FATIGUE STRENGTH OF WELDED JOINTS AFTER PNEUMATIC SHOT PEENING

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SUMMARY

The paper presents results of fatigue tests, performed on the welded joints, which have been strenghtned by different methods and particularly by the pneumatic shot peening method, worked-out at Technical University of Rzeszow, Poland. Research was carried on the maraging N18K9M5T steel (R_m = 1848 MPa; 51.5 RHN) and on the acid resistant 12H18N10T steel (R_m = 633 MPa; 205 BHN). Tests have been performed on the butt TIG-weldments by pure symetric rocking bending. The results of these tests indicate a possibility of increasing by circa 50% the fatigue strength limit of the 12H18N10Tsteel weldments as a result of treatment by pneumatic shot-peening. In case of N18K9M5T steel the fatigue limit in comparison with a weldment, strengthened by machining, increases additionally by 9 - 11% whereas in case of joints, not worked mechanikally, even by 20 - 38%. Like for the uniform, not welded material, the results of treatment by pneumatic shot peening could be represented by a reliable mathematical model and that eases the process control and enables to forecast the fatigue characteristics of the pneumatically shot-peened parts.

KEYWORDS

Weldments, welded joints, fatigue strength, strenghtening, blast-burnishing, pneumatic shot-peening, surface layer

INTRODUCTION

In many cases the fatigue strength of a welded joint has a real effect upon the operational dependability of a structural component. The fatigue strength limit (FSL) of a welded joint (WJ) depends chiefly upon the WJ construction, the welding technology and to definite extent upon after-weldment operations. In many cases the WJ causes the 3 - 8 times FSL reduction in comparison with an original material (without weldment). The structural changes in the very weld and in the at-weld area, the geometrical changes of the surface layer (SL) in the weld zone and the formation of inner tensile stresses of great gradients are resulted in such a considerable FSL - decrease.
There are many various methods for WJ - strenghtning [1], for instance: sand blasting, shot peening, coating, deformation or overcharging of WJ and others. The scope of these research tests has been an evaluation of possibilities for increasing the welded joint FSL by means of the pneumatic shot peening (as described in [2]). For the purpose of evaluation, the WJ researches have been performed on two steels, characterized by quite different properties and meanwile the a.m. method has been compared with others, competitives strenghtening methods.

TESTING METHODOLOGY

The shapes and dimensions of test specimens are shown on Fig. 1. The tested steels had following characteristics: martensitic maraging steel N18K9M5T (R_m = 1848 MPa; A_5 = 6,4%, 51.5 RHN), austenic acid resistant steel 12H18N10T (R_m = 633 MPa; A_5 = 51%; 200 - 205 BHN).
The fatigue tests has been performed after Wohler´s method by means of a device, the schema of which is shown on Fig. 2.

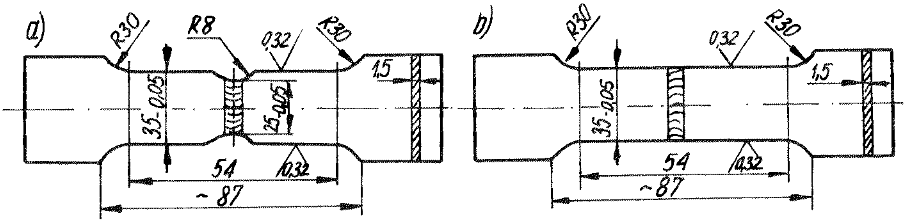

Fig. 1 Shapes and dimensions of specimens used for fatigue tests

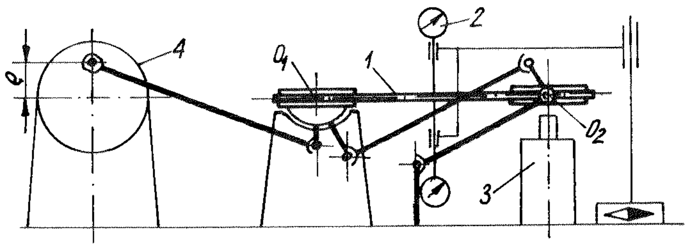

Fig. 2 Fatigue test station scheme: 1 - specimen, 2 - sensor (for setting the stress value before the test), 3 - circuit-breaker, 4 - driving motor together with adjustable circular cam

