D. AGUIRRE-GUERRERO, A. JUÁREZ-HERNÁNDEZ,
M. A. L. HERNÁNDEZ-RODRÍGUEZ, R. MORALES, I. RUIZ

ISSN 0543-5846
METABK 52(2) 227-230 (2013)
UDC – UDK 669.15:620.17:539.5=111

THE EFFECT OF PRE-STRAIN ON FATIGUE FOR A HIGH STRENGTH LOW ALLOY (HSLA)STEEL

Received – Prispjelo: 2012-06-17
Accepted – Prihvaćeno: 2012-10-10
Preliminary Note – Prethodno priopćenje

The effect of initial plastic strain cycle fatigue lives of HSLA specimens is investigated. Specimens were monotonically, quasi-statically loaded under strain control in tension to produce plastic strains (prestrain conditions $s_0 = 0$, $s_1 = 4{,}6$, $s_2 = 35{,}6$ and $s_3 = 66{,}7$ % deformation). Surface analysis on the annealed Zn coat on the prestrain surfaces shows that, the higher the deformation the bigger and deeper the cracks on the Zn coat. Results show that the higher prestrain the higher fatigue resistance for all stress applied, specimens with s_3 shows the highest fatigue resistance for these experimental conditions.

Keywords: HSLA steel, fatigue, predeformation, stamping

INTRODUCTION

During the stamping process sheet steels are prestrain at different levels that have an effect on the fatigue strength of the component, some previous research have shown that the prestrain on this conditions need to be consider in the structural designs. It has been found that HSLA steels get hard during fatigue test, and fatigue strength decreases as deformation increases decreasing its ductility, on the other hand for lower deformation amplitudes there is a lower plastic deformation on a prestrain material increasing its fatigue strength [1]. Fatigue behavior of prestrain and as as-recived is different for IF and DP steels [2], some studies shown that there is an effect of fatigue strength for different prestrain levels in HSLA decreasing fatigue strength as prestrain increases for high cycles above 10^5 [3].

Other study on a DP600 steels shows that fatigue strength decreases as prestrain increases at cycles below 10^4 but fatigue strength increases for cycles above 10^4. On the other hand a study in Advanced High-Strength Steels showed that the DP steels exhibit a continuous yielding behavior, low yield point, and a high strain-hardening coeffcient [4,5] and for TRIP steels, the main parameters that can affect the monotonic deformation are retained austenite and its carbon content, morphology, and distribution [6]. TRIP 780 showed an improved strain life compared with a DP 590, which may be related to a combination of higher yield strength, higher ductility, and crack tip retardation by austenite to martensite transformation. Both steels exhibited cyclic softening, similar levels of softening are believed to be due to similar ferrite volume fractions of the two steels, as well as similar low-strain work-hardening rates [7].

Researches examining the fatigue properties of several steel grades of similar strength have shown endurance limits increasing in the order of high-strength low-alloy HSLA, DP, and TRIP [8,9]. These results indicate that while the fatigue performance of steel is often linked to monotonic tensile strength, the microstructure may have some effect on the endurance limit. The aim of this work is to measure fatigue strength for a HSLA steel at cycles < 10^5 under different prestrain conditions.

EXPERIMENTAL PROCEDURE

An HSLA steel with a thickness of 1,4 mm was employed in this work, chemical composition was obtained by spark spectroscopy as shown in Table 1.

Optical and electronic microscopies were employed to measure microstructure as received and after fatigue tests, in order to analyzed grain size and crack formations. Sample preparation and grain size were made according ASTM E3 and ASTM E112 respectively.

Tensile test were made in order to characterize HSLA steel mechanically, tests were made in a Universal Shimadzu Autograph AG-X, 300 kN capacity. Tensile specimens were machined and made according ASTM E8, geometry and dimensions of the specimen are shown in Figure 1, in order to determine the maximum level of uniform elongation for the as-received material before fatigue testing. Four different prestrain levels were introduce to the specimens, prestrain conditions $s_0= 0$, $s_1=4{,}6$, $s_2=35{,}6$ and $s_3=66{,}7$% deformation using uniaxial stretching, these deformation values were s_1 yield point, s_3 maximum tensile strength and s_2 a point in between.

D. Aguirre-Guerrero, A. Juárez-Hernández, M.A.L. Hernández-Rodríguez, University Autonumous of Nuevo León, Faculty of Mechanical and Electrical Engineering, Nuevo León, México. R. Morales, I. Ruiz, PEMSA Co. Celaya, Guanajuato, México.

