EFFECT OF RESIDUAL STRESSES ON JOURNAL FIXING IN GRINDING MILL BODY DURING SURFACING

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External surfaces of journals of the raw processing mills are subjected to intensive wear due to friction in bearing parts. The wear reduces journal thickness. This can result in formation of longitudinal cracks in combination with residual tensile stresses from external repair surfacing. Recovery of journal strength by their surfacing on internal surface is proposed. Therefore effect of journal fixing is achieved, at that, lying in that the negative residual stresses reduce the operating stresses and allow the hollow cylinders to bear higher loads. Design analysis and experimental check of stressed state, forming in surfacing of the mill journal on internal surface, showed that the residual compression stresses are formed on the journal external surface. They are significant on value and develop autofixing effect increasing crack resistance of the journals from operating loads. 8 Ref., 3 Figures.

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End walls of mills (MSTs 3.6×4.5 etc.) represent themselves a disk with pressed-in it journal. The disk is worn out at operation in regions of abutment to mill body, as a result of pulp penetration under the seal, and journals on external surface due to friction in the bearings. Their repair surfacing was mastered by «Komposit» Ltd. at the end of 90th. The disk was firstly deposited by «soft» steel in order not to have difficulties during mechanical processing and by hard alloy for wear resistance increase after grooving with removal of 3 mm layer «to size». The journals were deposited by semi-automatic welding machine (Figure 1) and grooved up to dimension on a drawing. More than 50 pcs of end walls were repaired for Kachkanarsky and Vysokogorsky ore mining and processing enterprises, Sredneuralsky and Krasnouralsky copper smelting plants at economy around 1 mln. of rubles on each item.

Repair significantly, by almost 2 times, prolonged the service life of the end walls during which increase of wear of internal surface of the journals contacting with charging spouts takes place. It achieved 20 mm on some journals. The wear reduces the journal thickness and, as a result, increases the operating stresses, which in combination with the residual tensile stresses in external surfacing promote formation of longitudinal cracks. Around 10 pcs. of journals, having cracks on the external surface, some of which transformed in through-the-thickness cracks, were discovered in a course of two last years. Thus, it is necessary to increase the strength of the repaired mill journals.

Surfacing of journals on the internal surface is an obvious measure for strength recovery. At that, surfacing proportional to wear (20 mm) is seemed to be impossible due to probable journal shrinkage and loss of strength of its fixing (press fit) in the end wall. Surfacing of thinner layer (around 5 mm), in order to avoid shrinkage, at first glance, does not seem to be justified since complete repair of journal cross-section and, respectively, complete strength recovery are not provided. But attitude to it can change, if possibility of concurrent autofixing of the journals by welding stresses is considered. The autofixing effect lies in that the opposite sign residual stresses, i.e. reducing operating stresses, allow the hollow cylinders to bear higher loads, applied to them [2, 3]. In conformity with the present case, resistance to longitudinal crack formation can be increased by residual circumferential compression stresses on the external surface of journals. Possibility of their inducing from surfacing on the internal surface was studied in the present work.

Analysis of residual stresses forming in surfacing of mill journals on the internal surface. Residual stresses in welding (surfacing) are formed as a result of heat shrinkage of heated metal, representing itself deposited metal and part of heat-affected zone (HAZ) in base metal, received plastic compression deformation in heating [4–6]. Scheme of formation of residual stresses in the journal with surfacing on internal surface is given on Figure 2. It can be seen from the Figure that internal part *1* drags external

