THE INTERNATIONAL CONFERENCE OF THE CARPATHIAN EURO-REGION SPECIALISTS IN INDUSTRIAL SYSTEMS
6th edition

THE FRACTURE TOUGHNESS OF THE HARDENED CAD-WHEELS

Ye. I. Kryzhanivskyi[1], D.Petryna[2] , Ye.Yu.Petryna[3] ,O.Onystchuk[4]
[1,3] Professor Ph.D. Eng., [2] Assoc. Professor Ph D. Eng, [4]Assistant Eng.
Ivano-Frankivsk National Technical University of Gas and Oil,
Ukraine, Ivano-Frankivsk, 15, Karpatska str.

Abstract: *The activity is devoted to increase of cylindrical cog-wheels of load-carrying transmissions reliability and longevity by hardening a lateral area them teethes with the developed method of vibrational-centrifugal hardening processing. On bases of theoretical-experimental researches of hardener dynamics centrifugal operation the method of surface hardening with an increased level of deformation energy of a material necessary equipment for high-duty hardening processing is developed. Their fracture toughness has been studied.*
Key words: *fracture toughness, cad-wheel, hardening, deforming, vibrations, resistance*.

The Gearings still become often enough a limiting unit of the equipment longevity. Considerable dynamic loading, sophisticated operating conditions lead to intensive deterioration of the tooth surface material, its crumbling and fatigue breaking. Proceed to using the expensive high-alloy steel for its production is not always reasonable not only from the economic point of view, but because of high durability and solidity of this materials are inseparably linked with the plasticity reducing which is extremely undesirable for the material of the tooth core. Therefore the technological aspects of its production, among them performing of strengthening operations at the completion stage, remain to be the main direction in improvement of reliability and longevity of the tooth gear of the power train. The most promising here are methods of the surface plastic deformation that inhere high level of the deformation energy.

The method of oscillate centrifugal strengthening of the tooth gear belongs to the cohort of dynamic methods of the surface plastic deformation. Distinguishing features that differ it a lot from others are combination of the high level deformation energy and the considerable process productivity. [1]

The method is based on the surface plastic deformation of the strengthening detail material as a result of impact interaction with the deforming bodies that receive the deformation energy from the massive rolling unit. The rolling motion of the rolling unit is self-excited by the vibratory rotation assistance that was initiated by its axis harmonic fluctuation.

As to the tooth gears – the tooth surface strengthening using oscillate centrifugal processing can be realized by two schemes. First one lies in usage of freely based deforming hardened steel balls in the tooth cavities, solidity of which exceeds the solidity of the material of the processed tooth gears. In the second case the deforming units fixed in the separator are used. The impact area of these units iterates fragment of the tooth cavities profile line they are fixed in. The constructive structure of the reinforcer with deforming elements usage is shown on figure 1.

The reinforcer consists of the separator body – 3. Its teeth 4 are based on the processing gear cluster 2 that is gathered and based on the axle 1 using the dowel. In the body 3 perforation is made opposite each of the tooth gear cavity. The deforming unit 7 which is spring-loaded by the spring 6 and is revolving on its axis is set in the perforation. The shape of the deforming units corresponds to the shape of the tooth cavity of the processed tooth gear at the area between the separatory diameter and the dedendum, and its material solidity exceeded the material solidity of the processed tooth gear. Each deforming unit (figure 2) has impact A and deforming B parts where the impact part overhangs the cylindrical part of the separator body. 3. The rubber-lined reinforcer 9 is freely located in the form of cylindrical ring between the overhangs 8 of the separator body.

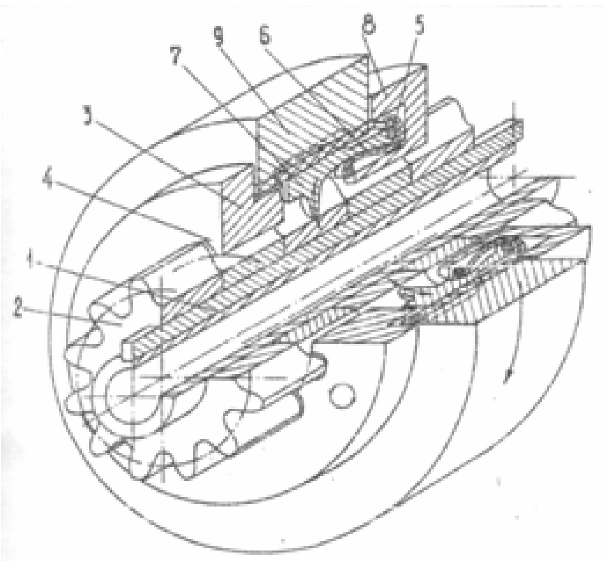


Figure 1 – The tooth gears strengthening with the deforming units.

