

Evaluation of the Effectiveness of High-Density Couplants in Ultrasonic Tests

Abstract: The article presents the analysis of the effectiveness of acoustic feedback required in ultrasonic contact tests. The analysis included high-density couplants, the use of which aimed to provide the most effective transfer of the beam of ultrasonic waves from the probe to an element subjected to an ultrasonic test. The tests involved the use of standard specimens nos. 1 and 2 and special steel specimens having various test surfaces. The tests were performed using a normal probe emitting longitudinal waves and an angle probe emitting shear waves.

Keywords: ultrasonic testing, coupling agents, ultrasonic waves, acoustic properties of materials, transfer losses

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Introduction

Ultrasonic tests of materials and welded joints belong to the group of most popular non-destructive tests (NDT). Ultrasonic tests are commonly used when assessing the quality of structural materials and various (usually welded) products. The tests enable the complex quantitative assessment of materials, providing both the complete identification and location of indications as well as the qualitative assessment of objects subjected to tests [1]. Numerous advantages of the above-named testing method have led to an increased number of applications both of the basic variant of the UT method, i.e. the echo technique, and new variants including TOFD or the Phased Array technique. Apart from numerous advantages, the use of ultrasonic tests also faces certain difficulties resulting from the very nature of physical phenomena. The aforesaid problems include phenomena connected with the transfer of ultrasonic

waves from the probe transducer (where waves are generated) to a material subjected to tests. Even a small gap of air between the surface of the ultrasonic probe and the surface subjected to tests generates resistance impeding the passage of ultrasonic waves. The elimination of the above-named undesired phenomenon requires the use of coupling agents (couplants) characterised by various properties aimed to provide the most effective transfer of an ultrasonic wave from the probe transducer to an element being tested.

The subject of the study was the analysis of results of test performed to verify the effectiveness and applicability of various couplants in ultrasonic tests. The tests were performed using a straight probe of longitudinal waves and an angle probe of shear waves and involved steel materials having various surfaces. The analysis of the test results should provide important information enabling the proper performance of

ultrasonic tests of structural elements in various test conditions. Because of the extensive range of the tests, the study presents results concerning materials characterised by high density. The remaining results related to materials characterised by lower density will be presented in a subsequent article.

Damping phenomenon and determination of transfer losses

Damping is a phenomenon reducing the energy of ultrasonic waves entering a material being tested, at the same time impeding the testing of the material itself. The phenomenon includes two primary constituent “sub-phenomena” [2, 3]:

- scattering of a wave on two surfaces, i.e. a test surface and a surface opposite to the test surface,
- absorption of the energy of a passing ultrasonic wave and the transformation of vibration energy into heat (as a result of internal friction).

The primary factors affecting the size of damping are the following:

- material manufacturing technology (rolling, forging, casting, welding),
- type of a material being tested and its structure (grain size),
- type of quality of a heat treatment,
- direction of the structure of a material being tested (anisotropy).

The primary factor decisive for damping is the scattering of the wave, constituting approximately 90% of all damping-related losses. Other damping factors include resistance encountered by the ultrasonic wave when passing from the ultrasonic probe to a material being tested; the above-named resistance being referred to as acoustic feedback. The quality of acoustic feedback is affected by the type of a coupling agent (couplant) and its adhesability both to the ultrasonic probe surface and the surface subjected to tests. For this reason, to avoid the effect of the above-named phenomenon on testing

sensitivity, when performing ultrasonic tests it is necessary to determine allowance for transfer losses as the difference of echo amplitude identified in relation to the standard specimen and a material subjected to tests. Allowance for transfer losses includes both losses related to acoustic feedback on the surface of contact (not depending on the length of a wave path) and losses related to the damping of a material (depending on the length of a wave path). The above-named allowance for transfer losses can be determined using two methods [2, 3, 8]:

- constant path length technique, where losses of acoustic energy triggered by damping are low in comparison with coupling losses),
- comparative technique, where the complete compensation of both components, i.e. coupling-related losses and material damping-related losses, is performed.

In the tests performed to assess the effectiveness of acoustic feedback, the determination of transfer losses was performed using the constant path length technique.

