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Defectoscopy of Composite Fiberglass Fittings by the Acoustic Waveguide Technique

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Abstract. In this paper we propose the procedure of non-destructive testing of composite fiberglass reinforcements by using the acoustic waveguide technique. Experiments on defectoscopy of the composite armature with rod waves were conducted. More than 1000 composite fiberglass reinforcements with length of 6 meters were tested according to the developed procedure. The experimental results shown that rejection level of 2 % allows to detect, confirm and identify flaws by type. Furthermore, we derived the dependence between signal amplitude and discontinuities or changes in the cross-section of the composite reinforcement body. The simulation of flaw as an element with a cross-sectional difference was performed. A graphical dependence of the signal amplitude from the flaw and from the defect zone cross-sectional area value was obtained. The photographs of typical defects and the corresponding echograms are given in this paper.

Keywords: acoustic non-destructive testing, waveguide technique, defectoscopy, development of procedure, composite fittings.

INTRODUCTION

In the construction industry, composite fittings has recently been increasingly used (Figure 1). It has a relatively low cost compared to metal fittings and better serviceability, while the manufacturing process is simpler. Composite fittings do not have a negative impact on human health.

In connection with the anisotropic properties of the material, high attenuation coefficient, a large amount of processing deficiency, low quality of the components included in the material, non-destructive testing (NDT) of the composite fittings is a difficult process. The quality of buildings and structures directly depends on the quality of the composite fittings. The use of low-quality fittings can result in death or injury to people [1–2].

Most NDT methods based on electromagnetic phenomena and are not applicable to composite materials testing. The problem is the lack of methods for non-destructive testing of such products [3–5]. However, testing of this type of fittings is possible using the acoustic guided wave method.

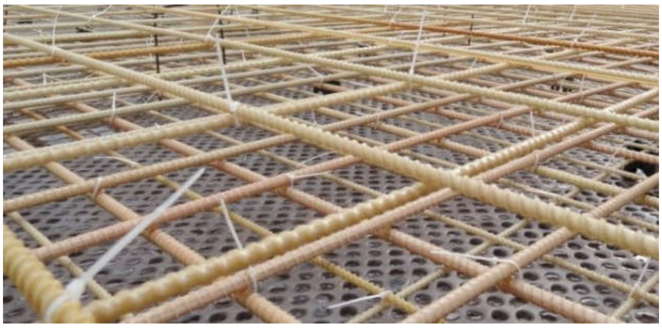


Figure 1. Composite fiberglass fittings

The most interesting is the implementation of testing technology for composite fittings using guided waves. The technology of acoustic guided wave testing can be implemented for extended objects, which length many times exceeds the dimension of the cross-sections [6–12]. Guided wave technique has been successfully implemented in non-destructive testing of bars, pump compressors rods, sucker rods, tubings, fluid level measurement in wells, etc. [13–15].

Advantages of the technique:

- does not require the use of contact and immersion liquids, any preparation of the surface of the object of testing;
- sensitivity to defects throughout the cross-section of the bar;
- no need to scan;
- possibility of testing at local access to the flat end of the object;
- high productivity;

The rod wave used is characterized by a small dispersion of the velocity peculiar to the other Pochhammer types of waves [6]. The equipment of the acoustic defectoscope for pumping rods ADNH [16–18] was used to control the composite fittings. In the experiment, the shape of the echogram was evaluated. Fittings with local defects include fittings having a clear local impulse in the analyzed area (1.5–5.5 m), with a level exceeding 2 % of the value of the bottom signal.

EVALUATION OF FITTINGS USING A ROD WAVE

The groups of fittings on which the experiments were performed are given in Table 1. Missing numbers correspond to fittings whose diameter was higher than the claimed one and did not allow the sensor to be installed, which in itself is a manufacturing defect (GOST 31938-2012).

Table 1. Fittings groups from different manufacturers

Group	Color	Total	Tested	Missing numbers
No. 1	Light brown	300	238	01, 04, 07-09, 17, 26, 29, 31, 38–39, 47, 52, 58, 71–73, etc.
No. 2	Light yellow	298	269	216, 193, 191, 110, 112, 106, 191, 80, 81, 57–59, 61, 62, 45, 27
No. 3	Light yellow	300	296	194, 196, 200
No. 4	Black	150 (No. 001 – No. 150)	150	
No. 5	Black	150 (No. 151 – No. 300)	149	151
Total		1198	1105	

Fittings are divided in groups based upon manufacturers. There are 15 defective fittings were detected in the first group (that is 6.3 % of all fittings in the group), in the second – 4 (1.5 %), in the third – 18 (6.1 %), in the fourth – 0, and 2 (1.3 %) in the fifth group. The 2 % level selection is due to the average noise level for all parties.

