Control of Restored Parts of the Automotive Machinery

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Abstract. The restoration of automotive parts is accomplished with a variety of technologies, with the ultimate goal of getting properties close to the original ones. One of such technology is welding recovery. In this activity, the material of the parts is subjected to thermal influences that generate internal stresses. This article shows an internal stress test for crankshaft welding by an internal combustion engine.

Keywords: restoration, automotive technology, internal stresses, deformation.

1. INTRODUCTION

1. 1. Operation of features of the parts

During the period of the vehicles, the increase in the mileage leads to changes in the technical characteristics of the parts and the assemblies in which they participate. These changes are associated with increased wear, corrosion, fatigue of materials, deformation of parts and other transformations. The accumulated changes are continuous and irreversible. In such cases, the need for repair of the machines is dictated by the actual condition of the individual units and their further operation is decided after a precise technical and economic evaluation.

One way to increase the resource of the parts is to restore them. During the restoration, full or incomplete restoration of the technical characteristics of the parts is achieved. Incomplete returns lead to a reduction in the life of the parts compared to the new ones. According to the regulatory documents, the life of the repaired parts must be at least 80 % of the life of the new ones. This percentage also determines the lower limit of the durability of the parts recovered. In some cases, the technical characteristics of the recovered parts are improved over the new ones, without the need for additional costs, as they are determined by the capabilities of the defect repair methods themselves.

The durability of the restored parts is largely determined by the durability of their restored surfaces. In this case, the restoration of worn parts in various ways aims not only to restore the original dimensions, but also to achieve high physico-mechanical properties of the restored work surface and, above all, to achieve high wear resistance.

The most commonly used method of repairing automotive parts is electric arc welding.

Welded automotive parts are known to be made of structural carbon and alloy steel and are heat treated to high hardness, mainly wear and tear under heavy loads, in many cases alternating. During restoration by welding, the parts are subjected to high thermal effects. In doing so, it is important to provide the necessary firmness, strength and durability. The achievement of these parameters is related to the quality of the recovered parts and the efficiency of their further use.

1. 2. Quality of restored parts

The model of researching of the properties of flux coated substrates is shown in Fig. 1 and includes control and evaluation of chemical composition, macro and microhardness, macro and microstructure and internal stresses (Slivarov & Stanev, 2009).

The output parameters of the model shown in Fig. 1 determine the mechanical properties of the coating.

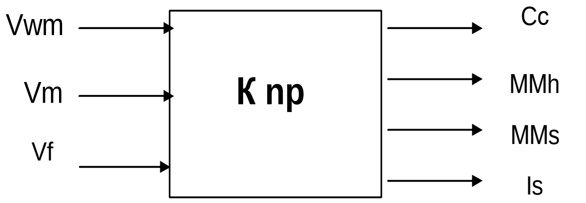

Figure 1. Model of researching of the properties of flux coated substrates. Knp - quality of the welded coating; Vwn - vector of welding mode; Vm is the vector of the material; Vf - flux vector; Cc - chemical composition; MMh - macro and micro hardness; MMs - macro and micro structure; Is - internal stresses

1. 3. Analysis of the problem in the literature

A little studied parameter of the mechanical properties of welded parts is the parameter “Internal stresses” appearing after welding.

The analysis of publications related to the occurrence of internal stresses after welding shows that in order to solve this problem it is necessary to research this parameter in more depth as it affects the strength of the details.

For this purpose, it is necessary to establish regularities of formation and change of internal stresses.

It is known from the literature that tensile stresses significantly reduce the hardness, while the stresses on the surface of machined parts due to mechanical, thermal, thermo-mechanical or thermo-chemical treatments not only increase the hardness and wear resistance of the parts, but and to increase fatigue strength.

The internal stresses in the welded parts according to the type of their formation are due to thermal influence (Tietz, 1982). When welding metals, stresses and deformations are always created in the welded surface, commonly called welding stresses and deformations. These stresses act in the welded body without being exerted by external forces, i.e. the forces and moments caused by the internal tensions are mutually balanced. This gives us the right to list them in the so-called category. own or internal stresses. It follows that due to the static equilibrium in different layers of the workpiece, the internal stresses will have different signs and that there will be a transition without stresses.

