Boundary Element Technology XIII

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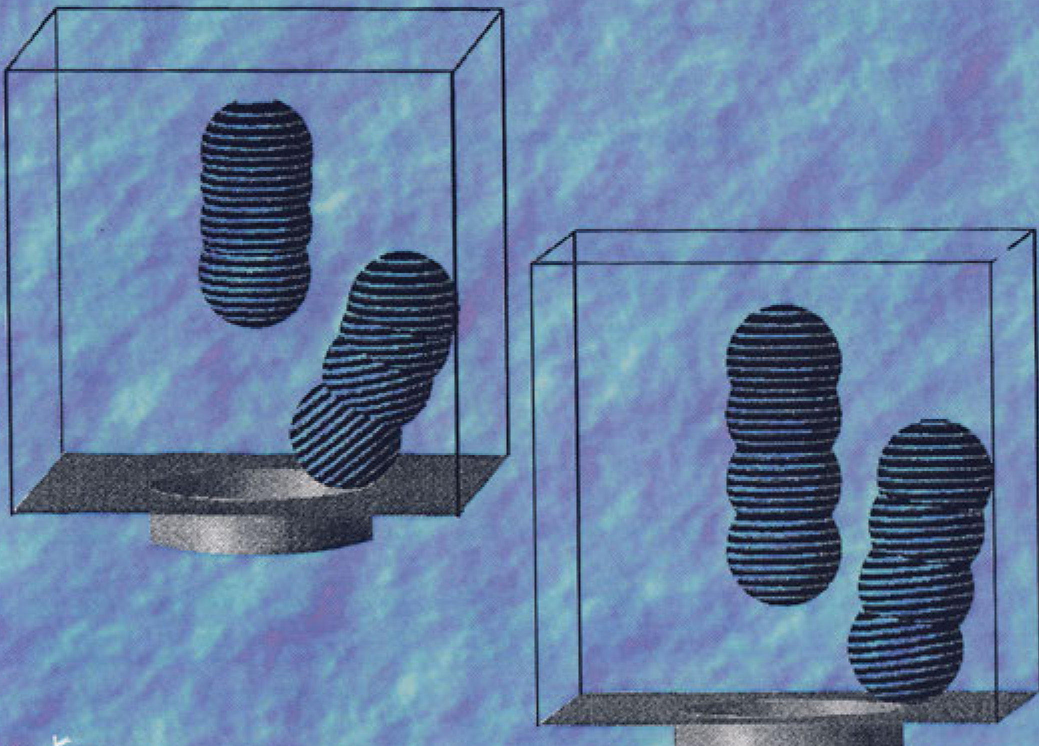
Editors



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Computational Methods and Testing for Engineering Integrity

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Section 2: Simulation

Section 3: Behaviour of Materials

Wear Reduction on Working Surface of Railway Wheels

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Abstract

Improved design of tread profile is a way to enhance wheel performance. Computer aided analysis of contact interaction in the wheel - rail pair was used to improve the design. A decrease in the contact pressure was achieved due to changed working surface profiles. Also decreased was the relative longitudinal slip at wheel and rail surfaces. The design perfecting work included metallographic characterization of steel structure changes occurring across the tread in long operation. Computation results for contact stresses agreed well with the metallographic data on used wheels. Laser beam hardening of tread surface by continuous and pulsed illumination was tested as a way to reduce surface wear of wheels. Structure changes and steel hardening behavior were investigated for a variety of laser illumination conditions.

1 Introduction

For a number of reasons, increased wear of railway wheels has become a commonly encountered problem in Ukraine. Reduction of wear on wheel working surfaces is an urgent task for main and in-plant railways alike. An approach enabling reduced wear of locomotive and car wheelsets was outlined previously that consists in improving wheel working surface contour design [1]. Such improved contours can be developed based on research into contact interaction in the wheel-rail pair aimed at determining the dimensions and locations of the contact zones, constructing the distributions of contact stresses, and finding the variables describing severity of wear on wheel working surfaces. The present analysis is special in that it was applied to actual contours of wheels and rails, as-shipped and used alike. The contours were measured following certain times of service and inputted in a computer via a scanner.

