THE INFLUENCE OF RETAINED AUSTENITE ON SHORT FATIGUE CRACK GROWTH IN CASE CARBURIZED STEEL

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The influence of the amount of retained austenite on short fatigue crack growth in case carburized SAE 8620 steel was studied in this work. Four point bend fatigue tests were carried out at room temperature, using three different levels of stress and R=0.1. Four different amount of retained austenite in the microstructure of the carburized case were obtained through different heat treatment routes, carried out after the carburizing process. Crack length versus number of cycles and crack growth rate versus mean crack length curves were obtained. The results showed that the testpieces with higher levels of retained austenite in the carburized case exhibited longer fatigue life.

INTRODUCTION

Case carburized steels may present a microstructural composition which results in high superficial hardness, and an increased mechanical, fatigue and wear strength. The combination of these properties, make them the most recommended material for application where high stress and cyclic loading are involved, such as: shafts, housing and gears (1). Case carburized steels, present a very complex microstructure and close to the surface it is composed of high carbon tempered martensite, retained austenite and carbides. The retained austenite is a very ductile phase and its presence in the microstructure has been a controversial subject. High retained austenite level in the carburized case may decrease the wear resistance or the contact fatigue in gears (2). However, some researches (3, 4), suggested that due to the strain induced austenite-martensite transformation, the presence of retained austenite may have some beneficial effect on the flexural fatigue, while Hu et al (5) suggested that the γ will transform into brittle martensite, accelerating the crack propagation and decreasing fatigue resistance. The amount of the retained austenite in the carburized case may vary as a function of the carburizing process and heat treatment used, and its effect on the mechanical properties is direct related to its amount and distribution on the microstructure, as well as, the type of loading that the carburized material is to be

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submitted. The main aim of this work is to evaluate the influence of different levels of retained austenite on the flexural fatigue behaviour of case carburized SAE 8620 steel. Therefore, the fatigue crack growth of short cracks were evaluated using acetate replication technique.

EXPERIMENTAL

Specimens were removed from a 19 mm hot milled round bar from SAE 8620 structural steel, which the chemical composition is presented in Table 1.

TABLE 1 - Chemical Composition (wt.%) of SAE 8620.

C	Mn	Si	Ni	Cr	Mo	P	S
0,22	0,84	0,26	0,48	0,53	0,16	0,018	0,021

Forty specimens were machined to 8 x 10 mm2 cross section and 100 mm length, and they were divided in four groups which were submitted to the same carburizing process and different heat treatments, as described in Table 2. After the heat treatment, samples were removed from each group for microstructural evaluation, carburized case depth, X-ray analysis (for the evaluation of the amount of the retained austenite) and hardness measurements. The fatigue tests were carried out at room temperature, using load control, senoidal wave and 3 Hz frequency. The specimens were load in four point bending and. Table 3 presents the stress amplitude (σ_a), the stress ratio (R) and the maximum stress at the surface (σ_m).

TABLE 2 – Carburizing process and heat treatments following different routes.

Heat Treatment	A		B		C		D	
	Temp. (°C)	Time (min)	Temp. (°C)	Time (min)	Temp. (°C)	Time (min)	Temp. (°C)	Time (min)
1° Pre-heating	400	40	400	40	400	40	400	40
Carburizing	930	180	930	180	930	180	930	180
1° Austenitization					160	20	840	20
Quenching	840	20	840	20	840	20	840	20
Martempering	160	20	160	20	160	20	160	20
2° Pre-heating					400	40		
2° Austenitization					840	20		
1° Tempering	160	120	240	120	240	120	240	120
Sub-zero							-196	20
2° Tempering							160	120

TABLE 3 - Stress amplitude, $\Delta\sigma$, maximum stress, $\sigma_{máx}$, and stress ratio, R.

$\Delta\sigma$ (MPa)	$\sigma_{máx}$ (MPa)	$R=\sigma_{mín}/\sigma_{máx}$
1107	1230	0,1
1181	1312	0,1
1255	1394	0,1

During the test the short fatigue cracks initiation and propagation, were periodically monitored by acetate replication technique. For the size measurement of the short cracks, the specimens was kept loaded at the mean fatigue load. The fatigue tests stopped only after complete failure of the specimen. From these tests the maximum stress versus number of cycles (S-N) curves, crack size (2c) versus number of cycles and the crack growth rate (d2c/dN) versus de mean size of the crack ($2c_{mean}$) curves were obtained. The crack surface of the specimens were analyzed using a scanning electron microscope.

