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STUDIES AND INVESTIGATIONS REFERRING TO THE ADHERENCE OF THE METALIZED LAYER AT THE GROUND-UNDERGROUND INTERFACE

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Abstract: *The paper presents theoretical and experimental investigations on the shear test performed in order to assess the adherence of the metallic or ceramic layer deposited on a metallic ground, in the case of pulverized metallic coatings. The test consists in applying a compression load along the specimen axis until the deposited layer loses its adherence due to shear stresses (STAS 11684/4-83). The coating regime used when preparing the specimen must be similar to the one used when performing the pulverizing coating of crank shafts. Three channels are machined together with an end of the specimen in order to obtain three ring zones containing deposited material. The test is performed on a class 1 universal tension/compression testing machine (STAS 1510-80).*

Key words: *Adherence, metallic coatings, retrofitting, maintenance, shear test*

1. INTRODUCTION

The wearing of automobile crank shafts has different origins: moral, chemical, mechanical, corrosion, and friction [1, 2]. The controllable wearing phenomena (due to friction, abrasion or corrosion, e.g.) are estimated to cause losses of about 700 billion USD. These losses are supported by numerous companies in the present-day industrial world [2, 4].

Under such circumstances, the 4R requirements consisting in the reuse, repairing and retrofitting combined with modernizing and recycling [1, 4] become more and more stringent everywhere in the world. There are many investigations aiming to avoid the use of recycling procedures with numerous operations and large consumptions in terms of time, energy and materials.

The development of advanced retrofitting procedures allows replacing the traditional methods characterized by numerous and expensive operations with a much shorter retrofitting cycle: "worn part – retrofitted part – reused part".

The "maximum efficiency" alternative of reintegrating in the economic circuit and thus reusing the automobile crank shafts consists in preserving these engine components as spare parts, on which a retrofitting operation is performed in order to give them a reliability comparable to the one of newly manufactured parts. Of course, the retrofitting should be as cheap as possible. As a consequence, the crank shaft maintenance and retrofitting procedures must be efficiently planned in accordance with the industrial organization principles.

2. MICRO-ADHERENCE

Micro-adherence is defined as being equal to the force needed to separate an elementary volume from a substrate interface having a unit area. During the thermal metallization process, the particles forming the spraying jet adhere to a surface. One may thus consider that the integrity of the metalized layer and it behavior in exploitation is the cumulative result of an extremely large number of micro-adherences.

The micro-adherences that exist at the level of a metalized layer can be divided into the following categories [1]:

- Particle – substrate (specific to the metalized layer vs. background interface)
- Particle – particle (specific to the interface particle vs. particle)
- Inclusion – substrate (specific to the metalized layer vs. background interface, in regions where inclusions exist)
- Particle – inclusion (specific to the interface particle vs. inclusion).

The sum of all the micro-adherences associated to the layer vs. background interface determines the macro-adherence of the metalized layer to the background. The micro-adherences associated to the particle vs. particle and particle vs. inclusion determine the cohesion of the metalized layer. In general, the interaction mechanisms and the relative weight of different interfaces determine the macro-adherence of the metalized layer.

Thermal metallization is one of the technological procedures applied to metallic and non-metallic materials that allow the regeneration of the outer surfaces of parts in accordance to given requirements referring to their mechanical strength and wearing resistance. Thermal metallization mainly consists in depositing a material layer on a substrate.

3. STUDY ON THE ADHERENCE OF THE METALIZED LAYER

The adherence of ceramic or metallic layers deposited by pulverizing on a metallic ground is mainly conditioned by mechanical factors and, at a lesser extent, by physical and chemical factors. In general, adherence depends on the following aspects [5]: configuration of the metalized part, manner in which the ground surface has been machined, roughness of the ground surface, nature of the deposited material (elastic modulus and thermal expansion coefficient), overall dimensions of the metalized part, dimensions of the particles resulted from pulverizing the molten material, purity of compressed air after passing through the oil separator, etc. The layer thermally deposited by pulverizing must ensure a good wear resistance, a good resistance against high temperatures, and an increased resistance against corrosion.

The thickness of the deposited layer depends on the destination of the retrofitted part and the depositing method. The thickness of such a layer usually is 0.05 … 10 mm, but it may be larger in special cases [1, 2].

An empirical formula that can be used to estimate the adherence of the layer deposited on cylindrical parts is [5]

$$\tau = \frac{E\alpha(\theta_2 - \theta_1)hK}{\pi d_1}, \quad (1)$$

where:

$\tau -$ shear stress that causes the loss of adherence [daN/cm^2];

$E -$ elastic modulus of the deposited layer [daN/cm^2];

$\alpha -$ thermal expansion coefficient of the deposited layer [1/°C];

$\theta_1 -$ temperature of the pulverized particles before impact [°C];

$\theta_2 -$ temperature of the pulverized particles after solidification [°C];

$h -$ thickness of the deposited layer [cm];

$d_1 -$ diameter of the retrofitted part before coating [cm];

$K -$ adherence coefficient.