2 Investigation into sliding in wheelset side motion

For the track to be suitable for running in, the gauge must exceed the nominal distance between wheelset flanges, thus necessitating a gap. When the flange distance is set to a negative tolerance while the gauge to a positive one, the gap will be even wider. Furthermore, the wheel flanges and/or the rail inner edges may be worn. For example, the standards existing in Ukraine allow locomotive wheel flange to be worn to 25 mm from an initial thickness of 33 mm, and the wear tolerances for in-plant railways are even less stringent. Moreover, elastic displacement of a rail may be caused by the wheel-rail contact interactions, sometimes leading to an excessive actual gage and eventual derailment.

The various forces operating on wheelsets during vehicle movement result in side motion of wheelsets and bogies. Sliding of wheels relative to rails is possible even in straight track sections due to creep. A reliable analysis of sliding conditions, prediction of wear, and determination of lateral forces should be based on actual contours of the wheel and rail. However, in the majority of studies (see, for example, [2]), a conical tread is assumed together with the usual conventions of a constant vehicle velocity, an ideally circular curve etc.; next, the guiding forces and other variables are determined from the vehicle position found by trial and error. To determine the relative longitudinal sliding of wheel on the outer rail from

$$\eta_e = \frac{r_i}{r_e}\left(1 + \frac{s_1}{R}\right) - 1 \tag{1}$$

(here, the modulus sign is omitted) or on the inner rail from

$$\eta_i = \frac{r_e}{r_i}\left(1 + \frac{s_1}{R}\right) - 1 \tag{2}$$

it is necessary to know r_i and r_e, the local radii of wheels at the initial contact points for the inner and the outer rail respectively. In the above equations, R is the circular arc radius, $2s_1$ the track gauge. The values of r_i and r_e are normally determined from the drawings - a method unfit for use in mathematical modelling of wheel-rail interaction involving actual contours.

The wheel-rail contact interaction was addressed for actual contours of wheel and rail working surfaces in an earlier paper [1]. The study involved contour numerical modelling; it included measurements of actual contours on used wheels and rails followed by scanning and computer interpolation. An IBM PC application package was developed to estimate dimensions and locations of contact zones for various relative positions of the wheelset and the track. A brief description of the calculation algorithm was given [1].

Currently, Ukraine and some other countries of the Commonwealth of Independent States use existing rolling stock for a narrower gauge of 1520 mm instead of the former 1524 mm. The gauge in curved track sections was reduced accordingly. Contemplation of negotiation of curves for wheelsets of a given contour revealed that at small curve radii ($R <$ 500 m) the gauge according to new specifications is too narrow to eliminate sliding; it was therefore concluded that the original standards for circular curve track gauge should be preferred. This conclusion is supported by plots in Fig. 1 depicting relative longitudinal sliding η versus side displacement Δ of the wheelset. The plots were constructed for a curve radius R=400 m, the solid and the broken lines corresponding to the new (1520 mm) and the former (1524 mm) standard gauge respectively. The plots are similar in shape owing to similarity of the contours of interacting wheel and rail. That the discontinuity on the plot for the former gauge is shifted 7.5 mm to the right side is due to the gauge being 15 mm wider than the new one. The $\eta(\Delta)$ curve intersects the Δ axis at $\Delta \approx 9$ mm.

Examination of the plots in Fig. 1a revealed that the relative longitudinal sliding is small for intermediate positions of the wheelset such that no flange contact exists, so in case of dry and clean working surfaces the only consequence would be creep-induced microslip. However, the wheelset normally is forced against one of the rails, most frequently the outer one. The sliding value is therefore increased by an order of magnitude and has a significant impact on the severity of wear. Repeated contact between the flanges and the rail inner edges is also caused by wheelset side motion in gentle curves or straight track sections. The contact stresses then may be high enough to cause plastic deformation which facilitates wear. Hence new contour designs should minimize the relative longitudinal sliding between the wheel and the rail in side motion of wheelset. The contact stresses should be reduced to a minimum as well.

These considerations made a basis for a model study into wheel-rail contact interactions that lead to development of a curvilinear contour of wheel tread. The new contour offers dramatic reductions in contact stress levels, especially in the flange region. Fig. 1b shows a plot of the relative longitudinal sliding η as a function of wheelset side displacement Δ for the new contour. It is seen that in the absence of a contact in the flange region the plots and the values of η are similar to those for the standard wheel contour. Upon such contact, however, the increase in η is 2.3 times less than with the standard wheel. This behaviour also results in lower flange thinning. Another advantage of the new contour is a much smaller advance of the flange contact zone at nonzero angles of attack compared to that of the standard wheel.