RESULTS AND DISCUSSION

The microstructural evaluation from the carburized case, showed that after carburizing process the four heat treatments applied promoted a microstructure composed of high carbon tempered martensite, retained austenite and carbides. However, they presented a large variation in the amount and distribution of these microconstituents and different prior austenite grain size. From the X-ray diffraction pattern results, Fig. 1, it is possible to see that the samples treated by routes A and C exhibited the higher amount of retained austenite, approximately 35 and 32 %, respectively; while those treated by route B and D promoted 12 and 5 % of retained austenite, respectively. The difference between the amount of retained austenite obtained from rout B and those obtained from routes A and C, is mainly due to tempering temperatures, which was 160 °C for routes A and C. This temperature is inside the first range of tempering temperatures (150 - 200 °C) where only stress relive and carbide formation is promoted. It has been reported (1), that carburized steel tempered in this range of temperature exhibit excellent mechanical properties. Route B produced a reduced amount of retained austenite due to a higher tempering temperature, 240 °C, which is located inside of the second range of tempering temperature, where it may occurs the total or partial transformation of the retained austenite into ferrite and carbide. The sub-zero heat treatment (-196 °C) in route D, promoted the lowest amount of retained austenite which was transformed in martensite. In this route the first tempering was executed to reduce risk of cracking on the carburized case. By comparing all the microstructures obtained from the four heat treatments used, route C promoted a more refined microstructure, and consequently the retained austenite appear finely distributed on the matrix. This recrystalization at 840 °C, was mainly due to the martensitic microstructure formed during the first martempering heat treatment. Also, the carbide shape changed from elongated to a spherical shape, which is expected to confer an excellent wear resistance to the matrix. The microstructures in other carburized case obtained from routes A, C, and D, with a tempering temperature of 160 °C, a normal trend was found , i. e., as the amount of retained austenite increased the hardness value decreased. While for route B, which the tempering temperature was 240 °C, the microstructure presented the lowest hardness value, even thought the amount of retained austenite was higher than the amount found in microstructure produced by route D.

The S - N curves obtained from the fatigue tests, Fig. 2, show that the routes that promoted an increase in the amount of retained austenite in the microstructure of the carburized case, also promoted an increase in the fatigue life. The same behaviour was observed in the crack growth test results, Fig. 3, for the three different stress levels. The microstructures with higher amount of retained austenite and same test conditions, exhibited a lower fatigue threshold, ΔK_0, The superior performance exhibited by the microstructure obtained by route C, when compared to route A, is due to a more refined microstructure obtained from route C. Hyde et al (6), found that the size of the austenitic grain in the carburized case, influence the fatigue life in a similar way that the grain size in the Hall - Pech equation, and the fatigue life is directly proportional to the inverse of the square root of the grain , ($d^{-1/2}$). Another important factor is that during crack propagation, the microstructure may act as a barrier, and the most refined microstructure presents the lower space between each barrier (grain boundaries, spherical particles and martensite colonies) which makes the crack spend more energy to growth De Los Rios et al (7). In this study the route C caused the most refined microstructure, therefore it conferred the highest fatigue life due to the reduced crack growth rate. As can be seen from Fig. 3b, that the cracks exhibited a typical short crack behaviour, i. e., an sporadic growth, which is the main difference between short and long cracks characteristics. To the test conditions used in this work, flexural low cycle fatigue, the presence of retained austenite in the carburized case microstructure, has showed a beneficial effect in increasing fatigue life. Generally, the improvement in the fatigue life is attributed to both the capacity of the retained austenite to transform in martensite during the local plastic deformation process and the presence of compressive residual stress originated during this phase transformation. Some researchers (4, 8), observed this type of phase transformation in steel carburized case after low cycle fatigue tests. Gu et al (9) and Lou et al (10), performed fatigue crack growth tests in carburized steels and observed a reduction in the crack growth rate in testpieces with high retained austenite content in the carburized case. They attributed this fact to both the induced plastic strain austenite - martensite phase transformation and the crack closure, caused by the compressive residual stress generated during this transformation that occurred in the plastic zone ahead of the crack tip.