In the diagram (Figure 2) the blue color indicates the number of fittings whose signal amplitude from the defect exceeded the level of 2 %. It also includes samples whose signal amplitude exceeded the levels of 5 % and 10 %. The pink color indicates a group of samples whose amplitude of the echo signal from the defect exceeded the level of 5 %, and also includes samples with signal amplitude exceeding the level of 10 %. Green color indicates the number of samples whose signal amplitude from the defect has exceeded the level of 10 %. The number of the group is plotted along the abscissa axis, the percentage of the number of defective samples per group is plotted along the ordinate axis.

Thus the most part of defective fittings belongs to the first group.

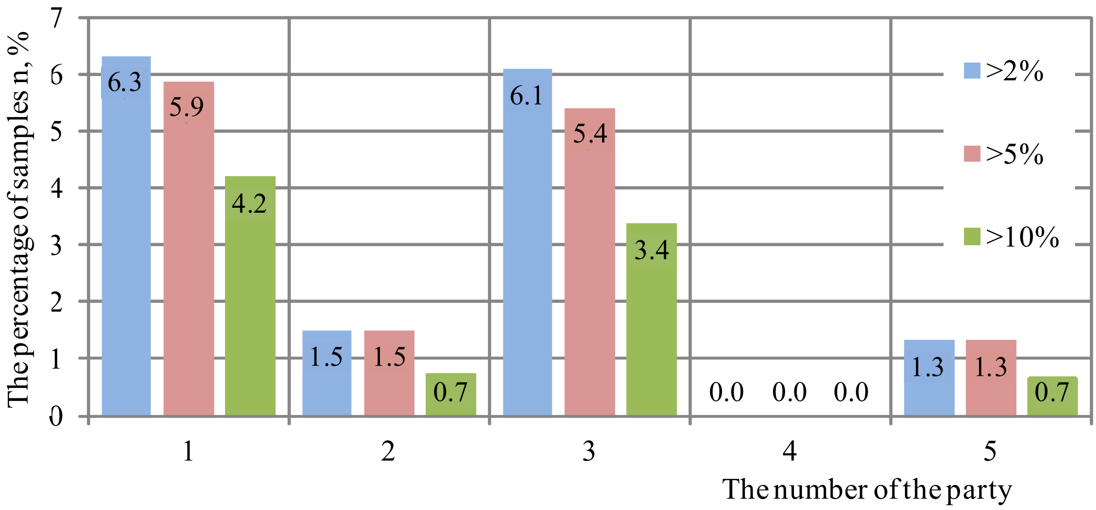


Figure 2. Composite fiberglass fittings

Defectoscopy of Composite Fiberglass Fittings

When carrying out defectoscopy using rod waves, the amplitude of signals from local defects depends on the value of the ratio of the cross-sectional area along the entire length of the object to the cross-section area in the defect zone. In accordance with the patterns of propagation of the rod wave, the reflection from the defective zone of the waveguide is determined by the change in the mechanical impedance of the waveguide $Z = \rho CS$ (S – cross-section square, C – wave speed, ρ – density). In the simplest case, when moving from a section with a mechanical impedance Z_1 to a section with a mechanical impedance Z_2 the reflection coefficient R is defined by formula: $R = (Z_2 - Z_1) / (Z_2 + Z_1)$. If the material properties of the waveguide do not change (C = const), and only its cross section changes (surface defects leading to the loss or addition of some part of the metal), R is defined by formula: $R = (S_2 - S_1) / (S_2 + S_1)$ [19–20]. This makes it possible to evaluate the interaction of acoustic waves with defects that weaken the cross-section of the object: captives, weights, inclusions, rubs, delaminations, etc. For defects that are concentrators of mechanical stresses (cracks with small opening) that do not significantly change the mechanical impedance of the object, the mechanism of emission of acoustic emission waves from regions where the stress exceed the mean value over the cross section of the monitoring object during the passage of the probe impulse (stretching-compression) works.