3 Metallographic characterization of wheels after service

A study into changes occurring during wheel service in metal layers underlying the tread is important for an understanding of railway wheel wear mechanisms. The contact between surfaces of wheel and rail is intermittent, thus resulting in nonuniform distributions of the external loads, contact stresses and, consequently, structural changes in the metal, leading to nonuniform wheel wear.

The wheel tread is in a complex state of stress causing plastic shear capable of attaining limiting values. Besides, severe friction occurring e.g. during braking may give rise to release of heat and considerable increase in metal surface temperature sufficient for a phase transformation to take place. As the wheel service continues, the structural changes and the phase transformations may proceed to a depth determined by the service conditions and the tread geometry.

Structural changes in the steel were investigated following about 5 year long service of wheels that had different initial tread contours. Standard wheels (1) with a piecewise linear contour to GOST 9036-88 comprised of two portions with tapers of 1:20 and 1:7, and experimental wheels (2) with a contour developed by the present writers were subjected to material characterization.

It was found that a flow of metal from the 1:20 to the 1:7 portion and from the latter to the bevelled edge occurred during service of wheel 1. Fig. 2a clearly shows metal buildup at the bevelled edge. The entire tread is occupied by a region of severe plastic deformation (Fig. 2b-e) which apparently was not uniform, with maximum strains occurring in the flange fillet and the buildup. The entire tread subsurface region has white layer areas comprised of cryptocrystalline martensite (Fig. 2c), as well as subsurface fatigue cracks and discontinuities (especially in the buildup region, Fig. 2c,e). The depth h of plastic shear penetration is nonuniformly distributed across the rim (see Fig. 3a) due to a nonuniform distribution of contact stresses. The structural changes also are reflected in the nonuniform distribution of microhardness H_μ across the rim, see Fig. 3a.

Curvilinear tread wheel 2 displayed structural changes in the surface layers that are similar in nature; however, they were less pronounced and indicative of a reduced flange wear in service. First, no metal buildup or any drastic change in the rim contour was observed. Second, the degree of grain deformation ε was 10-20 % less and the depth of deformation penetration 1.6 times shallower than that of wheel 1, see Fig. 3b. This is attributed to an improved initial tread geometry and reduced contact stresses in wheel 2. The microhardness H_μ again is indicative of structural changes below the tread, see Fig. 3b; microhardness jumps (Fig. 3b) not related to tread contour shape were sometimes observed and associated with very hard white layer areas.

Feasibility of wheel tread hardening by laser beam that introduced controlled changes in the surface metal structure and phase constitution was studied. It was found that pulsed or continuous laser illumination with or without surface melting produces a wide variety of wheel steel microstructures, including cryptocrystalline martensite and fine acicular martensite (Fig. 4) and thus enables tread hardness variation over a wide range. The degree of hardening is affected by laser processing conditions, existence of a second phase, amount of residual austenite, dispersion of martensite, characteristics of fine structure formed in phase transformations, and surface melting.

Among the processing conditions studied, pulsed illumination at 10.0 to 20.5 J per pulse was found to be well-suited for the flange fillet, and continuous illumination at a scanning speed of 1 to 6 mm/s for the tread. The issue of laser processing of wheels should be considered together with that of rail hardening to ensure a proper balance of hardness between the wheel and the rail while improving their wear resistance.

Thus comprehensive studies into wheel-rail interactions make it possible to improve working surface contours, reduce wheel wear, and enhance wheel durability.

References

1. Yessaulov, V., Taran, Y., Sladkovsky, A., Kozlovsky, A. & Shmurygin N. Design of wagon wheels using the finite element method, *Computers in Railways V*, Vol.2, pp 69-77, Computational Mechanics Publications, Southampton & Boston, 1996.
2. Verigo, M.F. & Kogan, A.Ya., *Interactions between rolling stock and railroad track*, Transport Publishing House, Moscow, 1986. In Russian.