For each variant 14 - 16 pcs of specimens have been used at there levels of stresses and with test base amounted to 2.10^6 cycles (with loading frequency 50 Hz) and R = -1. During that rocking-bending test the FSL has been determined, later designed as Z_{gw}. In order to estimate the influence of the pneumatic shot-peening variables on the FSL, the fatigue life has been also determined at stress level of 240 MPa. The welding and used strengtening methods techniques were in detail described in [3]. The specimen weldments have been performed across fibres after TIG method and zones of beginning and of ending of a weldment have been cut out; the weldment were checked (by X-rays) for a presence of latend defects. The WJ of the N18K9M5T steel were strengthened after mechanical working (miling + grinding) and without such a working by means of following methods: glass bead peening(in Vacu-Blast, p = 0.5 MPa, t = 40 s, 1 = 120 mm, glass beads 50 - 100 µm dia), shot peening (shot 0.7 - 2.0 mm dia, p = 0.55 MPa, 1 = 540 mm, t = 1 min) pneumatic shot peening (balls 3 mm dia, p = 0.45 MPa, t = 3 min, by use of special hand peening head, described in [4]). The WJ of the 12H18N10T steel have been worked according to following methods: sand blasting (p = 0.45 MPa, 1 = 150mm, t = 2 min), hydro-abrasive blasting (aloxite 99A, 100 - 150 um dia, p = 0.35 MPa, 1 = 100 mm, t = 1.25 min), glass bead peening (p = 0.4 MPa, 1 = 100 mm, t = 4 min glass beads 100 - 150 um dia in a air-water jet), rolling (in the Jetline rolling device, P = 17.5 kN, d_r = 100 mm, V = 4 m/min).

RESULTS OF FATIGUE TESTS

a) Results of testing the N18K9M5T steel.
The results of fatigue test are shown in Fig.3. The FSL for this steel (calculated at $N = 2.10^6$ cycles) amounts to 517 MPa. Execution of the WJ decreases the FSL by 56.8% (to 223.2 MPa, which consists 0.12 tensile strength) in reference to the original material. The milling, the ageing (it takes place a hardening of the material and of the weldment) and the grinding reduces the teoretical factor of stresses concentration in the WJ to $\alpha_k = 1$ and results in the increase of the FSL by over 100% (to 452.1 MPa) and that is still lower by 12.6% than the FSL of the original material. If on so worked welded joints, the strenghtening operations have been performed, the further increase in FSL is obserwed, namely: in case of the pneumatic shot peening by 9.2% (493.9 MPa) and in case of the glass bead peening by 10% (537.9 MPa). In the last case the FSL of a WJ is greater by 3.9% than analogous property of a material without the weldment. Shot peening the not worked mechanically WJ is a much cheaper and a very effective method, which increases the FSL to 477.9 MPa and this just less by 7.7%, than the original material FSL. Additionally performed fatigue tests on the EB welded joints (by means of Steingerwald welding unit) using an electrodinamical vibrator (the method is described in [2]) have proved a great effectiveness of the pneumatic shot peening (Fig. 4), which increases the FSL even by 38% (variant 3) [5].

