

Improvement of service life of thin-walled steel products by the example of saw blades.

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Summary

Analysis of existing methods of heat treatment of thin-walled products by the example of saw blades of cotton gins in Russia, the USA and Germany has been carried out. New technology of improving the service life of these products was developed. The influence of nano structure on the wear resistance has been found, calculation of stresses, arising during heat treatment of saw blades, has been done. Their wear resistance at treatment according to the new technology is 2 - 3 times greater than the wear resistance of saws, treated by the known (basic) technology. For the manufacture of saw blades instead of instrument steel 48Г it is possible to use the cheaper steel 65Г, reinforced according to new technology,. The new way to improve the service life of saw blades does not require capital expenditures for the purchase of special equipment and can be easily implemented on the now acting installations of high frequency current (HFC).

Keywords: strength, hardness, wear resistance, nanostructure, heat treatment, saw blades, stress, troostite, sorbite, bainite, phase transformations.

Introduction. The developed heat treatment technology has been applied to increase the service life of saw blades of cotton cleaning machines and can be used in agricultural engineering (hardening of disks of tillage combines and sowing units), as well as in tool production (hardening of disk cutters) and in wood processing industry (hardening of circular knives). At cotton gin plants for processing the raw cotton the gin and linter toothed saw blades with outer diameter - 320 mm, internal - 61mm and a thickness of 0,95mm are widely used. The teeth of saw blades during operation are subjected to abrasive wear and get out of order while in service, that is why the annual production of gin and linter saw blades for cotton cleaning machines reaches several millions of pieces. To improve the service life these products are heat-treated. At hardening saw blades the volume and induction hardening (HFC) are applied. Carbon instrument steels Y8Г with hardness HRA 67-70 are applied to manufacture these products. Despite increased hardness, the lifetime of saw blades is insufficient. In connection with this annually for the manufacture of saw blades several hundred tons of extremely expensive steel Y8Г are used up. Further increase of wear resistance through the use of steel of higher hardness is not possible because of the difficulty of machining (cutting-out of discs, teeth notching).

Choice of material and technology of hardening to the required level of wear resistance, maintenance of flatness of saw blades during heat treatment and reduction of their cost is **an actual problem**.

Objective: increase of wear resistance of saw blades of cotton cleaning machines.

Tasks: - analysis of the existing heat treatment methods of saw blades in Russia, the USA and Germany;

- development of new hardening technology of thin-walled steel products (saw blades);

- identification of the role of nanostructure on wear resistance of saw blades;

- calculation of stresses, generated during the heat treatment of saw blades;
- study of wear resistance of pre-hardened saw blades both according to basic and new technologies of heat treatment.

Materials and methods of study.

Saw blades made of steel Y8Г and 65Г. Metallographic and X-ray structure analysis, test methods on wear resistance, computers to calculate the stresses, occurring from heat treatment of thin-walled steel products, are used.

Results of the work. During the operation of saw blades on the side surfaces of teeth the tracks of "plowing" are formed by hard abrasive particles, which results in blunting of edges and tips of saw teeth. Presence of abrasive particles is due to dustiness of raw cotton by particles of sand (silica) and alumina. (Fig.1).

Saw blades of different manufacturers (Russia, the USA, Germany) have been studied.

The structure of saws of American production is perlite, which differs by the degree of dispensability of cementite particles, hardness HRC 22-24. (Figure 2a). Analysis of the state of the matrix (of the base) of the saw blade has found that these products were subjected to cold plastic deformation (hammering harden) with higher level of dislocation density.

Structure of saw blades of German production consists of lamellar perlite with a small inclusion of ferrite. Such a structure is formed at normalization with hardness HRC 26-28. (Fig.2б).

Structure of saw blades of Russian production has a troostite - sorbitol granulated structure, although there are areas of pearlite of sheet-like nature, formed at the improvement (thermo hardening plus high-temperature temper). (Fig.2в).

