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NON-DESTRUCTIVE TESTING OF JOINTS OF ANTIFRICTION PARTS CRIMPED BY PULSED MAGNETICDEFORMATION

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Abstract: Possibilities of non-destructive testing (NDT) methods to assess the quality of permanent joints of powder metal parts were evaluated. Antifriction bushing-bushing couples used in transport braking systems were investigated. The parts made of bronze graphite were crimped by pulsed magnetic deformation by means of electromagnetic equipment with a maximum discharge energy of 30 kJ. The gap between joint parts in the couples was assessed by ultrasonic and radiographic methods. A standard ultrasonic flaw detector Krautkramer USM-25 with an Olympus 4MHzdual-element echo transducer and an industrial x-ray apparatus YXLON EVO 200D were used, correspondingly. In first trial, both methods were equally sensitive to tight and weak connection of joints, however, further studies are necessary to find quantitative estimations of the mechanical integrity. If not limited by the object size, the ultrasonic method is easier in application and can be standardized for use in production lines.

Keywords: powder metal joints, ultrasonic testing, radiography, electromagnetic crimping

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Introduction

Antifriction parts made of powder metal for use in transport can be joints composed of two or more bushings. To obtain permanent joints of powder metal parts, different technological methods are widely used in mechanical engineering, including axle pressing, radial crimping, welding, soldering, and etc. [1].The connection of the powder metal parts can be carried out both in the solid phase and liquid-phase sintering. For parts with a low density, the diffusion soldering method can be effectively used. Parts with a higher density and minimum porosity are usually treated as fully dense deformable materials and connected by means of arc, gas, electron beam and laser welding.

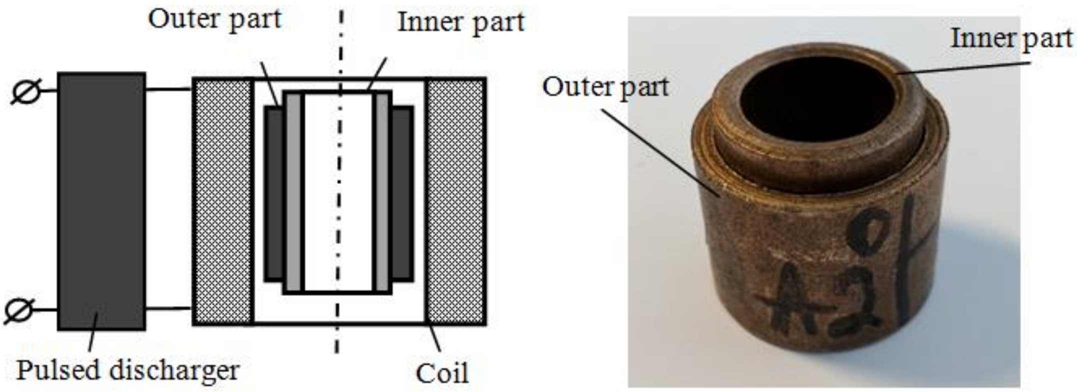
To connect tubular and ring parts with a small residual porosity on the basis of copper and iron-copper alloys, the most effective methods are radial crimping using isostatic, hydro-mechanical or pulsed magnetic deformation. The method of pulsed magnetic deformation (PMD) realized by a pulsed electromagnetic equipment is the most expedient for use with parts with a sufficiently high electrical conductivity, based on copper and aluminum [2].

Non-destructive testing (NDT) of bonds between metal-metal, metal-polymer and composite-composite parts is an established field of industrial research and practice [3, 4].Ultrasonic testing embraces a variety modalities, including through-transmission, pulse-echo, phased array, linear and non-linear spectroscopy and other techniques, sensitive to diverse defects of connectivity and inclusions. The most developed, commercialized and standardized inspection techniques relate to welding, including ultrasonic testing, eddy current and radiography [5].

