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The effect of combined processing schedules on the value and nature of residual stresses in the surface layer of cylindrical friction pairs

S Fedorov[1], A Albagachiev[2,4], M Isaenkova[3], A Yakovleva[1,5], V Zaripov[1] and R Minushkin[3]

[1]Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation

[2]Mechanical Engineering Research Institute of the Russian Academy of Sciences (IMASH RAN)

[3]National Research Nuclear University MEPhI

[4]MIREA - Russian Technological University

[5]Email: yakovleva525@mail.ru

Abstract
The purpose of the paper was to study the macroscopic stressesafter the combined processing. The combined processing essentially consists in the sequential implementation of electromechanical processing and diamond smoothing. We obtained the formula for calculating the residual stresses arising in the surface layer after the combined processing. For convenience of calculations, a computer program was developed to calculate the parameter for estimating the residual stresses in the language Visual Studio 2017 C #. To determine the residual macrostresses, the standard x-ray method sin ^{2} ψwas used. The study was performed on samples of steel 40X.

Introduction

The operation of machines and mechanisms requires the work of friction pairs, i.e. rods, pistons, plugs, seats, spools, pins, rolls for grinding non-metallic materials. These are parts of engines, pumps, spinning machines including guide rollers, thread guides, tensioning devices, as well as cultivators and other machines, which are used in construction, automotive equipment, agricultural machinery, etc. Most of them are cylindrical [1-3]. Due to the low operational reliability of cylindrical friction pairs, the consumption of spare parts is high [2-7].

The reliability of the machines is directly related to the quality of the surface layer, which is characterized by geometrical and physico-mechanical parameters. The quality of the surface layer is crucial for the operational properties, i.e. wear resistance, corrosion resistance, contact fatigue resistance, etc. [2, 3, 8-12].

In many cases the level of residual stresses is an important parameter that determines the quality of the surface layer of products [4, 6, 13].

In the surface layer of the metal there are always various defects that serve as crack nuclei, therefore, the reliability of parts is determined mainly by the value of crack propagation work [1, 4, 8, 9, 14]. The compressive residual stresses appearing on the surfaces of parts due to various technological methods prevent the nucleation and propagation of fatigue microcracks, increasing their work. Therefore, for parts operating under conditions of slipping friction, especially in cases of fatigue and abrasive wear during operation, it is important to make a surface layer with compressive residual stresses [4, 5, 9, 10-17].

Description of the Experiment

In view of the foregoing, the technology of combined processing (CP) has been developed. The combined processing essentially consists in the sequential implementation of electromechanical processing and diamond smoothing [5, 12]. Using this technology, it is possible to technologically control the properties of the working surfaces of cylindrical parts and make compressive residual stresses on the surface [1, 4, 6, 12].

To test this assumption, the value of tangential residual stresses was theoretically calculated. In the present CP embodiment, the value of residual stresses will be composed of the following components:

$$\sigma_{res} = \sigma_{temp} + \sigma_{ph} + \sigma_{mech}, \quad (1)$$

where σ_{temp} is the residual temperature stress, σ_{ph} is the structural phase residual stress, σ_{mech} is the mechanical residual stress.

Examining in detail each component of formula (1), it is possible to derive a general view of the dependence of the tangential residual stress value on the combined processingschedules:

$$\sigma_{res} = \propto E \frac{2\alpha_m (P_g V_p + IU)}{\lambda_2 l_{tool}^2 \sqrt{\pi}} \left(\sqrt{at} e^{\left(\frac{-z^2}{4at}\right)} \right) - \frac{P_g}{\pi} * \left[\frac{3}{2\left(l_{tool}^2 + z^2\right)} - \frac{1,2}{l_{tool}^2} \ln\left(\frac{z}{2l_{tool}}\right) - \frac{3}{10 l_{tool}^2} \right] + \\ + E\left(1 - \sqrt[3]{\frac{\rho_1}{\rho_2}}\right) \quad (2)$$

z is the current coordinate, m; α_t is the heat sharing ratio (Sharon's heat absorption coefficient); P_g is thereduced pressure force of the tool during the combined processing, H; $V_p$is the sample rotation speed, m / min; I is the current strength, A; U is the voltage, B; λ_2 is the thermal conductivity of the sample material, $Wm^{-1}K^{-1}$; $l_{tool}$is the length of the tool contact with the work surface (the width of the roll electrode), m; ais the thermal conductivity of the sample material, m^2/s; t is the contact time, c; ρ_1, $\rho_2$is the density of the sample material and tool, respectively, kg/m^3; E is the modulus of elasticity of the sample material, Pa.