The mentioned methods of hardening do not provide high abrasive wear resistance of products because of the low density of nanostructure (of dislocation).

For manufacture of saw blades instead of tool steel Y8Г it is possible to use cheaper steel 65Г, hardened by known (Russian) technology and technology, developed by us.

New method of hardening is preliminary heating of saw blades up to 400-450 ° C followed by 3-fold electro thermo cyclic treatment (ETCT) in the temperature range of 920-700 ° C, hardening and tempering at 250-300 ° C in a specially designed fitting-out [1, 2]. Heating up to 400-450 ° C was carried out in order to reduce heat stresses during subsequent ETCT. Grinding austenite grains and increasing the dislocation density is achieved as the result of multiple phase transformations at triple ETCT. After hardening from the last cycle of heating ETCT fine-needled martensite is formed with a maximum density of dislocation, which after tempering 200-250 ° C passes into bainite structure (hardness HRC 40-42) (Fig.2г).

It is known that the increase of defects presence (dislocation) of metal lattice increases the wear resistance. Influence of the fine structure of the alloy (nanostructure) on wear resistance of steel is so significant that with increasing density of dislocations the abrasive wear resistance of surfaces of steel products increases [3].



a)



b)

Fig 1. Microstructure of steel Y13
a – after hardening by HFC;

b – after ETCT + IPT;



a)



b)

Fig 2. Dislocation structure of steel Y13(found out by method of etch pits)
a – after ETCT

b – after ETCT + IPT



a)



b)

Fig 3. Dislocation structure of steel Y13(electron microscopy)
a – after ETCT

b – after ETCT + IPT

The density of dislocations was determined by X-ray diffraction along broad ending lines of interference of X-ray patterns, depending on the reflection angle (θ). To calculate the density of dislocations (ρ) the following ratio was used [4]:

$$\rho = \beta^2 / 2b^2 \times \text{ctg}^2 \theta$$

Where: β – physical width of the X-ray lines;

b – Burgers vector (for VCCL6 = 0.25mm);

θ – angle of reflection.

Saw blades, which have passed hardening both according to the basic and new technologies, were tested for wear resistance in a special unit, that simulates the products' operation at cotton cleaning machines. The essence of the test is that a pile of saw blades is mounted on the shaft and imbedded by $\frac{1}{4}$ of the diameter of the saw blade into a sand bath. The shaft speed is 750 rev / min and corresponds to the speed of rotation of saw blades in the cleaning machine, the test time is from 10 to 80 minutes. Before the test the measurements of height of the saw teeth in four mutually perpendicular directions to diameter were carried out. Wear rate was judged by difference in the heights of the saw teeth before and after the test. The results are presented in table 1.

Density of dislocations, hardness, wear rate.

Table 1

№	Steel grade	Type of hardening	Density of dislocation $\rho * 10^{11} / \text{cm}^2$	Hardness HRC	Wear, mm
1	Steel Y8Г	Basic technology (hardening, high –temperature tempering)	2,15	34-36	0,36
2	Steel 65Г	Basic technology (hardening, high temperature tempering)	2,10	32-34	0,40
3	Steel Y8Г	New technology (preliminary heating, ETCT)	3,60	42-44	0,15
4	Steel 65Г	New technology (preliminary heating ,ETCT)	3,55	40-42	0,20

From Table 1 it follows that steels Y8Г and 65Г, which have passed hardening according to the new technology (pre-heated to 400-450 ° C and subsequent ETCT), have a higher hardness, dislocation density and low amount of wear compared to the basic technology (hardening HFC plus high-temperature tempering).