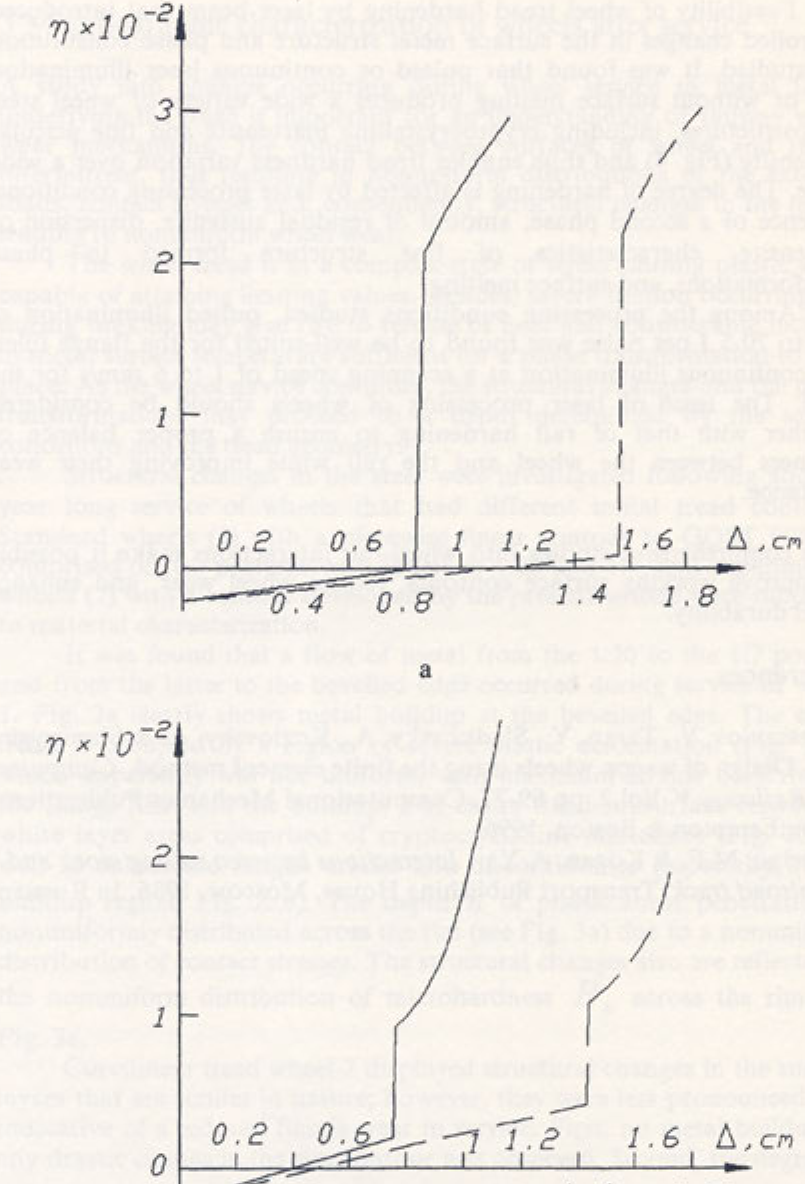


Figure 1. Relative longitudinal sliding η as a function of side displacement Δ of wheelset for wheels with standard (a) and curvilinear (b) tread contours

