

FATIGUE PROPERTIES OF GALVANIZED HIGHER-STRENGTH STEEL SHEETS

Received - Primljeno: 2006-06-18
Accepted - Prihvaćeno: 2007-05-20
Preliminary Note - Prethodno priopćenje

The paper analyzes the fatigue properties of galvanized microalloyed steel sheets H220LAD and H380LAD. Under flat bending conditions and the symmetrical cycle, the fatigue limit of the H220LAD sheet is $\sigma_{co} = \pm 152$ MPa and that of the H380LAD sheet is $\sigma_{co} = \pm 188$ MPa, and the fatigue limit to tensile strength ratio is 0,41 and 0,37, respectively. During fatigue tests with an increasing number of cycles or an increasing stress value, the degradation of the zinc coating increases (relief formation, damage of integrity). As a result, local corrosion, but also continuation of fatigue damage after 10^7 cycles, and hence corrosion fatigue, can take place during operation.

Key words: *galvanized steel sheet, bending fatigue limit, surface layer degradation*

Svojstva zamora materijala galvaniziranih ojačanih čeličnih traka. Članak analizira svojstva zamora materijala galvaniziranih mikrolegiranih čeličnih traka H220LAD i H380LAD. Pod uvjetima plosnatog savijanja i simetričnog ciklusa, granica zamora materijala trake H220LAD je $\sigma_{co} = \pm 152$ MPa a trake H380LAD je $\sigma_{co} = \pm 188$ MPa, a granica zamora materijala prema otporu na istezanje je 0,41 odnosno 0,37. Tijekom testova zamora materijala s rastućim brojem ciklusa ili rastućom vrijednosti pritiska, povećava se degradacija cinčane obloge (formiranje reljefa, oštećenje integriteta). Posljedično, tijekom rada može doći do lokalne korozije, ali i daljnjeg oštećenja uslijed zamora materijala nakon 10^7 ciklusa, a time i zamora materijala uslijed korozije.

Ključne riječi: *galvanizirana čelična traka, granica zamora materijala uslijed savijanja, degradacija površinskog sloja*

INTRODUCTION

Recently, a change in the philosophical approach of application of steels in the automotive industry has taken place. Among others, this change consists in the application of higher-strength steels to individual automotive parts. The service life is the primary requirement and with steels having a higher strength we can achieve the optimum fatigue resistance, and hence higher working stress values [1]. The service life of parts can be increased, among others, by their surface treatment [2]. Galvanization of steel sheets is used to reduce or prevent their corrosion degradation [3]. Therefore a combination of higher-strength steel sheet and its surface treatment is a prospective material, which is used even today for the manufacture of higher-loaded automotive parts which are dynamically impact loaded and cyclically loaded during operation, also under corrosion conditions [4, 6].

It results from the above-mentioned that it is also necessary to create a database in the field of resistance of

galvanized steel sheets against fatigue loading. Possible damage of the surface layer can degrade the fatigue properties of steel sheet (formation of fatigue failure nuclei) as a result of local corrosion and stress concentration.

The paper is aimed at the analysis of the fatigue properties of galvanized sheets made of microalloyed steels with the yield point of 220 and 380 MPa, respectively.

MATERIAL AND EXPERIMENTAL METHODS

Experiments were made on samples taken from H220LAD and H380LAD steel strips, which were cold formed to the thickness of 2 mm and then hot dip galvanized. These sheets made of microalloyed steels (microalloying elements Ti, Nb, V) are intended for the manufacture of higher loaded pressings in the automotive industry. The microstructure of the tested sheets is ferritic with a small portion of pearlitic grains arranged in rows. Figure 1. shows the microstructure of H380LAD strip (C < 0,1 %, Ti < 0,015 %, Nb < 0,09 %, V < 0,1 %). The zinc layer thickness ranged from 8 to 14 μm .

Samples were taken from the tested sheets in the rolling direction and test bars were made for tensile tests

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and flat bending fatigue tests, Figure 2. The cycle was symmetric (tension - compression) with the frequency of 30 Hz.

The limit number of oscillations at $N_C = 10^7$ cycles was considered as the flat bending fatigue limit σ_{Co} . The behaviour of the zinc layer after cyclic loading was observed using light microscopy, also with polarized light, and using scanning electron microscopy.



