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LOCATION OF THE ADHESIVE PATH IN JOINTS OF THIN CAR BODY SHEETS

Summary

Bonding technology is one of the oldest technologies of joining car body elements. Bonding steel in real industrial conditions may cause various incompatibilities in the joints area. The main ones consist in the lack of adhesion and no adhesive in the area of the joints. Currently there are destructive methods of controlling adhesive joints that require destruction of the joint. Destruction of joint generates significant costs especially when assessing joints in commercial vehicles. However assessment on vehicles being repaired or operated is not possible, because it causes total destruction of the joint. As a part of the work it was decided to check whether the ultrasound echo technique would enable locating these areas in the vehicle body in which there is no adhesives or lack of adhesion occurs - not only on prepared samples but also on the element - the door of a currently produced car vehicle. The ultrasonic measurements were verified during the destructive control of adhesive joint in the doors of a motor vehicle. The tests confirmed that the proposed measures of quality enable the location of the adhesive path between the two body shells.
***Key words**: bonding, vehicle body, steel, adhesion*

LOKALIZACJA ŚCIEŻKI KLEJU W POŁĄCZENIACH CIENKICH BLACH KAROSERYJNYCH

Streszczenie

Technologia klejenia jest jedną z najstarszych technologii łączenia elementów karoserii pojazdów samochodowych. Klejenie stali w rzeczywistych warunkach przemysłowych może powodować różne niezgodności w obszarze połączenia. Główne z nich to deadhezja oraz brak kleju w obszarze założonego połączenia. Obecnie funkcjonują niszczące metody kontroli połączeń klejowych, które wymagają zniszczenia połączenia. Zniszczenie połączeń generuje znaczne koszty, szczególnie w przypadku oceny połączeń w pojazdach dostawczych. Nie umożliwiają one jednak oceny na pojazdach naprawianych lub eksploatowanych, ponieważ powodują całkowite zniszczenie połączenia. W ramach realizowanych prac postanowiono sprawdzić czy ultradźwiękowa technika echa umożliwi zlokalizowanie tych obszarów w karoserii, w których brakuje kleju lub nastąpiła deadhezja – nie tylko na spreparowanych próbkach, ale również na elemencie rzeczywistym – drzwiach współcześnie produkowanego pojazdu samochodowego. Wykonane prace zostały zweryfikowane w czasie kontroli niszczącej połączeń klejowych w drzwiach współczesnego pojazdu samochodowego. Przeprowadzone badania potwierdziły, że zaproponowane miary jakości umożliwiają lokalizację ścieżki kleju między dwiema blachami karoseryjnymi.
***Słowa kluczowe**: klejenie, nadwozie pojazdu, stal, adhezja*

1. Introduction

During the production stage of car body elements, cabs for farm tractors and heavy machinery various joining technologies are used [8-10]. The most common methods are: welding, braze welding, laser welding, bonding and spot welding. In some cases combined techniques are used, e.g. spot welding and bonding or bonding and braze welding. Taking in to account not only the production of vehicles but also the work related to their repair and maintenance some problems with the assessment of the quality of adhesive joints are noticed. The main discrepancies found in adhesive joints are in practice: no adhesive in the joint and lack of adhesion [4-5, 9].

There are destructive methods to control the quality of adhesive joints which are successfully used in industrial - manufacturing conditions. However these methods do not allow assessment of the joints on repaired or operated vehicles because they cause total destruction of the joint [6-7, 11]. As part of the work it was decided to check whether the ultrasonic echo technique enable location of these areas in the car body in which there is no adhesives or lack of adhesion occurs. Ultrasonic echo technique was used during the research. This technique is based on the phenomena of reflection and refraction of ultrasonic waves. Placed in the ultrasound transducer the piezoelectric converter generates ultrasonic waves. This wave passing through the coupling medium propagates through the metal sheet and reaches the joint (sheet – adhesive area). Part of the wave will be reflected from the joint area and some part will propagate into the adhesive where it will be dampened. The wave reflected from the joint area will return to the piezoelectric transducer as a result of pulses which will appear on the flaw detector screen.

When the ultrasonic transducer is selected for research one should take into account its near field, damping and wavelength in the tested material. The transducer should be chosen taking into account the expected defects which are located outside the near field. Reduction of the wavelength increases the resolution of the measurement system. For the most commonly used ultrasound probes with a frequency of 2 and 4 MHz the wavelength in steel is 3 and 1.5 mm. When elements with a thickness less than 1 mm are tested this wavelength is definitely too high. A wavelength of about 0.3 mm will be obtained for an ultrasonic transducer with a frequency of 20MHz and this probe has been chosen in research of thin steel sheets. Due to the dead zone of the ultrasonic transducers a probe with a water delay line was used. The distance from the transducer to the membrane is from 14 to 16 mm for this probe.