b) Results of testing the 12H18N10T steel.
The WJ of this steel, which is much more plastic than the previous one, was not worked mechanically up, but was in the first stage of tests put to the different strengthening operations. Results of these tests are displayed in Fig. 5. The FSL of the original material amounts to 264.5 MPa and that one of the WJ to 145.7 MPa it is to 0.23 tensile strength. The strengthening operations resulted in increase of the WJ FSL in average by 20 - 45% and namely: sand blasting by 37.5%, hydro-abrasive blasting by 23.7%, glass bead peening by 18.4% and rolling by 45.7%. Influence of the pneumatic shot peening upon the FSL was examined in second stage of researches. Results of these test are shown in Fig. 6. and they indicate, that for an intensity - measured by bending of the Almen plate type A, and amounting to I = (6 - 7)A - the FSL increased by 47.3% and for I = (10 - 11)A by 53.6%. In spite of such great increase the WJ FSL remains less by 15% than the FSL of the original material. These results are pointing to the great effective-

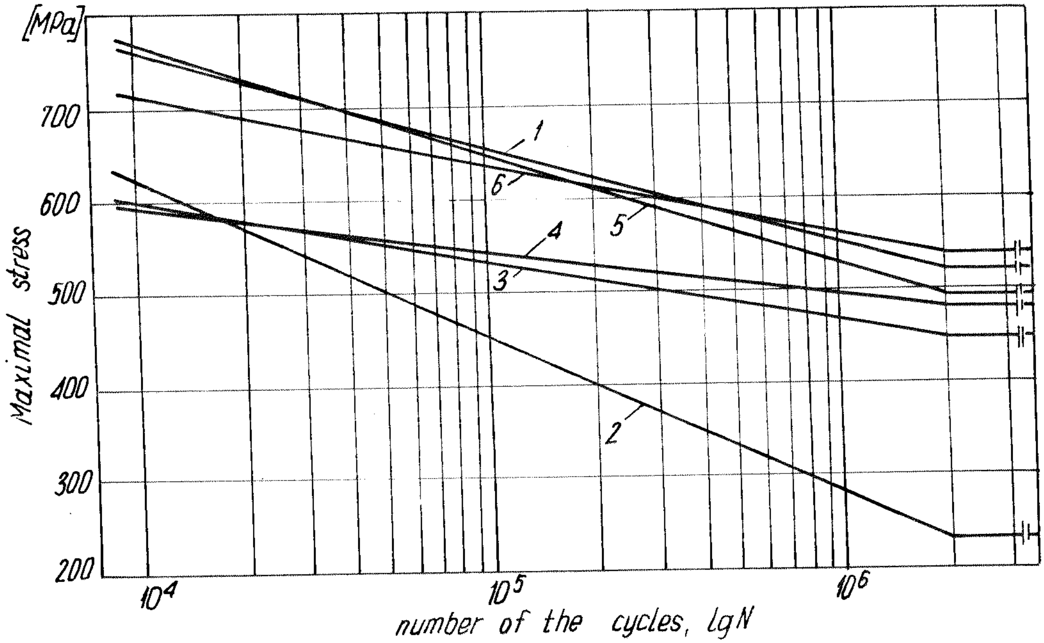

Fig. 3 Fatigue strength of the N18K9M5T steel weldments after performing the various methods working-up: 1 - original material, 2- brushed welded joint (BWJ), 3 - milling (M) + grinding (G), 4- BWJ + shot peening, 5 - M + G + pneumatic shot peening, 6 - M+ G + glass bead peening