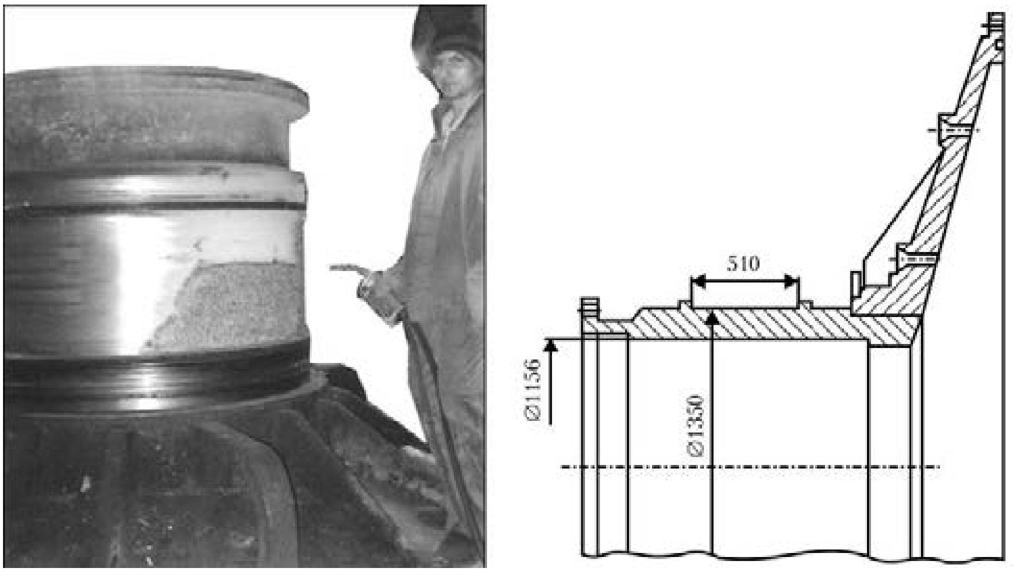

Figure 1. Surfacing of mill journal by semi-automatic welding machine and journal draft

part *2* as a result of heat shrinkage, creating in it the circumferential compression stresses G_t. Formula for the circumferential stresses in elastic region of arbitrary selected hollow cylinder ($a \le r \le b$) according to data of work [7], has the following view:

$$G_t(r) = \frac{G_r(b)b^2(r^2 + a^2) - G_r(a)a^2(b^2 + r^2)}{(b^2 - a^2)r^2}. \quad (1)$$

Let's write expression (1) for external surface ($r = b$) part *2* under the following conditions:

• external surface, being free, has no radial stresses ($G_r(b) = 0$);

• radial stresses $G_r(d) = p$ act on lower boundary of part *2* ($r = d$):

$$G_t(b) = -G_r(d)\,\frac{2d^2}{b^2 - d^2}, \quad (2)$$

where $G_t(b)$ are the circumferential stresses on external surface ($r = b$) of the journal; $G_r(d)$ are the radial stresses on radius ($r = d$).

Since the radial stresses in hollow cylinders are multiply smaller than the circumferential ones, then talking about autofixing effect of the internal surfacing makes sense only under $\frac{2d^2}{b^2 - d^2} \ge 1$ condition, meeting at

$$d \ge 0{,}6b. \quad (3)$$

It should be considered for estimation of $r = d$ radius that it is located inside HAZ in direction from surfacing. It is shown in works [4–6] that the boundary of plastic compression is located in the range of 100–600 °C isotherms depending on conditions of welding heating and rigidity of the part. In order to reduce the calculations, consideration of HAZ can be omitted and assumed that a force action on the external part of insert is made only by deposited metal. Finally, this approximation reduces the possibility that a calculated autofixing would not proved in reality. Then, value of radius d is found from the expression $d = a + h$, where a is a radius of the internal (worn) surface of insert before surfacing; $h = 4$ mm is a penetration depth at surfacing current 400 A (from calculation of 1 mm per each 100 A of welding current [8]).

Applicable to the journal (Figure 1) of $b = 675$ mm and $a = 578$ mm dimensions, the value of radius d, on which radial stresses are formed, promoting journal autofixing, makes: $d = (578 + 10) + 4 = 592$ mm, where 10 (mm) is a depth of journal wear on the internal surface.