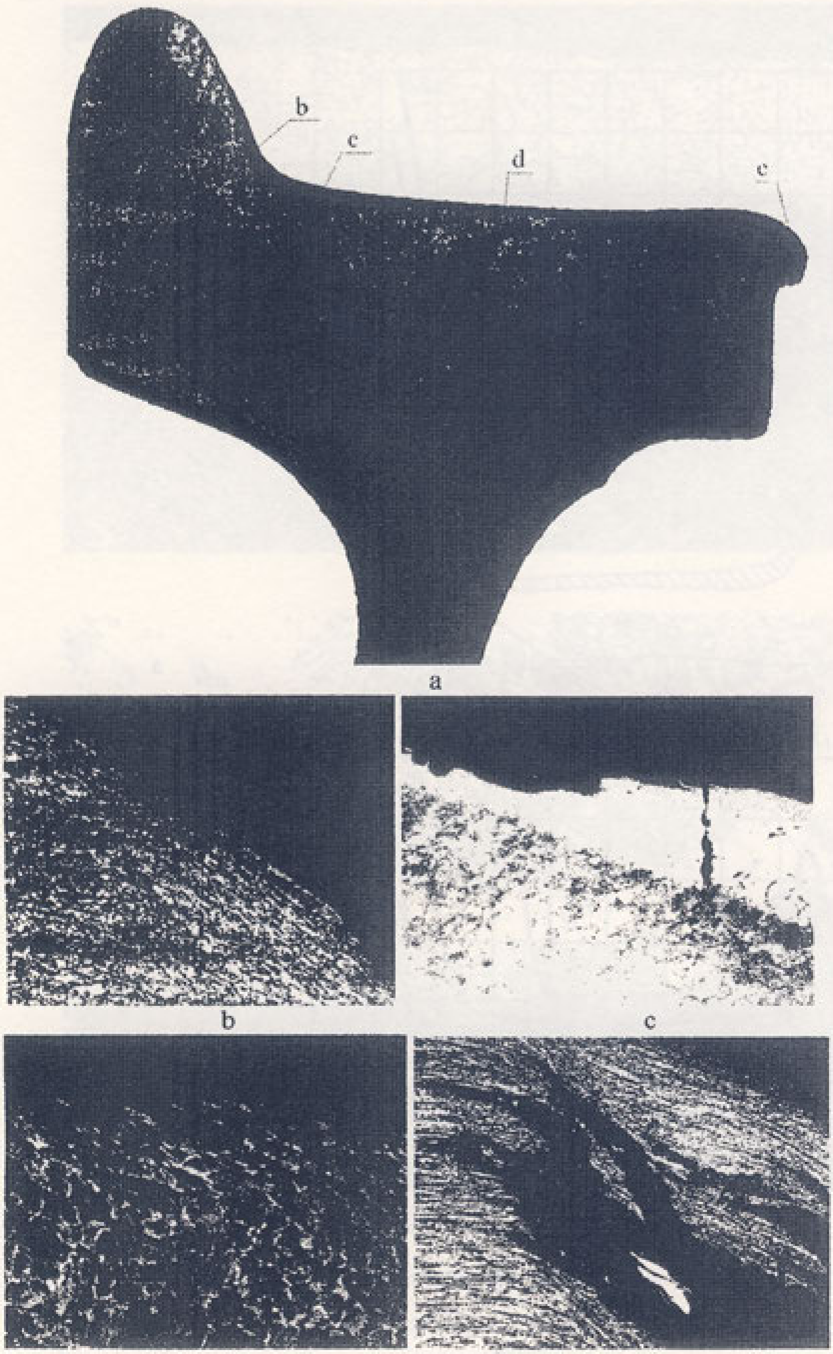


Figure 2. Macrostructure of a used wheel (a) and structural changes in the tread metal (b-e)

