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ROBERT ULEWICZ*

INFLUENCE OF SELECTED TECHNOLOGICAL FACTORS ON FATIGUE STRENGTH

WPŁYW WYBRANYCH CZYNNIKÓW TECHNOLOGICZNYCH NA WŁASNOŚCI ZMĘCZENIOWE

Abstract

The determination of the material fatigue limit is important with regard to the determination of safe service life of structural materials. Depending on the type of treatment and the type and size of introduced stresses, technological procedures can affect negatively or positively the fatigue properties of steel. Based on literature research and our own research, the article presents the influence of selected technological factors on fatigue properties. Our own studies were performed with the use of load high frequencies of 20 kHz in the ultra-high-cyclic area.

Keywords: fatigue, *S–N curve*, *coatings*, *shot peening*

Streszczenie

Wyznaczenie granicy zmęczenia materiału jest istotne ze względu na określenie bezpiecznego resursu. W zależności od rodzaju zabezpieczeń antykorozyjnych i typu obróbki oraz wielkości wprowadzonych naprężeń zabiegi technologiczne mogą wpływać negatywnie lub pozytywnie na własności zmęczeniowe stali. W artykule przedstawiono na podstawie badań literatury oraz własnych, wpływ wybranych czynników technologicznych na własności zmęczeniowe. Badania własne przeprowadzono z zastosowaniem wysokich częstotliwości obciążenia 20 kHz w obszarze ultra wysokocyklowym.

Słowa kluczowe: zmęczemie, *S–N krzywa*, *powłoka*, *kuleczkowanie*

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* Assoc. Prof. D.Sc. Ph.D. Eng. Robert Ulewicz, Institute of Production Engineering, Faculty of Management, Czestochowa University of Technology.

1. Introduction

Contemporary trends to reduce the consumption of materials in the construction of machines and devices require the use of high-strength, and therefore materials which are generally more fragile and susceptible to fatigue. The analysis of the causes of machines and equipment elements failures shows that about 90% of all reported cases of cracking is caused by the process of fatigue. Using anticorrosion coverings, and, in particular, coverings of galvanic-technical coatings, does not have a beneficial effect on the fatigue properties of structural steel. In the case of fatigue cracking, the cracking is caused by periodically--variable stresses of a much smaller value than their tensile strength specified in the static tensile test, but also with a sufficiently high number of cycles of load changes in the range of 10^5–10^8.

The analysis of fatigue cracking confirms that the nucleation and propagation of fatigue cracks are controlled by local processes in micro areas of the material [1, 2].

2. Influence of selected factors on fatigue characteristics of materials

The fatigue process is influenced by many factors which can significantly delay or accelerate the process of fatigue. These factors can be divided into internal and external. Internal factors include material structure, chemical composition, grain size, sample size as well as shape and distribution of non-metallic inclusions, while external factors include frequency, asymmetry of the cycle, the size of mean stress and the stress state. In practice, one cannot be limited to a single factor (Table 1), in the operational and research assumptions one should respect a current impact of several factors [13].

Table 1

Effect of selected factors on fatigue curve characteristic

Role of the factor	K_{th} [MPa·m$^{1/2}$]	$V_p = da/dN$ [m/cycle]	σ_c [MPa]
Asymmetry of the cycle	↓	↑	↓
Frequency	↑	↑↓	↑
Temperature	↓	↑↓	↑↓
Aggressive environment	↓	↑	↓
Grain size	↑↓	↑	↓
R_e	↓	↓	↑
R_m	↓	↓	↑

↑ – high impact, ↓ – small impact, ↑↓ – no information

In order to increase the low yield strength on fatigue, in practice, many methods of technological treatments are applied, which is particularly useful for parts which have a sharp undercut construction. Since fatigue cracks are generally formed on the element surface or just under the surface, mechanical properties of surface layers should primarily be improved [5, 6]. This condition can be achieved by surface treatment of the element, inter alia: mechanical treatment: shot peening or surface rolling, thermal treatment: surface hardening, thermal-chemical treatment: carburizing, nitriding.

As a result of a mechanical or thermo-chemical treatment, the strength of the surface layer of metal increases, as well as, even though usually prohibitively, the fatigue strength limit. At the same time their own stresses are formed, which are compensated by stress resulting from the tensile force of the core [3, 4, 8]. However, the decision about which of the two operations is more important will depend on the type of used treatment and occurring stress.