The main causes for the formation of the own and therefore the welding stresses are the uneven linear and volumetric deformations of the metal, which can be caused, for example, by uneven heating of different areas of the body; shrinkage after cooling the weld metal; structural changes of the metal in the thermal impact zone of the weld arc; the rigid attachment of the workpiece or the entire article during the welding process.

When welding a worn surface, there are no external forces acting on the workpiece, so there is no linear deformation. Therefore, Hook’s simple law cannot be applied to determine the internal stresses caused by the application of welding to a worn surface of a workpiece.

Internal stresses can be determined by a polarization-optical method for determining stresses, which method requires sophisticated apparatus, highly sensitive devices and complex calculations. The advantage of this method is that the workpiece is not destroyed.

In this study, a “trimming method” is used to determine the intrinsic stresses of a welded piece of automotive equipment.

The method was developed by Rizin et al (Rizin, 1975) for rings and modifies and complements the known Davidenko method for thin-walled tubes. It was applied by Andreas Naydel in studying the dependence of welding on internal stresses in rotationally symmetrical details (Naydel, 1986).

The “trimming method” belongs to the destructive methods. This method quantifies the tangential residual internal stresses of rotating parts. Since this method is destructive, a part of an identical part is used to examine the part, which part is machined in a certain way, welded, and then the specified method for determining internal stresses is applied. Therefore, this method requires the production of sample to be tested for internal stress.

The specimens represent a welded cylindrical body on which the core is removed by turning to produce a ring of specified dimensions. The results obtained for the magnitude of the internal stresses of the loaded sample are compared with the values of the obtained results for the control of the non-loaded sample.

2. OBJECT OF RESEARCH

The object of study was a crankshaft from an bus engine (Fig. 2).

The crankshaft is a very precise detail. The shaft camshaft diameters are made to within 0.005 mm. Its weight is 72 kg. It is made of structural steel.

The depth of the surface-hardened layer ranges from 2.5 to 6.5 mm. The necks are hardened with HDF to a hardness of HRC 52-62.

The difference between the nominal and the last repair size is in the range of 1.5-2 mm, which means that the thickness of the reconstructed layer is up to 3.5 mm, and in some cases it is a little more.

After the repair dimensions are exhausted, the crankshaft becomes practically unusable. The restoration results in nominal sizes of the main and reel necks, which is a prerequisite for maintaining the dynamic and ergonomic characteristics of the transport machines.

A major problem with crankshaft repair is the welding of the main and crankshafts to nominal size after the repair sizes have been used up.

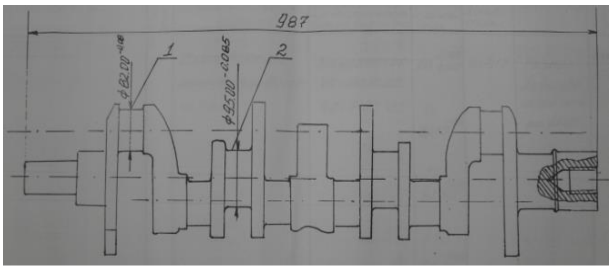

Figure 2 Crankshaft diagram of an bus engine.

This method has been successfully applied in many repair shops, and the technological process requires heat treatment after welding to homogenize the structure and reduce residual stresses.

Knowledge of the internal stresses caused by thermal impact during welding gives information about the characteristics of the welded coating - at what depth from the surface are the stresses and their type (tensile or compressive). According to these characteristics, it is possible to judge the thickness of the welded surface and the thickness of the metal layer, which must be removed upon final machining of the workpiece. Knowledge of the internal stresses of specimens loaded with different modes and materials may indicate which mode and material is more appropriate to apply in reducing the internal stresses.

3. METHODOLOGY

3. 1. Control and evaluation of internal stresses

For the control and evaluation of internal stresses by the method described, a welded sample of a worn crankshaft main shaft from an bus engine was used.

The sample is single-layer welded with a certain mode and material. After welding, each sample is machined to reach a ring of the following dimensions: outer diameter Ring. = 95.00 mm; inside diameter Inside. = 55.00 mm; ring thickness h = 5.00 mm; ring width δ = 20 mm.