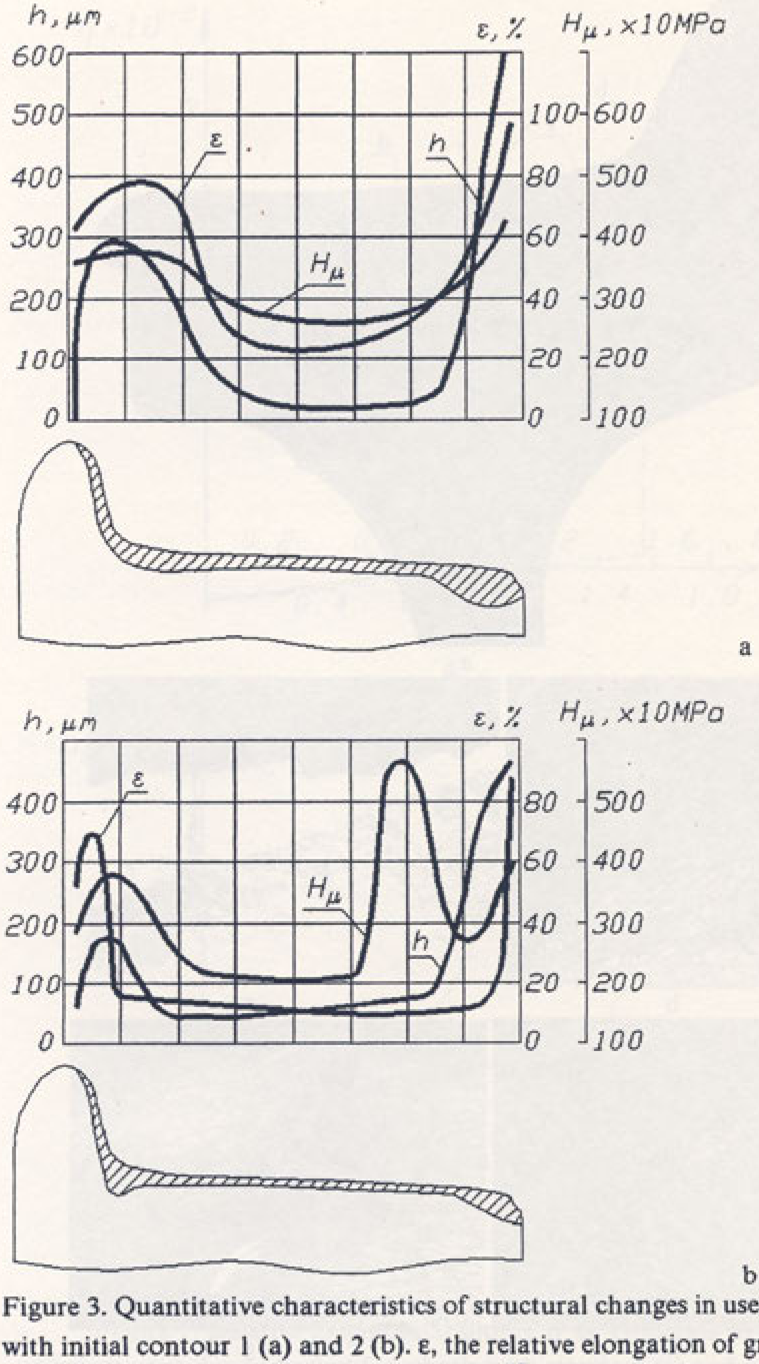
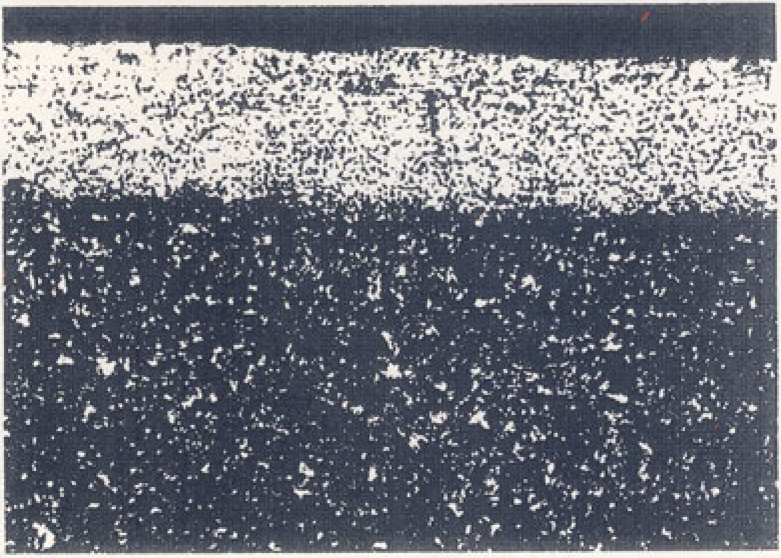
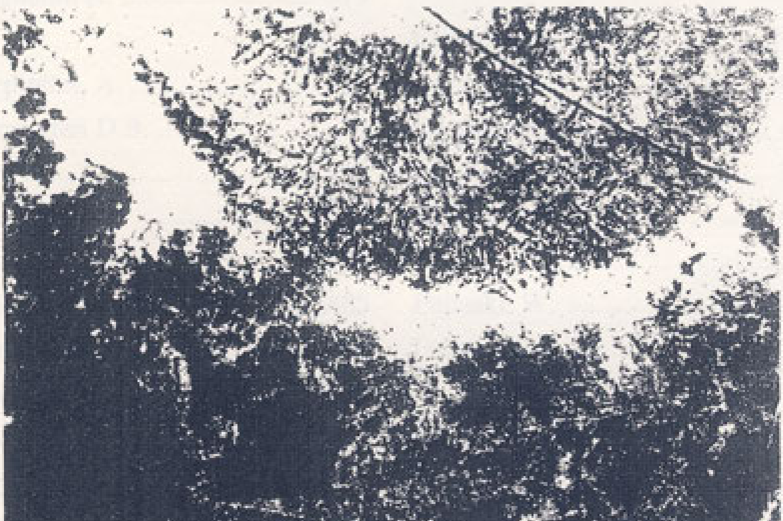


Figure 3. Quantitative characteristics of structural changes in used wheels with initial contour 1 (a) and 2 (b). ε, the relative elongation of grains; h, the plastic deformation depth; H_μ, microhardness



a



b

Figure 4. Wheel steel microstructure in areas subjected to pulsed (a, 100×) and continuous (b, 400×) laser illumination