Ryszard Krawczyk

Evaluation of the Effectiveness of Low-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 low-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 were performed using a normal probe emitting longitudinal waves and an angle probe emitting shear waves. The tests involved the use of standard specimens as well as steel specimens having various test surfaces.

Keywords: non-destructive testing, NDT, ultrasonic testing, ultrasonic waves, acoustic properties of materials, low-density couplants

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Introduction

This study constitutes the continuation of tests concerning the effectiveness of acoustic feedback necessary during contact-based ultrasonic tests of materials and welded joints. The first part of research discussed in the article entitled *Evaluation of the Effectiveness of High-Density Couplants in Ultrasonic Tests* involved the assessment performed using steel specimens with various types of surfaces and couplants characterised by high density [1]. This study aims to analyse results of tests concerning the effectiveness of low-density coupling media, both used and usable in ultrasonic tests. The tests were performed using a straight probe of longitudinal waves and an angle probe of shear waves as well as steel specimens 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 conditions.

Scatter of ultrasonic waves

An ultrasonic wave entering a material subjected to tests gets scattered when passing from the probe to the material being tested, in the test material itself and on the surface opposite to the test surface. The primary factors significantly affecting the scatter of ultrasonic waves when passing from the probe to the test material are the following:

- properties of a coupling medium,
- conditions on the surface of contact between the probe and the coupling medium,
- properties of the test surface,
- conditions in the contact between test surface and the coupling medium.

Both these factors are jointly referred to as acoustic feedback. The quality of acoustic feedback is affected by the type of a 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

dr inż. Ryszard Krawczyk (PhD (DSc) Eng.) – Częstochowa University of Technology; Welding Department

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 concerning low-density coupling media 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,
– est specimens examined by ultrasonic probes of longitudinal and shear waves,
– media coupling the probe with a test element.

The tests involved the use of an Epoch 600 versatile digital ultrasonic defectoscope (Olympus) and two ultrasonic probes:

– straight double longitudinal wave probe DL4R-6X20 (Olympus),
– angle single shear wave probe AM4R-8X9-70 (Olympus).

The tests were performed using 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 1a, b and c.

The second group of specimens, made of steel S355, were semi-cylindrical specimens having

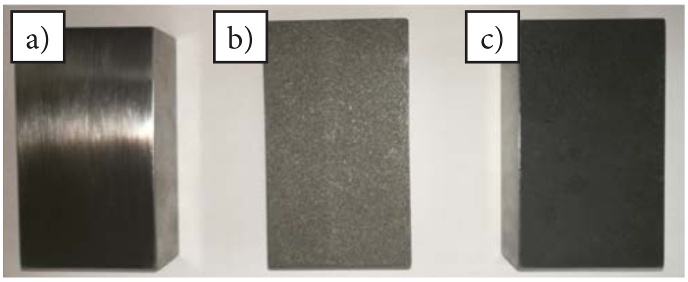

Fig. 1. Flat specimens used in longitudinal wave probe testing on: a) ground; b) shot-blasted and c) raw surface after rolling [7]

radius *R* 25 mm and a thickness of 30 mm. The semi-cylindrical specimens were subjected to tests performed using the angle probe 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 2a, b and c.

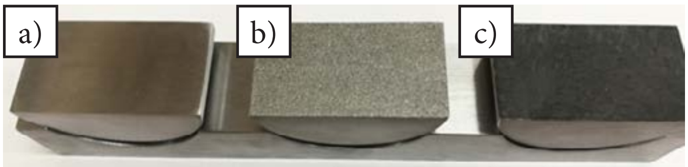

Fig. 2. Semi-cylindrical specimens for shear wave probe testing on: a) ground; b) shot-blasted and c) raw surface after rolling [7]

Both types of specimens were used in the previous tests of high-density couplants

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 an UT couplant 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), used 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 low density. The results concerning the materials of the first group (characterised by high density) were discussed in the previous study.

Assessment of low-density couplants

The tests of low-density couplants were performed using specimens having various surfaces. The tests involved the application of couplants 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 couplant. 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 couplant. 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 3a presents the test surface directly after the application of the gel, whereas Figure 3b presents the test surface after the repeated placing of the probe.

Silicon oil Castrol C3

The oil is brown, fat and characterised by an intense smell and medium density. After the repeated placing of the probe on the test surface, the oil does not lose its properties. The oil 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 4a presents the test surface directly after the application of the oil, whereas Figure 4b presents the test surface after the repeated placing of the probe.