Figure 1. Microstructure of H380LAD steel strip
Slika 1. Mikrostruktura čelične trake H380LAD

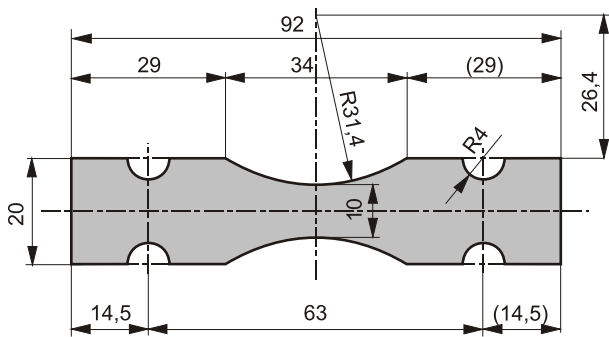


Figure 2. Flat bending fatigue test bar
Slika 2. Epruvete za testiranje zamora materijala uslijed plosnato savijanja

EXPERIMENTAL RESULTS AND THEIR ANALYSIS

The basic mechanical properties of the tested sheets, determined using the tensile test, are shown in Table 1.

Table 1. Mechanical properties of tested materials
Tablica 1. Mehanička svojstva testiranih materijala

Steel mark	$R_{p0.2}$ /MPa	R_m /MPa	A_{80} /%	R_e / R_m	σ_{Co} /MPa	σ_{Co} / R_m	a	b
H220LAD	246	371	32,7	0,66	± 152	0,41	11,814	-0,0332
H380LAD	382	509	24,8	0,75	± 188	0,37	14,392	-0,0411

The tensile test results confirmed that the tested sheets had high strength properties (R_e , R_m), but also favourable cold formability characteristics (A_{80} , R_e/R_m), therefore they are suitable for the manufacture of flat pressings that are subject to higher loading.

The main aim of the paper is to analyze the fatigue properties of the tested sheets under flat bending conditions, since such a way of loading is dominant in automotive parts. Also, this way of loading is the most demanding as

regards the behaviour of surface layers in the operation process.

The results of the fatigue tests of the tested sheets under flat symmetric bending conditions are shown in graphs, Figure 3. and Figure 4.

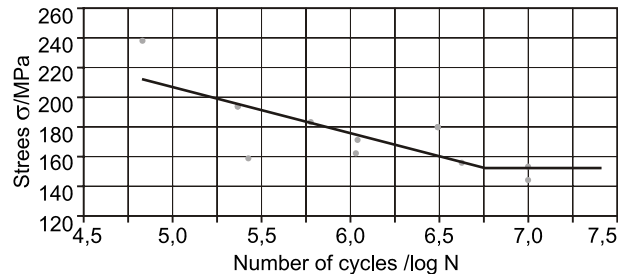


Figure 3. Wöhler curve of steel sheet H220LAD
Slika 3. Wöhler krivulja čelične trake H220LAD

The bending fatigue limit was determined at 10^7 cycles in accordance with technical standards. The σ_{Co} values for

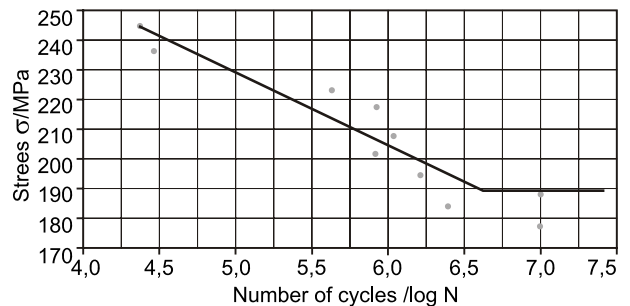


Figure 4. Wöhler curve of steel sheet H380LAD
Slika 4. Wöhler krivulja čelične trake H380LAD

the tested sheets were determined using linear regression and are shown in Table 1. Also in the inclined section of the $\sigma - N$ function (Wöhler curve) the a , b parameters of the regression relationship

$$\log N = a + b \cdot \sigma,$$

were determined.

Knowing the a , b parameters, shown in Table 1, enables us to determine the time fatigue limit σ_N for the number of cycles $N < 2 \cdot 10^6$:

$$\sigma_N = \frac{a - \log N}{b}.$$

During the tensile test, the cracking of the zinc layer takes only place in the neck area, immediately before the failure. From the viewpoint of the pressing technology, as well as the behaviour of sheets during operation, this is out of the sphere of interest. Therefore the attention was focused on the behaviour of the zinc coating during

cyclic loading, since any surface defect can accelerate the fatigue process.