Despite the fact that in recent decades this problem has been considered utterly important and investigated very intensively (a lot of experimental research results have been published), it failed to draw up comprehensive and theoretically justified guidelines that are likely to allow for determining the effects of a chosen method of treatment in a given specific case. However, given a large number of factors that affect the final results (type of treatment, type of material, shape of the body element, dimensions, type of stress, loading, etc.) results obtained on samples during research cannot be used for actual elements, which are normally of larger dimensions; they can be used only as documents that form the basis for drawing up qualitative, and possibly partly quantitative opinions, in order to give opinions on the impact of type of treatment of a surface layer on the fatigue strength limit.

A positive effect in the form of the introduction into the surface of a layer of high compressive stress is obtained in the process of shot peening.

Stresses forces in the curved surface have a positive impact not only on slowing down of the process of initiation of the first fatigue cracks, but also on the expansion of the already formed ones and lead to a significant inhibition of the growth of the existing cracks [9]. The degree of stresses in shot peening process is visibly associated with the type of surface coverage, where this factor is readable as well at this stage of fatigue damages.

The increase of the limit of fatigue strength is typically less than 20%, and in some cases, this limit was lower than the limit of fatigue strength of the polished samples. In this case, on the one hand, there is a positive effect on the increase of durability of the surface layer, on the other hand, the negative action arises as a result of irregularities in the surface of the

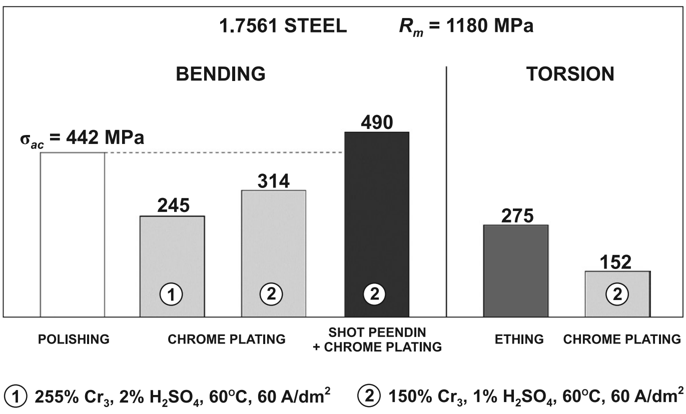

Fig. 1. Scheme of the residual stresses in the surface layer of the material after shot peening [9]

element. Shot peening is desirable for elements with a rough surface, and it particularly finds application in forgings and elements which are not further subjected to subsequent treatments after heat treatment.

The application of a product galvanized coating on the surface in order to prevent corrosion or to increase abrasion resistance, usually produces considerable tensile stresses in the coated-parental material, thereby reducing resistance to fatigue. During the chrome plating, but also during other galvanic treatments, the negative effect of treatment increases with the increase of material strength (R_m). We observe the increase in adverse effects with the increase in thickness of the applied layer (coating). The described adverse effect can be corrected to some extent by precipitation conditions (temperature of the electrolyte). Other possibilities for the removal of adverse actions of galvanic treatment are provided by the method of shot peening of a part of the elements prior to processing, Fig. 1 [9, 10, 14, 15].

3. Experimental material and procedure

The 1.0117 steel was used for this research. The first series of samples was coated with chromium coating. There, the CHEMOCHROM 3 S bath was used. The second series of samples was coated with nickel coating in the SUPRAGAL bath. The third series of samples was subjected to the shot peening process (shot peening parameters: shot diameter 0.45 mm, angle of the attack 75°, speed v_T = 78.1 m·s^{-1}, amount of shot q_n = 45 kg·m^{-2}). The fourth series of samples was the parental material. Fatigue tests were carried out on a high-frequency fatigue machine KAUP-ZU in the ultra-high-cyclic area at the load frequency of 20 kHz. The samples for fatigue tests were made in accordance with the assumptions described by Salam and Lamerand.

4. Results and discussion

Fatigue research in the area of very high load cycles ($N \approx 6 \cdot 10^6 - N \approx 1 \cdot 10^{10}$ cycles) was made at high-frequency loads of stretching-compressing type with sinusoidal course (f = 20 kHz, R = –1, T = 20 ± 10°C with cooling the samples in distilled water with anticorrosive inhibitor). The research results are shown in Fig. 2.