The ultrasonic measure of the adhesive joint quality can be the acoustic pressure of the longitudinal ultrasonic wave incident on the converter of the ultrasound probe used in adhesive joint testing. The acoustic pressure of the ultrasonic wave depends on the quality of the tested joint. The higher the quality of the tested joint, the higher energy of the ultrasonic wave passes through this joint. At the same time a smaller part of the ultrasonic wave energy will be reflected from this joint. The acoustic pressure of the ultrasonic longitudinal wave reflected from the border of the high-quality joint affecting the ultrasonic transducer will be relatively low. Lower acoustic pressure will generate lower voltage on the ultrasonic transducer which is reflected. It is shown as smaller amplitudes of the wave pulses obtained on the screen of the ultrasonic flaw detector. In standard ultrasonic tests probes with a water delay line are not used. The use of a water delay line and a flexible membrane causes a high impact of the transducer pressure on the height of individual pulses. For this reason in further works the heights of the first four pulses and the number of pulses from the joint area were recorded. The height of pulses is greater than 20% of the flaw detector screen height (n).

The ultrasound tests of adhesive joints carried out so far focused primarily on the detection of defects in joints [1]. One of them is kissing bond in which the adhesive layer is not fully bonded to the substrate. This type of connections by ultrasound was investigated by the authors of the work [2]. Cracks are another example of defects in adhesive joints. Defects of this type can also be localized by ultrasound [12]. Another direction of nondestructive adhesive joints research is to study the properties of the joint itself. Ultrasonic technique allows testing properties of both the adhesive and the joint [3]. Nevertheless, the authors of this publication did not encounter non-destructive tests that would allow to locate an area with no adhesive in the joint of thin car body sheets.

The main goal of the research is to apply the ultrasound echo method (nondestructive technique) for location of the adhesion between the car body plates of contemporary passenger cars.

2. Experimental tests

The ultrasonic flaw detector USLT2000 made by Krakutkramer company was used in the research along with an ultrasonic probe with a frequency of 20MHz. It was decided to choose such a measuring system because it is an apparatus that is dedicated to the examination of elements of small thickness and allows testing elements with a thickness less than 1 mm.

The research consisted of two basic stages. The first stage - the experimental study - was aimed at determining measurement errors, the impact of ultrasonic flaw detector settings and preparation of the surface to be bonded on the test results. In order to estimate the measurement error, 100 measurements were conducted with a 3 mm diameter of converter in the presence and without adhesive in the joint area. Also the confidence interval L0.9 was calculated. The results are presented in Table 1 and Table 2 [4].

At a later stage of the work it was checked how the basic settings of the flaw detector affect the results obtained during the tests. Each time during the measurements the gain of ultrasonic wave was changed. The first measurement was carried out with the smallest gain which made it possible to obtain the correct image on the flaw detector screen. The last measurement was made at the highest gain which the pulse useful for the ultrasonic examination tests was obtained. In these measurements gain, the number of pulses, the height of the first four pulses from the areas of the joint were obtained. A gain of ultrasonic wave of 0.5 dB was assumed. All obtained results are presented in Table 3. The influence of the gain on the number of pulses n and the height of the first pulse is shown in Figs. 1 and 2.

Table 1. Determination of the measurement error for the transducer with a diameter of converter 3 mm in the place where the adhesive was applied

Tab. 1. Wyznaczenie błędu pomiarowego dla głowicy o średnicy przetwornika 3 mm w miejscu, w którym nałożono klej

	□x	σ_X	t	e
n [-]	11	0.66	1.66	1.10
I [-]	0.91	0.06	1.66	0.11
II [-]	0.74	0.08	1.66	0.14
III [-]	0.58	0.07	1.66	0.11
IV [-]	0.46	0.05	1.66	0.09

where: n – number of pulses; I, II, III, IV – height of pulses: first, second, third and fourth

Source: own elaboration / Źródło: opracowanie własne

Tab. 2. Determination of the measuring error for the transducer with a diameter of converter 3 mm in a place where no adhesive was applied

Tab. 2. Wyznaczenie błędu pomiarowego dla głowicy o średnicy przetwornika 3 mm w miejscu, w którym nie nałożono kleju

	□x	σ_X	t	e
n	22	3.24	1.66	5.37
I	0.94	0.03	1.66	0.06
II	0.85	0.04	1.66	0.07
III	0.77	0.04	1.66	0.07
IV	0.71	0.04	1.66	0.07

where: n – number of pulses; I, II, III, IV – height of pulses: first, second, third and fourth

