Research of composite coverings wear resistance for forestry machines by electro contact sintering

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Abstract. Many parts of the chassis in forestry machines are exposed to heavy wear due to operation under heavy-duty conditions. Parts exposed to the heaviest wear are friction bearings and axles; whereas it is often cheaper to replace bearings than to restore them, axles might be quite expensive. This study examines a promising method of axle-class parts, improving their wear resistance. Analysis of the study results allows to come to a conclusion that coating produced by electric-contact sintering of composite materials featured a > 1.5x wear resistance of 40Kh steel from which the representative roller axle was made. Therefore, the service life and reliability of joints made of or restored by means of composite materials is considerably better than that of the standard forestry-machine chassis connections.

1. Introduction

Many parts of the chassis in forestry machines are exposed to heavy wear due to operation under heavy-duty conditions. Parts exposed to the heaviest wear are friction bearings and axles; whereas it is often cheaper to replace bearings than to restore them, axles might be quite expensive. Abrasive friction is the cause of wear of axles in the forestry-machine chassis. Friction is a very common phenomenon. It occurs in every relative motion of contiguous bodies or parts thereof. The roller axle of an Onezhets-300 skidder (Fig. 1) was chosen as the representative part for studying wear resistance.

Electric-contact sintering of composite material can prolong the service life of roller axles while strengthening their operating surfaces; as such, it is proposed as a method for roller pin restoration. One fact that must be born in mind is that implementing an electric-contact sintering unit is not associated with considerable financial investments and is affordable for most enterprises in the industry.

This study examines the wear resistance of parts restored by this technology under close-to-real operating conditions. Special attention is paid to analyzing the effect of different sintering parameters (current, voltage, and electrode pressure force) on the wear resistance of restored parts.
Figure 1. Skidder roller axle

2. Research methodology

Figure 2 demonstrates technology of electric-contact sintering of metal powders unto part surfaces. The technology shown therein is intended for the restoration of cylindrical parts. Current is applied to the welding zone via two welding rollers. This eliminates contact transitions from the outer loop, thus considerably reducing the power loss.

The process of electric-contact welding is essential concerning sintering a layer of metal powder onto the part surface pressurized by the forming roller and exposed to high-density current applied to the powder layer (3000 to 5000 A/cm²). That is, the powder is sintered by the heat generated by the electric current against active resistance [3].

Friction is referred to as external friction if it occurs in the relative displacement of two contiguous bodies. It depends on the external superficial interaction of these bodies near the point of contact, but not upon inner conditions. External friction and wear is a three-stage process: first the surfaces interact, then the superficial-layer material is altered by friction, then the surfaces are destroyed. In this case, the roller axle is exposed to friction against a harder part, a roughness 15 (pure bearing steel) steel bearing. Surfaces of solids feature micro relief. Micro relief in its turn features such attributes as shape deviation, waviness, and roughness. One can conclude that friction-caused structural alteration occurs at certain points of contact. This is why the structure and properties of the superficial layer are different from the structure and properties characteristic of volumetric deformations and heat treatment.

1. the part to be restored; 2. the weld metal; 3. the welding roller; 4. metal powder; 5. the bunker; 6. the strengthening roller.

Figure 2. Electric-contact sintering of powder materials.

In this case, the roughness of both parts equals to Ra 2.5, which minimizes the effect of this factor. When considering external friction, three factor groups must be borne in mind, see Table 1 [1].

| Input factors | Internal factors | Output factors |
|---------------|------------------|----------------|
| Nature of solids exposed to friction | Alteration of roughness | Friction force |
| Lubricant | Alteration of properties of superficial films | Wear intensity |
| Load | Heat output | |
| Velocity | Alteration of structure | |
To reproduce natural friction conditions, we used a DM-15 machine, i.e. a dynamic machine with a 15-kN maximum load of the tested joint.

This machine is able to reproduce abrasive friction by applying such abrasive elements as sand, soil, etc. to the part contact point. The real roller-axle to inner bearing race joint was used as the friction couple. Before testing, both parts were lubricated with UNIOL-1 (GOST 1033-79).

The parts were marked at the measurement points. The conjugate diameters were measured post-disassembly by means of an electronic micrometer and a caliper with an accuracy of 0.001 mm; measurements were done in two perpendicular planes and three points (center and edge points), whereby wear was assumed to be the average value of those points.

