Influence of Prestraining and Ageing on the Fatigue Properties of a Dual Phase Sheet Steel

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ABSTRACT

The influence of different pretreatments typical to production of car bodies on fatigue properties in fully reversed straining was studied for a dual phase steel with tensile strength of 410 MPa. The pretreatments were prestraining in uniaxial tension, equibiaxial stretching and plane strain deformation followed by ageing. All prestrainings were tested both with and without ageing. The monotonic flow stress increased significantly when the material was pretreated. A much smaller effect was observed on the cyclic stress amplitude at half fatigue life. Both positive and negative effects of pretreatments on the stress amplitude were observed. The specimens showed cyclic softening during the first tenth of fatigue life. Pretreated materials softened more than the as received material did, resulting in a sometimes negative influence of pretreatments on the fatigue properties.
The influence of pretreatments on fatigue life was investigated by plotting life versus total strain amplitude, stress amplitude and Neuber factor. Different pretreatments produce amplitudes at constant life within a 30 percent band or smaller around the data for as received material.

KEYWORDS

Steel sheet; dual phase steel; prestraining; ageing; pressing; strain controlled fatigue.

INTRODUCTION

High strength steel sheet in cold rolled gauges are coming to use in auto bodies in order to save weight by reduction of sheet thickness. Special interest has been drawn to the continuously annealed dual phase steels. These steels have a ferritic-martensitic structure with a relatively low yield strength but a high tensile strength. This means that the steels obtain important strength increments during pressing. Another important property of the continuously annealed dual phase steels is the strength increment during ageing (bake hardening) as in the baking treatment after painting.

Detailed information is available in the literature, Fredriksson et.al(1988), Davies(1981) and Tanka et.al(1979) on how the monotonic strength of dual phase steels depends on straining and baking. Most of these tests were performed with prestraining and mechanical testing in the same mode - uniaxial tension. Strength increments of typically 50 MPa from prestraining or from baking were observed. In some cases total strength increments from prestraining and baking of up to 300 MPa have been recorded, Fredriksson et.al(1988).

Much less information is available on fatigue properties than on monotonic properties of high strength steel in cold rolled gauges. It has been shown for smooth and notched specimens fatigue tested in tension ($R=P_{min}/P_{max}=0$) that the fatigue strength increases with the ultimate tensile strength of the steel and with prestraining and baking, Sperle(1985), Nagae et.al(1982) and Shinozaki et.al(1985). However, results obtained in fatigue tests with reversed straining (R= -1) show a very small effect of prestraining and baking on the fatigue strength, Fredriksson et.al(1988), Nagae et.al(1982) and Shinozaki et.al(1983). It is thus unclear when and if prestraining and baking contributes to the fatigue strength. If the continuously annealed high strength steels are to be used in severe fatigue loading situations the fatigue properties must be extensively evaluated. In particular the effect of prestraining and baking must be established.

The present paper forms part of an extensive research programme where several low and high strength steels in cold rolled gauges were investigated, Fredriksson et.al(1988). In this report one dual phase steel is studied in great detail. The steel which has a tensile strength of 410 MPa is specially processed to give a high bake hardening response. The fatigue tests were performed on smooth specimens in fully reversed strain control. The influence of several prestraining and baking treatments was investigated. The paper is a condensed version of references, Fredriksson et al(1987) and Melander and Johansson(1988). The reader is referred to these papers for further results.

MATERIAL

A cold rolled dual phase steel with large ageing (bake hardening) capability was studied. The chemical composition is given in Table 1 and the microstructure of the steel is presented in Fig.1. The steel is produced in a continuous annealing line. The microstructure consists of polygonal ferrite grains (white phase) and carbon rich structural components (darker areas) consisting of martensite (light grey) and pearlite (dark grey).

Table 1 Chemical composition (weight percent)

C	Si	Mn	P	S	N	Cr	Ni	Cu	Al
.043	.01	.18	.008	.015	.0040	.02	.01	.03	.058

Table 2 Mechanical properties and microstructure

Proof stress at 0.2% elongation (MPa)	UTS (MPa)	Total elongation	Thickness (mm)	Grain size (μm)	Volume fraction caron rich phase	Volume fraction on inclucions
340	410	0.19	1.46	9.1	0.031	0.0046

The mechanical properties, in the rolling direction, of the as received material are given in Table 2 together with microstructural data. The tests were performed in a mechanical Schenck-Trebel testing machine at an initial strain rate of 0.002 per second. The gauge length was 50 mm and the width 12 mm. The mechanical data in Table 2 represent averages of double tests.

