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The effect of the production process of medium-carbon steel on fatigue strength

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Abstract

The experimental material comprised semi-finished, high grade, medium-carbon structural steel for the production of mining chains. Steel was melted in a 140 ton electric furnace and desulfurized (E). In the second analyzed variant, steel was additionally refined with argon (EA). In the third variant, steel was melted in a 100 ton converter. Secondary treatment involved vacuum circulation degassing. Specimens with a diameter of 10 mm were prepared by hardening and tempering at 200, 300, 400, 500 and 600°C. Fatigue tests were performed with the use of a rotary bending machine at a frequency of 6000 cpm. The results were processed and presented in graphic form.

Keywords: Steel, Fatigue Strength, Metallography, Durability, Production Process

1. Introduction

Structural materials are subject to degradation during use. Those processes account for:

- progressive damage (degradation) due to, for example, corrosion, erosion, etc.,
- accidental damage whose effects are revealed after its occurrence.

Fatigue degradation is a type of damage that occurs over time and causes significant losses. Examples of such damage are standard failures in the railway [1, 2], aviation [3] and power generation industries [4]. Fatigue occurs and develops gradually due to cyclic service load that causes stress. Initial stages are marked by the incubation of slips whose number increases in individual grains. In the following stage, slip bands in adjacent grains are connected to form the crack nucleation zone. With an increase in the number of cycles, the number slip bands develops rapidly in adjacent grains. Previous material deformations are transformed into microcracks due to the loss of material plasticity. When critical values are exceeded, the material cracks and becomes fit for scrap. None of the above stages are clearly detectable, and the above division has been introduced solely for the purpose of systematizing theoretical deliberations.

The fatigue strength of steel is a complex scientific field, and processes that cause the material to crack under periodically varying loads are stochastic events. The above results mainly from material heterogeneity caused by imperfections of the production process and its effect on alloy properties [5, 6, 7]. As demonstrated by phenomenological research, the expansion of cracks resulting from fatigue is determined by the number of cycles, stress intensity and material properties. The combined effect of internal microstresses resulting from the presence of non-metallic inclusions in steel and stress caused by external load plays an important role in the formation and development of fatigue cracks. Internal stress is a function of the morphological composition of impurities, but it is most affected by the heat processing environment [8÷14]. The above is inclusive of the thermal expansion of structural components under the influence of heat.

2. Aim of the study and methods

The objective of this study was to determine the effect of the production process of high-grade structural steel, including production and heat processing, on steel's fatigue strength.

The samples were quenched and austenitized at a temperature of 880°C for 30 minutes. They were then cooled in water and tempered by holding the sections at a temperature of 200, 300, 400, 500 and 600°C for 120 minutes and air-cooled.

The process of steel production was introduced in detail in [15].

Coefficients m and k have been determined for the function representing durability of steel. The correlation was approximated by the following function describing the number of cycles (lgN) leading to specimen damage at low-cycle fatigue range (1):

$$\ln N = m - k\,\sigma \qquad (1)$$

where: m and p are material constants:
m- initial ordinate of curve,
k- angular coefficient of curve.

3. The results of investigations and their analysis

The structure of specimens after various heat treatments involving an electric furnace and argon refining is presented in Figures 1÷5. The principal structure of steel is identical for the remaining two production methods with respective heat treatment variants.

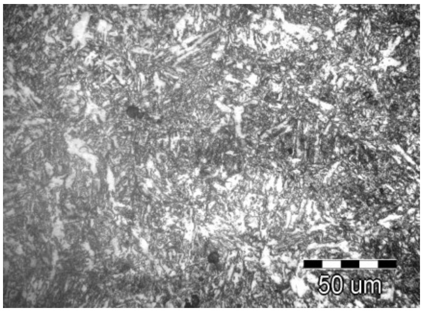

Fig. 1. Microstructure of steel hardened and tempered at 200°C. Tempered martensite

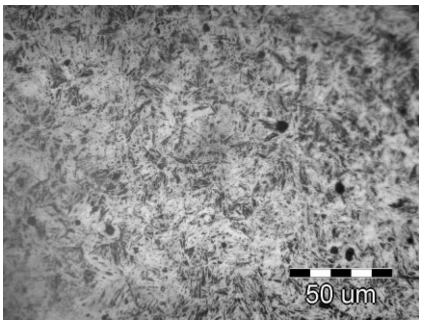

Fig. 2. Microstructure of steel hardened and tempered at 200°C. Tempered martensite with metastable carbidies

