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Fatigue lifetime of 20MnV6 steel with holes manufactured by various methods

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Abstract
In this paper, the authors publish their own experimental results of the examination of the different holes (milled, drilled and drilled + shot peened) on the fatigue lifetime of 20MnV6 steel. The experiments were carried out at low-frequency loading (f = 10 Hz, pulsating tension loading) in the region from $N = 2\times10^5$ up to $N = 2\times10^6$ cycles. The best fatigue properties were obtained in the parts with drilled + shot peened holes.

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1. Introduction

High cycle fatigue lifetime of structural materials has been systematically investigated for more than 170 years. The stress vs. number of cycles plot (S-N dependence) including conventional fatigue limit and fatigue limit usually referred to N = 2 × 106 ÷ 107 cycles (steel and cast iron) are the main parameters used for evaluation of fatigue properties of structural materials. The fatigue lifetime is influenced by many factors, e.g. temperature, environment, grains size, micropurity, inclusions, shrinkages, pores and holes. The holes, their size and shape play very important role in the field of structural materials fatigue lifetime (BOKŮVKA, O. ET AL. 2002, BOKŮVKA, O. ET AL. 2014, HOLZMAN, M., KLESNIL, M. 1972, KLESNIL, M., LUKÁŠ, P. 1975, KUNZ, L. 2003, SKOČOVSKÝ, P. ET AL. 2015, TRŠKO, L. ET AL. 2014, ULEWICZ, R., MAZUR, M. 2013).

Deformation strengthening of the structure layer is one of the methods used to increase the fatigue properties of structural materials. Shot peening is a cold-working process of surface treatment, where the surface is impacted by small and hard media of various shape and size. As a result, the plastic deformation is created and compressive residual stresses are observed in the surface and subsurface layers. The compressive residual stresses increase the time necessary for the fatigue crack initiation, which, as a result, can increase the total fatigue life of a construction component (ABADIE, F., ET AL. 2009, HOLZMAN, M., KLESNIL, M. 1972, LAGO, J. ET AL. 2017, MIKOVÁ, K. ET AL. 2013, TRŠKO, L., ET AL. 2017).

In this paper, the authors publish their own experimental results concerning fatigue lifetime of 20MnV6 steel with the holes manufactured by different processes obtained by low-frequency loading (f = 10 Hz).

2. Experimental part

Steel 20MnV6 was used in this study as an experimental material. The 20MnV6 is low-alloyed, weldable manganese steel, with good wear resistance and high tensile properties. The ultimate tensile strength of this steel is in the range of 900-1050 MPa, yield strength 650 MPa while tensile elongation is still 13%.

Fatigue tests were performed on the hydraulic testing machine ZD 100 PU (Fig.1), operated in the range 50 – 1000 kN. For the evaluation of fatigue life specimens with the shape and size shown on the Fig.2a were used. The specimens for fatigue tests contained a hole, manufactured by different methods. There was set of specimens with milled holes (Fig.2b), set of specimens with drilled holes (Fig.2c), and the last set of specimens with the shot peening applied on the drilled holes.

The specimens were loaded by means of pulsating tension loaded with the f = 10 Hz at the temperature of 20±5°C. To evaluate the effect of the holes produced with the different methods, fatigue tests were carried out in the range $N_f = 2 \times 105 \div 2 \times 106$ cycles.

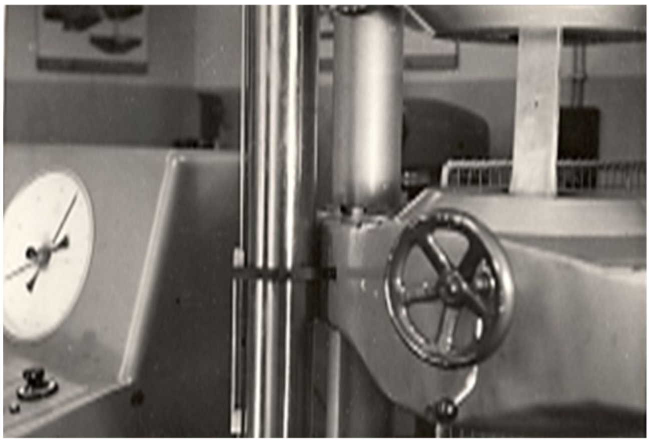

Fig. 1. Fatigue testing machine ZD 100PU with the specimen

a) b) c)