Table 1 **Chemical composition in wt %**

Fe	C	Mn	Si	P	Al	Cr	Nb	Ti	Ni	Cu
97,74	0,05	1,645	0,3809	0,0583	0,0409	0,0314	0,026	0,0225	0,0198	0,0158

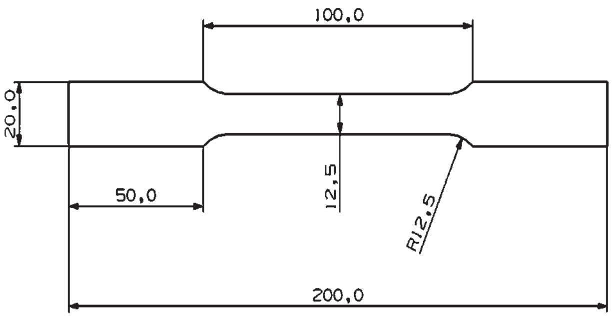


Figure 1 Specimen size in *mm*

Fatigue test were made in an Instron machine, 801 model of 100 kN capacity for four different prestrain levels s_0, s_1, s_2 and s_3 deformations using four maximum loads σ_1=465,1, σ_2=427,8 , σ_3=390,78 and σ_4=279,5 MPa for each prestrain condition respectively at 1Hz frequency, fatigue tests were made in the direction of the applied prestrain, and were conducted under stress control in tension loading at room temperature, fatigue tests were stopped if failure existed or if specimen did not fail after 200,000 cycles.

RESULTS AND DISCUSSION

Microstructure of HSLA steel obtained results in a ferrite and cementite phases where grain boundary and lamination direction are observed, grain size results in 6,3 ± 0,3 μm Figure 2 a, on the surface a Zn coat was observed.

Three tensile tests were made parallel to the lamination direction for the same sample, Figure 3 a, in order to obtain strain-hardening exponent *n* and the strength coefficient *K* only a portion between 10 % and 20 % of true strain is taken to plot a log σ vs log ε, plastic zone, Figure 3 b. The value of the slope is the strain - hardening *n*, extrapolation of log ε = 0 is the value of the strength coefficient *K*.

Results show a maximum stress at 464,7 ± 1,4 MPa, a yield stress of 350,85 ± 0,24 MPa an elongation percentage of 26,47 ± 1,18 %; on the other hand in the plastic region shows a value of n = 0,21 ± 0,003 show-

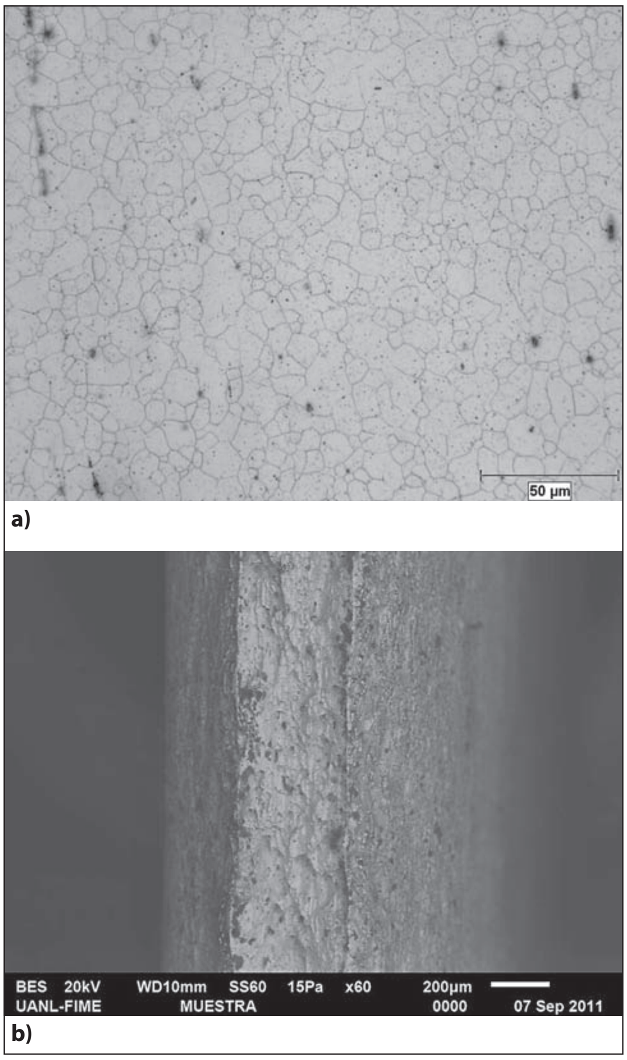


Figure 2 a) Optical micrograph shows grain size and orientation, b) SEM micrograph