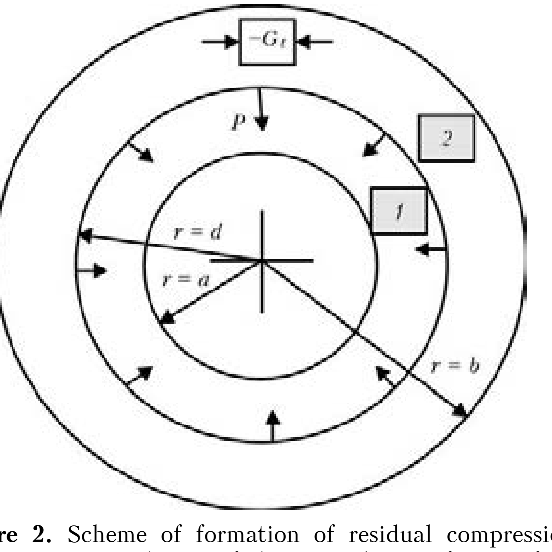

Figure 2. Scheme of formation of residual compression stresses in external part of the journal in surfacing of its internal surface: *1* — zone of deposited metal and high-temperature area of HAZ; *2* — zone of external part of the journal; *P* (arrows) — direction of force action of internal part *1* on external part *2* of the journal

Thus, condition (4) is fulfilled: 592 > > 0.6·675 = 405, that means the possibility of appearance of significant on value circumferential compression stresses on the external surface from single-layer internal surfacing. This, in turn, shows that the internal surfacing is accompanied by autofixing of the journals and can facilitate prevention of crack appearance on their external surface in operation.

Formula from work [9] was used for estimation of the heat radial stresses at $r = d$:

$$G_r(r) = \frac{\alpha E}{r^2}\left[\frac{r^2 - a^2}{b^2 - a^2}\int_a^b T(r)rdr - \int_a^r T(r)rdr\right]. \quad (4)$$

Calculations using it are made with the following assumptions:

- yield strength of the material is constant (G_y = const) at T < 600 °C;
- yield strength of the material is negligibly small ($G_y = 0$) at T > 600 °C;
- cooling of the deposited layer takes place due to heat exchange with ambient medium, i.e. part 2 on Figure 2 does not increase temperature that means:
- $T(a) = T(d-) = -600$ °C, where $T(d-)$ is a temperature on the boundary of surfacing from internal side;
- $T(d+) = T(b) = 0$ °C, where $T(d+)$ is a temperature on the boundary of surfacing from external side;
- minus mark means that thermal stresses appear at temperature reduction.

Taken assumptions are not original, the similar were used in works on welding stresses and deformations mentioned above. Considering them, expression (6) takes a form:

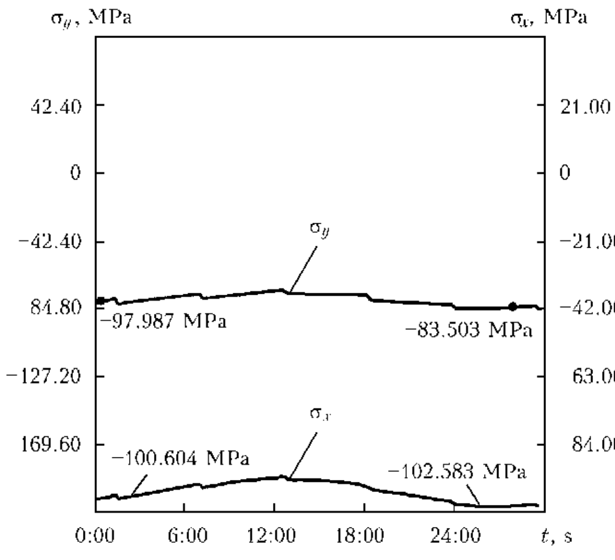

Figure 3. Oscillograms of residual stresses: σ_y in Y direction (axial); σ_x — in X direction (circumferential)

$$G_r(d) = -600\alpha E\left[\frac{(d^2 - a^2)(d^2 - a^2)}{2(b^2 - a^2)d^2} - \frac{d^2 - a^2}{2d^2}\right]. \quad (5)$$

A minuend in square brackets in formula (5) is significantly smaller than deduction that allows omitting it from consideration. Then, the radial stresses at $r = d$ are found from the expression

$$G_r(d) = 600\alpha E\,\frac{d^2 - a^2}{2d^2}, \quad (6)$$

where $\alpha = 14\cdot10^{-6}$ 1/°C is a coefficient of linear expansion; $E = 1.5\cdot10^5$ MPa is an elasticity modulus; values of a and d radiuses are given above.