For convenience of calculations, a computer program was developed to calculate the parameter for estimating residual stresses by formula (1) in the language Visual Studio 2017 C #. All data is entered into a table, and at the output we obtain the value of the parameter of residual stresses depending on the combined processing schedules.

Experimental Result

An x-ray evaluation method was used to verify the theoretical values obtained.

A BRUKER D8 Discover X-ray diffractometer (Fig. 1) using chromium K-radiation was used to study the phase composition of the sample material and to measure the residual macrostress. Data processing was carried out using the software DIFRAC.EVA and DIFRAC.LEPTOS.

For this purpose, steel 40X samples were made with a diameter of 40 mm, a length of 200 mm and treated with a combined processing in the following schedules.

Electromechanical processing: current I is 2000 A; U voltage is 4 V; contact roller pressure P1 is 300 N; part rotation speed is 2.0 m / min; feed S1 is 1.2 mm / rev. Diamond smoothing: the pressure of the diamond smoother P2 is 300 N, feed S2 is 0.02 mm / rev, the radius of the diamond smoother is 1 mm.

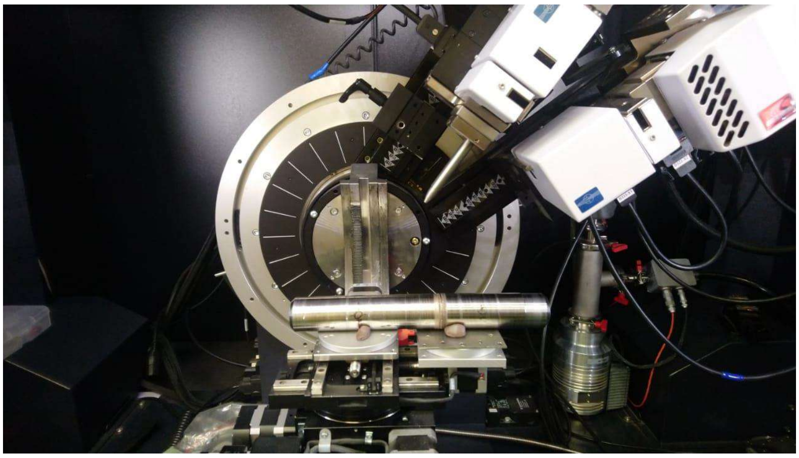

Fig. 1. X-ray diffractometer BRUKER D8 Discover

In accordance with GOST 16865-79 and with ASTM E2860-12, the most accurately residual macrostresses are measured in the precision X-ray spectrum area, i.e. the lines located at large angles of 2Θ, which also allow the use of large angles of rotation of the samples. To determine the residual macrostresses, the standard x-ray method $\sin^2\psi$ was used [18, 19]. The location of the investigated surface areas on the samples in which the measurement of stress was performed is schematically shown in Fig. 2. The size of the investigated area is determined by the size of the collimator and is ~ 5 mm^2.