In order to increase the adherence, one may pulverize an intermediate layer having a good adherence followed by a second layer having an even improved adherence due to the roughness of the previously deposited layer. The shear test described in STAS 11684/4-83 allows assessing the adherence resistance of material or ceramic layers deposited on a metallic ground.

4. ASSESSING THE ADHERENCE OF PULVERIZED LAYERS BY SHEAR TESTS

4.1 Methodology and specimen configuration

The test consists in applying a compression load along the specimen axis until the deposited layer separates from the metallic ground due to the shear stresses acting on the interface. The configuration of the specimen used in this test corresponds to the specifications of the norm

STAS 11684/4-83 (Fig. 1). The thickness of the deposited layer is recommended to be in the range 2.0 ÷ 2.5 mm [1, 5].

The following requirements are also specified by the norm STAS 11684/4-83:

- Overall tolerances according to the international norm ISO 2768 MK

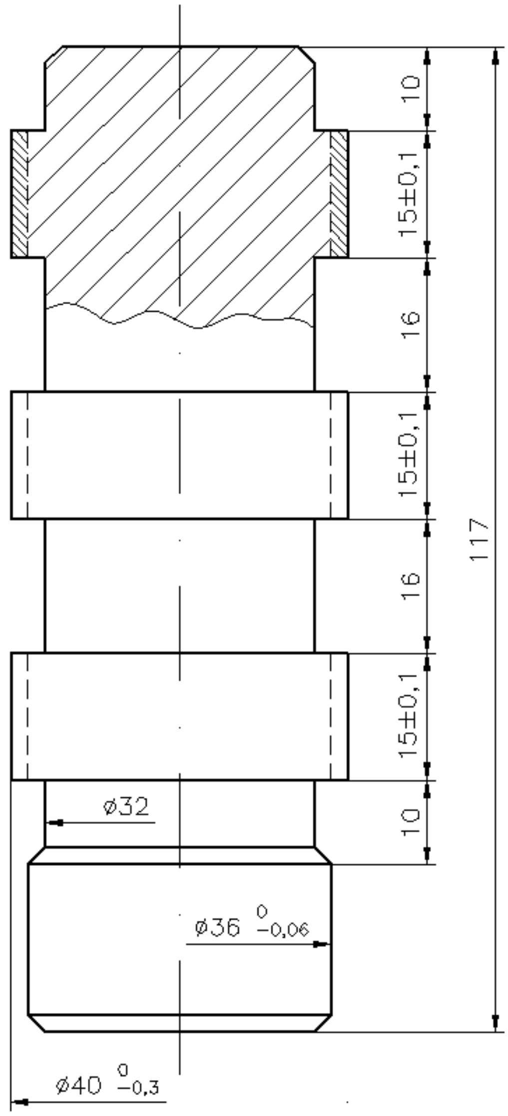

Fig. 1. Geometry of the specimen used in the shear test

- Ground material: S235JR, C45, EN AW 2001
- Diameter of the zones subjected to material deposition: 32 mm
- Metalized zones should be machined by grinding at the diameter: 40 mm.

A tubular support is needed when performing the shear test (see the setup presented in Fig. 2). The shape and dimensions of the tubular support are also specified by STAS 11684/4-83.

4.2 Testing equipment and experimental methodology

The specimen (Fig. 1) together with the tubular support must be placed on the bed of the universal tension/compression testing machine as presented in Fig. 2. The operator should carefully check the perpendicularity of the compression force on the upper surface of the tubular support.