For comparison of internal stresses, a non-peculiar sample from the same crankshaft was used.

The defining parameter in controlling the internal stresses of the welded surfaces is the deformation of the sample after each step (step) in the shear cut. The deformation is the change in the outer diameter after each layer of metal is removed during the shear cut. The deformation of the samples and the values of their stresses σ [MPa] are expressed by the depth of the metal taken away from the “a”.

3. 2. Methodology for stress testing

The manufactured ring is cut radially (segment removal) with dimensions: segment length bc = 10.00 mm, segment width δ = 10 mm, i.e. the entire width of the ring. As a consequence, the outer diameter changes ΔD (Fig. 3).

Then, on the diametrically opposite side, a slot with a length b = 10.00 mm and a depth a = 2.00 mm is sanded. This slot is gradually enlarged by a step of 2.00 mm, which changes the ΔD with each removal of metal.

After each step, the change in the outer diameter is measured.

An important condition is that the mechanical treatment of the samples is carried out at ambient temperature or the use of coolant.

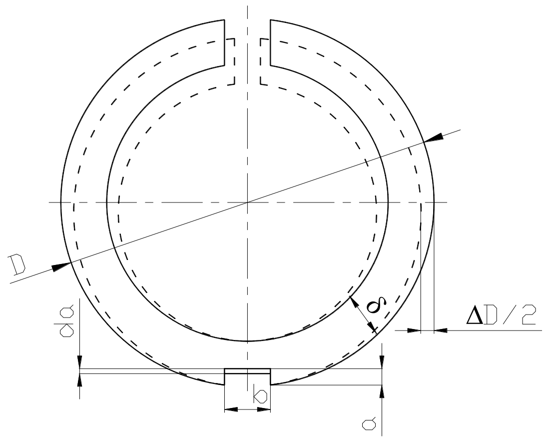

Figure 3 Scheme of the method for determining tangential internal forces:
D-outer diameter of the ring; ΔD/2 - half of the change in the outer diameter; δ - width of the ring; b - slit length; a - depth of slot; da - change of slit depth

The tangential internal stresses are calculated using the methodology developed by Andreas Naydel (Naydel, 1986) represented by formulas (1), (2), (3) and (4).

$$\sigma_t^E(a) = \sigma^{'}(a) + \sigma^{''}(a) + \sigma^{'''}(a) \tag{1}$$

$$\sigma^{'}(a) = \frac{2E\left(\frac{\delta}{2} - a\right)}{d_m^{\;2}} \Delta Ds \tag{2}$$

$$\sigma^{''}(a) = -\frac{E(\delta - a)^2}{3b(d_m - a)} \cdot \frac{d\Delta D}{da} \tag{3}$$

$$\sigma^{'''}(a) = \frac{2E}{3b} \cdot \int_0^a \frac{(2b - 3a + \chi)}{(d_m - \chi)} \frac{d\Delta D}{d\chi} . d\chi \tag{4}$$

where σ_t^E (a) is the total tangential stress, MPa; σ'(a) is the first full cutoff voltage, MPa; σ'' (a) - internal stresses in layer 'a' before its removal, MPa; σ''' (a) - the stress in the layer, as a consequence of the previously removed layers, MPa.

After the experimental determination of the values of the pair (D, a), due to the change in ΔD of the diameter of the ring depending on the thickness “a” taken away, they are approximated by a third degree polynomial.

$$y = Ax^3 + Bx^2 + Cx + D \tag{5}$$

Respectively

$$\Delta D = Aa^3 + Ba^2 + Ca + D \tag{6}$$

Accurate calculation of the location of the tangential stresses across the cross section is achieved by summing σ'(a), σ''(a) and σ'''(a), followed by polynomial division and integration of the equation using the regression coefficients A, B, C (D as an absolute term in the approximation function in the differentiation is eliminated).