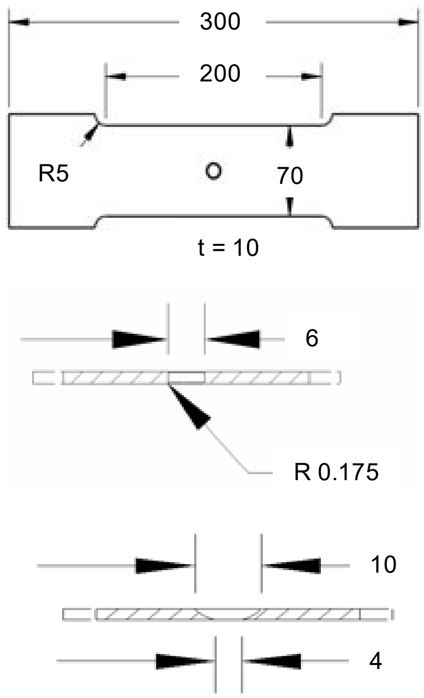

Fig. 2. a) Drawing of the testing specimens, with the detailed view of the holes manufactured by different methods, b) specimens with the drilled holes and c) specimens with the milled holes

3. Results and discussion

Figure 3 shows the results of the fatigue tests in the form of the S-N curves. It is evident, that the way how the holes were manufactured and treated significantly affects the resulting fatigue properties. In the evaluated range of the fatigue life ($N_f = 2 \times 105 \div 2 \times 106$ cycles) the best fatigue properties were recorded for the drilled holes, with the shot peening applied as a post-machining treatment. For holes manufactured and treated that way, the fatigue limit $\sigma_{max} = 361.3$ MPa for N = 2×106 was recorded. Specimens with just drilled holes, without post-machining shot peening, exhibit decrease of σ_{max} values, for the same number of cycles, the value $\sigma_{max} = 340$ MPa was recorded, what represents decrease in fatigue life about 20 MPa. The lowest values of fatigue limit were recorded for the specimens with milled holes, where value $\sigma_{max} = 330$ MPa for N = 2×106 was recorded. The results of fatigue tests showed positive effect of the shot peening as a post machining treatment on the fatigue properties, as the specimens with the shot peening applied after drilling exhibits the highest values of fatigue limit. The introduction of the residual stresses together with the deformation strengthening in the subsurface layer after shot peening process has a positive effect on fatigue properties, mainly in the retardation of the fatigue crack initiation. These observations are in consistency with the studies of other authors, (HOLZMAN, M., KLESNIL, M. 1972, KLESNIL, M., LUKÁŠ, P. 1980, LAGO, J. ET AL. 2017, MIKOVÁ, K. ET AL. 2013, TRŠKO, L. ET AL. 2013, TRŠKO, L. ET AL. 2014, TRŠKO, L. ET AL. 2017) according which the increase of the fatigue strength obtained by the application of shot peening can reach about 20% when compared to not-peened specimens. In the following study, the recorded increase of fatigue strength was around 6.3%. It should be noted, that shot-peening could even have a negative effect on the fatigue properties, which is documented in the study (HOLZMAN, M., KLESNIL, M. 1972, KLESNIL, M., LUKÁŠ, P. 1980), where the positive effect of surface strengthening and the introducing of residual stresses can be neglected by increasing of the surface roughness. In case of the specimens with the milled holes, the lowest recorded values of fatigue strength are the result of the surface character of the milled holes, with strong notch-effect machined surface. The fatigue crack initiated on the sharp-notch ending of the hole and propagate throughout the materials until the final fracture (Fig. 4 a 5). The notches caused by the machining process are strong stress concentrators, and its effect grows with the increasing mechanical properties and decreasing toughness, resulting in the lower Kath and lower fatigue strength (BATHIAS C., BONIS I. 1998, BROEK D., 1978, MURAKAMI Y. 2002).