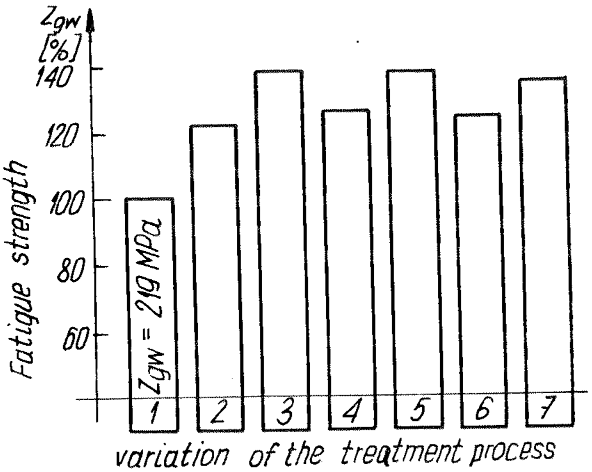

Fig. 4

Comparing the FSL of the N18K9M5T steel specimens electron beam welded and tested in a electrodinamic vibrator(one-side bending): 1 - WJ+ ageing (AG), 2 - WJ + AG, 3 - WJ+ AG + pneumatic shot peening, 4 - WJ + AG + polishing (P), 5 - WJ + AG + P + pneumatic shot peening, 6 - WJ+ AG + glass bead peening (in Vacu-Blast), 7 - WJ + AG + pneumatic shot peening

ness of the pneumatic shot peening the weldments of the tested steel, and that peening was more effective than others previously discussed methods, that is of most importance since this process is relativelly easy to be technically performed.

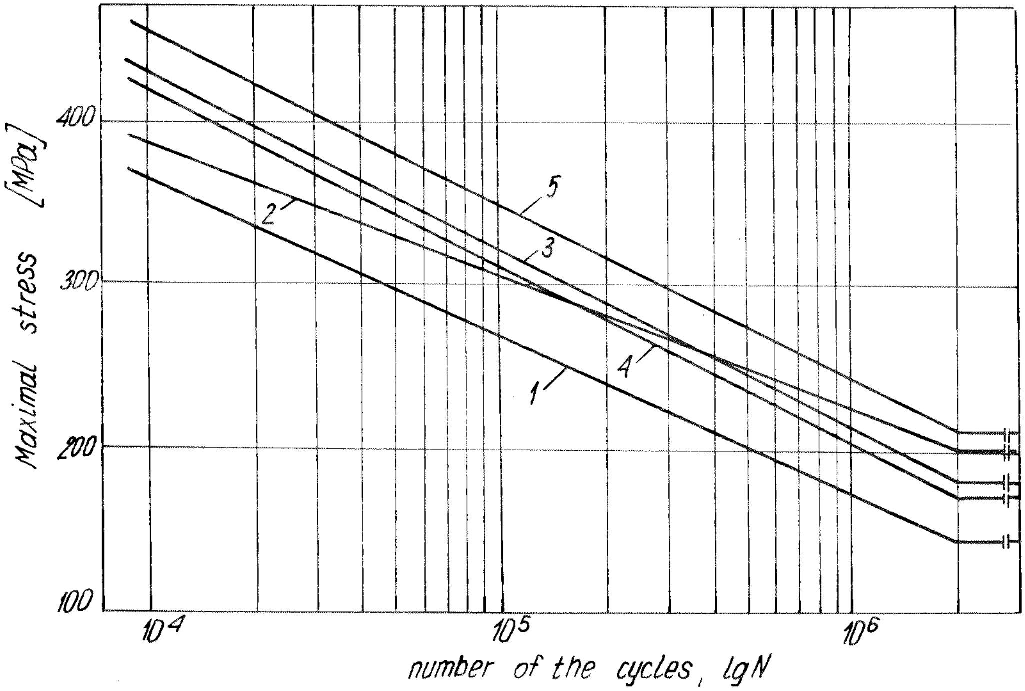

Fig.5 Fatigue strength of the 12H18N10T steel weldments after performing the various methods working-up: 1 - WJ without working-up, 2 - WJ + sand blasting, 3 - WJ + hydro-abrasive blasting, 4 - WJ + glass bead peening, 5 - WJ + rolling