Calculations on formula (6) show that the radial stresses on the boundary of plastic deformations, creating circumferential autofixing stresses on journal external surface during surfacing, equal $G_r(d) \approx 29$ MPa.

Inserting this value in expression (2), residual circumferential stresses on the journal external surface $G_t(b) \approx -168$ MPa are received.

Their comparability with the yield strength (270 MPa) of journal material (steel 35L) can be noted and a conclusion about significant autofixing effect accompanying surfacing of journals on internal surface can be made.

Experimental check of calculation. Single-layer surfacing on the internal surface of mill journal was carried out on a technology similar to the external surfacing by semi-automatic welding machine.

Calibrated working transducers were preliminary glued to the journal external surface in circumferential and axial directions (plates were welded for force-balance transducers). Resistive-strain sensors of FKPA 10-100 type having 10 mm length base and 91.6–92.0 Ohm resistance were used as transducers. Signal amplifiers, modules for transducer connection and KCKWin software from developer and manufacturer of measuring system CJSC «Teploenergeticheskie tekhnologii» were used.

Balancing of measuring signals from the transducers («0» setting) was carried out after assembly of strain-gauge circuit, but before surfacing of journal on the internal surface. The equipment was switched off before surfacing and switched on again after it performance and the values of stresses in circumferential and axial direction were registered. Figure 3 shows measurement results. It is seen that the residual stresses on external surface of the journal are compression ones. They are on the level of 90 MPa in circumferential direction and 80 MPa in longitudinal.

The experiment justified the calculation prediction of appearance of compression stresses on the journal external surface. The experimental values appeared to be two time lower than the calculation ones (similar accuracy is typical for calculations in welding), but at that, they make around 30 % of yield strength of the journal material (steel 35L; $\sigma_{0.2}$ = 270 MPa) and, therefore, can be considered as a significant factor, increasing crack resistance in operation. Thus, surfacing of internal surface of the journal can simultaneously repair its wear (from contact with the charging spout) and perform fixing role, increasing journal resistance to operating loads.

It should be noted in the conclusion that the calculation analysis and experimental check of the stressed state, forming in surfacing of the mill journal on internal surface, showed formation of the residual compression stresses, significant on value and creating autofixing effect, which increases the journal resistance effect to crack formation from operating loads.

1. Korotkov, V.A., Zamotin, V.A. (2001) Repair of mine equipment parts. *Gorny Zh.*, **8**, 53–56.
2. Smirnov-Alyaev, G.A. (1940) *Theory of autofastening of cylinders*. Moscow: Oborongiz.
3. (1971) Control of strength of press-fit connections in the presence of residual stresses. *Izv. Vuzov. Mashinostroenie*, **8**, 29–33.
4. Bakshi, O.A. (1953) Strains and stresses at local heating of steel sheet. *Avtogen. Delo*, **2**, 1–6.
5. Talypov, G.P. (1957) *Approximate theory of welding strains and stresses*. Izd-vo LGU.
6. Korotkov, V.A. (1996, 1997) Study of thermal deformations of sleeves at local heating. *Izv. Vuzov. Mashinostroenie*, **10–12**, 90–98; **1–3**, 96–103.
7. Ilyushin, A.A., Ogibalov, P.M. (1960) *Elastic-plastic strains of hollow cylinders*. Moscow: Izd-vo MGU.
8. (1975) *Handbook of welder*. Ed. by V.V. Stepanov. Moscow: Mashinostroenie.

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