Test rig

The tests performed to assess the effectiveness of acoustic feedback in ultrasonic tests involved the use of a test rig composed of the following elements:

- ultrasonic defectoscope,
- ultrasonic probes of longitudinal and shear waves,
- conduits connecting the defectoscope with the probes,
- universal standard specimens numbered 1 and 2,
- test specimens examined by ultrasonic probes of longitudinal and shear waves,
- media coupling the probe with a test element.

Ultrasonic defectoscope

The tests involved the use of an EPOCH 600 versatile digital ultrasonic defectoscope (OLYMPUS) (see Fig 1).



Fig. 1. Digital defectoscope EPOCH 600 used in the research

Ultrasonic probes

The tests assessing the effectiveness of acoustic feedback were performed using two ultrasonic probes:

- straight double longitudinal wave probe DL4R-6X20 (OLYMPUS),
- slant single shear wave probe AM4R-8X9-70 (OLYMPUS).

The heads used in the tests are presented in Figure 2a and b.

Conduits connecting the defectoscope and the probes

The tests involved the use of single or double standard conduits connecting the probes and the defectoscope (depending on the type of a probe used in a test). In each case, the effectiveness of signal transfer was tested in relation to each series of tests performed on specimens.

Universal standard specimens no. 1 and 2

The tests involved the use of universal standard specimens no. 1 and 2. The standard specimens were used to check the defectoscope and the probes, i.e. the complete equipment, for the satisfaction of the requirements specified in the PN-EN 12668-3 standard [6]. In addition, both standard specimens were used to determine initial conditions of tests performed using a related ultrasonic probe.

Specimens for tests performed using the probe of longitudinal and shear waves

The performance of tests concerning the effectiveness of the acoustic feedback of the welding head with the test object required the development of special two types of specimens made of one steel grade s355. Specimens of the first type made as flat cuboids (length × width × thickness: 100×50×25 mm) were used in the tests performed by means of the longitudinal wave probe. The above-named specimens were made in three variants characterised by various types of test surfaces:

- surface subjected to grinding performed using a flat-surface grinder,
- surface subjected to fine shot blasting,
- raw surface after rolling, having a thin film of scale.

The test specimen surfaces satisfied requirements in terms of adjustment to the probe surface to a significantly greater extent than the one required by the PN-EN ISO 17640:2011 standard [5]. The opposite surface, parallel to testing, i.e. the reflecting surface, was ground using a flat-surface grinder. Regardless of their test surfaces, all of the flat specimens had the above-named opposite surface to avoid ultrasonic wave beam scattering [3, 4]. The three types of the flat specimens used in the tests performed using the longitudinal wave probe are presented in Figure 3a, b and c.

The second group of specimens, made of steel s355, were semi-cylindrical specimens having radius R 25 mm and a thickness of 30 mm. The semi-cylindrical specimens were subjected to tests performed using the angle probe

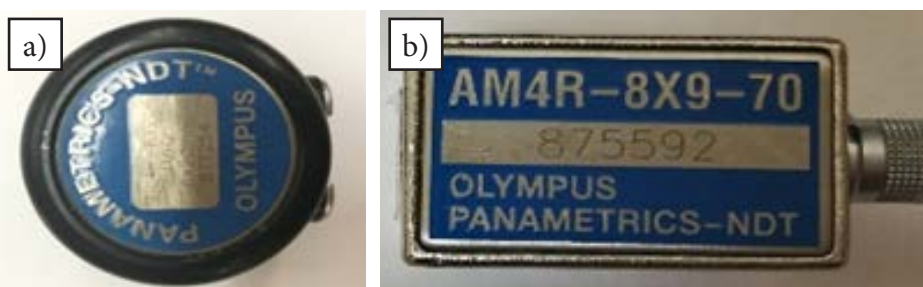


Fig. 2. Ultrasonic probes: a) straight double longitudinal wave probe DL4R-6x20; b) slant single shear wave probe AM4R-8X9-70

