Investigation of the complex granulometric composition of suspended particles in seawater

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Abstract. The material for our study was collected at the Far Eastern Federal University, Ajax Bay, Sea of Japan and studied at the St. Petersburg Polytechnic University of Peter the Great. The main indicators of the genesis of marine sediments are the complex granulometric composition of suspended particles. However, their study has not been widely used in marine oceanology research. The purpose of this work is to study, using the Analysette 22 NanoTec plus (Fritsch) laser particle analyzer, the granulometric composition of suspended particles formed during underwater welding and cutting using welding wire. The presence of micro-sized particles, which are extremely dangerous for human and animal health, is shown. According to the results of the study, it is shown that during underwater welding, particles with a diameter of less than 10 microns occur in fractions from 30 to 60%. This level of pollution can have a negative toxicological effect on representatives of aquatic organisms of marine ecosystems.

1 Introduction

This article focuses on the study of the complex particle size distribution of suspended particles in sea water formed by underwater welding with the help of welding wire and continues the series of our works on the study of the negative impact on the environment [1]. The range of chemical elements when using a special wire for underwater welding is much wider in comparison with the particles formed when using electrodes. For example, components (Mn, K,Na, Cl, etc.) appear in significant quantities, which can be toxic to the marine environment at high levels [1]. The method of underwater welding has also found its wide application, due to the fact that in some cases it is impossible to lift un-derwater structures to the water surface with transportation to dry docks for scheduled or emergency repair work, so it is necessary to carry out high-quality work underwater. It should be noted

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that the underwater welding method has a number of peculiarities, usually related to limited space and time to perform the work.

Underwater welding is used in various industries, the developed technological solutions allow to quickly and efficiently perform repair and installation works in shipbuilding, construction and operation of hydraulic structures [2-4]. Various methods of underwater metal welding are used to carry out these works [5]. An indispensable attribute of underwater welding operations is the formation of suspended particles [6], which are formed by the chemical reaction of calcium and magnesium salts in seawater with metals released during underwater welding [1, 7-9]. For timely analysis of anthropogenic load on marine ecosystems, it is necessary to thoroughly and comprehensively study the composition of particulate matter produced by underwater welding. The works [10, 11] discuss underwater welding technologies and alloy composition, but do not consider the negative impact on the environment.

Various welding components are investigated using Euler and Lagrangian methods [12]. Using the Taguchi method, a simple and computationally efficient method for optimizing the friction stir welding process parameters of 6061 aluminum alloy (FSW) is presented. In particular, this Taguchi method shows how to minimize the distance from the heat affected zone (HAZ) to the weld line in the parts to be joined [13]. The toxicity of welding fumes depends on their composition and reactivity. The aim of this study was to investigate the effect of sodium, which are intentionally added to powder electrodes for welding stainless steel, on the solubility (in physiological solution with phosphate buffer) and toxicity of the resulting welding fume particles.

Slag-protected methods, which have been found to generate the highest levels of airborne particulates and Cr(VI), are potentially the most harmful [14]. With ever-tightening restrictions placed to protect workers, measures to minimize human exposure are critical. It has been confirmed that respirable particles are less acutely toxic in HBEC-3kt cells compared to standard powder wires. The highest cell viability (survival rate) was observed in the metal core wire [14]. Acute-angle nano- and microparticles are extremely cytotoxic, capable of damaging body cells and tissues [15].

The aim of the work was to analyze particle size from anthropogenic impact during metal work under sea water using laser granulometry and the author's sampling technique.

2 Materials and methods

For this experiment, 20 water samples were collected from the surface layer 30 m from the shore off Ajax Bay, Sea of Japan (Figure 1).

Fig. 1. Location of the seawater sampling point.

Samples were delivered to the laboratory where the experimental setup is located using 2.7 liter samplers.

The particles used in the experiment were obtained by welding and cutting metals in seawater using special flux cored welding cladding wire PPS-APL2 D-1.6 mm (technical requirements 1274-001-83763787), speed - 265 mm/min. A "VD-309P welding rectifier" was used as a welding machine. Samples were taken after 60 sec, which corresponds to the burning time of 1 electrode for underwater welding.

Table 1. Samples of welding suspensions.