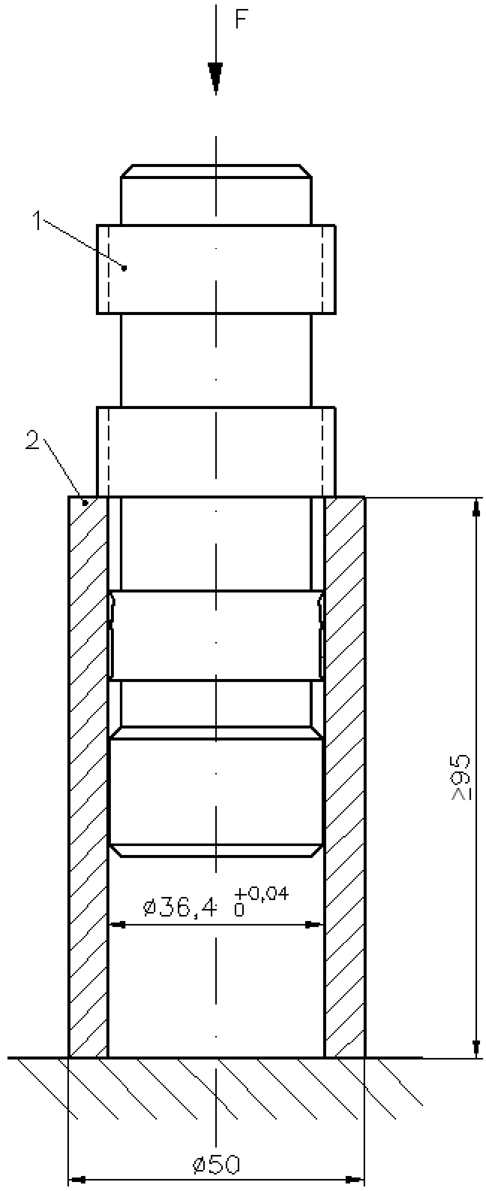

Fig. 2. Experimental setup of the shear test: 1 – specimen, 2 – tubular support (heat treated)

The specimen is loaded with a uniformly increasing axial force until the layer deposited on the lower ring separates from the ground. The value of the axial force corresponding to the moment when the separation occurs is recorded. The loading speed of the specimen should be kept constant at about 8500 N/s.

The specimen must be removed from the testing machine and the layer separated from the first ring must be evacuated from the tubular support. After performing these maneuvers, the compression test may continue in a similar way for the layers deposited on the middle and upper rings, respectively (Fig. 2). The shear test must be performed using at least two specimens except for the cases when other requirements are specified by the technical documentation of the product.

The adherence resistance resulted form the shear test can be computed using the relationship [5]

$$\tau_{ad} = \frac{F_{max}}{S} \quad [\mathrm{N/mm^2}], \tag{2}$$

in which:

$F_{max}-$ maximum value of the compression load applied to the specimen [N];

$S-$ area of the surface subjected to shearing [mm^2].

According to the specifications of the norm STAS 6300-81, the test must be performed at room temperature.

5. EXPERIMENTAL RESEARCH

The adherence of the deposited layers has been assessed using specimens machined from two sorts of unalloyed steel: S235 JR (SR EN 10025-2:2004) and C45 heat treated (SR EN 10083-2:2007). Both specimen types have been coated with Molybdenum and Molybdenum + SpraySteel (Fig. 3). The shear tests have been performed on a universal tension/compression testing machine Zwick/Roell 150.

Figure 4 shows the diagram compression force vs. beam displacement obtained in the case of S235 JR specimens metalized with a Molybdenum layer. The peaks shown in the diagram correspond to the separation of the metalized layers deposited on different ring zones.

The numerical results of the shear tests are listed in Table 1. Specimens 1 and 2 are machined from steel S235 JR, while specimens 3 and 4 are machined from steel C45. Specimens 1 and 3 are metalized with Molybdenum, while specimens 2 and 4 are metalized with Molybdenum + SpraySteel.

Three separation mechanisms can be identified when examining the manner in which the deposited layer has been removed from the background:

- Adhesive separation
- Cohesive separation
- Mixed separation.