Monotonic and fatigue tests were performed on as received material, after prestraining and after ageing. Prestraining in uniaxial tension and in plane strain was made on plane specimens of different notched geometries. Prestraining in equibiaxial stretching was done by stretch forming with a hollow cylindrical punch. The strains were evaluated from a square grid which was etched to the specimens before prestraining. The corresponding effective strains were calculated according to von Mises theory. Prestraining was performed to 5% effective strain in all modes. In the case of uniaxial tension prestraining was also performed to 2% effective strain. The ageing treatments were performed on the fatigue and tensile specimens at 190°C for 15 minutes. The specimens were prepared as soon as possible after delivery of the sheets and thereafter kept in a refrigerator at -20°C, to prevent natural ageing during storage. All tensile and fatigue tests were performed in the rolling direction.

Fig.1 The microstructure of the steel. The rolling direction is horizontal.

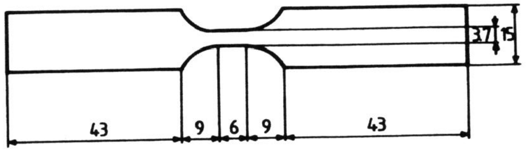

Fig.2 Specimen geometry. The specimen thickness is 1.4 mm.

FATIGUE TESTING PROCEDURES

Strain controlled fatigue tests were performed with fully reversed straining. The difficulties associated with this type of tests on sheet specimens has been extensively reviewed by Miller(1985) and Miller and Reemsnyder(1983).

The design of specimen used in this work is illustrated in Fig.2. A servo-hydraulic MTS machine with a maximum load of 100 kN was used. A rigid set-up of grips was designed which allowed very accurate alignment. Twisting of the actuator part of the grips was prevented by the action of guiding pins. The free length of the specimen when mounted in the grips is 18 mm. This means that the grips overlap into the reduced section by some 3 mm on each side of the parallel gauge section. The original surfaces of the sheet were preserved during specimen preparation and the specimen contour was milled. The extensometer was fastened with rubber bands to one short side of the specimen. The distance between the edges of the extensometer was 6 mm. In order to prevent crack initiation at the knife edges of the extensometer, 0.02 mm thick and 1 mm wide brass tabs were glued to the specimens before the extensometer was mounted.

All tests were run at a constant strain rate of $\dot{\varepsilon}$=0.02 per second. The first loading was in tension. A data acquisition system was built up. Stress-strain cycles were registered and stored at preselected intervals. Programmes were made for data fitting and presentation.

With the above described procedure for the testing some 25 percent of the tests were unsuccessful. In the case of small strain amplitudes failure outside the area between knife edges of the extensometer was the most frequent reason for unsuccessful tests. For large amplitudes buckling of the specimen was the most usual cause of rejected tests. For the specimens of this study, which had a thickness of 1.4 mm, the maximum attainable strain amplitude was $\Delta\varepsilon/2$=0.004.

The fatigue life was defined as the number of strain reversals to 25 percent load drop. It was shown by Fredriksson et.al(1988) that the exact level of load drop was not critical to the number of reversals to fatigue failure.

RESULTS FROM FATIGUE TESTS

Cyclic stress-strain hysteresis loops

In the present section the cyclic hysteresis loops are characterized by two parameters, namely the total strain range, $\Delta\varepsilon$, and the total stress range, $\Delta\sigma$

Fig.3 gives a few examples of how the cyclic stress amplitude varies during fatigue tests at the imposed strain amplitude 0.0025. Results are presented for as received material and for all types of predeformations used in this study. In one case only in Fig.3 was baking performed after a prestraining namely after equibiaxial stretching.

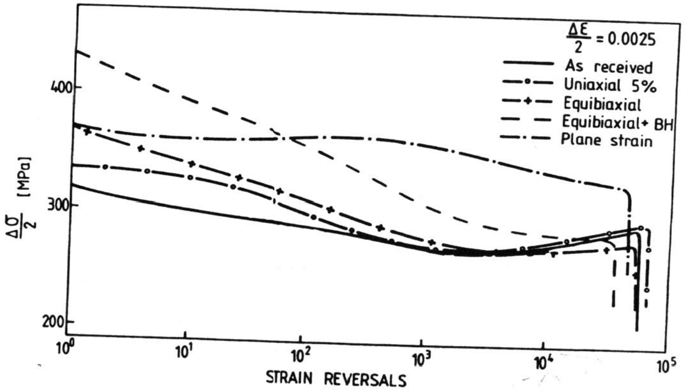

Fig.3 Stress amplitude versus number of reversals for different pretreatments

The material in as-received condition shows cyclic softening during the first $5\cdot10^3$ cycles and subsequently hardening until failure. Prestraining produces an initial increment of the stress range compared to as-received material but softening usually proceeds more rapidly after prestraining so that similar stress ranges are obtained at the half lives. Prestraining in plane strain is an exception to this description. Very little softening is observed initially in this case. Baking after equibiaxial prestraining gives initially an increment of the stress range. Softening, however, proceeds so rapidly that the stress range at the half life is only slightly larger than the ranges of as-received and of equibiaxially prestretched materials.