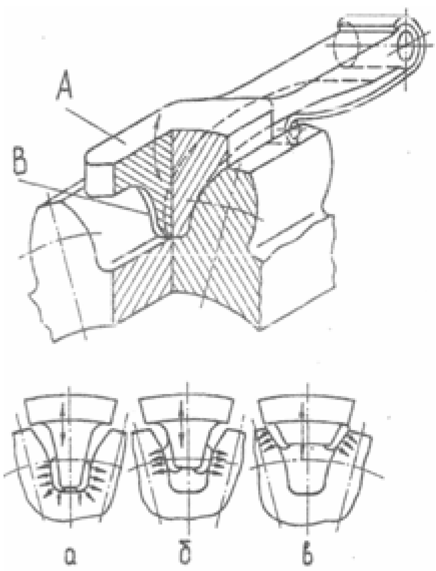


Figure 2 – The constructive structure of the deforming unit and the schema of the tooth surface fragments strengthening.

The internal diameter of the reinforcer 9 realized as:

$D_0=D_к+4A$,

where D_k – the external diameter of the separator body 3;

A – the amplitude of oscillation of the vibration machine frame that holds the strengthener. It is accepted to be equal to the magnitude of the processed tooth gears.

The axes 1 provide the plane-parallel circular vibrations in the vertical plane with strong amplitude A and the frequency f. Under the influence of the frame vibrations reinforcer 9 of the strengthener based on it, is entering so called mode of rotation vibration boost that is accompanied with the rolling of the reinforcer 9 by its internal surface over the separator body 3 cylindrical surface. At this moment the reinforcer rolling frequency is equal to the frame oscillation frequency of the vibration machine f. That is during one period of the frame oscillation the reinforcer performs one rolling movement (one rotation) over the separator body 3 surface with its internal surface returning to the starting point. Since springs 6 hold units 7 (figure 2) in the ultimate top position their impact areas A overhang the cylindrical surface of the separator body 3. Running on the impact areas A of the deforming units during its rolling movement and overcoming the spring 6 the reinforcer 9 moves the deforming units in radial direction to the hard impact of the deforming area B and the surface of that cavity of the tooth of the processed tooth gear 2 which holds this deforming unit. The impact force at this moment is:

$$P = m_0 \cdot \varepsilon \cdot \omega^2 = 4\pi^2 \cdot m_0 \varepsilon f^2 \quad (1)$$

where m_0 – the reinforcer mass;

$\varepsilon \le 4A$ - the reinforcer eccentricity;

A=m_n – the amplitude of oscillation of the driving unit (in this case – the strengthened tooth gear with module m_n);

$\omega = 2\pi f$ - circular frequency of the rolling movement;

f – oscillation frequency of the driving unit.

Deforming energy of the tooth surface material is obtained according to equation:

$$E_y = A_1\left(1 - \frac{2\pi}{\gamma \cdot n}\right)\frac{\sin^2\frac{\pi}{n}}{B + \cos^2\frac{\pi}{n}} \qquad (2)$$

where γ - central angle between two neighboring teeth cavities;

D_1 – diameter of centers location of the spring-loaded deforming units;

J_0 - moment of inertia of the reinforcer;

n – number of teeth cavities of the strengthened gear;

$$A_1 = 2\pi^2 f^2 m_0 D_1^2 \left(1 + B\right)u\,; \qquad B = \frac{4J_0}{m_0 D_1^2}$$