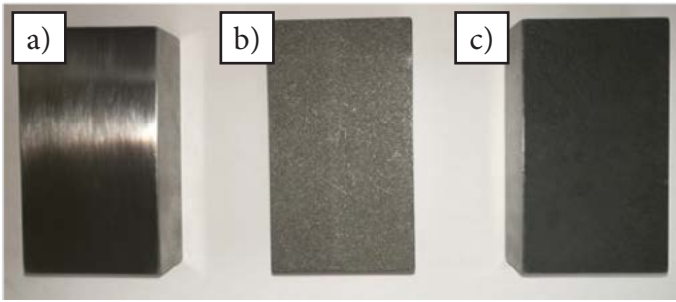


Fig. 3. Flat specimens used in longitudinal wave probe testing on: a) ground; b) shot-blasted and c) raw surface after rolling [7]

of shear waves. The above-named specimens were also made in three variants having various test surfaces:

- surface subjected to grinding performed using a flat-surface grinder,
- surface subjected to fine shot blasting,
- raw surface after rolling, having a thin film of scale.

The semi-cylindrical surface having radius R 25 mm, opposite to the test surface, i.e. the reflecting surface, was ground using a grinder for rollers. All of the specimens, regardless of types of test surfaces were prepared in the above-named manner. The three types of the semi-cylindrical specimens subjected to tests performed using the angle probe of shear waves are presented in Figure 4a, b and c.

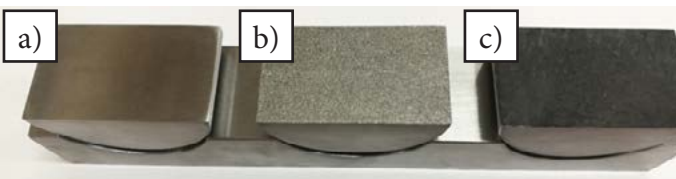


Fig. 4. Semi-cylindrical specimens for shear wave probe testing on: a) ground; b) shot-blasted and c) raw surface after rolling [7]

Test couplants

The assessment of the effectiveness of acoustic feedback in ultrasonic tests involved the selection of a number of materials, including those characterised by high density, such as a UT coupling agent in the form of gel (MR 750), lubricant (LITEN ŁT-43), silicon lubricant (LEDA), copper lubricant (LEDA) and natural bee honey as well as materials characterised by lower density including engine oil (Castrol C3),

washing-up liquid (Tymek jesień), wallpaper paste (Specjal), glycerine and water. Because of the extensive range of the tests, the study presents results concerning the materials characterised by high density. The remaining results related to the materials characterised by lower density will be presented in a subsequent article.

Assessment of high-density coupling agents

The tests of high-density couplants were performed using specimens having various surfaces. The tests involved the application of coupling agents on feedback surfaces and the verification of a signal level (by performing repeated tests with the probe placed on the surface). The tests involved the recording of the amplitude of the first and second echo. The above-named tests were preceded by the calibration of the system. The calibration of the straight probe was performed using standard specimen no. 1 (having a thickness of 25 mm) and the UT MR 750 coupling agent. The observation range applied in the tests involving the use of the straight probe amounted to 50 mm. The application of the above-named range enabled the observation of two reflected echoes, the first of which was adjusted to the entire height of the defectoscope screen. In turn, the calibration of the angle probe was performed using standard specimen no. 2 and the same coupling agent. The observation range applied in the tests involving the use of the angle probe amounted to 100 mm. The application of the above-named range enabled the observation of two reflected echoes, the first of which was present at a distance of 25 mm and was adjusted to the entire height of the defectoscope screen. In turn, the second echo was present at a distance of 100 mm in relation to standard specimen no. 2 or at a distance of 75 mm (from the beginning of the system) in relation to semi-cylindrical specimens R25. The test were performed under constant conditions of the environment, at a temperature of 21°C.

Gel UT MR 750

The gel is blue, not fat, characterised by the lack of smell and high density. After the repeated placing of the probe on the test surface, the gel does not lose its properties. The lubricant does not contaminate surfaces and is easy to remove. In addition, the gel remains stable on various types of surfaces (ground, shot-blasted and raw). Figure 5a presents the test surface directly after the application of the gel, whereas Figure 6b presents the test surface (partly covered by the gel) after the repeated placing of the probe.