Code designation	Definition	Description
WE	Welding Electrode	Manual electric arc welding using Arcair size 5/32X14 (3.97 x 356 mm) electrodes cat.no.:42-984-004. A sample was taken after 60 seconds of welding
WW	Welding Wire	Welding with PPS-APL2 wire (1.6 mm) of steel plate grade 20, dimensions 300x100x80 mm, direct polarity method with a current of 180 amperes and voltage of 32 volts. Welding angle 90±15°, speed 20 mm per minute. A sample was taken after 60 seconds of welding
CE	Cutting Electrode	Hand cutting using Arcair size 5/16X14 (8.0 x 356 mm) electrodes cat.no.:42-059-007. A sample was taken 60 seconds after welding started
CW	Cutting Wire	Cutting by wire PPR-APL1 (2.0) of steel plate grade 20, dimensions 300x100x80 mm, direct polarity method with a current strength of 280-300 amperes and a voltage of 37 volts. Welding angle 90±15°, speed 0.18-0.20 m per minute. Two samples were taken after 60 seconds from the start of cutting

Sampling from the experimental setup was carried out in seawater before and after welding and cutting, where particle samples were taken in 5 repetitions for particle size analysis on a laser particle analyzer Analysette 22 NanoTec plus (Fritsch). Repetitions are shown in tables and graphs by numbers from 1 to 5.

This laser particle size analyzer is a universal instrument for measuring particles up to the nanoscale, suitable for all standard measurement tasks in the range of 0.01-2000 μm. To investigate particles, the analyzer uses the principle of diffraction of semiconductor laser radiation on dispersed samples with green light (532 nm, 7 mW): when hitting a powder particle, the laser beam is deflected by some angle depending on the particle size. The scattered beam then hits the detector. Measurement of the intensity of the radiation hitting each element of the detector and subsequent mathematical processing of the signal make it possible to determine the size of the sample particles and estimate their shape. The intensity of the radiation absorbed by the detector is measured and the results are mathematically processed. The mathematical processing is performed using the Mie model, which assumes that radiation can pass through the particle [16]. Calculation by this model provides more accurate results.

In this work, a 0.82 x 0.46 x 0.38 m welding bath made of organic glass with 1 cm wall thickness was used. The filling volume of seawater was 60 liters. A steel plate was used as a welding material.

Depending on the metal to be welded and its thickness, inert or active gases or their mixtures are used as shielding gases. Due to the physical characteristics, welding stability and process properties are higher when DC current with reverse polarity is used. When using direct current with forward polarity, the amount of molten electrode metal increases by 30%, but the welding stability is significantly reduced, and metal spatter losses increase. Samples for particle size analysis were washed from seawater by successive centrifugation, addition of distilled water and resuspension. The process was repeated 20 times. To study the isolated particles, their suspensions of 10 μl were spread on a copper grid coated with Formvar film and then dried at room temperature. The spectra were collected for 300 seconds.

3 Results and discussion

Data on particle size distribution of suspended particles without anthropogenic impact are summarized in Table 2.

Table 2. Particle size distribution of suspended particles in seawater without anthropogenic impact.

Predominant fraction of microparticles (Q3(x)), %	Fraction (x), µm	Sum of fractions, %	Particle size composition of samples, %*				
			1	2	3	4	5
10	294.3	65.9	73.7	232.5	120.5	549.9	495.2
20	542.0	13.0	510.8	527.0	442.6	655.3	574.2
30	606.9	11.2	585.9	593.4	507.9	718.1	629.3
40	659.2	10.5	643.1	646.6	557.3	771.9	677.2
50	707.7	9.9	695.2	696.3	602.3	822.2	722.4
60	756.8	9.6	745.9	745.3	648.2	874.9	769.9
70	810.7	9.2	802.6	800.7	697.5	932.2	820.2
80	875.1	8.9	870.4	866.8	753.8	999.6	885.0
90	967.3	8.7	965.7	960.3	833.8	1100.3	976.1

* Numbers from 1 to 5 indicate the sampling repetitions.

Table 2 shows the results of suspended particle fraction composition in seawater without anthropogenic impact (background values) on Analysette 22 NanoTec analyzer, where significant differences are observed between the results of complex particle size distribution in underwater welding and cutting (Tables 2-6), where the predominant 10 % includes particles over 294.3 μm.