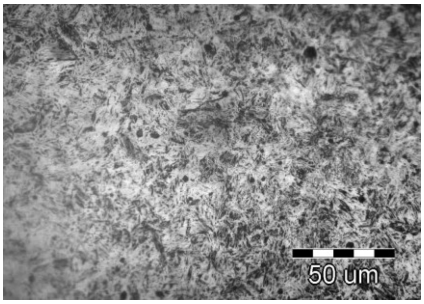

Fig. 3. Microstructure of steel hardened and tempered at 400°C. Tempered martensite with cementite formations coherently bonded with the groundmass

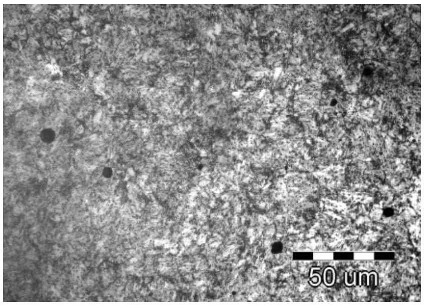

Fig. 4. Microstructure of steel hardened and tempered at 500°C. Sorbite – mixture of ferrite and submicroscopic carbidies

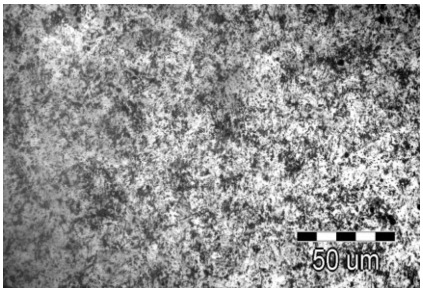

Fig. 5. Microstructure of steel hardened and tempered at 500°C. Sphroidit – glogular cementite in ferrite matrix

The observations of microsections etched with nital revealed that steel tempering at various temperatures significantly affected the material's phase structure. Structural changes ultimately led to variations in material hardness (Fig. 6).

The Vickers hardness for all tempering temperatures is presented in Figure 5. In the analyzed melting methods, lower hardness was noted for tempering temperature of 300°C in the converter method (KP) and for the remaining temperatures in the argon refining method (EA). In general, steel hardness was determined mainly by the structure forming process. The average number of lgN cycles for every tempering temperature is presented in Figure 7.

No significant differences were noted in the number of lgN cycles at tempering temperatures of 200°C and 300°C. Differences were reported in the converter method (KP) where the number of lgN cycles was 10% lower at 200°C and 8% lower at 300°C in comparison with the method involving electric furnace melting and desulfurization (E). The differences between (E) and (EA) heats reached around 1%. After tempering at 400°C, the number of cycles increased by 3% for method (E) and 1% for method (EA) in comparison with heats processed at 300°C. An insignificant decrease in strength values was noted for method (KP). An increase in tempering temperature to 500°C led to a drop in the number of cycles by 5% for (E), 4% for (EA) and 1% for (KP) in comparison with 400°C. When steel tempering temperature was raised to 600°C, the number of cycles increased for both melting methods – by 4% for (E) and 1% for (KP).