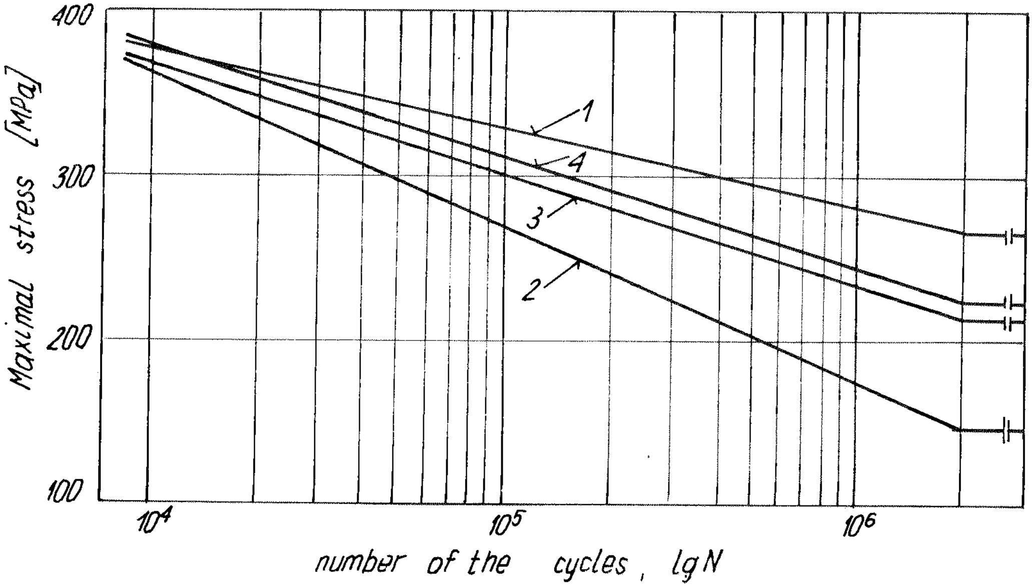

Fig. 6 Fatigue strength of the 12H18N10T steel weldments after pneumatic shot peening: 1 - original material, 2 - WJ without working-up, 3 - WJ + pneumatic shot peening with the intensity I = (6 - 7)A, 4 - WJ + pneumatic shot peening with the intensity I = (10 - 11)A.

c) Results of fatigue life testing the 12H18N10T steel.

The pneumatic shot peening process has been run in the production unit ([2] Fig.3) in order to determine a mathematic model of process and to eveluate an extent of correlation of obtained results with the fatigue life. The fatigue life t_{zu} has been determined as an average numerical value of cycles used for destruction of 6 specimens at stress level of 240 MPa. The specimens were worked by the pneumatic shot peening up and following variables ranges has benn kept on: p = 0.25 - 0.4 MPa, t = 15 - 30 min. Results of these tests are shown in Fig. 7. After elaboration the following relation has been obtained:

$$t_{zu} = 173.8 + 1590.7\,p \qquad (1)$$

That relation suggests the fatigue life depends, in the tests range, upon the air pressure. The linear correlation factor of measured and calculated after (1) values amounts to $r \approx 0.91$.

If we assume the angles of inclination of Wohler curves determined in these tests are analogous to previous ones (Fig. 6), then the FSL values for $N = 2.10^6$ cycles, corresponding with measured t_{zu}, can be calculated. As a result of making these calculations, following FSL values has been obtained for corresponding variants (Fig. 7): 1 -(without strengthening) 153 MPa, 2 - 210.9 MPa, 3 - 203.2 MPa, 4 - 204 MPa, 5 - 216.3 MPa. The calculated values indicate the FSL increases, after the pneumatic shot peening, for the variant without strengthening, amounted in the range from 32.8% (variant 3) to 41.2% (variant 5). Above values indicate, that in spite of changing the technological equipment, the FSL strengthening increases are great and they are little influenced by the pneumatic shot peening conditions. Just smaller FSL increases are caused by using the lower parameter values (intensities, calculated after (2), were comprised in range 1.5A - 5.1A.)