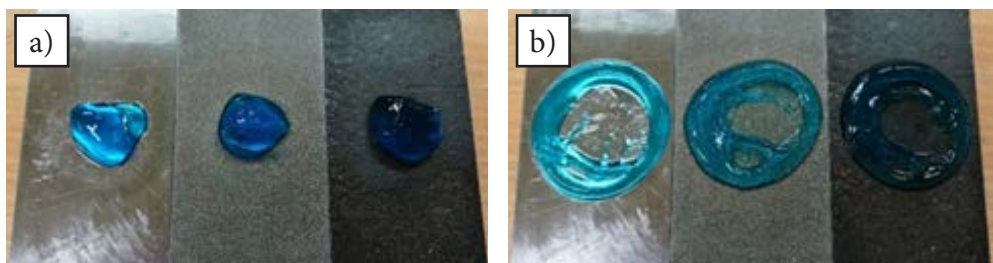


Fig. 5. Portions of the MR 750 gel on various surfaces: a) immediately after application; b) after the repeated placing of the probe

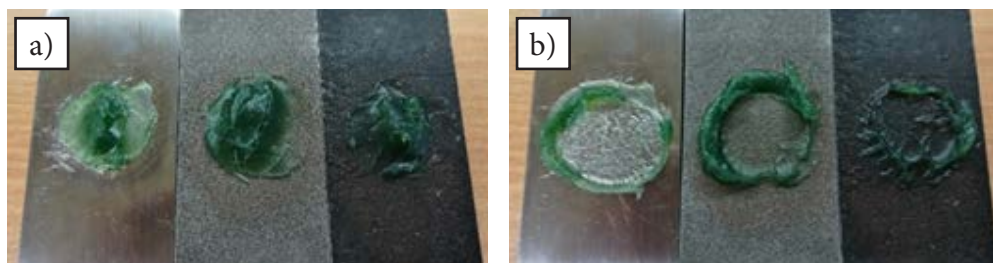


Fig. 6. Portions of the LITEN LT-43 lubricant on various surfaces: a) immediately after application; b) after the repeated placing of the probe

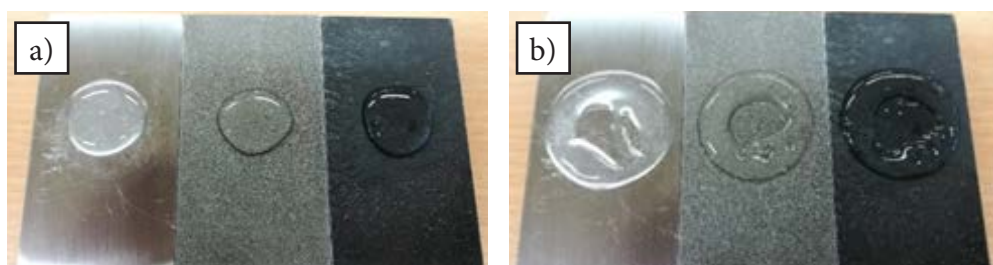


Fig. 7. Portions of the LEDA silicon lubricant on various surfaces: a) immediately after application; b) after the repeated placing of the probe

Lubricant LITEN LT-43

The LITEN LT-43 lubricant is dark-green and fat, characterised by an intense smell and high density. After the repeated placing of the probe on the test surface, the lubricant does not lose its properties. The lubricant easily contaminates surfaces, is difficult to remove and leaves fat stains. In addition, it remains stable on various types of surfaces (ground, shot-blasted and raw). Figure 6a presents the test surface directly after the application of the lubricant, whereas Figure 6b presents the test surface (partly covered by the lubricant) after the repeated placing of the probe.

Silicon lubricant LEDA

The LEDA silicon lubricant is milk-white and fat, characterised by the lack of smell and high density. After the repeated placing of the probe on the test surface, the lubricant gradually loses its properties. The silicon lubricant easily

contaminates surfaces, is difficult to remove and leaves fat stains. In addition, it is rather unstable on various types of surfaces (ground, shot-blasted and raw). Figure 7a presents the test surface directly after the application of the lubricant, whereas Figure 7b presents the test surface (partly covered by the lubricant) after the repeated placing of the probe.