Source: own elaboration / Źródło: opracowanie własne

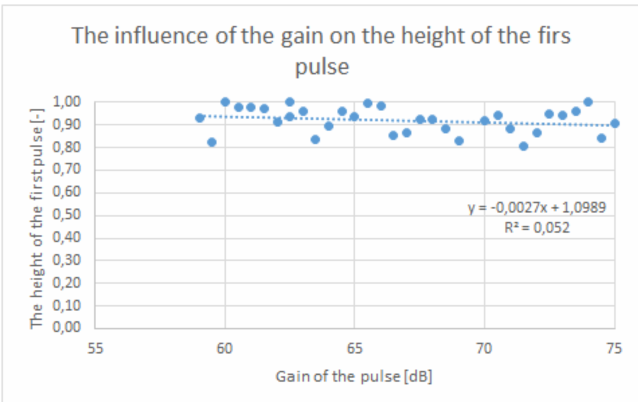

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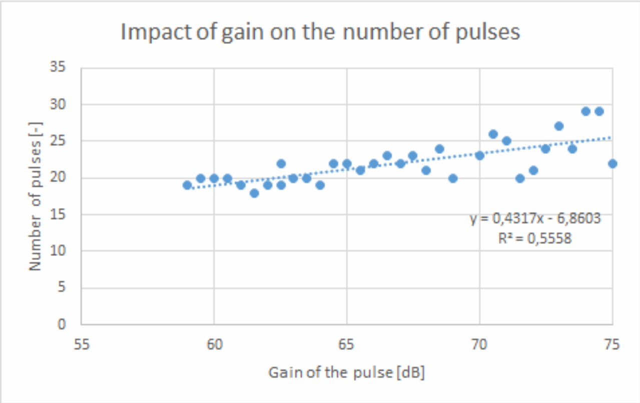
Fig. 1. Impact of the ultrasonic wave gain on the height of the first pulse on the flaw detector screen

Rys. 1. Wpływ wzmocnienia impulsu fali ultradźwiękowej na wysokość pierwszego impulsu na ekranie defektoskopu



Source: own elaboration / Źródło: opracowanie własne

Fig. 2. Impact of ultrasonic wave gain on the number of pulses on the flaw detector screen
Rys. 2. Wpływ wzmocnienia impulsu fali ultradźwiękowej na liczbę impulsów na ekranie defektoskopu

Table 3. Test results obtained during measurements - the gain was increasing by 0.5 [dB] for the area in which no adhesive was applied
Tab. 3. Wyniki pomiarów uzyskane w czasie pomiarów przy zwiększaniu wzmocnienia o 0.5 [dB] dla obszaru, w którym nie nałożono kleju

No	W [dB]	n [-]	I [%]	II [%]	III [%]	IV [%]
1	59.0	19	0.93	0.81	0.64	0.63
2	59.5	20	0.82	0.74	0.65	0.60
3	60.0	20	1.00	0.89	0.80	0.65
4	60.5	20	0.98	0.87	0.73	0.69
5	61.0	19	0.98	0.87	0.77	0.62
6	61.5	18	0.97	0.84	0.75	0.65
7	62.0	19	0.91	0.83	0.66	0.64
8	62.5	22	1.00	0.91	0.82	0.73
9	63.0	19	0.94	0.83	0.71	0.67
10	63.5	20	0.96	0.82	0.74	0.63
11	64.0	20	0.84	0.79	0.72	0.66
12	64.5	19	0.90	0.81	0.72	0.63
13	65.0	22	0.96	0.89	0.81	0.74
14	65.5	22	0.94	0.84	0.71	0.72
15	66.0	21	0.99	0.87	0.78	0.66
16	66.5	22	0.98	0.84	0.78	0.75
17	67.0	23	0.86	0.82	0.73	0.67
18	67.5	22	0.87	0.77	0.72	0.65
19	68.0	23	0.92	0.87	0.81	0.77
20	68.5	21	0.93	0.82	0.76	0.70
21	69.0	24	0.88	0.79	0.74	0.70
22	69.5	20	0.83	0.75	0.64	0.62
23	70.0	23	0.92	0.81	0.68	0.68
24	70.5	26	0.94	0.86	0.77	0.72
25	71.0	25	0.88	0.84	0.79	0.74
26	71.5	20	0.81	0.77	0.71	0.65
27	72.0	21	0.87	0.80	0.77	0.66
28	72.5	24	0.95	0.86	0.85	0.86
29	73.0	27	0.94	0.85	0.80	0.80
30	73.5	24	0.96	0.90	0.86	0.80
31	74.0	29	1.00	0.91	0.87	0.83
32	74.5	29	0.84	0.80	0.76	0.75
33	75.0	22	0.91	0.84	0.74	0.71