Comparison of cyclic and monotonic flow stresses

The flow curves in monotonic uniaxial tension are illustrated in Fig.4 for all pretreatments but equibiaxial stretching and equibiaxial stretching and aged. The monotonic flow stresses increase significantly upon prestraining. An ageing treatment increases the monotonic flow stress in all cases of Fig.4. The effect is largest in the cases of plane strain and in specimens without prestraining.

The stress amplitudes at half fatigue life versus the strain amplitude are illustrated in Fig.5 together with the monotonic flow curve of the as received material. The cyclic stress amplitudes are smaller than the monotonic flow stresses due to cyclic softening. The influence of prestraining and ageing is significantly smaller for the cyclic stress amplitude than for the monotonic flow stress. Prestraining in plane strain has a positive effect on cyclic flow stress. Ageing is positive in the cases of prestraining in uniaxial tension (5 and 2 percent) and equibiaxial stretching but negative in as received and prestrained in plane strain conditions. The maximum difference between different pretreatments is less than 70 MPa in the cyclic case but 170 MPa in the monotonic case (30 and 50 percent respectively).

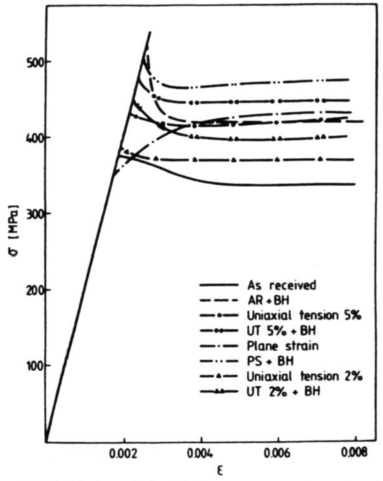

Fig.4 Flow stress (σ) versus strain (ε) for monotonic tests in uniaxial tension after various pretreatments.

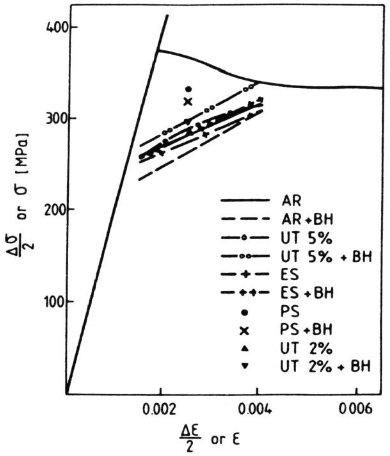

Fig.5 Stress amplitude ($\Delta\sigma/2$) at half fatigue life versus strain amplitude ($\Delta\varepsilon/2$) after various pretreatments and the monotonic flow curve for the as received con-. ditions from Fig.4.

Fatigue life

In this subsection the fatigue life is at first presented as a function of the imposed strain amplitude and subsequently as a function of the stress amplitude and of the Neuber factor $\sqrt{\Delta\sigma\Delta\varepsilon E}$. All tested conditions are compared

Fig.6 illustrates the number of reversals to 25% load drop as a function of the total strain amplitude. It can be observed that as-received material and material prestrained by 5 percent in plane strain have similar lives before ageing. A small increase in fatigue life is obtained after prestraining in uniaxial tension and equibiaxial stretching. An ageing treatment decreases the life after prestraining in uniaxial tension by 5% and after equibiaxial stretching. Small increments in fatigue life are obtained after ageing as received material. The maximum difference is 20% on the negative side and 5% on the positive side counted from the as-received material.

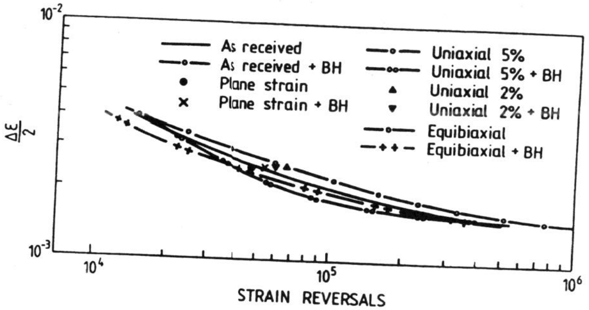

Fig.6 Fatigue life versus total strain amplitude for various pretreatments.