The load upon the conjugate parts was assumed on the basis of the real value $P=15000$ N as measured by a DOSM-5-1 (Rus: ДОСМ-5-1) dynamometer, TU25.06.629-74. The following requirements: were also met: rotary motion, maximum sliding velocity of the friction couple $V_{\text{max}}=0.07$ m/s at the output shaft rotation speed $n=30$ min- as transmitted to it by the machine's motor. Prior to experimentation, each friction couple was broken in at $P=5000$ N and $V=0.01$ m/s. During the experiments, the temperature in the friction zone was measured by means of a thermometer placed in a hole in the bearing race.

To evaluate the wear rate, the following dependencies were assumed [4]:

$$I = \frac{U}{t}$$

where $U$ is the wear of the conjugate parts, mm;
$t$ is the machine runtime, h.

$$I_{\text{total}} = I_{\text{axle}} + I_{\text{bearing}}$$

where $I_{\text{total}}$ is the total connection wear rate, mm/h;
$I_{\text{axle}}$ is the axle wear rate, mm/h;
$I_{\text{bearing}}$ is the bearing wear rate, mm/h.

Assume: the uncoated roller-axle wear rate to be the nominal wear rate ($I_{\text{nominal}}$), then by preliminary experimentation, we find that $I_{\text{nominal}} = 0.014$ mm/h. Nominal wear resistance was studied under the same conditions as the wear resistance of coated axles.

The following factors of the composite-material sintering process were assumed to have an effect on the wear intensity: Current ($I$), Voltage ($U$), and electrode pressure force ($P$). The factor levels and their variation intervals are given in Table 2.

Using Prof. Yu. M. Zubarev's method [2], one can find from the table:

$$X_1 = 2 \times (\ln x_1 - 2.3)/[2.3 - 2.64] + 1 = -5.88 \ln x_1 + 14.5$$

$$X_2 = 2 \times (\ln x_2 - 0.69)/[0.69 - 1.39] + 1 = -2.86 \ln x_2 + 5.83$$

$$X_3 = 2 \times (\ln x_3 - 0.69)/[-0.69 - 0.4] + 1 = 0.96 \ln x_3 - 0.63$$

We further performed regressive analysis. The experimental results are encoded and summarized in Table 3. For greater confidence, we added 7 support experiments to the 8 main experiments. [2]

### Table 2

| Factor level | $I$, kA | $U$, kV | $P$, kN |
|--------------|---------|---------|---------|
| $x_1$        | $ln x_1$| $x_2$   | $ln x_2$| $x_3$ | $ln x_3$ |
| Lower (-1)   | 10      | 2.30    | 2       | 0.69  | 0.5     |
| Basic (0)    | 12      |         | 3       |       | 1       |
| Upper (+1)   | 14      | 2.64    | 4       | 1.39  | 1.5     |
| $-\alpha$    | 7.85    | -       | 1.57    | -     | 0.285   |
| $+\alpha$    | 17.01   | -       | 4.86    | -     | 1.715   |

Using Prof. Yu. M. Zubarev's method [2], one can find from the table:
Let us further write an equation introducing the terms that take into account the factor interaction, and represent it in encoded variables:

\[ Y = \tau = b_0 + \sum_{i=1}^{3} b_i x_i + \sum_{i,j} b_{ij} x_i x_j + b_{123} x_1 x_2 x_3 + \sum_{i=1}^{3} b_{i} x_i^2 \]  

(3) Regression-equation coefficients are found as follows:

\[ b_i = \frac{\partial Y}{\partial x_i} \]

By substituting \( b_i \) in equation 3, we obtain:

\[ Y = -33.85 - 1.97 X_1 - 0.47 X_2 - 0.47 X_3 \]

(4)

Formula 5 is used to find the experiment reproducibility variance, and the calculated values are summarized in Table 4.

| Experiment reproducibility variance |
|-------------------------------------|
| \( S_y^2 \) = \( \frac{\sum (\bar{Y}_u - Y_{uq})^2}{N - (r-1)} \) |

where \( Y_{uq} \) is the value of \( Y_u \) in the qth repeated experiment.