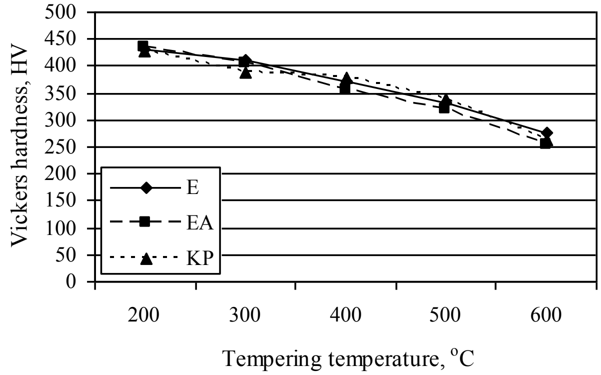

Fig. 6. Vickers hardness

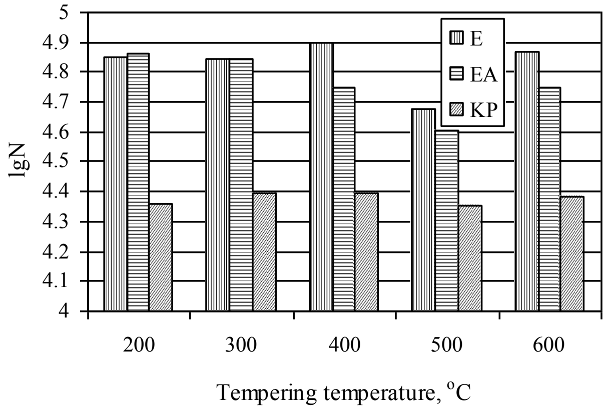

Fig. 7. Average number of lgN cycles for every tempering temperature

The above findings suggest that the converter method with vacuum circulation degassing (KP) significantly stabilizes the analyzed parameter. In the converter method, the number of cycles was only insignificantly affected by tempering temperature with variations in the range of 1%. The differences noted in the remaining two methods approximated 4%. Except for tempering temperatures of 200°C and 300°C, the highest number of cycles was noted in respect of desulfurized steel melted in an electric furnace. At 200°C and 300°C, the number of lgN cycles was insignificantly higher for method (EA) than for method (E). The noted results should also be attributed to steel structure. At the lowest tempering temperatures, tempered martensite has a hard structure with few variations. The remaining temperatures result in the formation of sorbite, and at 600°C – troostite, i.e. structures characterized by greater plasticity, elasticity and a higher degree of diffusion.

The average variable stress resulting in fatigue σ for every tempering temperature is presented in Figure 8. It clearly demonstrates the correlation between variable fatigue stress, temperature and, consequently, structure which follows from the effect of heat on hardened steel. The highest σ values for each melting method were noted at a low tempering temperature of 200°C. The average values of σ were reported for temperatures in the range of 300°C to 500°C, while the lowest values – for the highest tempering temperature of 600°C. The values of σ noted in the analyzed tempering methods differ insignificantly at various temperature settings.

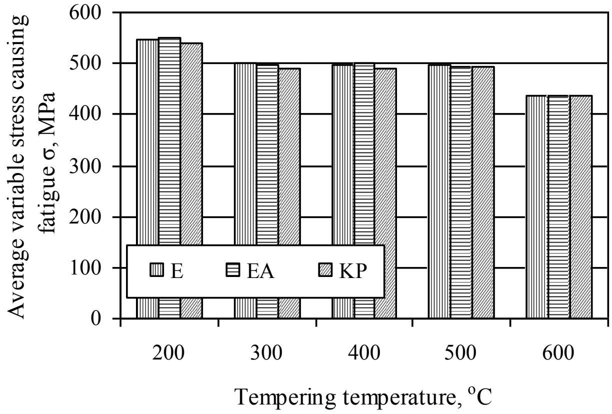

Fig. 8. Average variable stress causing fatigue σ

The average values of material parameter *m* are presented in groups in Figure 9.

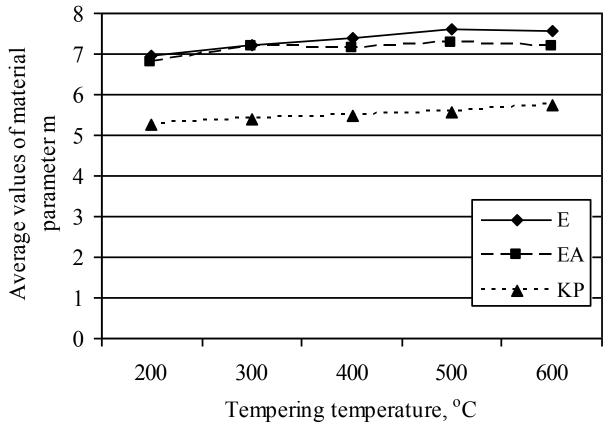

Fig. 9. Average values of material parameter *m* – in groups

The m coefficient was visibly lower in the converter melting method (KP). The value of ordinate m was identical in both methods involving electric furnace melting at tempering temperature of 300°C. At higher temperatures, ordinate m increased in method (E) in comparison with method (EA). A reverse trend was noted at 200°C.