Among the used methods of observation of the influence of cyclic loading on the zinc layer degradation, the best information was obtained by observing the surface of the fatigue tests bars using scanning electron microscopy after various numbers of cycles and at various stress levels. Figure 5. documents the zinc layer of the test bar made

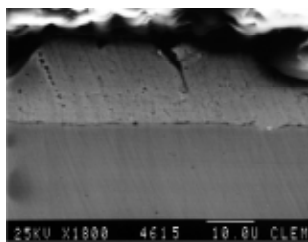


Figure 5. Damage of the Zn layer at $\sigma = 236$ MPa, $N = 28,600$ cycles
Slika 5. Oštećenje Zn sloja na $\sigma = 236$ MPa, $N = 28,600$ ciklusa/krugova

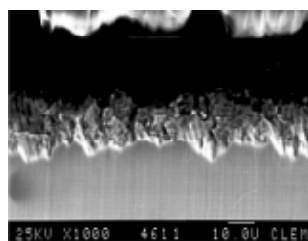


Figure 6. Damage of the Zn layer at $\sigma = 223$ MPa, $N = 413,600$ cycles
Slika 6. Oštećenje Zn sloja na $\sigma = 223$ MPa, $N = 413,600$ ciklusa/krugova

of the sheet H380LAD after $N = 28,600$ cycles at the stress $\sigma = 236$ MPa, Figure 6. after $N = 413,600$ cycles at $\sigma = 223$ MPa, and Figure 7. after $N = 10^7$ cycles at $\sigma = 177$ MPa, while none of the test bars failed as a result of a fatigue fracture.

It results from the analysis of results of observation of the zinc layer during cyclic loading that the layer gradually damages with the increasing number of cycles, in the

dependence on the upper stress value. As shown in Figure 7., the formation of cracks and the damage of the zinc layer also take place at stress values lower than σ_{Co} at 10^7 cycles.

It results from the experiments made and from literary knowledge that the zinc layer on the tested sheets does not influence the basic mechanical properties (R_e , R_m , A_{80}). During deformation up to the plastic stability limit, no damage of the zinc coating takes place.

The results of tests made under flat symmetrical bending show that the zinc layer does not influence the σ_{Co}/R_m ratio, which is favourable for the both tested grades and is equal to that of these grades without the zinc layer. The results confirmed generally valid knowledge that the σ_{Co}/R_m ratio decreases with the increasing tensile strength of steel

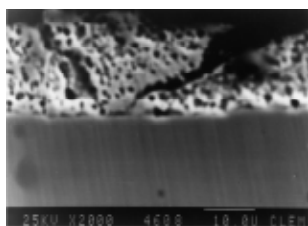


Figure 7. Damage of the Zn layer at $\sigma = 177$ MPa, $N = 10^7$ cycles
Slika 7. Oštećenje Zn sloja na $\sigma = 177$ MPa, $N = 10^7$ ciklusa/krugova

(see Table 1.) and the steepness of Wöhler curve increases (see Figures 3. and 4., or the b constant in Table 1.).

The primary role of the zinc layer on drawing sheets is the corrosion prevention. In terms of electrochemical nobility and corrosion resistance, zinc is significantly worse than iron and its purpose is to protect steel sheet against corrosion "at its expense". As the experiments showed, during cyclic loading the integrity of the zinc layer is damaged. The crack formation in the zinc layer particularly influences the resistance of steel sheet against local corrosion (point corrosion, pitting corrosion, etc.). Also cracks in the zinc layer, which can be considered as short cracks from the fatigue point of view, can initiate the formation and propagation of cracks even at lower stress than σ_{Co} , after 10^7 cycles, as stated in [4, 7, 8]. The study of the zinc coating showed that the accumulation of fatigue damage took place in the zinc coating even after 10^7 cycles, therefore a decrease in the fatigue limit can be expected at a higher number of cycles. In surface-treated steel sheets, local corrosion resistance can occur as a result of damage of the zinc layer. Consequently, we can assume that in such sheets the fatigue limit value will continuously decrease in the dependence on the working environment, which is adverse in automobile operation. At present, the fatigue limit of the tested sheets is determined up to 10^9 cycles.

CONCLUSIONS

The aim of the paper was to analyze the fatigue properties of galvanized steel sheets, 2 mm thick, H220LAD and H380LAD, having higher strength properties. These microalloyed steel sheets are suitable for higher-loaded pressings used in the automotive industry. Based on the results of tests and their analysis, the following can be stated:

- besides higher strength properties, the tested steels show, as a result of fine grains and a significantly decreased pearlite content, also favourable characteristics of cold formability;
- the bending fatigue limit at the symmetrical cycle under generally valid conditions (10^7 cycles) is not influenced by the zinc layer and the σ_{Co}/R_m ratio is 0,41 (for steel H220LAD), or 0,37 (for steel H380LAD), which is considered as very favourable;
- during static loading, the damage of the zinc layer only takes place after exceeding the plastic stability limit of the tested sheets, i.e. when a neck is formed on the test bar;
- during fatigue tests under flat symmetrical bending, the degradation of the zinc layer took place: initially, the formation of a surface relief and, with the increasing number of cycles or at higher stress levels, the damage of its integrity. The degradation of the zinc layer has not a saturation nature and continues even at stress lower than σ_{Co} or after more than 10^7 cycles to fracture.

On the basis of the results and the literary knowledge, we assume that in such treated specimens the fatigue limit will decrease even after 10^7 cycles to fracture.

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