The final result of the formula includes the following parameters:

E - linear deformation module, Pa;
δ - ring width, m
δ = (Douter - Dinside) / 2
b - slot length, m
a - depth of slot, m
$a_i = a_i$. i - is the extension number i = 1; 2; 3; 4; 5
dm - average diameter, m
dm = (Douter + Dinside) / 2
ΔD - change in the outer diameter, m
A, B, C, D - regression coefficients.

4. EXPERIMENTAL RESULTS

4. 1. Results for the ring without welding.

For the ring without welding, the diameter change ΔD is insignificant and has the following values corresponding to the depth of the slot a_i (Table 1).

TABLE 1. Values of change of the parameters “a” and “ΔD” for non-sample.

Deepening of slot "a", mm	Changing the outer diameter "ΔD", mm

$a_1 = 2.00$	$\Delta D_1 = + 0.005$
$a_2 = 4.00$	$\Delta D_2 = - 0.002$
$a_3 = 6.00$	$\Delta D_3 = - 0.004$
$a_4 = 8.00$	$\Delta D_4 = - 0.003$

Values of a_i and ΔD are used to determine the regression coefficients A, B, C, D using equation (6). The following matrix is obtained:

$$\begin{aligned}\Delta D_1 &= A.a_1^3 + B.a_1^2 + C.a_1 + D\\ \Delta D_2 &= A.a_2^3 + B.a_2^2 + C.a_2 + D\\ \Delta D_3 &= A.a_3^3 + B.a_3^2 + C.a_3 + D\\ \Delta D_4 &= A.a_4^3 + B.a_4^2 + C.a_4 + D\end{aligned} \tag{7}$$

Substitution with the numerical values for a_i and ΔD is obtained

$$\begin{aligned}+0.000005 &= A.8 + B.4 + C.2 + D.1\\ -0.000002 &= A.64 + B.16 + C.4 + D.1\\ -0.000004 &= A.216 + B.36 + C.6 + D.1\\ -0.000003 &= A.512 + B.64 + C.8 + D.1\end{aligned} \tag{8}$$

The regression coefficients A, B, C, D are determined by the following formulas (9):

$$A = \frac{\Delta A}{\Delta} \quad B = \frac{\Delta B}{\Delta} \quad C = \frac{\Delta C}{\Delta} \quad D = \frac{\Delta D}{\Delta} \tag{9}$$

where

$$\Delta = \begin{vmatrix} 8 & 4 & 2 & 1\\ 64 & 16 & 4 & 1\\ 216 & 36 & 6 & 1\\ 512 & 64 & 8 & 1\end{vmatrix} = 768$$

ΔA = − 3,2E-05;
ΔB = 0,000864;
ΔC = - 0, 00698;
Δ D = 0,000019.

For A, B, C, D we get:

A = - 4,17.10-8
B = 112.5.10-8
C = - 908.10-8
D = 1900. 10-8

For the stresses of the **unladen specimen,** the following values are obtained as a function of the deepening a_i of the slit and the change in the outer diameter ΔD (Table 2):

TABLE 2. Internal stress values σ_t as a function of the parameters “a” and “ΔD” - **for the non-sample**.

Deepening of slot "a", mm	Changing the outer diameter “ΔD”, mm	Internal stresses Values σ_t, MPa
$a_1 = 2.00$	$\Delta D_1 = + 0.005$	3,112968346
$a_2 = 4.00$	$\Delta D_2 = - 0.002$	-0,635308516
$a_3 = 6.00$	$\Delta D_3 = - 0.004$	-0,966108885
$a_4 = 8.00$	$\Delta D_4 = - 0.003$	-0,296850426

4. 2. Results for Welding Ring.

For the loaded ring, the values for a_i and ΔD are given in Table 3.