From the fracture surface analysis, it was noticed that the cracks growth mode was transgranular through the carburized case in all specimens. This micromechanisms of fatigue crack growth is related to microstructure originated in fine grains and high fatigue limit (1). The specimens with higher retained austenite in the carburized case (routes A and C), exhibited high hardness values, impact toughness and flexural fatigue strength, particularly the specimens from route C, due to the most refined microstructure. However, the routes that reduced the amount of retained austenite through a higher tempering temperature or a sub-zero treatment, there was a reduction in the fatigue life.

CONCLUSIONS

1. The presence of retained austenite in the carburized case, improved the fatigue life in low cycle fatigue.
2. The strain induced phase transformation micromechanism of the retained austenite into martensite and the additional presence of compressive residual stress due to this transformation, were responsible for the increase in the fatigue strength by promoting the crack closure phenomena, responsible for reducing the crack growth rate.
3. Route C produced a carburized case with a high fatigue strength due to the refinement of the microstructure. However, route D presented a lower amount of retained austenite, due to the sub-zero treatment and consequently a higher hardness and lower fatigue strength.

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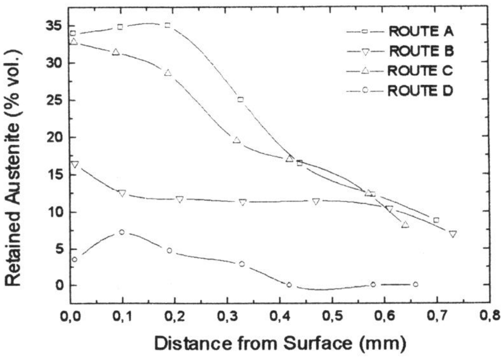

Figure 1 – Variation of the percentage of retained austenite in the carburized case measured in samples treated following routes A, B, C e D. X-ray measurements.

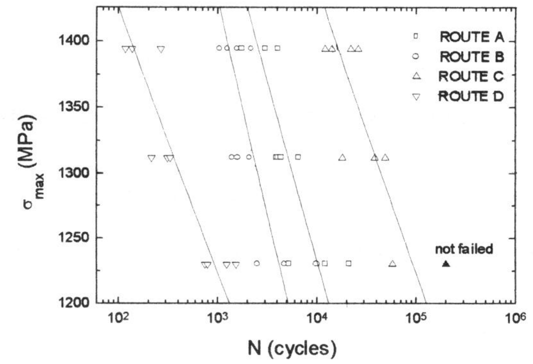

Figure 2 – S-N curves for routes A, B, C and D. Four point bend fatigue tests, R=1.

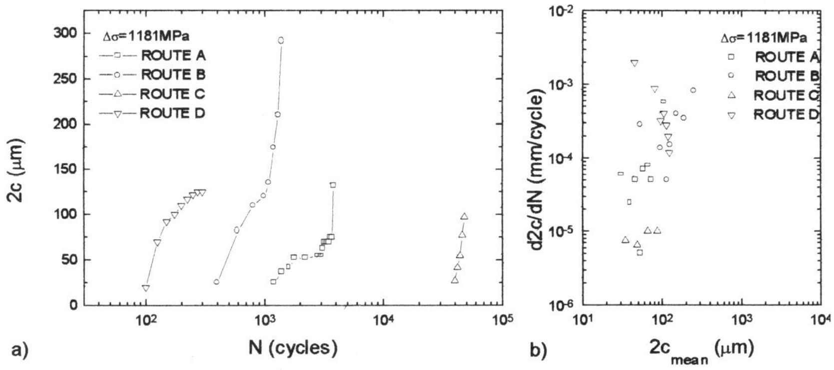

Figure 3 – Crack growth results for an amplitude stress of Δσ=1181MPa. a) crack size versus number of cycles. b) Crack growth rate versus mean crack size.