Depth of the strengthened layer in the tooth surface material is determined using corresponding dependences. If the deforming units are used:

$$a_\partial = \frac{K_2}{2\sqrt{bD_1 f}}\sqrt[4]{\frac{D_2 A_1 (1 - \frac{2\pi}{\gamma n})\sin^2\frac{\pi}{n}}{K_3 HB \cdot (B + \cos^2\frac{\pi}{n})}} \qquad (3)$$

where $K_2 = \frac{d_{\max}}{d}$ - the factor that includes ratio of the largest imprint diameter (that remains constant) D_{max} to imprint diameter d after the first impact during repeated dynamic deforming;

$K_3 = \frac{H_\partial}{HB}$ - the factor that includes ratio of dynamic solidity $H_д$ of the strengthened material to its solidity HB after Brinell;

$b = \frac{HB}{2\sigma_T}$ - the factor that includes ratio of the strengthened material solidity HB after Brinell to its liquidity limit □□ during stretching;

$R_2 = \frac{D_2}{2}$ - radius of curvature of the tooth surface at the area strengthened with the deforming units.

If strengthening with hardened steel balls:

$$a_k = \frac{K_2}{2\sqrt{\pi bdDf}} \cdot \sqrt[4]{\frac{m_0\varepsilon}{K_3 \cdot HB \cdot H \cdot B_1}} \qquad (4)$$

where D – diameter of the deforming ball;

H – width of the gear ring of the strengthened tooth gear;

B_1 - distance apart neighboring teeth of the strengthening gear on the gear tip diameter.

Duration of strengthening with the deforming units is determined using:

$$T_{3M.Д} = \frac{H \cdot m_1 \cdot n_1}{a_1 f} \qquad (5)$$

where m_1 – number of the repeated impacts during dynamic strengthening that is accompanied with imprint diameter growing that depends on properties and solidity of the strengthening material, $m_1 \approx 18\text{-}35$;

n_1 – the number of the repeated traversals, $1 \le n_1 \le 5$;

a_1 – width of the impact area of the deforming unit, a_1=0.5-1.6 mm

Processing duration while strengthening with the steel balls is:

$$T_{ЗМ.К.} = \frac{4m_1 \cdot d \cdot \ln\left[\frac{4D}{d}\left|\ln\left(1-\frac{\pi d^2}{4D^2}\right)\right|+1\right]}{\pi d^2 f \left|\ln\left(1-\frac{\pi d^2}{4D^2}\right)\right|}. \quad (6)$$

Character of the technological parameters influence of the oscillate centrifugal strengthening process on the strengthen quality factor is represented in the form of graphic experimental dependences. In such a way dependence of the depth of material strengthened layer on technological parameters of oscillate centrifugal strengthening process during 40X steel gear processing is obtained (figure 3).

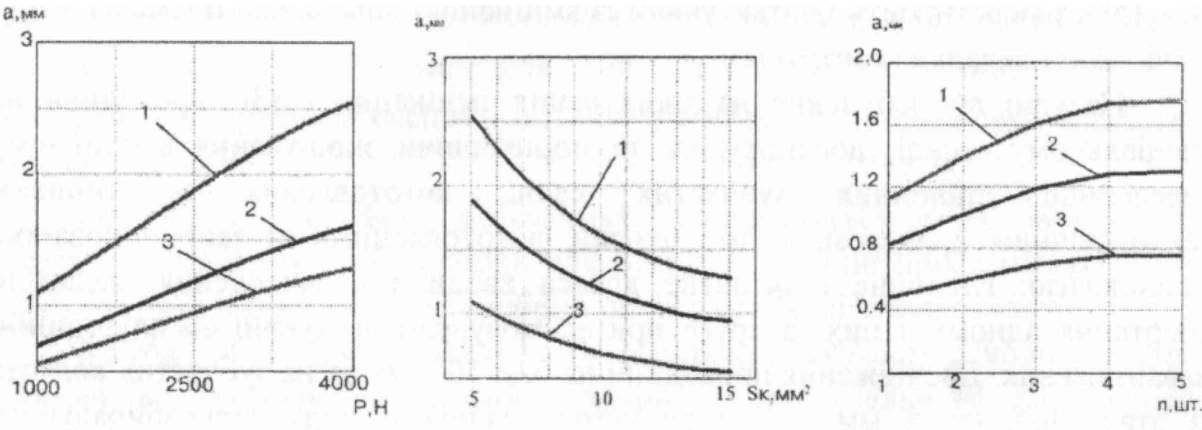


Figure 3 – Influence of the technological parameters of oscillate centrifugal strengthening process on the depth of strengthened layer of the tooth surface material:

a) deformation force P (the number of repeated traversals n = 3; contact area of the deforming units with tooth surface 1- S_k = 5 mm^2; 2 - S_k =10 mm^2; 3- S_k = 15 mm^2);

b) contact area of the deforming units with tooth surface S_k (the number of repeated traversals n = 3; deformation force: 1-P=4кH; 2-P=2,5кH; 3-P=1кH);

c) the number of repeated traversals n (contact area of the deforming units with tooth surface S_k = 10 mm^2; deformation force 1-P=4кH; 2-P=2,5кH; 3-P=1кH).

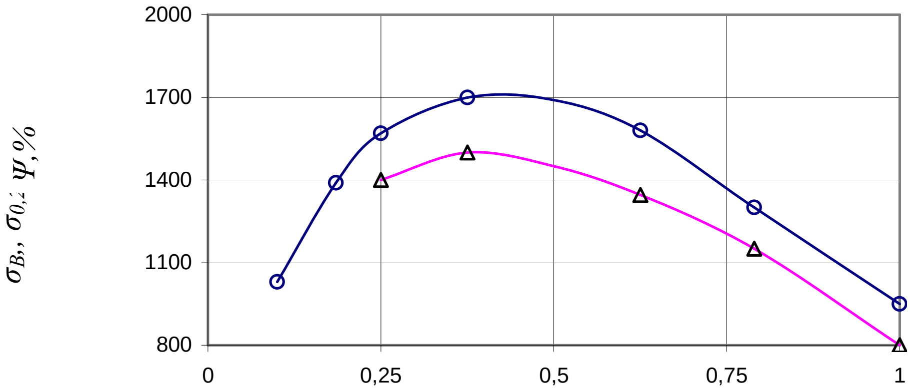
The depth of strengthened layer is a = 1.2 mm ensured by strengthening tooth gear with the deforming units of 40X steel in two repeated traversals. And a = 0.8 mm when strengthening with the steel balls of these gears.

Influence of the strengthened layer depth on durability and plasticity during stretching is complex enough (figure 4). To estimate the influence of the strengthened layer depth on stress-strain properties we used a factor that gives proper weigh to the sample size – relative square of viscous core. This factor is determined from ratio of the unstrengthened core square to the total square of sample in collapse area.

It was discovered that maximal values of durability and liquidity limits correspond to the relative square of viscous core in the range from 0.40 to 0.50 (figure 4). Properties values reduce with other values of the relative square of viscous core. Collapse takes place in the area of elastic deformation without considerable signs of the plastic deformation when testing samples with relative square of viscous core less than 0.25 mm.

$\sigma_{0,2}$

Increasing of the relative square of viscous core to and above 0.50 mm leads to reducing stress-strain properties with synchronous increase of ψ.



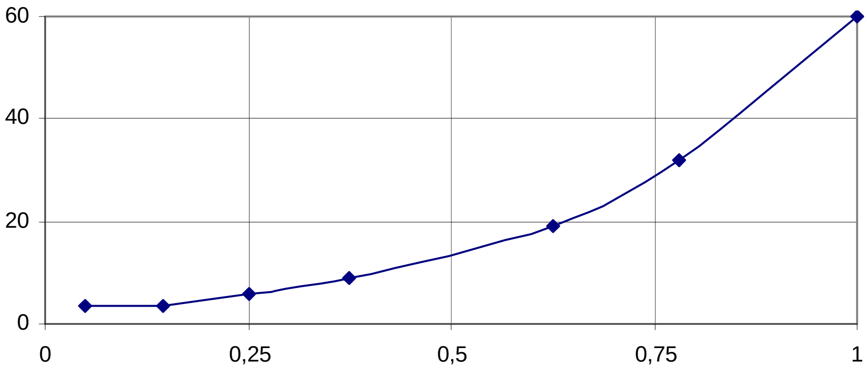


Figure 4 – Influence of the relative square of viscous core on 40X steel stress-strain properties. Relative square of viscous core

Influence of the relative square of viscous core on impact elasticity is shown at figure 4. This property depends on sample strengthening most of all. Strengthening of the surface layers even on insignificant depth leads to considerable reduce of impact elasticity.