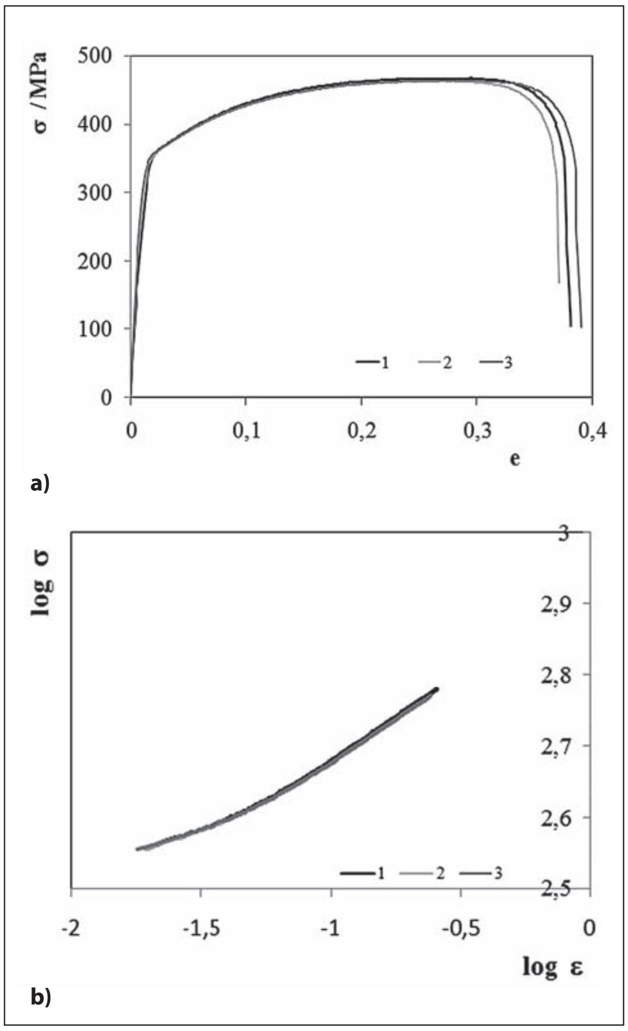
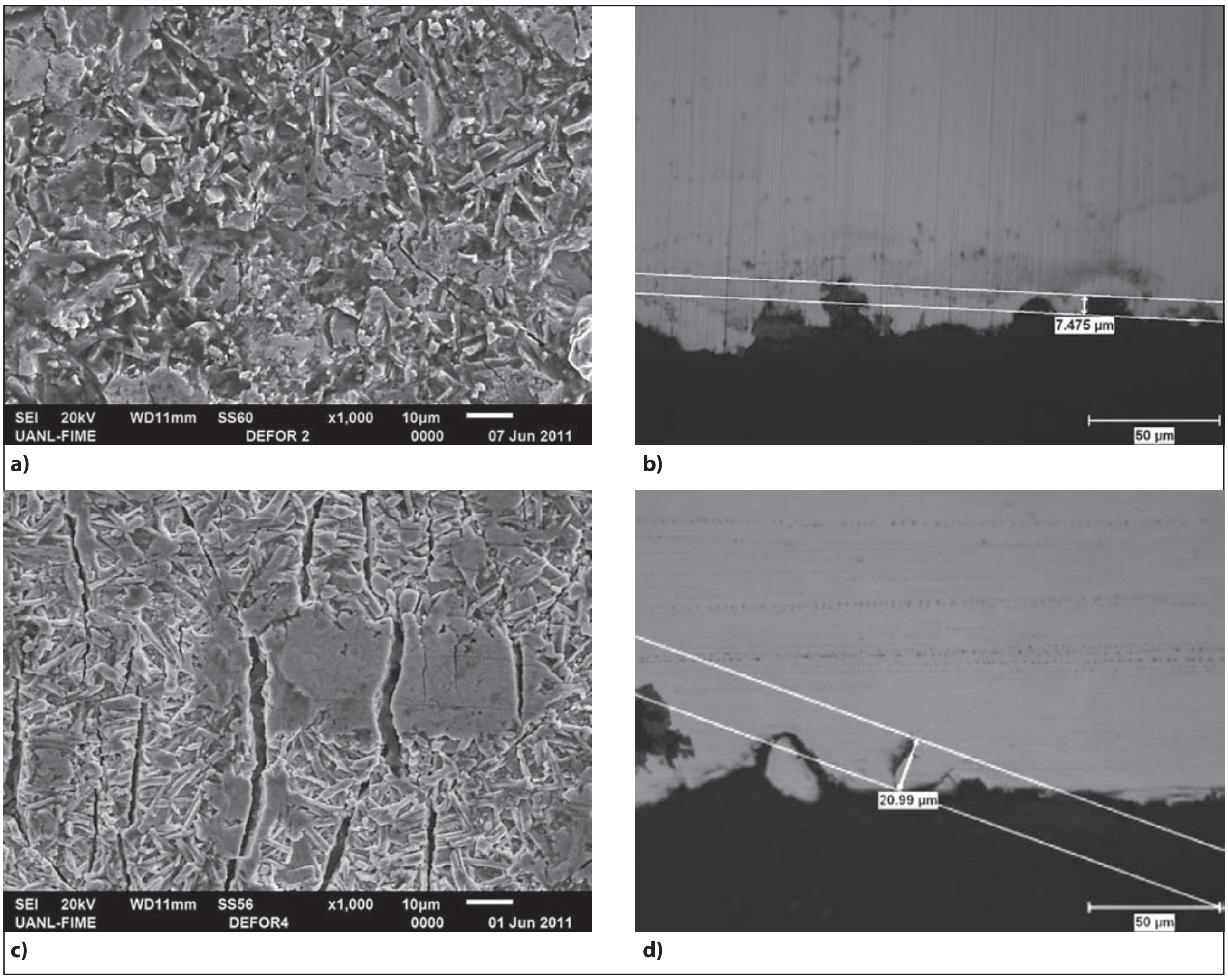