Joints obtained by PMD crimping are not such solid as welding since is not dealt with mutual penetration of surface layers of joint parts. Besides, specific structure of powder metal material of antifriction parts, particularly such compounds as bronze graphite, causes high attenuation of high frequency ultrasonic waves. It causes difficulties in application of standardized NDT approaches. The purpose of work was to test the sensitivity of ultrasonic and radiographic methods for discrimination of tight and weak PMD crimping using standard NDT techniques with its necessary adjustment.

Materials and methods

The testing objects were joints of antifriction bushings for transport. Bushing pairs joined by PMD are shown in Figure 1. The antifriction bushings were produced of bronze graphite powder by a typical process of powder metal sintering, where copper was the basic material and tin and graphite contents were approximately 9 and 3%. The sizes of outer and inner bushings were: length 30 and 36 mm, outer diameter 32 and 28.5 mm, wall thickness 3.5 mm. The PMD crimping was realized by means of a spiral inductor with height 90 mm and diameter 80 mm connected to a pulsed current discharger. The pairs were placed in the axial zone of inductor as shown in Figure 1. The magnitudes of the magnetic and electric components of the applied electromagnetic field in the inductor's axis reached 835 A/m and 17960 V/m. The reproducibility of the operating modes of the generator was not worse than 0.5%. The samples were subjected to an electromagnetic field with a ratio and mutual orientation of the magnetic and electrical components characteristic to the "near zone" formed at distances much smaller than the wavelength of the electromagnetic field.



a) b)

Fig. 1. Principle schematic of PMD crimping a) and bushing-bushing joint view obtained by PMD b).

Ultrasonic testing was conducted in accordance to the standards of LVS EN ISO 16810: 2014 Non-destructive testing - Ultrasonic testing - Transmission technique (ISO 16823: 2012) and LVS EN ISO 16811: 2014 Non-destructive testing - Ultrasonic testing - Sensitivity and range setting (ISO 16811: 2012) [6]. Pulse-echo method was carried out using a standard ultrasonic flaw meter USM 25 of Krautkramer GE Inspection Technologies GmbH (Figure 2A). USM 25 is designed to detect defects, such as discontinuity and non-uniformity of materials, in semi-finished products, finished products and welded joints, to measure the depth and coordinates of their occurrence, thickness measurement. It allows measurements in a broad frequency range from 0.5 to 20 MHz in materials ranging by ultrasound velocity from 1 to 15 km/s with broad ranges of calibration by depth and attenuation in the material. The dual-element transducer Olympus 01JJ4L at a working frequency of 4 MHz was selected taking into account the specificity of the bronze graphite material, its porosity, and with that the large attenuation of the signal. The split sensor scheme allowed minimization of the blind zone and the noise reduction. Before trials, the system was calibrated for measuring wall thickness in a bronze graphite bushing using a separate sample bushing.