Calculation of thermal stresses was done according to well-known formulae for heavy-walled cylinders having different temperature of inner and outside surfaces. Since the thickness (height) of

the cylinder is small (0,95mm) values of radial and circumferential (tangential) stresses were found according to equations:

$$\sigma_r = \frac{E}{1-\mu} \cdot \left[-\frac{1}{r^2} \cdot \int_{r_1}^r \alpha \cdot T \cdot r \cdot dr + \frac{r^2 - r_1^2}{r^2 (r_2^2 - r_1^2)} \cdot \int_{r_1}^{r_2} \alpha \cdot T \cdot r \cdot dr \right] \quad (1)$$

$$\sigma_\theta = \frac{E}{1-\mu} \cdot \left[\frac{1}{r^2} \cdot \int_{r_1}^r \alpha \cdot T \cdot r \cdot dr + \frac{r^2 + r_1^2}{r^2 (r_2^2 - r_1^2)} \cdot \int_{r_1}^{r_2} \alpha \cdot T \cdot r \cdot dr - \alpha \cdot T \right] \quad (2)$$

In these formulae:

E -elasticity modulus

μ - Poisson's ratio,

r^1 - inner radius of the saw(holes) - 30 mm,

r^2 - outer radius of the saw - 160 mm,

α - temperature coefficient of linear expansion,

T –temperature of the saw in the studied point of radius ,

r –shifting radius .

Necessary data for calculation about the parameters, properties of steels at various temperatures were taken from the reference manual [5]. Since a number of parameters and properties of steels at the change of temperature change quite significantly, the formulae (1) and (2) were rewritten in the form of :

$$\sigma_r = \frac{E\alpha}{1-\mu} \cdot \frac{-1}{r^2} \cdot \int_{r_1}^{r_2} Trdr + \frac{E\alpha}{1-\mu} \cdot \frac{r^2 - r_1^2}{r^2 (r_2^2 - r_1^2)} \cdot \int_{r_1}^{r_2} Trdr , \quad (3)$$

$$\sigma_\theta = \frac{E\alpha}{1-\mu} \cdot \frac{1}{r^2} \cdot \int_{r_1}^r Trdr + \frac{E\alpha}{1-\mu} \cdot \frac{r^2 + r_1^2}{r^2 (r_2^2 - r_1^2)} \cdot \int_{r_1}^{r_2} Trdr - \frac{E\alpha}{1-\mu} \cdot T . \quad (4)$$

Measurements of the temperature along the points of the saw radius showed that distribution of temperatures can be represented as a broken line. In general this corresponds to the adopted method of calculation, when the change of temperature from the hotter one, is considered approximately to be a linear one. So the general definite integral in the formula (3.4) was calculated as the sum of ratios, limited by a certain section of right line of change of temperature, depending on saw radius. On each temperature section the changes of the elasticity modulus and coefficient of linear expansion were taken into account. Structural and thermal stresses in the peripheral zone were calculated in accordance with the volume changes, caused by hardening cooling [6].

The occurring stresses(stress diagrams) were built according to data of computer calculations. The basic idea was to provide in the process of heat treatment the temperature conditions (outside the hardenable zone), excluding the occurrence of stresses above the flow limit.

Induction impulsive heating of saws at the saw gullet up to temperature of 900 °C under linear distribution of temperatures along the radius, means that the total heating zone of the saw along the radius reaches 8mm from gullets. At the same time at the depth up to 2 mm the heating takes place above A_3 (austenitic state), but at the depth of over 2 mm the temperature is below the point of phase transformation. The distribution of temperatures and occurring internal stresses are presented in tables (2,3). Integral $Trdr$ is computer calculated, using numerical methods, in particular the methods of rectangles or trapezoids. [7]

Radial stresses in the sawframe at heating the peripheral zone by high frequency current (HFC).