### Table 3: Continuation

| Experiment # | X1 | X2 | X3 | For r1 | For r2 | \( \bar{Y} = ln l \) |
|--------------|----|----|----|--------|--------|-----------------|
| 13           | 0  | 0  | -\( \alpha \) | 0.019  | 0.019  | 0.019          |
| 14           | 0  | 0  | +\( \alpha \) | 0.018  | 0.017  | 0.0175         |
| 15           | 0  | 0  | 0   | 0.016  | 0.018  | 0.017          |

### Table 4

| Experiment reproducibility variance |
|-------------------------------------|
| \( S_y^2 \) = \( \frac{\sum (\bar{Y}_u - Y_{uq})^2}{N - (r-1)} \) |

| Experiment # | \( \bar{Y}_u - Y_{uq} \) | \( (\bar{Y}_u - Y_{uq})^2 \) | Experiment # | \( \bar{Y}_u - Y_{uq} \) | \( (\bar{Y}_u - Y_{uq})^2 \) |
|--------------|--------------------------|-----------------------------|--------------|--------------------------|-----------------------------|
| 1            | -4.77 + 4.83 = 0.06      | 0.0036                      | 5            | -4.66 + 4.71 = 0.05      | 0.0025                      |
| 1            | -4.77 + 4.71 = -0.06     | 0.0036                      | 5            | -4.66 + 4.6 = -0.06      | 0.0036                      |
| 2            | -4.14 + 4.2 = 0.06       | 0.0036                      | 6            | -4.07 + 4.14 = 0.07      | 0.0049                      |
2  -4.14+4.07=-0.07  0.0049  6  -4.07+4.02=-0.05  0.0025
3  -4.34+4.27=-0.07  0.0049  7  -4.14+4.2=0.06  0.0036
3  -4.34+4.42=0.08  0.0064  7  -4.14+4.07=-0.07  0.0049
4  -3.91+3.96=0.05  0.0025  8  -3.82+3.86=0.04  0.0016
4  -3.91+3.86=-0.05  0.0025  8  -3.82+3.77=-0.05  0.0025

\[ \text{Sy}^2 = 0.0581/8 \cdot (2-1) = 0.00726 \]
\[ \text{Sy} = 0.085 \]

Variance homogeneity is verified by Cochran's test:

\[ G_{\text{pacy}} = \frac{S_{y_{\text{max}}}^2}{\sum S_{yu}^2} = \frac{0.0064}{0.0581} = 0.11 \]

For N=8; \( \alpha=0.05; f=r-1=1 \) the critical Cochran value is found from the table: GKP=0.6798.
As \( G_{\text{pacy}} < G_{\text{pacy}} \), accept the hypothesis.

We further verify significance of the regression coefficients:

\[ S_{bi}^2 = \frac{S_{y}^2}{N \times r} = \frac{0.00726}{8 \times 2} = 0.00036; S_{bi} = 0.0021 \]

The critical test value is determined from the table: \( t_{\text{KP}} = 2.306 \).

The half-length of the confidence interval is determined by:

\[ \Delta b_i = t_{\text{KP}} \cdot S_{bi} = 22.327 \cdot 0.019 = 0.42 \]

The coefficient is significant if \( |b_i| \geq \Delta b_i \). By removing the insignificant coefficients the regression equation is written as:

\[ Y = -33.85 - 1.97X_1 - 1.43X_2 - 0.47X_3 - 0.47X_1X_2 \quad (5) \]

Model adequacy verification. The adequacy variance is:

\[ S_{A/l}^2 = 2/(8 - 5) \cdot 0.022 = 0.0147 \]

The Fisher's test value can be found as:

\[ F = \frac{S_{A/l}^2}{S_y^2} = 0.12 / 0.00726 = 16.5 \]

If in the table FKP=19.37 > 16.5, therefore, the model is adequate.

3. Research results

By transition to natural variables and equation involution, we find:

\[ I = 0.0455 - 0.00175I - 0.0025U - 0.00175P \quad (6) \]

From this equation, one can conclude that all the factors of the process are significant.

Let us further optimize it by the Monte-Carlo method using SPSS v.13.

The process parameters: I = 14 kA, U = 4V n P = 0.5 kN at \( I_{\text{exp}} = 0.009 \) mm/ha are found by optimization.

Given that \( I_{\text{exp}} = 0.014 \) mm/h, we find the wear coefficient:

\[ K_{\text{degree of wear}} = \frac{I_{\text{nominal}}}{I_{\text{experimental}}} = \frac{0.014}{0.009} = 1.55 \quad (7) \]

4. Conclusions

Analysis of the study results allows to make a conclusion that coating produced by electric-contact sintering of composite materials featured a > 1.5x wear resistance of 40Kh steel from which the representative roller axle was made. Therefore, the service life and reliability of joints made of, or restored by means of, composite materials are considerably better than that of the standard forestry-machine chassis connections.

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