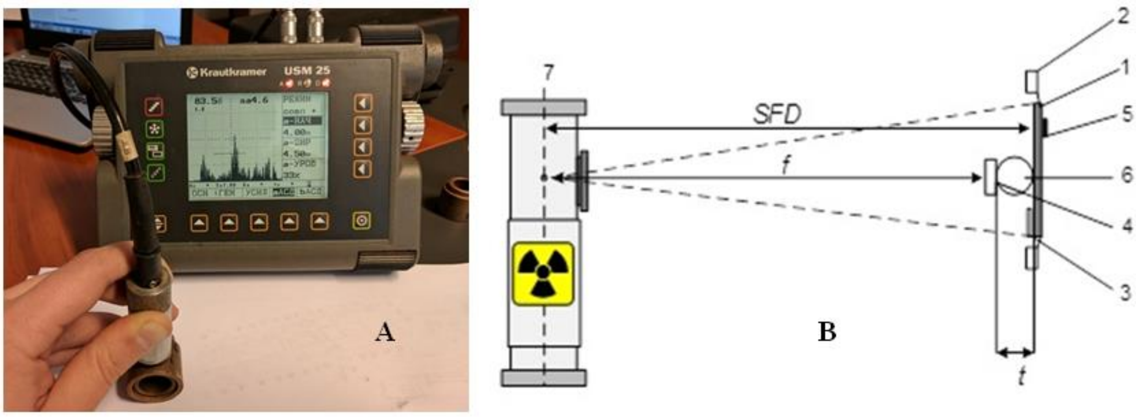


Fig. 2. Ultrasonic(A) and radiographic (B) testing of bushing-bushing joint: 1 – lead shield; 2 - film; 3 and 4 – marks of object and reference point; 5 – indicator of back radiation; 6 – object; 7–x-ray source; f – distance between source and object; SFD – source-film distance; t – object thickness.

For radiographic testing, a mobile industrial X-ray apparatus SMART EVO 200D of YXLON was chosen. The apparatus has a focal spot of 1.0 mm and a radiation power with a constant potential of 750 W, providing high performance, short exposure time and high resolution. The principal diagram of testing is shown in Figure 2B.The testing procedure was done according to the standards LVS EN ISO 17636-1:2013Non-destructive testing of welds: Radiographic testing [7].The translucence regime was set experimentally using a sample of bushing-bushing joint. The adjustment was carried out by consequent irradiating sides of larger thicknesses moving subsequently to smaller ones. The initial regime was calculated for the monolithic structure of the bronze graphite material. Four control exposures were performed with a decrease in the time interval. Due to this, a regularity was found between the coefficient of image darkening and the exposure time, which differed from 4 to 6 times depending on the irradiated thickness.

After nondestructive testing, the bushings were cut transverse to the axis in order to make microscopic observation of the boundary areas between inner and outer parts. Samples of a tighter and a less tight crimping resulting in differences of optically visible gaps between the inner and outer bushings varying from zero to several tens of micron are shown in Figure 3. In the case of tight crimping, adhesion between parts occurs at the level of mutual microcrystalline penetration that provides the mechanical integrity.

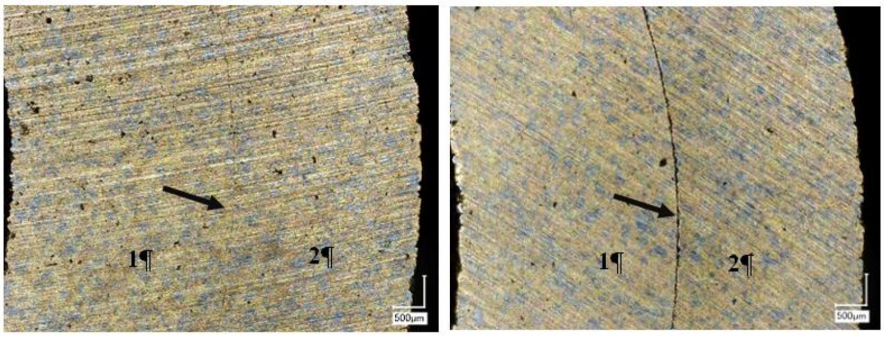


Fig. 3. Samples of joints fragments showing tight (left) and weak (right) PMD crimping: 1 – inner bushing; 2 – outer bushing; arrows show boundary between inner and outer parts.

Results and discussion

Ultrasonic testing. Bottom reflections impulse echo signals were compared. Sample echograms are shown in Figure 4. In the case of proper adhesion between joint parts, ultrasonic wave had an opportunity to pass unhindered through the boundary between outer and inner parts and reflect from the inner wall surface. Thus, the echo response had a delay corresponding to double wall thickness in both directions. In the case of weak crimping, the air gap between outer and inner parts prevented through propagation and the echo response had a twice shorter delay due to the full reflection from the wall surface of the outer part.