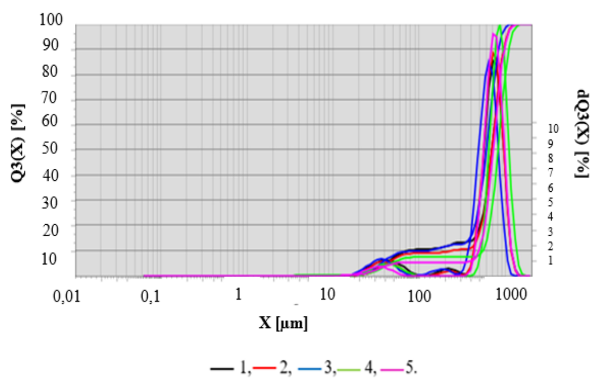

Fig. 2. Cumulative curve of background measurements of particle size distribution of suspended particles without anthropogenic impact.

The predominant particle fraction of 10 % is not hazardous to the environment, the data are shown in Figure 2. The cumulative curve shows peak values of 294.3 µm particles in all samples with a predominant fraction of particles mainly 10 % and no particles of 10 µm. Studies of particle size distribution of suspended particles after anthropogenic impact were carried out (Tables 3-6).

Table 3. Particle size distribution of suspended particles after underwater wire welding.

Predominant fraction of microparticles (Q3(x)), %	Fraction (x), µm	Sum of fractions, %	Particle size composition of samples, %*				
			1	2	3	4	5
10	1.8	65.3	3.9	1.9	1.3	1.0	0.7
20	3.2	57.8	6.6	3.5	2.5	1.9	1.5
30	4.6	51.7	9.0	5.1	3.7	2.9	2.3
40	6.1	46.9	11.4	6.7	5.0	4.1	3.4
50	7.8	43.5	14.0	8.5	6.5	5.4	4.5
60	9.9	41.4	17.3	10.9	8.4	7.0	5.7
70	13.0	40.8	22.5	14.7	11.3	9.3	7.3
80	345.0	113.7	812.6	837.9	37.2	27.6	9.7
90	964.9	7.8	1047.5	1051.9	877.3	963.1	884.7

* Numbers from 1 to 5 indicate the sampling repetitions.

Table 3 lists the results of determining the complex composition of suspended particle fractions after underwater wire welding on Analysette 22 NanoTec analyzer, where the predominant 70 % includes the fraction of more than 13 microns, and the predominant fraction of 60 % contains particles greater than 9.9 microns (PM10) which are hazardous to the environment. According to the data of particle size distribution of suspended particles after underwater welding, it can be concluded that the environmental situation in the marine environment is deteriorating.

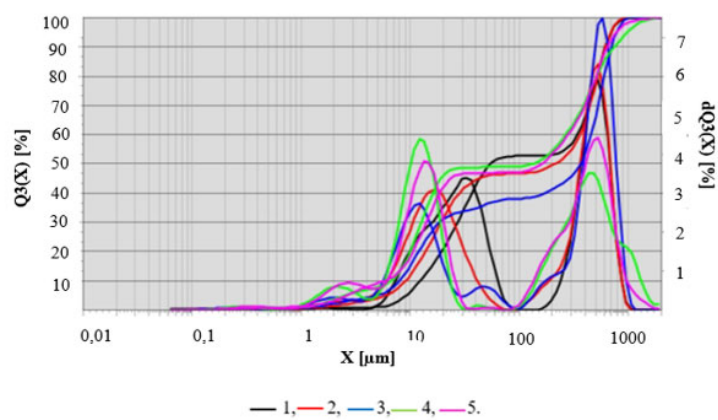

Fig. 3. Cumulative curve of suspended particle size distribution after underwater wire welding.

Figure 3 shows the cumulative particle size distribution curve of suspended particles after underwater wire welding, which is a visualization of the mathematical model of the measurement results in Analysette 22 NanoTec plus (Fritsch). The cumulative curve shows peak values of 9.9 µm microparticles in all samples with a predominant particle fraction of 60 %.

Table 4. Particle size distribution of suspended particles after underwater wire cutting.

Predominant fraction of microparticles (Q3(x)), %	Fraction (x), µm	Sum of fractions, %	Particle size composition of samples, %*				
			1	2	3	4	5
10	5.2	42.4	9.3	5.5	4.3	3.7	3.2
20	7.9	37.9	13.4	8.7	6.7	5.9	5.0
30	10.2	35.6	16.8	11.3	8.8	7.7	6.6
40	12.5	33.5	20.0	13.8	10.8	9.6	8.2
50	14.9	31.6	23.3	16.4	13.0	11.5	10.1
60	17.6	29.8	27.0	19.2	15.4	13.8	12.4
70	20.8	27.7	31.3	22.4	18.3	16.6	15.3
80	25.0	25.6	36.7	26.6	21.9	20.5	19.1
90	31.6	22.6	44.9	32.9	27.5	27.9	24.8

* Numbers from 1 to 5 indicate the sampling repetitions.