Used silicon oil Castrol C3

The oil is dark-brown, fat, characterised by an intense smell and lower density. After the repeated placing of the probe on the test surface, the oil does not lose its properties. The oil easily contaminates surfaces, is difficult to remove and leaves fat stains. In addition, it is less stable and spreads relatively fast on various types of surfaces (ground, shot-blasted and raw). Figure 5a presents the test surface directly after the application of the oil, whereas Figure 5b presents the test surface after the repeated placing of the probe.

Wallpaper paste Specjal

The paste is milk-white and characterised by the lack of smell and significant density. After the repeated placing of the probe on the test surface, the paste does not lose its properties. The paste is easy to remove and does not leave fat stains. In addition, it is

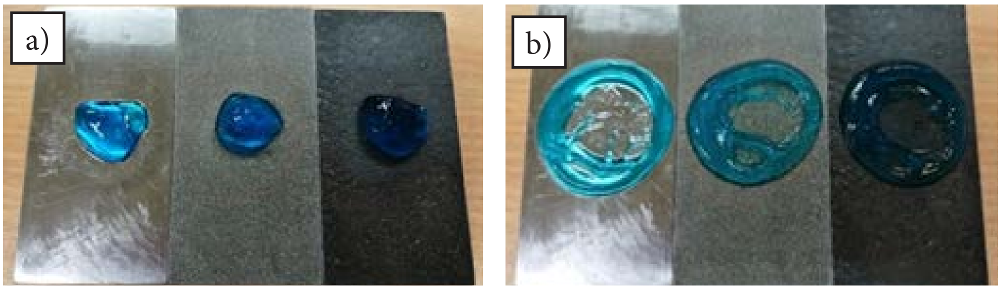

Fig. 3. Portions of the MR 750 gel on various surfaces: a) immediately after application; b) after the repeated placing of the probe

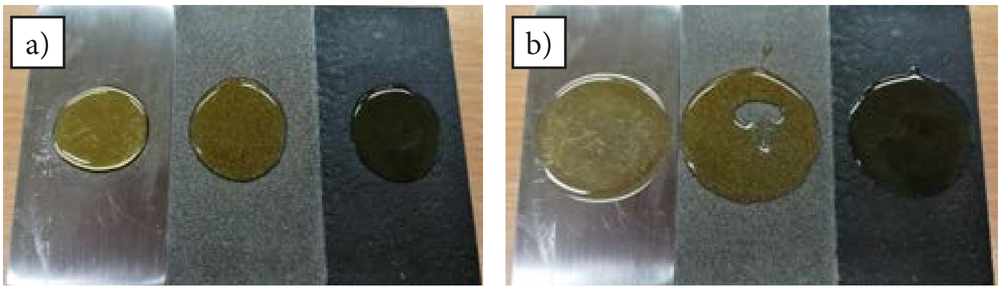

Fig. 4. Portions of the Castrol oil on various surfaces: a) immediately after application; b) after the repeated placing of the probe

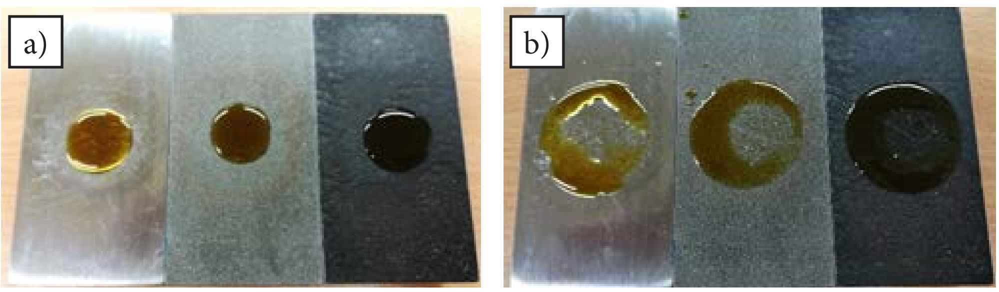

Fig. 5. Portions of the used Castrol oil on various surfaces: a) immediately after application; b) after the repeated placing of the probe

relatively stable on various types of surfaces (ground, shot-blasted and raw). Figure 6a presents the test surface directly after the application of the paste, whereas Figure 6b presents the test surface after the repeated placing of the probe.