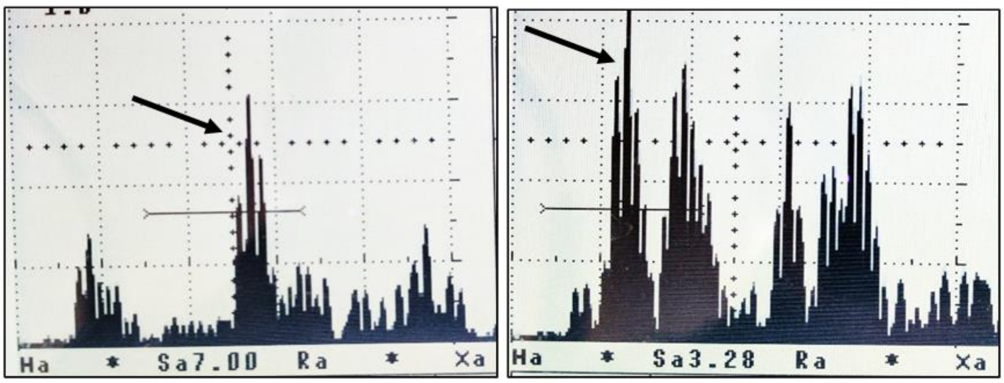


Fig. 4. Samples of ultrasonic echograms showing cases of tight (left) and weak (right) PMD crimping. Arrows show reflections corresponding to 7.00 and 3.28 mm thicknesses in these cases, i.e. from double and single walls.

Meanwhile, due to high attenuation of ultrasound in powder metal bronze graphite, a certain disturbance of continuity and a longer propagation path, echo signals in the proper joint are much more attenuated comparing with the weak joint. The dissipation of ultrasound in the bronze graphite material caused also broadening and more irregular form of the reflection peaks that are typically observed in cast metal products.

The average measurement error in tested samples was 0.14 mm that is an indicator of the highly acceptable measurement accuracy. Thus, ultrasonic testing testify principal applicability to NDT of permanent joints obtained by PMD crimping meeting the ISO standards for ultrasound control. However, the method is limited to testing parts, where the surface curvature allowed positioning of flat transducers. The examined bushings were at the margin of this condition.

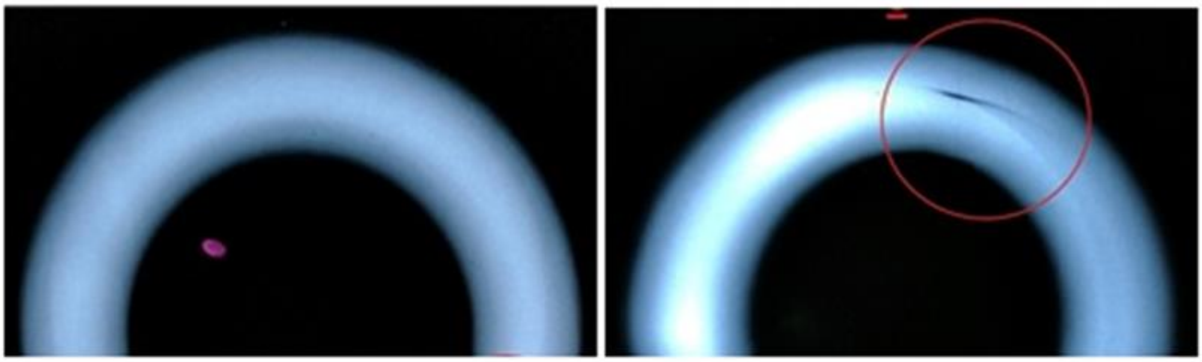


Fig. 5. Samples of X-ray films showing cases of tight (left) and weak (right) PMD crimping for bushing-bushing joints. Circle shows the area of improper connection. Images obtained from the end face of bushing.