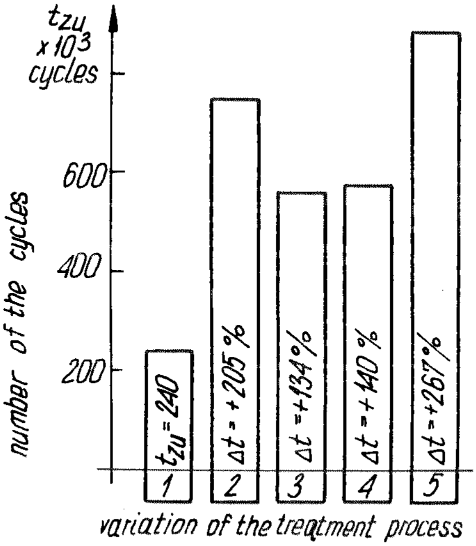

Fig. 7

Comparing the fatigue life of the 12H18-N10T steel butt weldments after pneumatic shot peening with parameters: 1 - WJ without working-up, 2 - WJ + pneumatic shot peening p= 0.25 MPa, t = 15 min, 3 - WJ + pneumatic shot peening p = 0.4 MPa, t = 15 min, 4 - WJ + pneumatic shot peening p = 0.25 MPa, t = 30 min, 5 - WJ + pneumatic shot peening p = 0.4 MPa, t = 30 min

ANALYSIS OF THE TESTING RESULTS

The pneumatic shot peening of the WJ zone, which is adjusted by the mechanical working-up, enables, for the hard N18K9M5T steel, the FSL increase still by circa 10% with that, the methods of the glass bead peening and of the shot peening are more advisable ones. In case of the joint not evened-up by machining, the process of pneumatic shot peening causes the formation in the WJ of the great internal compressive stresses of values amounting to 1200 MPa [5] (Fig. 8). That provides for decreasing the negative influence of the welding tensile stresses and of the surface micronotches in the weldment face and root. On the other hand, the geometrical parameters of the weld face and root are changing comparativelly little. A situation is quite different in case of the soft 12H18N10T steel. The influence of various strengthening methods on the weldment cross-section is shown in Fig. 9. It indicates, that the geometrical notches are subject to decreasing after the pneumatic shot peening on the fused zone. Metalurgical researches (Fig. 10) have indicated, that in all cases the crack proceeds along the fusion line and merely in case of rolling operation (Fig. 10) the crack goes across a weldment. These researches did not indicate, that metallographic factors are influencing the destruction character. When for various variants the intensity is being calculated after the relation given in the publication [2].

$$I = 0.46\ p - 0.05\ t + 0.096\ db + 0.5\ p\ t - 0.08 \qquad (2)$$

and when the calculated intensities for variants of Fig. 7 are assumed, it could be written for the pneumatuc shot peening processes of these weldments (in conjunction with results of Fig. 6 and Fig. 7), that:

$$Z_{gw} = 2{,}2\ I + 201.4 \qquad (3)$$

The linear correlation factor of measured Z_{gw} values and calculated after (3) amounts to $r = 0.93$

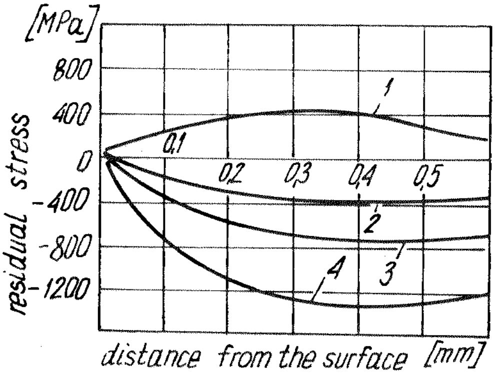

Fig. 8

Internal stress patterns in the WJ zone for the TIG weldments of the N18K9M5T steel 5 : 1 - WJ without working-up, 2 - WJ + glass bead peening, 3 - WJ + hydraulic shot peening, 4 - WJ + pneumatic shot peening