Washing-up liquid Tymek jesień

The liquid is pink, characterised by intense, yet nice smell and medium density. After the repeated placing of the probe on the test surface, the liquid does not lose its properties. The liquid is easy to remove and does not leave fat stains. In addition, it is very stable on various types of surfaces (ground, shot-blasted and raw). Figure 7a presents the test surface directly after the application of the liquid, whereas Figure 7b presents the test surface after the repeated placing of the probe.

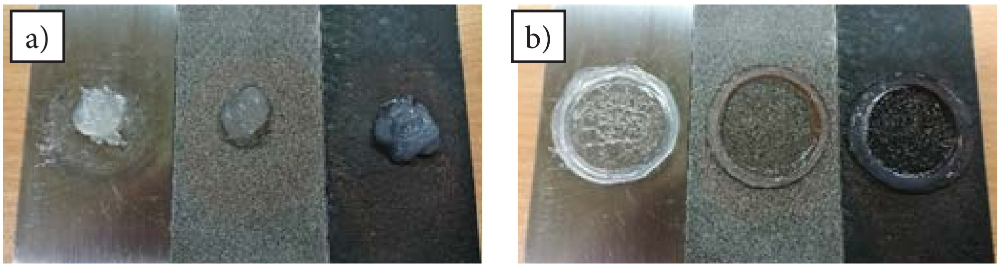

Fig. 6. Portions of the wallpaper paste Specjal on various surfaces: a) immediately after application; b) after the repeated placing of the probe

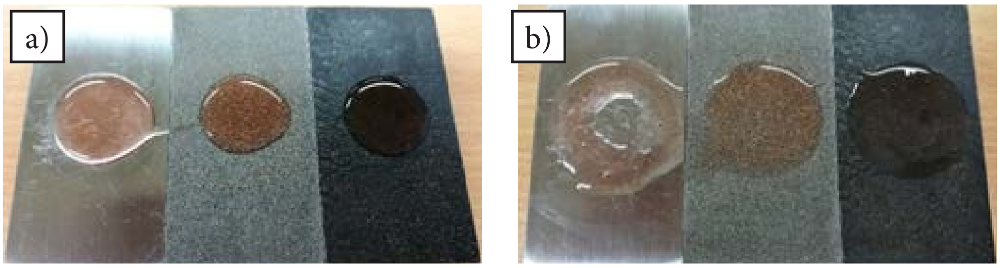

Fig. 7. Portions of the washing-up liquid Tymek jesień on various surfaces: a) immediately after application; b) after the repeated placing of the probe

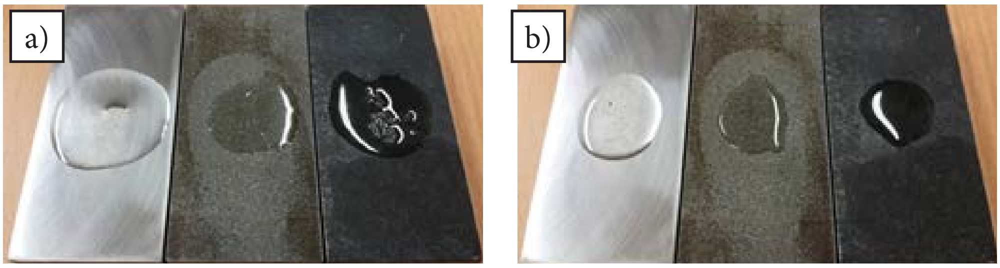

Fig. 8. Portions of glycerine on various surfaces: a) immediately after application; b) after the repeated placing of the probe

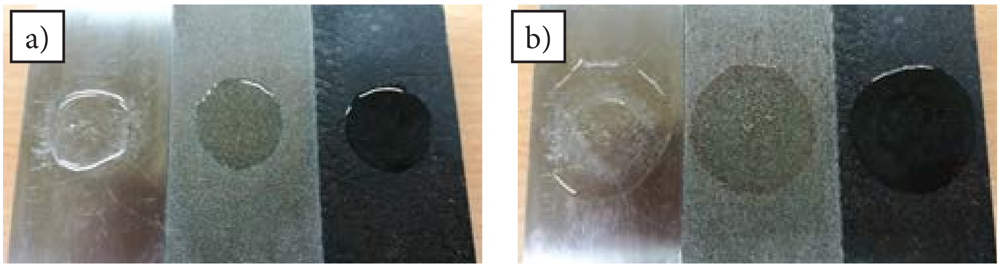

Fig. 9. Portions of water on various surfaces: a) immediately after application; b) after the repeated placing of the probe

Glycerine

Glycerine is milk-white, transparent, slightly fat, characterised by the lack of smell and low density. After the repeated placing of the probe on the test surface, glycerine does not lose its properties. It is easy to remove and does not leave fat stains. In addition, glycerine is very stable on various types of surfaces (ground, shot-blasted and raw). Figure 8a presents the test surface directly after the application of glycerine, whereas Figure 8b presents the test surface after the repeated placing of the probe.