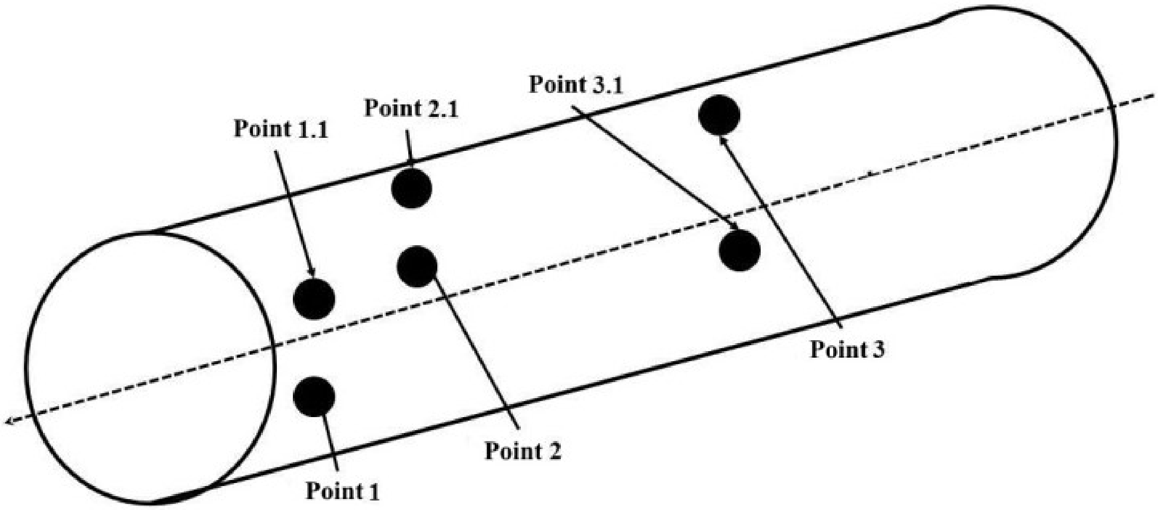

Fig. 2. The location of the investigated surface areas on the samples in which the measurement of stresses was done

In this case, to determine the value of the residual stresses, a line (211) (2Θ = 156.084 °) was recorded at different angles of rotation (Fig. 3, 4). To approximate and calculate the obtained lines, the Pearson VII function was used.

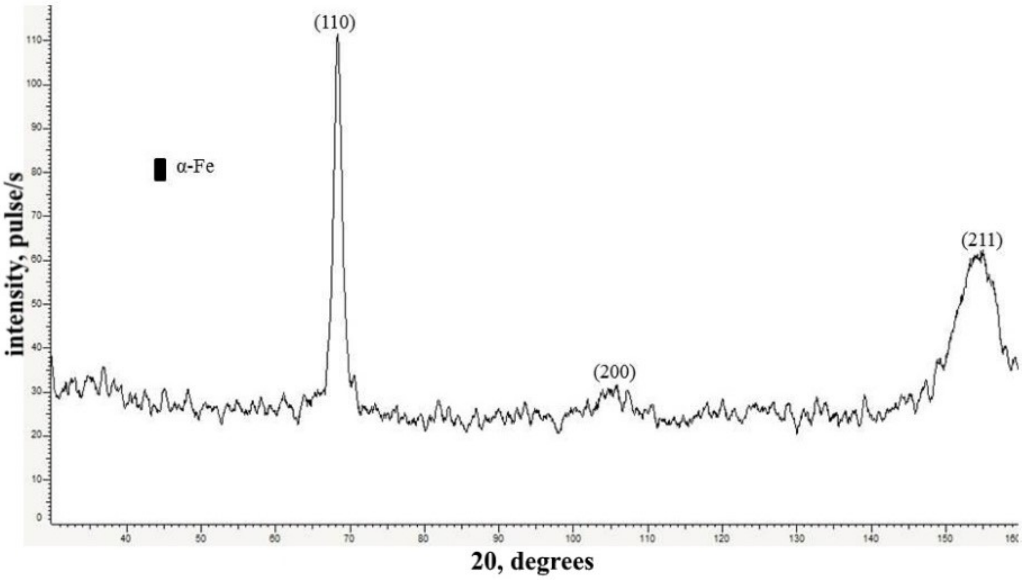

Fig.3. X-ray diffraction spectrum of the rod (the material of the anode of the x-ray tube is Cr)