Fig.7 shows the number of reversals versus stress amplitude at half life. Ageing of as-received material reduces fatigue life at constant stress amplitude. Prestraining in plane strain and uniaxial tension (2 and 5%) both with and without ageing increase the stress amplitude at constant life compared to as-received material. The increase is strongest for plane strain. Prestraining in equibiaxial stretching has only small effect on fatigue life and so has a sebsequent ageing treatment. The maximum recorded effect of pretreatments is within ±40 MPa in stress amplitude which is less than ±15% of the stress amplitude.

Prediction of fatigue life of notched components is often based on a study of the product of local stress and strain amplitudes. For that purpose the fatigue life is evaluated as a function of the Neuber factor $\sqrt{\Delta\sigma\Delta\varepsilon E}$. The stress and strain ranges are determined at half life. The effect of prestraining and ageing on the Neuber factor at constant life is quite small in Fig.8. The maximum difference in Neuber factor at constant life from the highest to the lowest is about 10%.

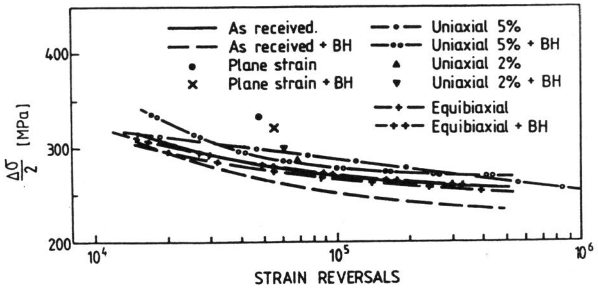

Fig.7 Fatigue life versus stress amplitude for various pretreatments.

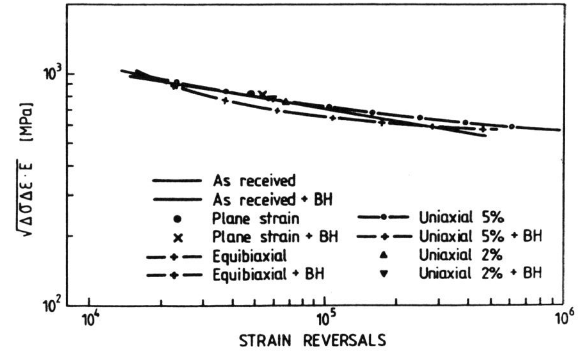

Fig.8 Fatigue life versus Neuber factor for various pretreatments.

DISCUSSION

It has been shown in this paper that fully reversed cyclic straining is often associated with softening for the present steel. Softening proceeds during the first stage of fatigue life and is followed by hardening. In as received material it is likely that softening is associated with a break down of the dislocation structure around the martensite islands. This dislocation structure is originally created during phase transformation. It is also possible that the fine carbides in the ferrite matrix which are created during the over ageing treatment in the continuous annealing line are broken down by the cyclic deformation so that their hardnening contribution decreases. The cyclic hardening which is often observed during the final stage of fatigue life is probably caused by the creation of a dislocation structure in the bulk of the ferrite. The results from prestrained and baked material show that the hardnening contribution from these dislocation and precipitation structures is broken down more rapidly than from the as received structure during cyclic straining. Prestraining in plane strain seems to produce a dislocation structure which is more resistant to the cyclic straining than the other predeformations.

CONCLUSIONS

The fatigue properties were evaluated for a cold rolled dual phase steel specially designed with bake hardening capability and with a tensile strength of 410 MPa. The influence of prestraining in different modes and baking was investigated. The tests were performed in fully reversed strain control.

1. Prestraining and ageing produce significant increments in monotonic flow stress in the investigated cases. The maximum observed increase of flow stress from pretreatments is 170 MPa which is 45 percent of the flow stress of as received material.
2. The cyclic stress amplitude at half fatigue life is less sensitive to pretreatments than the monotonic flow stress. The maximum observed increase of stress amplitude from pretreatments is 40 MPa corresponding to 12 percent. Also reductions of the stress amplitude are observed after pretreatments by up to 30 MPa or 10 percent. Increments in stress amplitude are observed after prestraining in uniaxial tension and plane strain but reductions occur after equibiaxial stretching.
3. Prestraining and ageing have small effects on the total strain amplitude at a certain fatigue life. The studied pretreatments influence the total strain amplitude by less than 20%. The effects are often negative.
4. The stress amplitude at a certain fatigue life increases with predeformation in plane strain and uniaxial tension. Prestraining in equibiaxial stretching does not change the stress amplitude significantly. Ageing after predeformation has a small effect on stress amplitude at constant life. The observed effects of pretreatments are within +20 percent to -10 percent in stress amplitude.
5. The Neuber factor at a certain fatigue life changes little with different pretreatments. The maximum difference in Neuber factor at constant life is 10 percent.

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