Water

Water is transparent, not fat, characterised by the lack of smell and colour as well as by low density. After the repeated placing of the probe on the test surface, water loses its coupling properties. It is easy to remove and does not leave fat stains. Water is very unstable on various types of surfaces (ground, shot-blasted and raw). Figure 9a presents the test surface directly after the application of water, whereas Figure 9b presents the test surface after the repeated placing of the probe.

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

Type of specimen	Amplitude of echo I and II [%]						
	Gel MR 750	Engine oil Castrol C3	Used engine oil Castrol C3	Wall-paper paste Specjal	Washing-up liquid Tymek	Glycer-ine	Water
Standard specimen no. 1	100 / 47	82 / 35	93 / 46	110 / 51	108 / 51	102 / 58	110 / 52
Ground specimen	93 / 43	64 / 26	90 / 42	93 / 45	102 / 49	100 / 57	92 / 35
Shot-blasted specimen	53 / 26	24 / 11	43 / 21	56 / 27	57 / 27	76 / 44	49 / 22
Raw specimen	78 / 36	32 / 18	67 / 34	82 / 36	86 / 107	109 / 61	65 / 26

Test results concerning the effectiveness of low-density couplants

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 low-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 couplant having the form of gel. Figures numbered 10 and 11 show graphs presenting dependences of the amplitudes of the first and second echo respectively obtained in relation to various low-density couplants and various test surfaces.

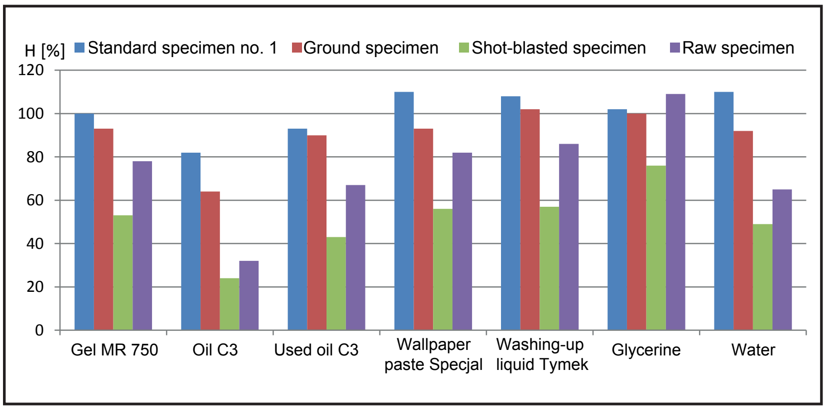

Fig. 10. Comparison of the amplitudes of echo I obtained using the straight longitudinal wave probe in relation to various couplants and various surface specimens

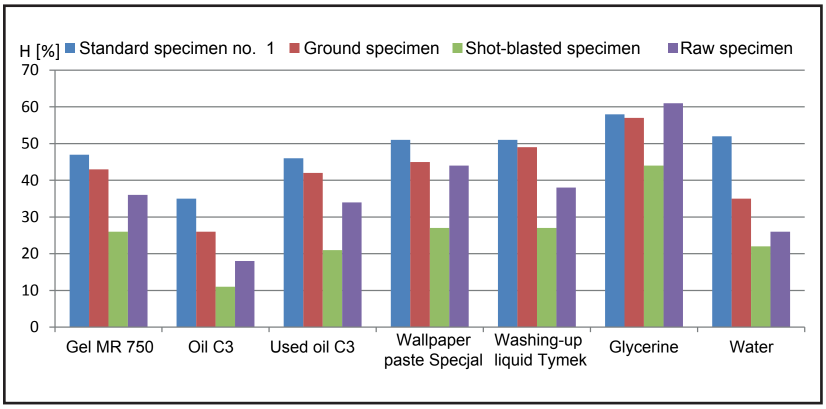

Fig. 11. Comparison of the amplitudes of echo II obtained using the straight longitudinal wave probe in relation to various couplants and various surface specimens

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 low-density couplants. The results were presented in percentage assuming that the basis was constituted by the measurement performed using the angle probe of shear waves, standard specimen no. 2 and the couplant having the form of gel. Figures numbered 12 and 13 show graphs presenting dependences of the amplitudes of the first and second echo respectively obtained in relation to low-density couplants and various test surfaces.