For the parent material, the applied stress of amplitude σ_a decreased from σ_a = 270 MPa (for N_f = 5.7·10^7 cycles) to σ_a = 160 MPa (for N_f =1.3·10^{10} cycles), which gives the amplitude difference of $\Delta\sigma_a$ = 110 MPa. In general, we can say that the amplitude of pressure continues to decline with the growing number of cycles to the growing damage beyond conventional border of cycles (N_C =1·10^6 – N_C =1·10^7 of cycles – typically used range of cycles to demarcate the fatigue limit σ_C) [11, 12]. This fact is vital because of the reliability and safety of machinery and equipment [7]. For the steel with a nickel coating, the applied stress of amplitude σ_a decreased from σ_a = 260 MPa (for N_f = 0.2·10^7 cycles) to σ_a = 170 MPa (for N_f = 0.9·10^{10} cycles), which gives the amplitude difference of $\Delta\sigma_a$ = 90 MPa. In the case of the chromium coating, the applied stress of amplitude σ_a decreased from σ_a = 260 MPa (for N_f = 0.3·10^7 cycles) to σ_a = 170 MPa (for N_f = 0.8·10^{10}

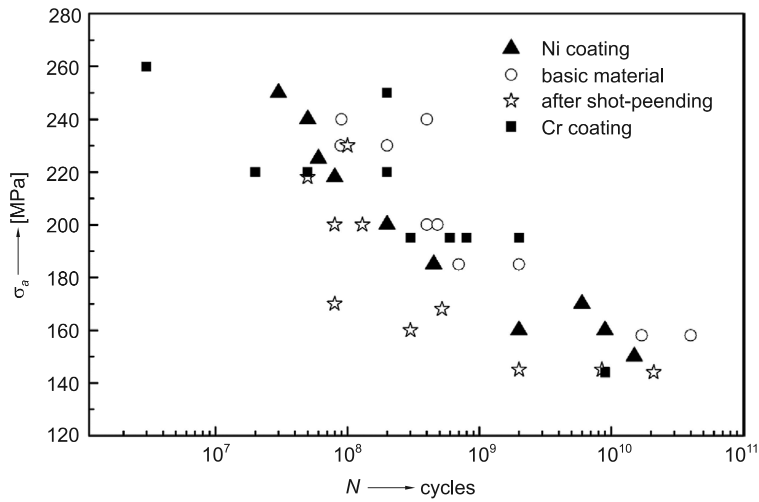

Fig. 2. The dependence of stress amplitude σ_a on number of cycles N (f = 20 kHz, T = 20 ± 10°C, R = –1)

cycles), which gives the amplitude difference of $\Delta\sigma_a$ = 90 MPa. In the fatigue life test results for 1.0117 steel after the process of ball peening, the applied stress of amplitude σ_a decreased from σ_a = 225 MPa (for $N_f = 5.3 \cdot 10^7$ cycles) to σ_a = 145 MPa (for $N_f = 1.7 \cdot 10^{10}$ cycles), which gives the amplitude difference of $\Delta\sigma_a$ = 80 MPa.

5. Summary

The optimization of structural material selection plays an important role in the processes of exploitation, which tends to carry out research activities related to the material resistance on working conditions, especially in the field of variable loads. In order to achieve more durable parts of machines, it is necessary to develop research on the impact of technological and structural factors as well as surface conditions. Anticorrosive protections, technical coatings or decorative coatings can significantly affect the fatigue strength of machine parts. The fatigue tests f = 20 kHz, T = 20°C, R = –1, $N_c > 10^7$ at high-frequency loading cycle were carried out for all the series of samples. There were experimentally determined dependencies $\sigma_a = f(N_f)$ in the areas of high and giga-cyclic range from $N_f = 0.2 \cdot 10^7 - 3.3 \cdot 10^{10}$ cycles. The results of all samples of 1.0117 steel with coatings in the area over a conventional fatigue limit, with stress amplitude decrease σ_a increases the number of cycles to fatigue crack, for steels with coating Ni $\Delta\sigma_a$ = 170 MPa, for steel with coating Cr_3 $\Delta\sigma_a$ = 90 MPa. For samples after shot peening in the area over the conventional fatigue limit with a decrease in the amplitude of the stress σ_a increases the number of cycles to fatigue crack, $\Delta\sigma_a$ = 80 MPa.

The obtained fatigue results in the giga-cyclic range with the use of the high frequencies of load demonstrated that the coatings to a much lesser extent affect the reduction in the fatigue properties with the use of load high-frequency, in comparison with the results obtained when the low frequencies of loading were used [11, 12]. However, considering the studies performed we can conclude that the shot peening treatment had the greatest impact of surface treatment on material fatigue. As a result of the performed tests, the new information was obtained on fatigue properties of steel with galvanic coatings in the area of very high load cycles and with surface treatment in the area of very high load cycles. It was also determined how the process of removing unnecessary, undesirable coatings by shot peening affects fatigue properties.

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