Copper lubricant LEDA

The LEDA copper lubricant is red and fat, characterised by the lack of smell and high density. After the repeated placing of the probe on the test surface, the lubricant gradually loses its properties. The copper lubricant easily contaminates surfaces, is difficult to remove and leaves fat stains. In addition, it is relatively stable on various types of surfaces (ground, shot-blasted and raw). Figure 8a presents the test surface directly after the application of the lubricant, whereas Figure 8b presents the test surface

(partly covered by the lubricant) after the repeated placing of the probe.

Natural bee honey

Natural bee honey is usually dark-brown and fat, characterised by an intense smell and high density in the liquid state. After the repeated placing of the probe on the test surface, honey does not lose its properties. Honey easily contaminates surfaces, is difficult to remove and leaves fat stains. In addition, honey is very stable on various types of surfaces (ground, shot-blasted and raw). Figure 9a presents the test surface directly after the application of the coupling agent (honey), whereas Figure 9b presents the test surface (partly covered by honey) after the repeated placing of the probe.

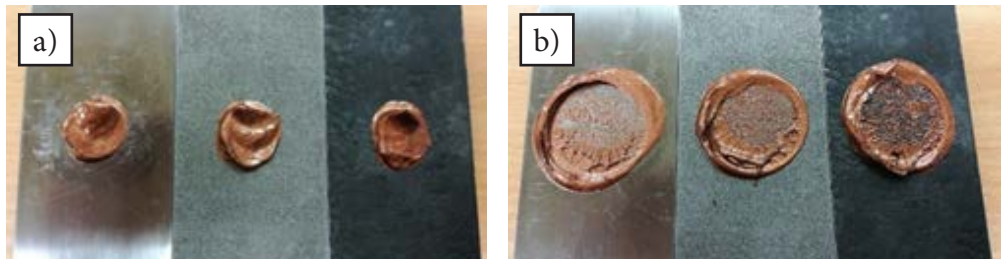


Fig. 8. Portions of the LEDA copper lubricant on various surfaces: a) immediately after application; b) after the repeated placing of the probe

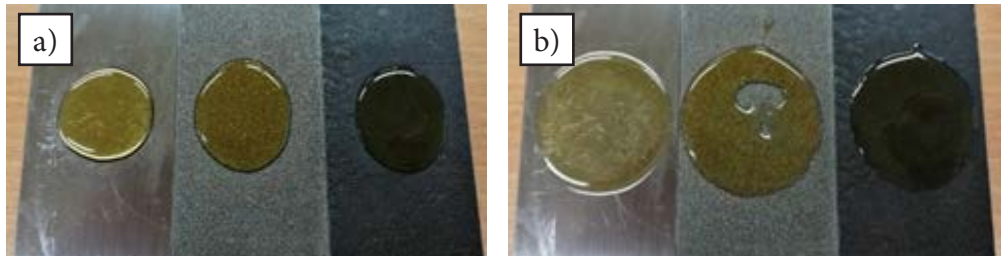


Fig. 9. Portions of natural bee honey on various surfaces: a) immediately after application; b) after the repeated placing of the probe

Test results concerning the effectiveness of high-density coupling agents

Table 1 presents test results related to the amplitude of the first and the second echo obtained in relation to standard specimen no. 1 and

steel specimens having various surfaces (ground, shot-blasted and raw), performed using the straight probe of longitudinal waves. The above-named results were recorded in relation to acoustic feedback and various high-density couplants. The results were presented in percentage assuming that the basis was constituted by the measurement performed using the straight probe, standard specimen no. 1 and the coupling agent