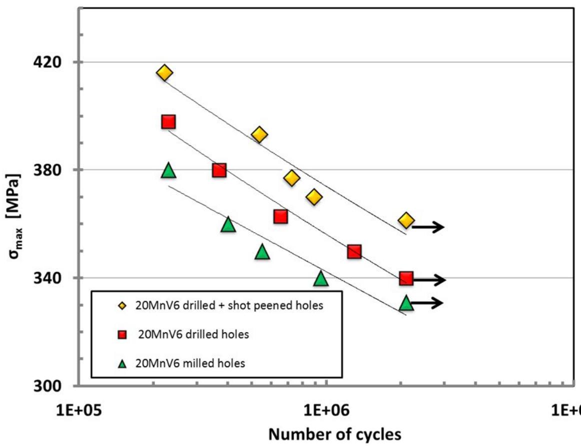

Fig. 3. Results of fatigue tests of 20MnV6 steel with the holes manufactured with various methods. The results are in form of S_{max}-N curve. Points marked with arrows represent run-outs.

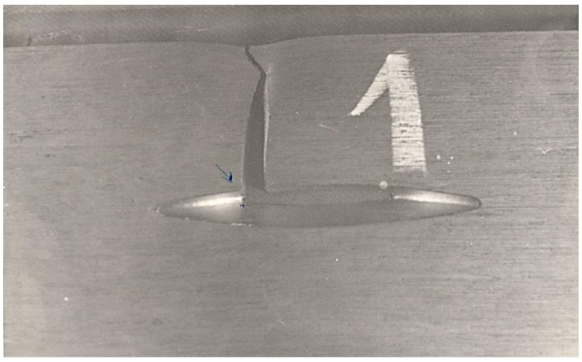

Fig.4 Specimen with milled hole, broken after N = 230 000 cycles at σ_{max} = 380 MPa

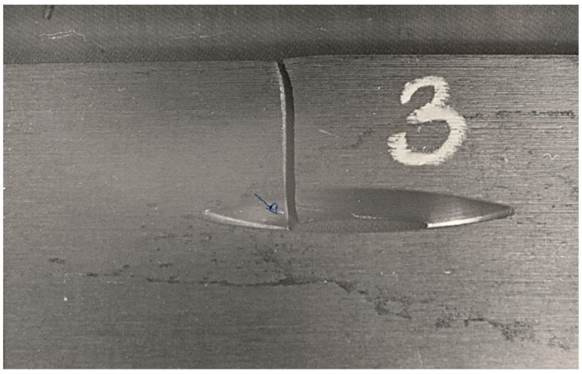

Fig.5 Specimen with milled hole, broken after N = 950 000 cycles at σ_{max} = 340 MPa

4. Conclusions

Based on the results of the fatigue tests carried out at low frequency cyclic loading of specimens of 20MnV6 steel with holes manufactured with different methods it can be stated that:

The manufacturing process of the holes preparation has a significant influence on the resulting fatigue properties of the structural parts containing these holes.

Specimens with holes manufactured by drilling with shot-peening applied as a post-machining treatment exhibit the highest fatigue limit (σ_{max} = 361.3 MPa). Specimens with drilled holes, without shot-peening, exhibit decrease of fatigue limit about 21.3 MPa (σ_{max} = 340 MPa). The lowest values of the fatigue limit exhibit the specimens with the milled holes, σ_{max} = 330 MPa.

Acknowledgements

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用各種方法製造的帶有孔的20MnV6鋼的疲勞壽命

關鍵詞

鋼20MnV6

疲勞壽命

高週疲勞

摘要

在這篇論文中，寫了20MnV6鋼的疲勞壽命。 實驗在低頻加載（f = 10 Hz，脈動張力加載）下進行，從 N = 2×10^5 到 N = 2×10^6 個循環。 具有鑽孔+噴丸孔的部件獲得了最好的疲勞性能。