Figure 3 Three experimental measurements a) stress strain curves for an HSLA steel and b) log σ vs log ε of the plastic zone



a) b) c) d)

Figure 4 Crack formations for specimens a) s_1 on the surface, b) transversal s_1, c) s_3 on the surface and d) transversal s_3

ing that neck formation will starts at 21 % deformation and K = 776,21 MPa, with a value of r = 1,21 ± 0,13 showing that this alloy has a degree of anisotropy due to its grain orientation.

Surface analysis was made after prestrain in order to see its condition before fatigue tests, crack formations were observed, the higher the deformation the bigger and deeper the cracks, most of the cracks are perpendicular to the strain direction, Figure 4, transversal micrographs shows that crack formation and propagations were observed only on the galvannealed Zn coating. For a galvannealed coating the alloying reaction results in a hard, relatively brittle coating, in this case the coating is around 200 microns and crack are observed only on this surface.

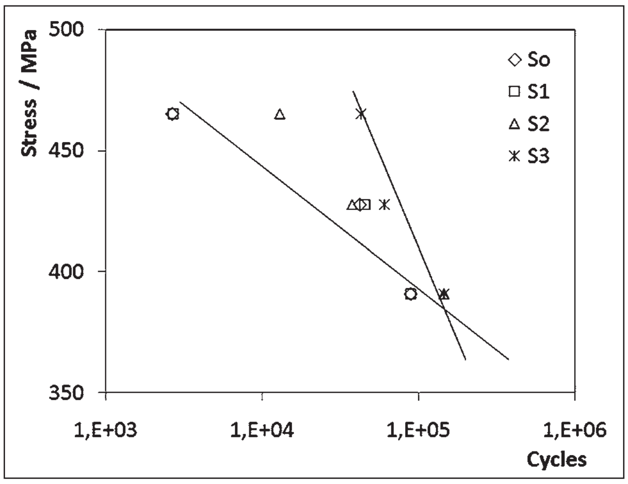


Figure 5 Stress – life curves for all prestrain levels

Fatigue test

Fatigue test results are shown in Figure 5, where at higher stress values fatigue life decreases and at lower stress values fatigue life increases as expected; at the lowest stress 279,5 MPa specimens did not fail and fatigue test was stopped after 200 000 cycles.

Results show that the higher prestrain the higher fatigue resistance for all stress applied, specimens with s_0 and s_1 seem to behave very similar under the different experimental conditions as s_1 prestrain is in the limit of the plastic rage. On the other hand s_3 shows the highest fatigue resistance for all stresses applied, these behavior is explain in terms of work hardening as s_3 and s_2 conditions were prestrain above the plastic limit.

Finally in all cases a transgranular fracture was observed having a higher deformation close to the fracture surface, see Figure 6.