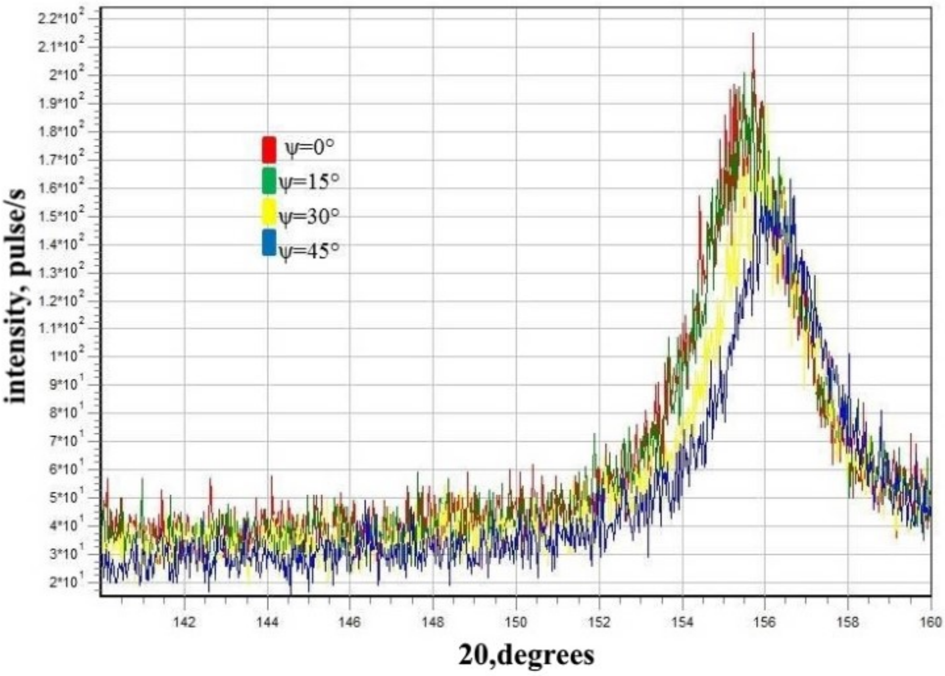

Fig. 4. X-ray line (211) for different angles of sample rotation

The interplanar distances, as well as the degree of deformations, are calculated from the angular positions of the X-ray lines, using the Wulff-Bragg formula. Further on, we plotted a graph of the dependence of the degree of deformations (ε) on sin2ψ (where ψ is the angle of sample rotation). In the general case, the dependence graph has a linear character ($\varepsilon=a*sin2\psi+b$), from the slope coefficient of which the value of the residual macrostress is calculated (Fig. 5). The error in the determination of macrostress is the deviation of the values obtained from the linear dependence [20, 21].

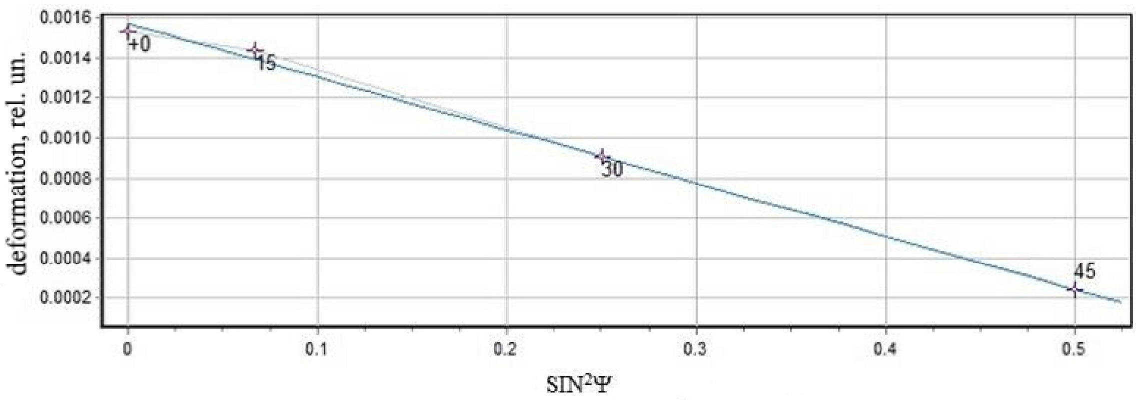

Fig. 5. A graph of the dependence of the value of deformations on sin2ψ

During the study, the following results were obtained:according to the obtained phase analysis data, the material of the studied samples is anα-phase (bcc-structure) of iron.

The stresses at the sample control points (Fig. 2) are presented in the table.

Stresses at sample control points

	Stress, MPa	
	Axial	**Tangential**
Point 1	-1901,2±87,7	-866,9±21,5
Point 1.1	-1774,2±91,5	-1409,1±44,1
Point 2	-1738,7±129,1	-1420,0±186,3
Point 2.1	-2019,8±172,5	-1127,5±114,9
Point 3	-760,5±14,6	-975,6±41,3
Point 3.1	-806,1±43,4	-455,7±17,8

This method allows us to determine the numerical value of axial and tangential residual stresses.

Conclusions

In this research, macrostresses have been studied, as theyappear to be the most significant from the point of view of practical application.

Comparing the results of theoretical and practical research, we arrive at a conclusion that the combined processing creates favorable compressive residual stresses on the surface of the samples under study. This is evidenced by the sign "-" before the numerical values of the axial and tangential stresses of the experimental studies and the tangential residual stresses in the theoretical study. The convergence of the results is 89%.

Furthermore, a positive feature of the combined processing is the fact that the value and nature of residual stresses obtained in previous operations do not affect the formation of the value and sign of residual stresses in the CP process, and the method presented may be a barrier to technological heredity.

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