The examined samples (Table 2) are located depending on the magnitude of the signal level from the local defect, expressed as a percentage of the 1st bottom impulse and calculated by the formula:

$$A = U_D / U_{Don} \cdot 100\ \%, \tag{1}$$

where U_{Don} – amplitude of the first bottom signal; U_D – amplitude of the first defect signal.

The defects are modeled in the Compass 3D solid modeling software environment. The coefficients of the square change in the area of sections of local defects ("area ratios") were calculated by formula:

$$K_S = S_0 / S_d \cdot 100\ \%, \tag{2}$$

where S_0 – square of the flawless area; S_d – square of the defect area.

Among the defects of tested fittings with measured cross-sectional squares, the node defects were 22.2 %, defects of the inflow type were 44.4 %, defects of the gap type were 22.2 %, defects of the thickening type were 5.5 %, defects of the delamination type amounted to 5.5 %.

Table 2. Dependence of the reflection ratio on the size of the defects

No.	**Sample**	**The reflection ratio *R***	**Area ratio K_s, %**	**The nature of the defect**
1	3-072	2.8	11.1	node
2	1-148	4.0	1.0	node
3	3-089	5.9	8.7	node
4	2-254	6.9	7.7	inflow
5	1-003	7.3	6.9	inflow
6	4-201	7.7	4.4	gap
7	3-045	9.4	26.3	inflow
8	2-219	10.5	23.5	gap
9	4-300	10.8	9.25	gap
10	1-263	12.0	10.2	node
11	1-260	12.1	26.8	inflow
12	1-013	12.2	21.3	delamination
13	3-249	12.7	3.2	thickening
14	1-059	14.8	32.1	inflow
15	1-151	15.8	37.5	node inflow
16	1-280	17.2	12.0	node inflow
17	3-047	21.0	40.9	thickening
18	3-273	21.5	31.8	inflow

A graphical dependence of the amplitude of the signal on the defect on the value of the square of the defect area is obtained (Figure 3).

Analysis of the graphical dependence showed that there are "fall out" points marked red and green. Red color indicates points that, with a relatively small sectional area of the local defect, give a large defect signal magnitude. This is because the defect is mainly determined by the destruction of the fitting body and is visible on the surface. The points marked green give a smaller defect signal magnitude from the defect. Such samples and their sizes are presented in Table 3.

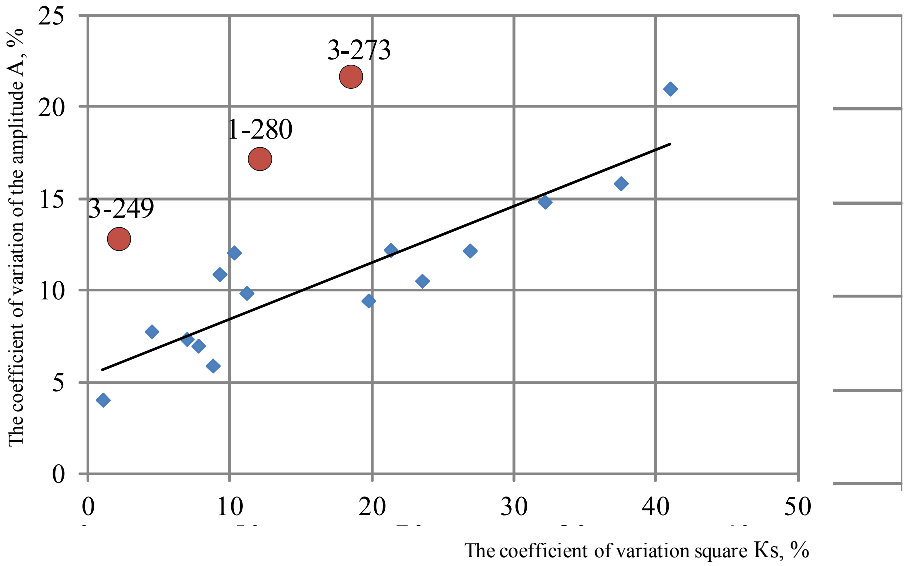
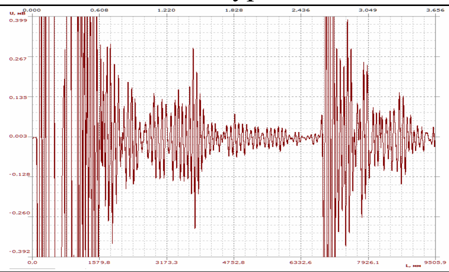
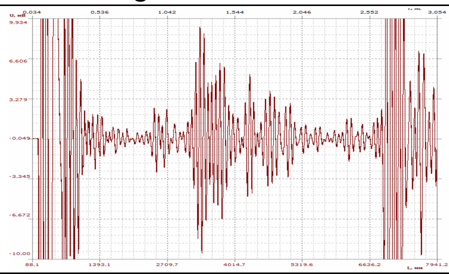
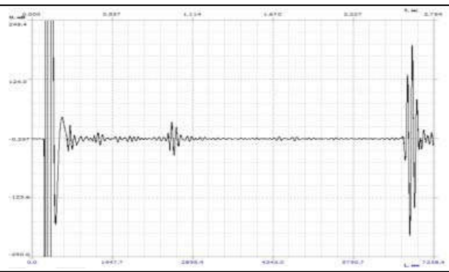