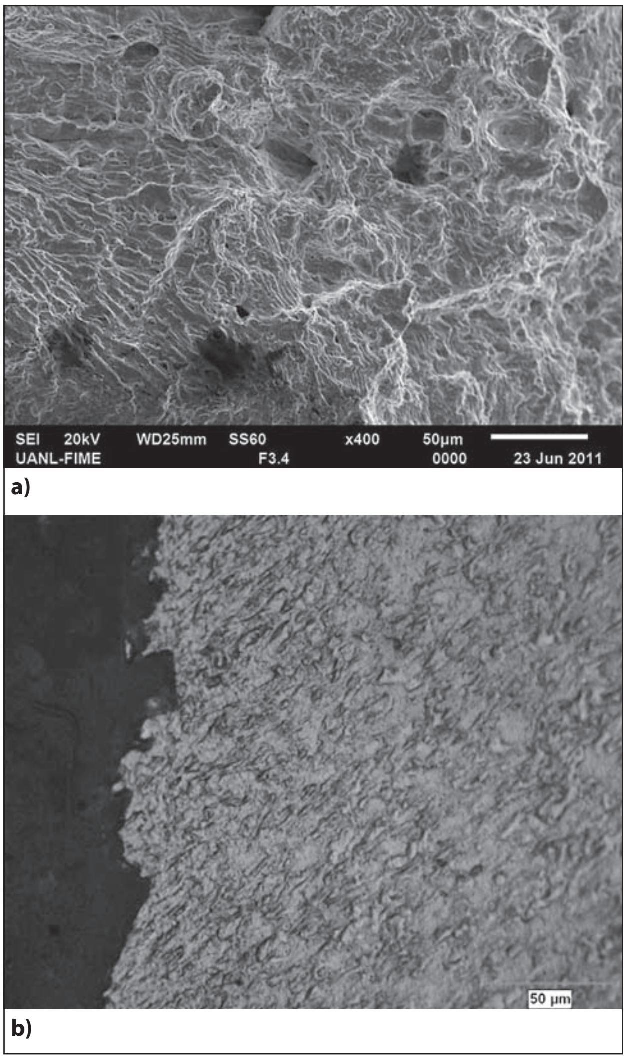


Figure 6 Micrographs a) on the surface fractura and b) transversal view of the facture.

CONCLUSIONS

A fatigue test behavior was studied for an HSLA steel, ferrite and perlite microstructure was observed

Tension test was evaluated at 90 º from the lamination direction having the maximum stress at 465 MPa, a strain hardening n = 0,21 ± 0,003 and strength coefficient K = 776,21.

Results show that the higher prestrain the higher fatigue resistance at the stresses studied, finding a transgranular fracture.

Acknowledgments

Authors would like to thanks to PEMSA and CONACYT Mexico, for its founding support.

REFERENCES

[1] M. Sherman, Fatigue Properties of High Strength-Low Alloy Steels. Metallurgical transactions A. 6A, May (1975) 1035-1040.

[2] Q. Le, H. Kang, G. Kridli, A. Khosrovaneh, B.Yan. Modified strain-life equation to consider the effect of different prestrain paths for dual phase sheet steel. Journal of Materials Processing Technology, 209 (2009) 3525–3531.

[3] K. Fredriksson, A. Melander and M. Hedman. Influence of prestraining and ageing on fatigue properties of high-strength sheet steels. Int. Journal of Fatigue, 10 (1988) 3, 139-151

[4] M. S. Rashid. Formable HSLA and Dual-Phase Steels, A.T. Davenport, Ed., TMS AIME, Warrendale, PA, 244 (1979) 1–24.

[5] O. Matsumura, Y. Sakuma, and H. Takechi. Trip and its kinetic aspects in austempered 0.4C-1.5Si-0.8Mn steel, Scripta Metallurgica, 21 (1987) 10, 1301–1306.

[6] I. B. Timokhina, P.D. Hodgson, and E.V. Pereloma. Effect of microstructure on the stability of retained austenite in transformation-induced-plasticity steels Metallurgical and Materials Transaction A, 35A (2004) 2331–2341.

[7] Timothy B. Hilditch, Ilana B. Timokhina, Leigh T. Robertson, Elena V. Pereloma and Peter D. Hodgson. Cyclic Deformation of Advanced High-Strength Steels: Mechanical Behavior and Microstructural Analysis. Metallurgical and Materials Transactions A, 40A (2009) 342-353.

[8] B. Yan and D. Urban. Characterization of Fatigue and Crash Performance of New Generation High Strength Steels for Automotive Applications (Phase I and Phase II). AISI/DOE Technology Roadmap Program Report, AISI, Washington, DC, Jan. 2003.

[9] T. Yokoi, M. Takahashi, and N. Ikenaga. SAE Technical Paper 2001 01-0042, SAE, Warrendale, PA

Note: The responsible for english language is the lector from Faculty of Mechanical and Electrical Engineering, Nuevo Leon, Mexico