The average values of angular coefficient k are presented in groups in Figure 10. The highest coefficient values were noted for method (E), insignificantly lower values were observed for method (EA), and significantly lower values – for method (KP). In the latter method, the function describing changes at different tempering temperatures had a nearly linear course, while the function for both methods involving electric furnace melting had a varied angle of inclination which was two-fold higher than that noted for method (KP).

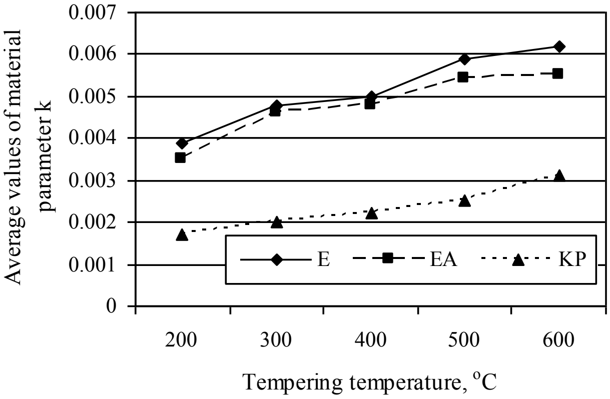

Fig. 10. Average values of material parameter k – in groups

4. Conclusions

Microscopic analyses revealed that steel structure for all three processes was a function of tempering temperature at constant hardening parameters. Therefore, it can be assumed that the structural differences observed in the analyzed melting processes do not affect the fatigue strength of the studied specimens. Vacuum circulation degassing lowers fatigue life and strength.

References

[1] S. K. Dhua, R. Amitava, S. K. Sen, M. S. Prasad, K. B. Mishra, S. Jha: Influence of nonmetallic inclusion characteristics on the mechanical properties of rail steel. JMEPEG 9, 2000, 700–709

[2] S. Gubenko, Y. Proidak, A. Kozlovsk'y, O. Shramko, M. Is'Kov: Influence of nonmetallic inclusions on microbreaks formation in wheel steel and railway wheels, Transport problems 3, 2008

[3] N. Ejaz, S.A. Rizvi: Cable failure resulted in the crash of a trainer aircraft, Engineering Failure Analysis 17, 2010, 394–402

[4] T. Niendorf, J. Dadda, D. Canadinc, H.J. Maier, I. Karaman: Monitoring the fatigue-induced damage evolution in ultrafine-grained interstitial-free steel utilizing digital image correlation, Materials Science and Engineering A 517, 2009, 225–234

[5] A. Z. Rashid, J. Purbolaksono, A. Ahmad, S. A. Ahmad: Thermal fatigue analysis on cracked plenum barrier plate of open-cycle gas turbine frame, Engineering Failure Analysis 17, 2010, 579–586

[6] N. Raje, T. Slack, F. Sadeghi: A discrete damage mechanics, model for high cycle fatigue in polycrystalline materials subject to rolling contact, Int J Fatigue 31, 2009, 346–60

[7] J. Xu, Z.L. Zhang, E. Řstby, B. Nyhus, D.B. Sun: Constraint effect on the ductile crack growth resistance of circumferentially cracked pipes, Engineering Fracture Mechanics 77, 2010, 671–684

[8] R. Dekkers, Ph.D: Thesis, Katholieke Universiteit Leuven, Leuven, Belgium 2002

[9] S. Loren: Estimating inclusion distributions of hard metal using fatigue tests, Int J. Fatigue 25 (2), 2003, 129-137

[10] Y. Murakami, S. Kodama, S. Konuma: Quantitative evaluation of effects of non-metallic inclusions on fatigue strength of high strength steels, I: basic fatigue mechanism and fatigue fracture stress and the size and location of non-metallic inclusions, Int J Fatigue 11 (5), 1989, 291–298

[11] T. Lis: Modification of non-metallic dispersion phase in steel, Metallurgy and Foundry Engineering 1/28, 2002

[12] M. A. Miner: Cumulative damage in fatigue. Trans. ASM 65, 159 (1945)

[13] S. Kocańda: Zmęczeniowe pękanie metali. 1985, WNT Warsaw (in Polish)

[14] Y. Murakami: Metal fatigue, Effects of small defects and nonmetallic inclusions, Oxford, Elsevier 2002, 57–115

[15] T. Lipiński, A. Wach: The effect of out-of-furnace treatment on the properties of high-grade medium-caborn structural steel. Archives of Foundry Engineering 10, 2010, 93-96