Table 2

Radius from saw axis to periphery, mm	Radial stresses σ , MPa	Radius from saw axis to periphery, mm	Radial stresses σ , MPa
30	0,00	105	101,23
35	29,2	110	102,21
40	48,21	115	102,9
45	61,35	120	103,48
50	70,65	125	103,97
55	77,51	130	104,46
60	82,81	135	104,95
65	86,82	140	105,35
70	90,06	145	105,64
75	92,70	150	105,94
80	94,86	152	106,13
85	96,62	154	94,57
90	98,09	156	69,48
95	99,37	158	45,66
100	100,45	160	0,00

Tangential stresses in the saw frame at heating the peripheral zone by induction method

Table 3

Radius from saw axis to periphery, mm	Tangential stresses, σ MPa	Radius from saw axis to periphery, mm	Tangential stresses, σ MPa
30	220,79	105	119,36
35	191,49	110	118,58
40	172,48	115	117,89
45	159,44	120	117,30
50	150,13	125	116,71
55	143,18	130	116,22
60	137,98	135	115,83
65	133,86	140	115,44
70	130,63	145	115,05
75	128,09	150	114,75
80	125,93	152	144,66
85	124,16	154	-793,01
90	122,59	156	-1909,23
95	121,42	158	-1990,62
		160	-3776,92

In the heating area the tangential stresses by far go beyond the yield strength of steel both in the area of austenitic state and in the area of temperatures below the phase transformation. In the austenitic area relaxation of stresses must take place, although as it will be shown below, a very fast impulsive heating during 0,8sec leaves stresses 250-450 MPa unrelaxed. If to take into account that at 240-350 °C the yield strength of steel Y8Г in the state as received does not exceed 1000 MPa, it turns out that at the depth of up to 6 mm from the gullets the stresses exceed the yield strength. Consequently, plastic deformation and stress relaxation will take place. After hardening

cooling the reduction of volume occurs due to the martensitic transformation. At other depths there is no such compensation and during cooling contractions are inevitable. The experiments confirmed the calculations – all saws after such heat treatment had a "bend in the form of a dish" up to 3-4 mm.

Subsequent straightening of saws is also unlikely because it is only possible during tempering of chilled steel under stress at sufficiently high temperature. In tempered or hot-rolled state (i.e. in areas deeper than 2 mm from saw gullets) the steels Y8Г are difficult to straighten. In case of treatment of saw blades according to new technology the stresses do not exceed the yield strength of steel Y8Г (1000MPa) and deformation (contraction) of products is insignificant and is within the pink limit.

Conclusion.

1. The principles of hardening saw blades of various countries-manufacturers (Russia, the USA and Germany) have been studied.

2. Calculations of stresses, occurring from the electro thermal treatment of saw blades, are represented.

3. A new technology of wear resistance increase and manufacture of defect-free saw blades of cotton cleaning machines have been developed.

4. Wear resistance of saw blades, subjected to processing according to the new technology is 2-3 times higher than the wear resistance of saw blades, treated according to basic technology

5. To manufacture saw blade instead of instrument steel Y8Г it is possible to use cheaper steel 65Г, hardened according to the new technology.

6. The new method of hardening saw blades does not require expensive special equipment and can be easily implemented on the now existing induction units (HFC).

Bibliography.

1. Islamkulov K.M., Kalmykpayev B.H., Method of heat treatment of saw blades. RK patent for invention, number 18631, Bull. № 5, 2010y.

2. Islamkulov K.M., Kolmykpayev B.H. An apparatus for induction hardening. RK patent for invention, number 18630, Bull. № 5, 2010y.

3. Dyachenko S.S. Heredity in phase transformations: mechanism of the phenomenon and influence on properties // Metal science. Heat Treatment of Metals, 2000, №4, pp.14-19.

4. Ivanov A.N., Klimanek L., Polyakov A.M. Research of substructure of metals by X-ray method. // Metal science. Heat Treatment of Metals 2000, № 8, pp.7-10.

5. Reference book in engineering materials. Mashkiz M., 1979y, Volume 1, p.507.

6. Zenkin A.S., Arsenyev B.M. Fit-up of fixed joints by thermal methods. M., Mechanical Engineering, 1987, p.125.

7. Bermant A.F., Aramanovich I.G. Short course of mathematical analysis. Nauka, Moscow, 1973, p.712.