TABLE 3. Modification values of parameters "a" and "ΔD" for the welded sample

Deepening of slot "a", mm	Changing the outer diameter "ΔD", mm
$a_1 = 2.00$	$\Delta D_1 = + 0.010$
$a_2 = 4.00$	$\Delta D_2 = + 0.245$
$a_3 = 6.00$	$\Delta D_3 = + 0.280$
$a_4 = 8.00$	$\Delta D_4 = + 0.210$

The determination of the regression coefficients A, B, C, D is carried out by equation (6):

$$\begin{aligned}+0.000010 &= A.8 + B.4 + C.2 + D.1\\ +0.000245 &= A.64 + B.16 + C.4 + D.1\\ +0.000280 &= A.216 + B.36 + C.6 + D.1\\ +0.000210 &= A.512 + B.64 + C.8 + D.1\end{aligned}$$
(10)

For Δ it turns out 768, respectively

ΔA = 0,00152;
ΔB = - 0,03744;
ΔC = 0,27232 ;
ΔD = -0,39936

For A, B, C, D is obtained

$A = 197{,}9.10^{-8}$
$B = - 4875.10^{-8}$
$C = 35460.10^{-8}$
$D = -52000.\ 10^{-8}$

For the stresses of **the loaded** sample, the following values are obtained as a function of the deepening a_i of the slot and the change in the outer diameter ΔD (Table 4):

TABLE 4. Internal stress values “σ_t” as a function of the parameters “a” and “ΔD” - **for the welded sample.**

Deepening of slot "a", mm	Changing the outer diameter “ΔD”, mm	Internal stress Values σ_t, MPa

$a_1 = 2.00$	$\Delta D_1 = +0,010$	-4,79716853
$a_2 = 4.00$	$\Delta D_2 = +0,245$	96,01976557
$a_3 = 6.00$	$\Delta D_3 = +0,280$	72,94137629
$a_4 = 8.00$	$\Delta D_4 = +0,210$	24,79807394

Fig. 4 and Fig. 5 show graphically the deformation of the samples and the stresses in the surfaces of the layers.

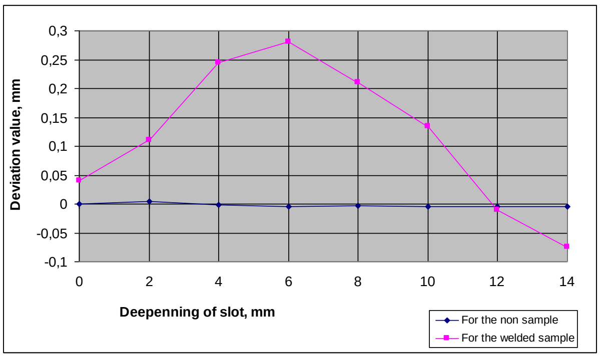

Figure 4. Deformation of the samples after cutting the slit to a depth of 14 mm.

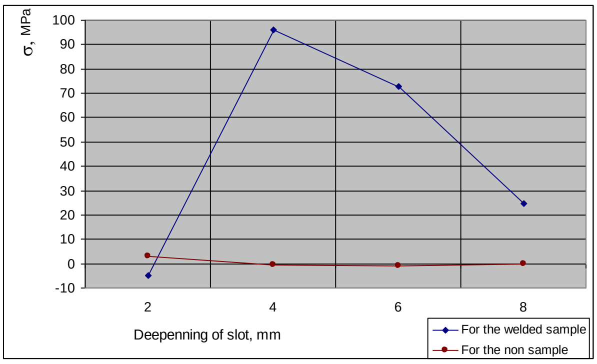

Figure 5 Internal stresses of the samples as a function of the slit deepening.

The deformation of the samples themselves is an indication of the presence of residual internal forces in the workpiece after welding. The unladen sample has a slight deformation after application of the control method and serves as a benchmark.

The loaded specimen has a maximum deformation at a = 6 mm.

After calculating the magnitude of the residual internal stresses, it is observed that the stresses in the loaded specimen are significantly larger than the unstressed ones, with a maximum value of 96 MPa and a positive sign at a = 4 mm.

After deepening of the slit of the loaded sample to a depth of a = 4 mm, the stresses begin to decrease, with the tendency to move to the negative sign. The stresses of the unloaded sample are kept near zero.

5. COMMENTS AND CONCLUSIONS

The comparative experimental studies carried out give the following conclusions:

1. The residual internal stresses of the unloaded sample are close to zero.

2. The residual internal stresses of the loaded sample shall have a positive surface depth value of up to 8 mm.

3. The maximum of the internal stresses of the loaded sample are at a depth of 4 mm, after which the stresses begin to decrease, with a tendency to pass with negative values.

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