Source: own elaboration / Źródło: opracowanie własne

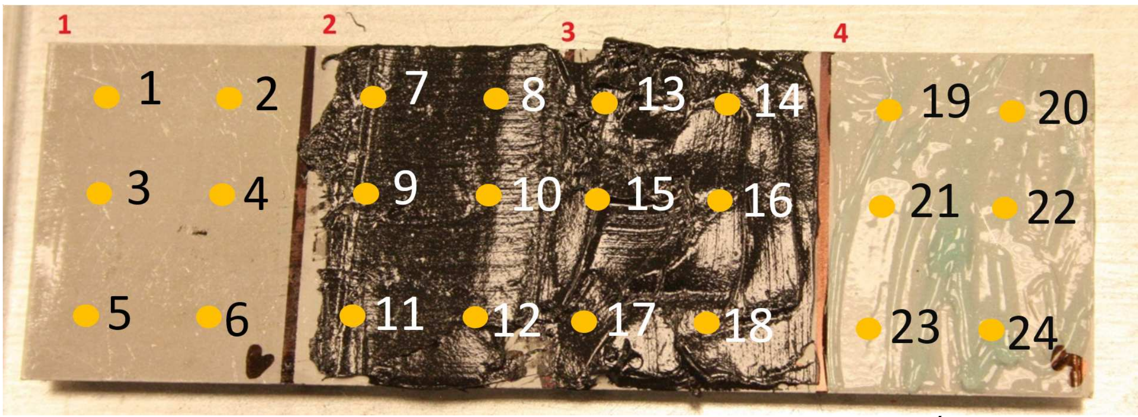
The obtained results confirmed that in the case of an ultrasonic probe with a frequency of 20MHz with a water delay line no significant effect of the gain on the obtained results was observed. At the same time it was found that the measurement error for areas with adhesive is smaller than for areas without adhesive.

In the further part of the work it was checked whether the surface preparation affects the ultrasonic wave parameters. Four zones were designated on steel sheet and the points that correspond to the places of measurement on the other side of the sheet were marked (Fig. 3). In the first (measurements from 1 to 6) a small amount of oil was applied to the plate which can be left after stamping process. In the second zone (measurements from 7 to 12) the oil on which the adhesive was applied to the sheet. In the third zone (measurements from 13 to 18) adhesive was applied to the sheet. In the fourth (measurements and 19 to 24) the coupling medium Karl Deutsch was applied. The measurements were carried out on one sample because it guaranteed a homogeneous sheet structure. The adhesives used for joining car body plates are strongly damping. This results in the fact that the thickness of the adhesive - applied in accordance with the guidelines of the adhesive manufacturer - does not affect the results of the ultrasonic measurements. All work was carried out at 20˚C in an air-conditioned room. The results are presented in Table 4.

Table 4. Evaluation of the effect of surface preparation for bonding on selected parameters of ultrasonic wave pulses
Tab. 4. Ocena wpływu przygotowania powierzchni do klejenia na wybrane parametry impulsów fali ultradźwiękowej

Area	Measurement point	n	I	II	III	IV
Area with oil	1	16	0.90	0.82	0.69	0.59
	2	16	0.96	0.82	0.76	0.64
	3	16	0.93	0.83	0.71	0.61
	4	17	1.00	0.93	0.74	0.69
	5	15	0.95	0.83	0.70	0.54
	6	15	0.93	0.80	0.70	0.60
The area where the oil and then the adhesive was applied	7	11	1.00	0.84	0.63	0.49
	8	10	1.00	0.81	0.66	0.52
	9	10	1.00	0.92	0.67	0.53
	10	10	1.00	0.80	0.62	0.48
	11	10	1.00	0.91	0.70	0.55
	12	11	0.97	0.78	0.60	0.48
Area with applied adhesive	13	11	0.96	0.80	0.62	0.50
	14	10	0.97	0.82	0.65	0.46
	15	11	0.92	0.82	0.61	0.49
	16	9	1.00	0.80	0.60	0.44
	17	11	1.00	0.82	0.63	0.48
	18	9	0.94	0.81	0.61	0.48
Area with coupling medium	19	17	0.93	0.76	0.64	0.55
	20	10	1.00	0.84	0.69	0.54
	21	17	1.00	0.81	0.60	0.52
	22	15	1.00	0.93	0.66	0.54
	23	13	0.97	0.88	0.72	0.59
	24	13	0.91	0.82	0.67	0.54