Figure 3. Dependence of amplitudes to defects squares

Table 3. Defects types and sizes

View of the defect	Echogram
Sample number / Defect size, mm / Defect type	
	
3-249 / 13x9 / Thickening	
	
3-273 / 6x13/ Inflow	
	
1-280 / 10x13/ Node	

Defects 3-249, 1-280, 3-273 on the echogram are expressed by a large signal, probably due to not visible internal breaking of the section.

CONCLUSION

Acoustic guided wave testing is applicable for composite fiberglass fittings defectoscopy with the use of a rejection level of 2 %.

The main types of defects detected are: a deficiency or excess of epoxy resin (44 %), delamination (5.5 %), fiberglass thread breakage (22 %).

Along with the apparent dependence between the size of the defect and the amplitude of the echo signal from the defect, samples that “fall out” of this dependence are found, characterized by the presence of internal defects. The percentage of such "fall out" samples was 16 %.

The technology of production of composite fittings assumes the obligatory restoration of the fiberglass thread breakage, while the technological process stops, which is determined by the defectoscope. For the case of responsible use of armature, the removal of fragments with such defects must be mandatory and unimportant in case of domestic use.

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REFERENCES

1. Grakhov, V. P., & Saidova, Z. S. (2017). Technique for determining the degree of cure in composite polymer reinforcements. *Intelligent Systems in Manufacturing, 15*(1), 96–98. doi:10.22213/2410-9304-2017-1-96-98.
2. Murashov, V. V., & Generalov, A. S. (2014). Testing of multilayer adhesive structures using low-frequency acoustics methods. *Aviation Materials and Technologies, 31*(2), 59–67.
3. Klyuev, V. V. (Ed.). (2006). *Non-destructive testing. Reference book in 8 volumes.* Moscow, Russia: Spektr.
4. Bergmann, L. (1954). *Der ultraschall und seine anwendung in wissenschaft und technik [Ultrasound and its application in science and technology].* Stuttgart: Hirzel. (in German).
5. Trifonova, S. I., Generalov, A. S., & Dalin, M. A. (2017). Sovremennyye tekhnologii i sredstva tenevogo ul’trazvukovogo kontrolya polimernykh kompozitsionnykh materialov [Modern technologies and means of shadow ultrasonic testing of polymeric composite materials]. *Tekhnologiya Mashinostroeniya [Mechanical-Engineering Technology], 2017*(7), 37–43 (in Russian).
6. Murav’eva, O. V., Murav’ev, V. V., Strizhak, V. A., Murashov, S. A., & Pryakhin, A. V. (2017). *Akusticheskiy volnovodnyy kontrol’ lineyno-protyazhennykh ob”yektov [Acoustic guided wave testing of linearly extended objects].* Novosibirsk, Russia: SB RAS Publ. (in Russian). ISBN 978-5-7692-1560-5.
7. Budenkov, G. A., Nedzvetskaya, O. V., Zlobin, D. V., & Lebedeva, T. N. (2004). The application efficiency of rod and torsional waves for checking rod-shaped roll stock. *Russian Journal of Nondestructive Testing, 40*(3), 147–151. doi:10.1023/B:RUNT.0000040171.56679.6b.
8. Murav’eva, O. V., Murashov, S. A., & Len’kov, S. V. (2016). Torsional waves excited by electromagnetic–acoustic transducers during guided-wave acoustic inspection of pipelines. *Acoustical Physics, 62*(1), 117–124.
9. Murav’eva, O. V., & Zlobin, D. V. (2013). The acoustic path in the method of multiple reflections during nondestructive testing of linearly extended objects. *Russian Journal of Nondestructive Testing, 49*(2), 93–99. doi:10.1134/S1061830913020058.
10. Murav’eva, O. V., Len’kov, S. V., Murav’ev, V. V., Myshkin, Y. V., & Murashov, S. A. (2016). Factors that affect the excitation effectiveness of torsional waves during waveguide inspection of pipes. *Russian Journal of Nondestructive Testing, 52*(2), 78–84. doi:10.1134/S1061830916020066.
11. Myshkin, Yu. V., & Muraveva, O. V. (2017). The features of the guided wave excitation and propagation at testing of pipes. *Journal of Physics: Conference Series, 881*(1), 012019. doi:10.1088/1742-6596/881/1/012019.