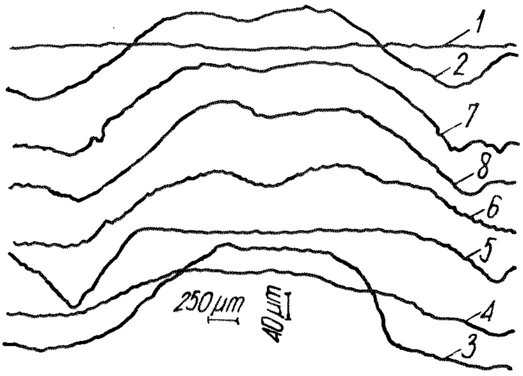

Fig. 9

Cross-sections of the 12H18N10T steel weldments, worked in accordance with various methods: 1 - material without weldment, 2 - WJ + without working-up, 3 - WJ + pneumatic shot peening with intensity I = (10-11)A, 5 - WJ + rolling, 6 - WJ + glass bead peening, 7 - WJ + sand blasting, 8 - WJ + hydro-abrasive blasting

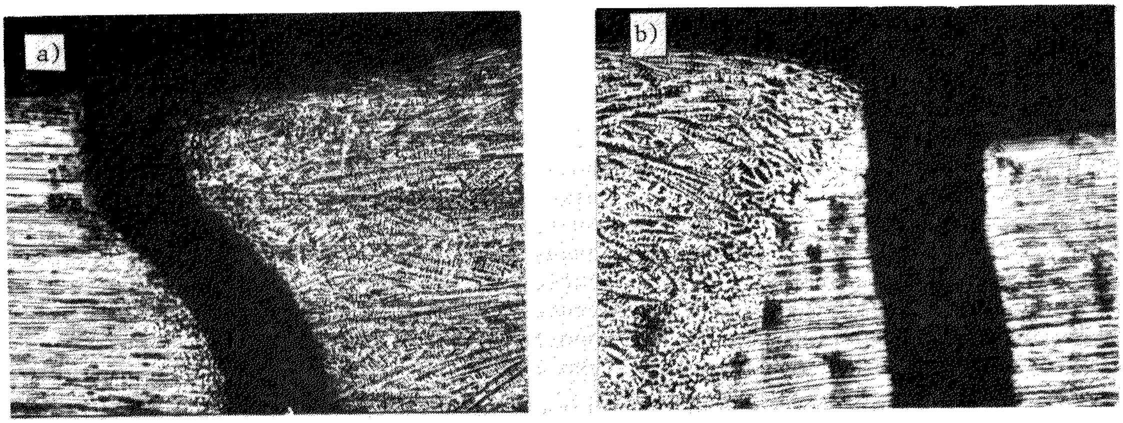

Fig. 10 Microstructures of the 12H18N10T steel specimens after fatigue tests: a) WJ + pneumatic shot peening with intensity I = (6 - 7)A, b) WJ + rolling; 80-times enlargements

CONCLUSIONS

a) The pneumatic shot peening process is it for the WJ strengthening in materials of small hardness and of great plasticity. This process is effective then, when shots, which are deforming the surface layer, cause evident deformations in the WJ zone, namely in the heat - affected zone, especially in the fusion zone, it changes the geometric notch factor.

b) The pneumatic shot peening process can also increase in effective way the FSL of the very hard steel by generating the great compressive stresses in the SL of the WJ zone (in the same time there is an elimination of the great welding stresses), which decrease also the negative influence of the geometrical micronotches in the weld face and in the weld root.

c) The pneumatic shot peening displayes the stabile and advantageus influence over the WJ FSL in the broad range of variable parameters. It enables to obtain for the determined material, the relationship of type $Z_{gw} = m I + b$, where: I - intensity, m, b - coefficients. This formula enables to forecast the FSL increase level after performed working-up. In meanwhile for the determined equipment there is a possibility to obtain the reliable relation of intensity depending upon the working parameters and that eases the processes of the working-up effects control.

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