Fig. 3. Shear testing of metalized specimens

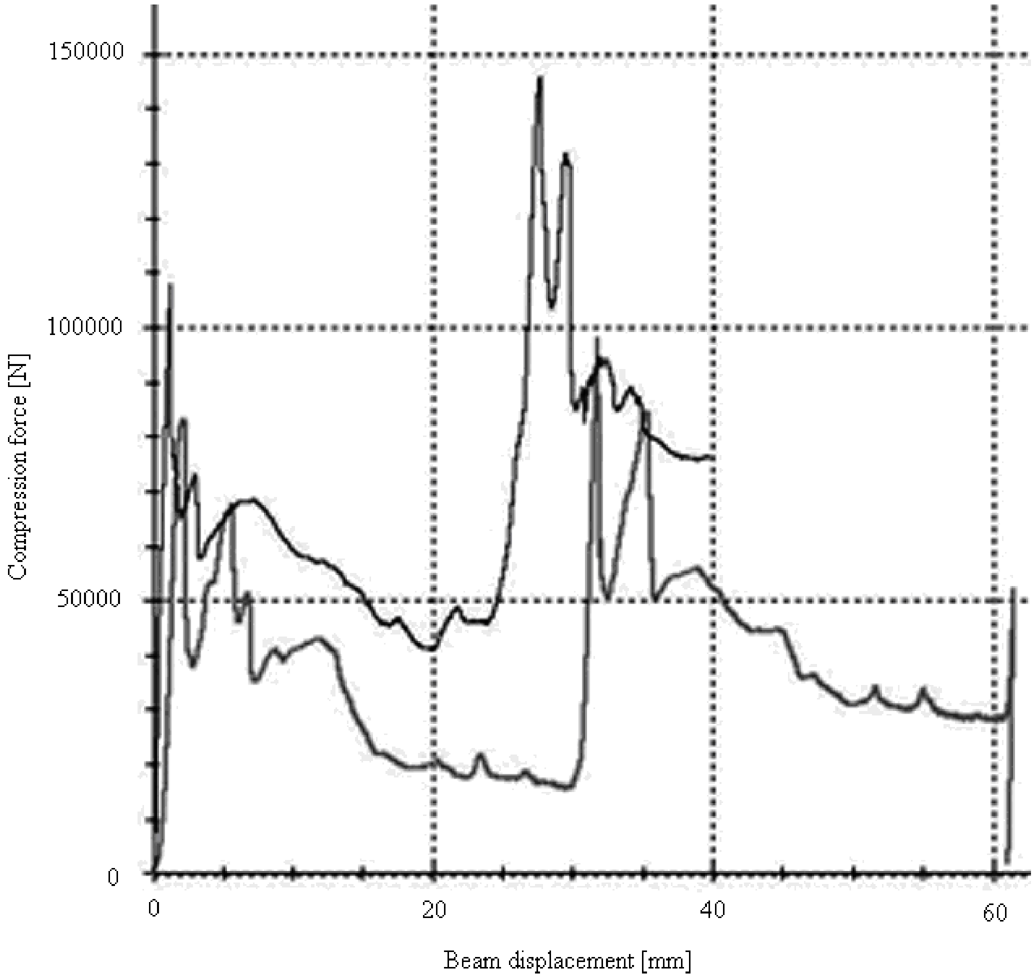

Fig. 4. Diagram compression force vs. beam displacement obtained in the case of S235 JR specimens metalized with a Molybdenum layer

Table 1

Results of the shear tests

Specimen no.	Ring no.	Ring dimensions		Shearing area	Force	τ_{ad}	Average τ_{ad}
		Diameter	Width				
		[mm]	[mm]	[mm^2]	[N]	[N/mm^2]	[N/mm^2]
0	1	2	3	4	5	6	7
1	1.1 1.2 1.3	36	15	1696.46	91000 112000 110000	53.64 66.02 64.85	61.50
2	2.1 2.2 2.3	36	15	1696.46	154000 162000 208000	90.78 95.49 122.61	102.96
3	3.1 3.2. 3.3	36	15	1696.46	112000 175000 169000	66.02 60.12 97.85	74.66
4	4.1 4.2 4.3	36	15	1696.46	232000 194000 220000	135.75 114.36 129.68	126.93

The shear stress τ_{ad} characterizes the adhesive separation at the interface ground-underground. The cohesive separation may occur either at ground or underground levels and can be also characterized by the τ_{ad} parameter. As for the mixed separation, this phenomenon can be localized at the ground or underground levels.

6. CONCLUSION

The analysis of the experimental data listed in Table 1 allows noticing that the multi-layer metallization (specific case of specimens 2 and 4) definitely increases the adherence of the ground to the underground layer. The shear test allows the examination of the specimen surface and the identification of the separation mechanism corresponding to each particular case.

The test consists in applying a compression load along the specimen axis until the deposited layer loses its adherence due to the shear stresses acting on the interface. The shear stress τ_{ad} characterizes the separation at the interface ground-underground.

One may conclude from the experimental investigations performed in this study that metallization is an efficient retrofitting procedure both from the technical end economic points of view. In the specific case of automobile crank shafts, metallization allows the life prolongation of worn parts with a minimum increase of expenditures and processing time.

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STUDII ŞI CERCETĂRI PRIVIND REZISTENŢA LA ADERENŢĂ A STRATULUI METLIZAT LA INTERFAŢA STRAT – SUBSTRAT

Lucrarea prezintă cercetări teoretice şi experimentale pentru executarea încercării la forfecare, în vederea determinării rezistenţei la aderenţă a materialului (metalic sau ceramic) depus pe un substart metalic, în cazul acoperirilor termice prin pulverizare. Încercarea constă în aplicarea pe axa longitudinală a epruvetei a unei sarcini de compresiune până la desprinderea prin forfecare a stratului de material depus (conform STAS 11684/4 - 83). Condiţiile de acoperire trebuie să fie identice cu cele pentru acoperirea termică prin pulverizare a arborilor cotiţi. Se execută trei canale şi se prelucrează un capăt pentru a obţine trei suprafeţe inelare de metal depus. Încercarea se execută pe o maşină universală de încercări la tracţiune/compresiune având clasa de precizie 1, conform STAS 1510-80.

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