Source: own elaboration / Źródło: opracowanie własne



Source: own elaboration / Źródło: opracowanie własne

Fig. 3. Prepared surface of the sheet: 1 – area with oil, 2 – the area where the oil and then the adhesive was applied, 3 – area with applied adhesive, 4 – area with coupling medium

Rys. 3. Powierzchnia blachy: 1 – obszar z naniesionym olejem, 2 – obszar, na który naniesiono olej, a następnie klej 3 – obszar z naniesionym klejem, 4 – obszar ze środkiem sprzęgającym

3. Verification of experimental tests

After experimental tests the presence of adhesive in the edge of the car door was assessed (Fig. 4).

The car door was examined with a 20MHz ultrasonic probe and 195 measurement points were determined. Eight measurements were rejected for the results. For this points it was not possible to read data from the flaw detector screen. Due to the large volume of obtained data the following parts were limited to a graphical transfer of obtained results (Fig. 5).

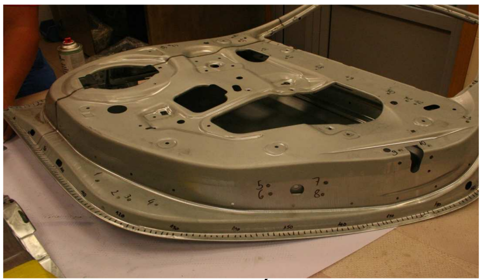


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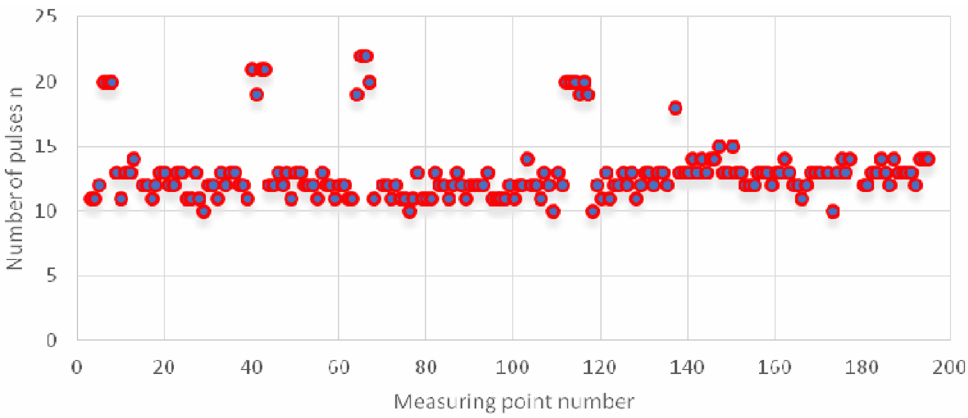
Fig. 4. Car doors subject to ultrasonic inspection in the scope of adhesive in the rim

Rys. 4. Drzwi samochodowe poddane kontroli ultradźwiękowej w zakresie kleju w obrzeżu

After the tests it was found an absence of adhesive in the part of the rim, based on selected ultrasonic measures, in particular the number of pulses with a height above 20 percent of the ultrasonic flaw detector screen height - as shown in Fig. 5. If from the ultrasound measurements the measured number of impulses from the joint areas was less than 15, this means the occurrence of adhesive in the combination of the car body sheet. The mechanical disruption of the joint confirmed the correctness of indications obtained during ultrasound examinations.

4. Conclusion

During the research the ultrasonic echo method was used to determine the quality of adhesive joints in the construction of car bodies. Based on the analysis it can be concluded that the ultrasonic method allows non-destructive assessment of the quality of adhesive joints. The easiest to use in industrial conditions ultrasonic measure is the number of pulses obtained on a flaw detector with a height of 20 to 100% of the screen. The standard, ultrasonic measures of the quality of adhesive joints based on the pulse heights are subject to a significant error. The ultrasound method allowed to locate those areas in which the adhesive was applied - about 10 pulses from joint area.



Source: own elaboration / Źródło: opracowanie własne

Fig. 5. Measurement results for car doors

Rys. 5. Wyniki pomiarów dla drzwi samochodowych

The presence of oil on the surface on which the adhesive was applied did not significantly affect the values of the analyzed, ultrasonic joint quality measures. Some of adhesive joints were tested and measurement errors were determined for them. The impact of flaw detector settings and the effect of surface preparation on test results were examined. The ultrasonic method was verified on car doors (195 measurements were made). On the basis of the results single areas with no adhesive in the tested joint were found.

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