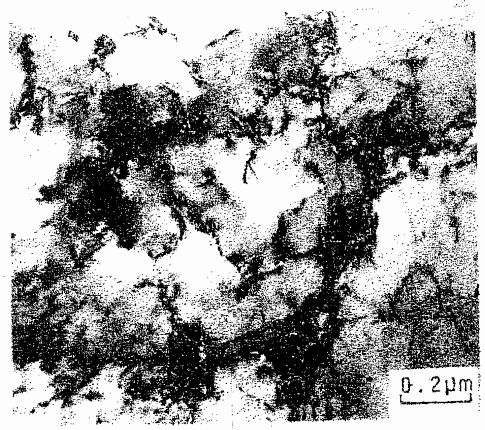
(d)

Fig. (3) TEM micrographs of as-received and 10% prestrained specimens before cyclic loading.

(a) , (b): as-received (c) , (d): prestrained



(a)



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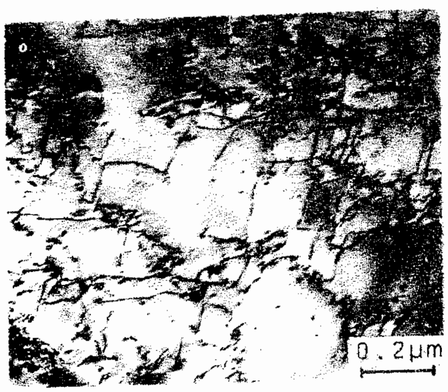


(c)

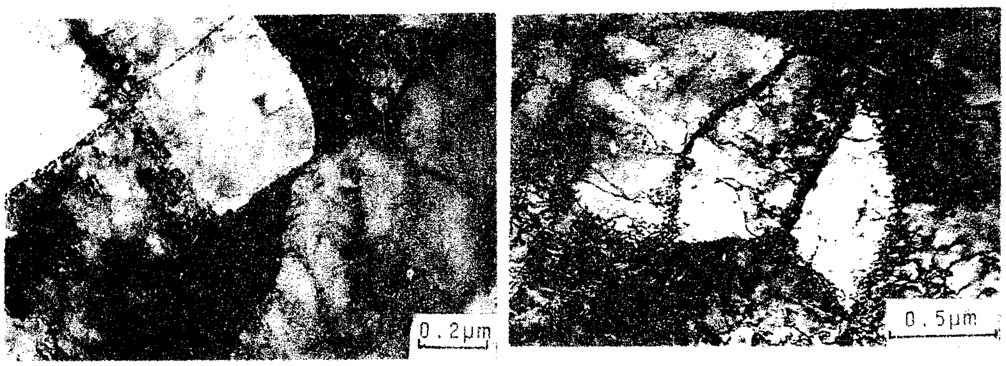
(d)

Fig. (4) TEM micrographs after fatigue at peak stress of 300 MP_a.

(a): as-received $N_f = 8.7 \times 10^5$

(b): 10% prestrained $N_f = 1.35 \times 10^5$

(c): 10% prestrained and aged at 175 °C for 30 min. $N_f = 1.02 \times 10^5$



(a) (b)

Fig. (5) TEM micrographs after fatigue failure.

(a): 10% prestrained , $\sigma = 370\ MP_a$, $N_f = 1.8 \times 10^5$

(b): 10% prestrained and aged at 175 °C for 30 min. , $\sigma = 360\ MP_a$, $N_f = 3.04 \times 10^4$

" خصائص الكلال للصلب عالى المتانة منخفض السبائك عند حالات مختلفة "

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ملخص البحث :

يهدف هذا البحث إلى دراسة تأثير كل من الإنفعال المسبق Prestraining وعملية التصليد (التصليد بمرور الزمن) Strain Ageing للصلب العالى المتانة على خصائص الكلال (التعب) وشكل (بنيان) الإنخلاعات Dislocation Structure .

وتحقيقاً لذلك الهدف فقد تم إعداد عينات إختبار الكلال من هذا الصلب بحيث يكون محورها الطولى مع إتجاه الدرفلة بالنسبة للوح المقطوعة منه . كذلك فإن جزء من هذه العينات تم تعريضه إلى إنفعال شد مسبق Tensile Prestraining (١٠٪). أيضاً فإن جزء آخر من العينات السابق تعريضها للإنفعال المسبق تم تطبيعه Temperedعند درجة حرارة ١٧٥ °م لمدة ٣٠ دقيقة .

وإشتملت الدراسة فى هذا البحث على إجراء إختبارات الشد الميكانيكية ، كما تم تعيين الإجهادات المتبقية Residual Stresses بإستخدام أسلوب حيود الأشعة السينية X- Ray Diffraction Technique وذلك لكل العينات السالفة الذكر .

كذلك أجريت إختبارات الكلال على ماكينة الإختبار دفع - شد عند درجة حرارة الغرفة . كما تم إستخدام الميكروسكوب الإلكترونى النفاذ TEM لدراسة (لفحص) البنية البلورية وشكل الإنخلاعات للعينات المنهارة فى إختبار الكلال . أيضاً تم إستخدام الميكروسكوب الضوئى لدراسة تركيب البنية البلورية للصلب الأصلى المستخدم فى الإختبارات As- Received .

ولقد خلصت الدراسة إلى عدة نتائج نوجزها فى النقاط التالية :-

١- الإنفعال المسبق بصفة عامة يؤدى إلى تحسين عمر الكلال لهذا النوع من الصلب. كما أظهرت النتائج أن عملية التصليد لهذا الصلب ليس لها تأثير يمكن تداركه على عمر الكلال بإستثناء منطقة تأثير سعة الإجهادات المرتفعة High Stress Amplitude فإنها تؤدى إلى تناقصه مقارنة بالصلب فى حالته الأصلية As - Received .

٢- التحميل الدورى Cycling Loading ينتج عنه تواجد عقدات إنخلاع Dislocation Tangles عند سعات الإجهادات المنخفضة Low Stress Amplitude بينما عند سعات الإجهادات المرتفعة High Stress Amplitude فإنه يؤدى إلى تواجد خلايا إزاحات Cell Dislocation فى البنية البلورية.

٣- بواسطة التحميل الدورى يمكن تعديل المورفولوجيه The Morphology والبنية تحت السطحية Substructure لطور المارتنسيت لهذا النوع من الصلب .

٤- تأثير كل من الإنفعال المسبق والتصليد الإنفعالى على سلوك الكلال أمكن تفسيره من التغيرات التى تحدث فى شكل الإنخلاعات ، الإجهادات المتبقية على سطح العينة وعملية التصليد بالتشكيل Work Hardening Characteristics.