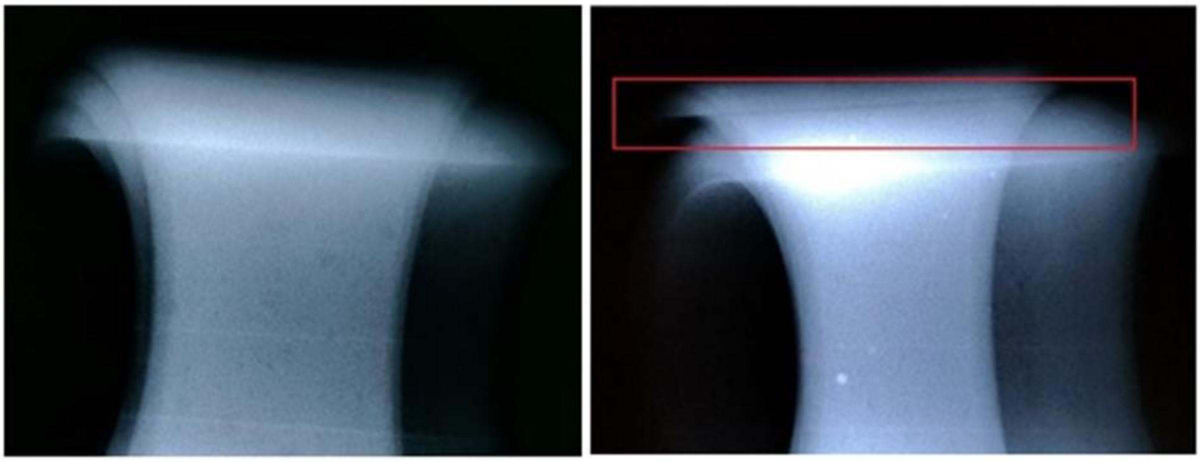


Figure 6. The same as in Figure 5, axial view. Images obtained at an angle approximately 30^0. Rectangle shows the gap of improper crimping.

Radiographic testing. Testing results were analyzed by visual observation of X-ray films after standard chemical processing. To make results comparable, an approximate dependence between the amount of gamma radiation for the same metal in a monolithic structure and in a powder one was found. A formula for the timing of exposure depending on the powder thickness in the examined part was a calculated. The optical density of films varied in the range from 2.3 to 3.5.

The films allowed revealing of connection defects in parts of both types. Both circumferential and axial views of the gaps between outer and inner parts were obtained. Figures 5 and 6 comparatively demonstrate tight and weak connections in bushing-bushing joints from the end face and side. To obtain side views with better highlighting of gaps between bushes, the pictures were taken at the angle approximately 30^0.

Comparison of methods. In the first trials, both NDT methods showed equal sensitivity in discriminating tight and weak crimping of powder metal parts produced by PMD. The difference between ultrasonic and radiographic methods stemmed from their physical principles, where ultrasound revealed a mechanical discontinuity preventing propagation of the elastic wave and X-rays sensed the presence of a void in the material between the parts. Regarding the prospective industrial application, ultrasound has advantages of more simple and low cost hardware, fast operation and quick data interpretation. The advantages of radiographic method are noncontact testing and imaging. Disadvantages of films processing can be overcome by use of digital radiography. Further studies are necessary to estimate resolution limits of the both methods and explore possibilities of quantitative evaluation of the mechanical integrity of joints.

Conclusion

The first attempt to assess non-destructively connection quality of antifriction powder metal bushings joined by pulsed magnetic deformation (PMD) showed sensitivity of both ultrasonic and radiographic methods in discriminating the conditions of tight and weak crimping. Complications of application the standard ultrasonic testing to bushing-bushing joints were caused by a higher attenuation of ultrasound in bronze graphite powder compound comparing to cast metal. Crimping by means of PMD produced a tight connection conducting ultrasound without disturbance and generating no echo response at 4 MHz. Areas of weak connection were revealed as early ultrasonic echoes coming from the wall of outer part and visible gaps in X-ray films. Both methods have a perspective for the industrial implementation in quality assurance of PMD crimping of powder metal parts.

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