Table 2. Amplitudes of echo I and II obtained in relation to various specimens using the angle probe of shear waves and low-density couplants

Type of specimen	Amplitude of echo I and II [%]						
	Gel MR 750	Engine oil Castrol C3	Used engine oil Castrol C3	Wall-paper paste Specjal	Washing-up liquid Tymek	Glycer-ine	Water
Standard specimen no. 1	100 / 11	92 / 12	103 / 12	106 / 15	101 / 12	108 / 75	102 / 10
Ground specimen	110 / 35	103 / 31	108 / 33	110 / 35	110 / 38	110 / 35	106 / 33
Shot-blasted specimen	40 / 15	15 / 5	34 / 12	42 / 15	44 / 15	62 / 17	31 / 11
Raw specimen	35 / 5	13 / 2	25 / 3	31 / 3	35 / 5	54 / 8	26 / 3

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.

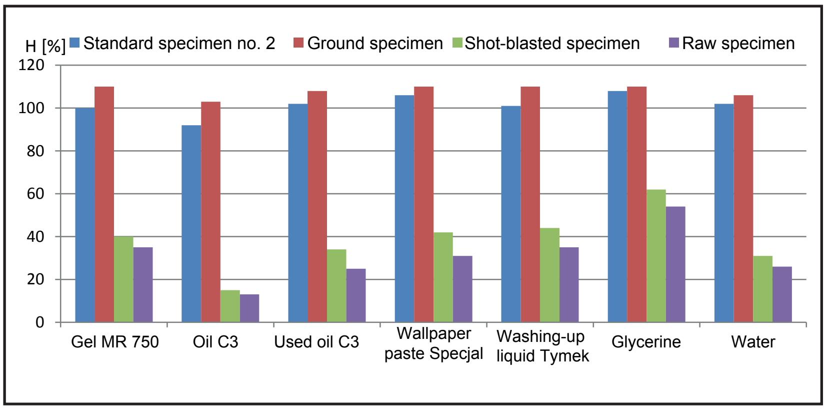

Fig. 12. Comparison of the amplitudes of echo I obtained using the angle shear wave probe in relation to various couplants and various surface specimens

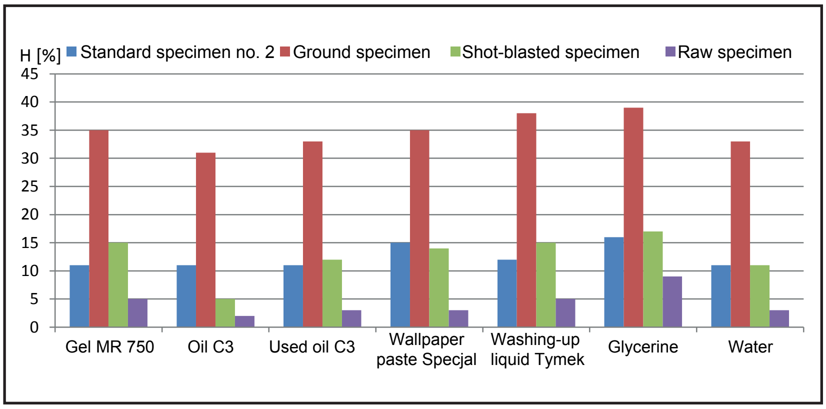

Fig. 13. Comparison of the amplitudes of echo II obtained using the angle shear wave probe in relation to various couplants and various surface specimens

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 couplants characterised by low density 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 glycerine. 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 glycerine. 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 glycerine, high coupling properties were also revealed in relation to the washing-up liquid Tymek, wallpaper paste (Specjal) and the MR 750 gel and, next, water and used engine oil.

4. The lowest coupling results were obtained using the C3 oil, both as regards longitudinal and shear waves as well as in terms of all test surfaces.

5. All of the low-density media provided a very effective transfer of a shear wave on the ground surfaces, as opposed to the remaining surface types (raw and shot-blasted).

6. In relation to the surface type, the highest effectiveness in relation to the transfer of ultrasonic waves was obtained, regardless of couplants, using ground surfaces. The lowest effectiveness was observed on the shot-blasted surfaces.

The testing of the high and low-density coupling media revealed that the most effective transfer of ultrasonic waves was obtained using bee honey and, next, glycerine, washing-up liquid and the UT gel. The remaining substances were characterised by worse transfer-related properties.

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