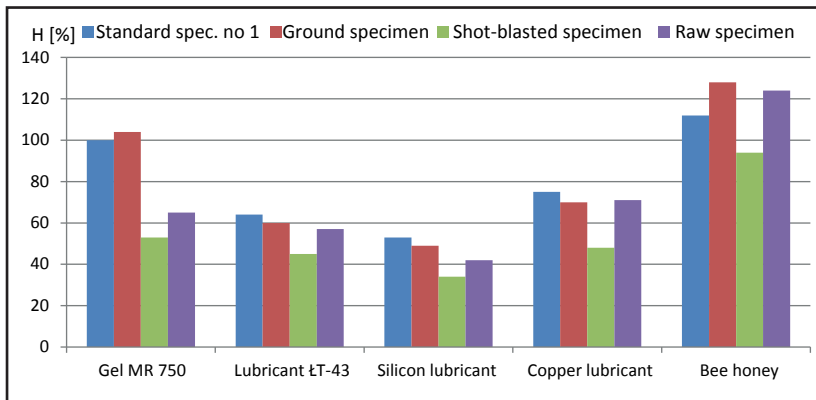


Fig. 10. Comparison of the amplitudes of echo I obtained using the straight longitudinal wave probe in relation to various coupling agents and various surface specimens

Table 1. Amplitudes of echo I and II obtained in relation to various specimens using the straight probe of longitudinal waves and high-density coupling agents

Type of specimen	Amplitude of echo I and II [%]				
	Gel MR 750	Lubricant ŁT-43	Silicon lubricant	Copper lubricant	Natural bee honey
Standard specimen no. 1	100 / 53	64 / 32	53 / 22	75 / 40	112 / 57
Ground specimen	104 / 56	60 / 29	49 / 22	70 / 36	128 / 65
Shot-blasted specimen	53 / 32	45 / 23	34 / 16	48 / 25	94 / 54
Raw specimen	65 / 36	57 / 27	42 / 19	71 / 35	124 / 62

Table 2. The scale of I and II echo amplitudes receive on different samples with the coupling of the transverse oblique head with high-density means

Type of specimen	Amplitude of echo I and II [%]				
	Gel MR 750	Lubricant ŁT-43	Silicon lubricant	Copper lubricant	Natural bee honey
Standard specimen no. 1	100 / 12	78 / 11	40 / 6	93 / 11	96 / 12
Ground specimen	110 / 35	70 / 22	24 / 11	89 / 27	102 / 33
Shot-blasted specimen	40 / 15	25 / 7	14 / 5	37 / 13	55 / 17
Raw specimen	35 / 5	26 / 3	14 / 2	29 / 4	47 / 4

having the form of gel. Figures numbered 10 and 11 show graphs presented dependences of the amplitudes of the first and second echo respectively obtained in relation to various coupling agents and various test surfaces.

Table 2 presents test results related to the amplitude of the first and the second echo obtained in relation to standard specimen no. 2 and steel specimens having various surfaces (ground, shot-blasted and raw), performed using the angle probe of shear waves. The above-named results were recorded in relation to acoustic feedback and various high-density couplants. The results were presented in percentage assuming that the basis was constituted by the measurement performed using the straight probe, standard specimen no. 2 and the coupling agent having the form of gel. Figures numbered 12 and 13 show graphs presenting dependences of the amplitudes of the first echo obtained in relation to various coupling agents and various test surfaces.

The lower values of the echo II amplitude obtained using standard specimen no. 2 were triggered by the extended wave path (by 25 mm) in relation to the measurements on the other specimens.

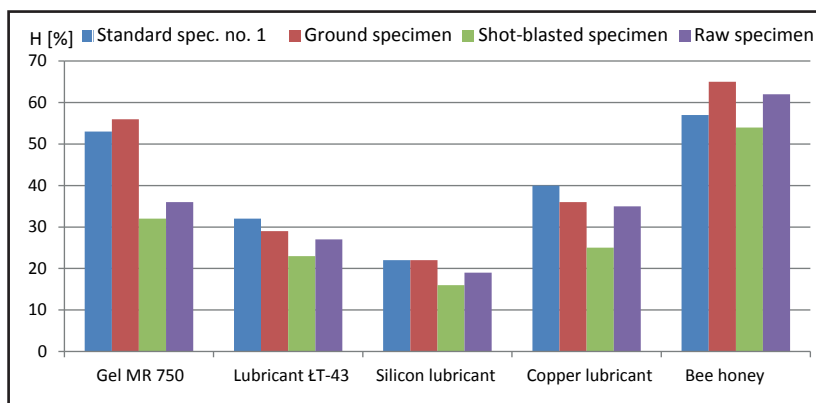


Fig. 11. Comparison of the amplitudes of echo II obtained using the straight longitudinal wave probe in relation to various coupling agents and various surface specimens