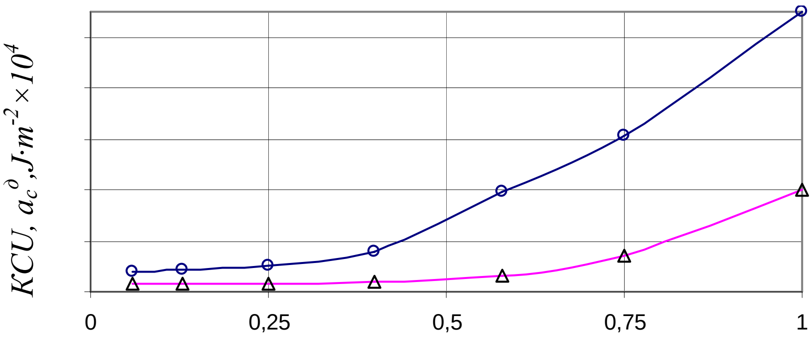


Figure 5 – Influence of the relative square of viscous core on impact elasticity and crack extension behavior of 40X steel.

It's senseless to use surface strengthening when the relative square of viscous core is less than 0.50 mm as it leads to the abrupt reducing of durability, plasticity and impact elasticity properties.

It's shown that crack resistance of the strengthened samples with changed near-surface structure may be estimated through the average values of the stress intensity critical factor K_{1c}^{es} [2].

Tooth strengthening related with the solidity increase and plasticity reducing of the surface layer. These changes reduce resistance of crack extension (fig. 6).

The depth of strengthened layer h, mm

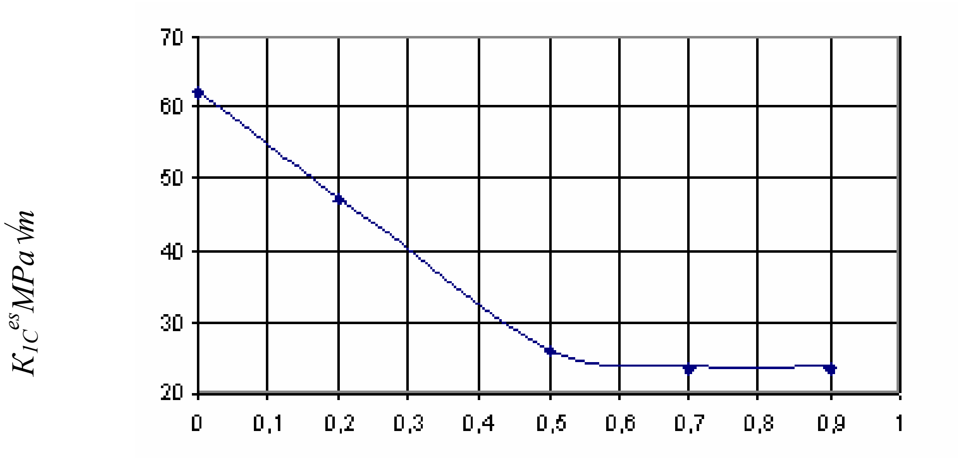


Figure 6 – Variation K_{1c}^{es} of steel 40X for the 10 mm depth samples.

Analytical estimation of the crack resistance of strengthened production is proposed considering geometric sizes of samples and depth of strengthened near-surface layer for rectangular cross section samples.

$$K_{1c}^{oc}\left(h,B\right)=\ln\left(1+e^{K_{1c}-\frac{qh(B+0.1)}{B(B+a)}-22}\right)+22 \qquad (7)$$

where h - is thickness of strengthened layer in mm; B is width of the girder sample; K_{1c}, q, a parameters depending on steel grade and type of thermotreatment.

BIBLIOGRAPHY

1. Афтаназів І.С. Струтинська Л.Р., Клименко О.Д. Efficiency of strengthening of gear-wheels by oscillation-centrifugal strengthening treatment of //Розвідка and development of oil and gases deposits.-2003.-№2.-С.22-28.
2. Романив О.Н., Кукляк Н.Л., Петрина Ю.Д. Влияние of structural состояния поверхностных слоев on сопротивление распространению трещин in стальных изделиях//Физ.-хим. механика материалов.-1973.-№2.-С.5-11.