12. Muraveva, O. V., Myshkin, Y. V., & Lenkov, S. V. (2016). Factors affecting attenuation of torsional waves in pipes loaded on contact viscoelastic media. *Russian Journal of Nondestructive Testing, 52*(9), 485–491. doi: 10.1134/S1061830916090035.

13. Murav'ev, V. V., Murav'eva, O. V., Strizhak, V. A., Pryakhin, A. V., & Fokeeva, E. N. (2014). An analysis of the comparative reliability of acoustic testing methods of bar stock from spring steels. *Russian Journal of Nondestructive Testing, 50*(8), 435–442. doi:10.1134/S1061830914080063.

14. Budenkov, G. A., Korobeinikova, O. V., Kokorin, N. A., & Strizhak, V. A. (2007). Opyt priemochnogo akusticheskogo kontrolya i uprochneniya nasosnykh shtang pri servisnom obsluzhivanii [Experience of acceptance acoustic control and hardening of pump rods at the time of maintenance service]. *V mire nerazrushayushchego kontrolya [NDT World],* 2007(4), 14–19 (in Russian).

15. Murav'eva, O. V., Strizhak, V. A., Zlobin, D. V., Murashov, S. A., Pryakhin, A. V., & Myshkin, Yu. V. (2016). Acoustic waveguide testing of downhole pumping equipment elements. *Oil Industry, 2016*(9), 110–115.

16. Strizhak, V. A., Pryakhin, A. V., Khasanov, R. R., & Efremov, A. B. (2017). Hardware-software complex for rods control by mirror-shadow method using multiple reflections. *Journal of Instrument Engineering, 60*(6), 173–178 (in Russian). doi: 10.17586/0021-3454-2017-60-6-565-571.

17. Muraviev, V. V., Strizhak, V. A., & Hasanov, R. R. (2016). Features of the software for the hardware-based system of acoustic tensometry and structural inspection of metal products. *Intelligent Systems in Manufacturing, 14*(2), 71–75 (in Russian).

18. Murav'eva, O. V., Strizhak, V. A., Zlobin, D. V., Murashov, S. A., & Pryakhin, A. V. (2014). Tekhnologiya akusticheskogo volnovodnogo kontrolya nasosno-kompressornykh trub [Technology of acoustic waveguide inspection of pumping and compression pipes]. *V mire nerazrushayushchego kontrolya [NDT World], 66*(4), 51–56 (in Russian).

19. Budenkov, G. A., & Nedzvetskaya, O. V. (2004). Principal regularities of Pochhammer-wave interaction with defects. *Russian Journal of Nondestructive Testing, 40*(2), 99–108. doi: 10.1023/B:RUNT.0000036552.46582.a0.

20. Muraveva, O. V., Strizhak, V. A., & Pryakhin, A. V. (2014). The effect of regular differences in a cross section on the testability of a rod tested by the acoustic waveguide method. *Russian Journal of Nondestructive Testing, 50*(4), 219–226. doi:10.1134/S1061830914040068.

21. Budenkov, G. A., Nedzvetskaya, O. V., Zlobin, D. V., & Murashov, S. A. (2006). Interaction of torsion waves with longitudinal cracks in tubes. *Russian Journal of Nondestructive Testing, 42*(6), 392–397. doi:10.1134/S1061830906060064.