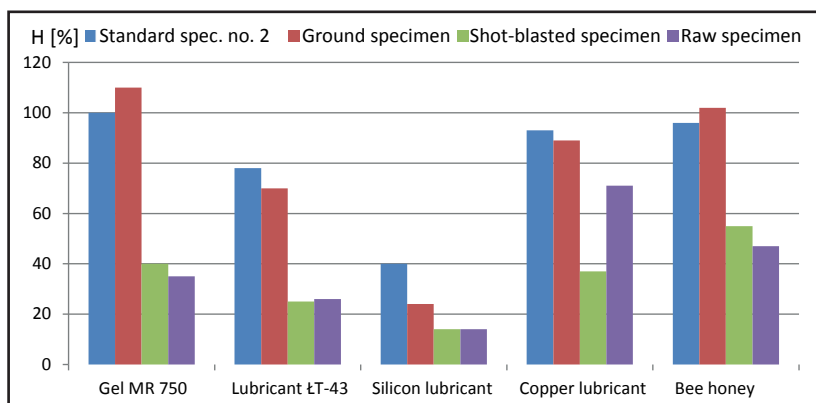


Fig. 12. Comparison of the amplitudes of echo I obtained using the angle shear wave probe in relation to various coupling agents and various specimen surfaces

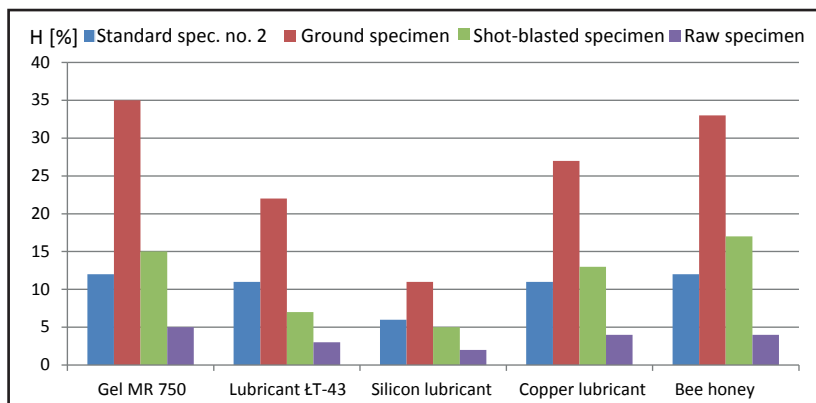


Fig. 13. Comparison of the amplitudes of echo II obtained using the angle shear wave probe in relation to various coupling agents and various specimen surfaces

Conclusions

The tests and related analysis concerning the dependence of the amplitude of the echo of an ultrasonic wave entering materials (having various surface characteristics) through various coupling agents enabled the formulation of the following conclusions:

1. The highest effectiveness of the transfer of a longitudinal wave from the probe transducer to the material being tested was obtained using natural bee honey. The analysis of the echo I and II amplitudes revealed that the above-named effectiveness was obtained on every specimen surface (i.e. ground, shot-blasted and raw).
2. The highest effectiveness of the transfer of a shear wave to the material was obtained using natural bee honey. The analysis of the echo I and II amplitudes revealed that the above-named effectiveness was obtained on every specimen surface (i.e. ground, shot-blasted and raw).
3. In addition to very effective bee honey, high coupling properties were also revealed in relation to the MR 750 coupling agent (gel) and, next, the copper lubricant. The copper lubricant proved the most effective in cases of the raw surface and shear waves.
4. The lowest coupling results were obtained using the silicon lubricant, both as regards longitudinal and shear waves as well as in terms of all test surfaces.
5. In relation to the surface type, the highest effectiveness in relation to the transfer of ultrasonic waves was obtained, regardless of coupling agents, using ground surfaces. The lowest effectiveness was observed on the shot-blasted surfaces.

The final sum-up of the research results will be presented in the subsequent article, following the analysis of test results concerning the group of coupling agents characterised by lower density.

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