Table 4 shows the results of determining the complex composition of suspended particle fraction after underwater wire cutting on Analysette 22 NanoTec analyzer, where the predominant 30 % of microparticles includes the fraction of more than 10.2 µm (PM10), and the predominant fraction of 20 % contains particles less than 7.9 µm which are hazardous for the environment. According to the data of particle size distribution of suspended particles after underwater cutting, it can be concluded that the environmental situation in the marine environment is deteriorating.

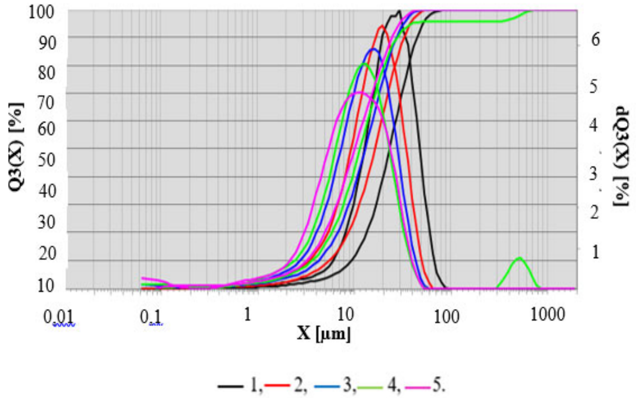

Fig. 4. Cumulative curve of suspended particle size distribution after underwater wire cutting.

Figure 4 shows the cumulative particle size distribution curve of suspended particles after underwater cutting, which is a visualization of the mathematical model of the measurement results in Analysette 22 NanoTec plus (Fritsch). The cumulative curve shows peak values of 10.2 µm microparticles in all samples with a predominant particle fraction of 30%. For comparison, we performed a series of similar tests using arc welding with Arcair size electrodes. The particle size distribution data are presented in Tables 5-6.

Table 5. Particle size distribution of suspended particles in seawater after underwater electrode welding.

Predominant fraction of microparticles (Q3(x)), %	Fraction (x), µm	Sum of fractions, %	Particle size composition of samples, %*				
			1	2	3	4	5
10	4.1	24.5	6.0	4.0	4.0	3.8	2.9
20	7.1	16.2	8.7	6.3	6.9	8.0	5.5
30	9.8	14.2	10.9	8.1	9.0	11.9	9.1
40	12.1	15.4	13.0	9.8	10.8	15.2	11.8
50	14.5	17.7	15.4	11.5	12.7	19.0	14.1
60	18.0	26.9	18.4	13.5	14.7	27.1	16.4
70	185.1	179.4	24.2	16.0	17.0	849.5	18.9
80	375.8	116.2	838.1	20.1	20.4	977.9	22.6
90	926.7	13.8	1021.7	882.1	775.5	1124.2	829.8

* Numbers from 1 to 5 indicate the sampling repetitions.

Table 5 shows the results of the determination of the complex compo-sition of the suspended particle fraction after underwater electrode weld-ing on the Analysette 22 NanoTec analyzer, where the predominant 30 % fraction includes particles of 9.8 µm (PM10), which are hazardous for the environment.

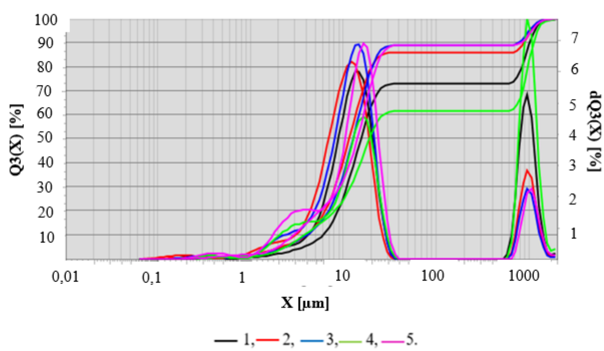

Fig. 5. Cumulative curve of particle size distribution of suspended particles after underwater electrode welding.

Figure 5 shows the cumulative particle size distribution curve of sus-pended particles after underwater welding, which is a visualization of the mathematical model of the measurement results in Analysette 22 Nano-Tec plus (Fritsch). The cumulative curve shows peak values of 10 µm microparticles in all samples with a predominant particle fraction of 30 %.

Table 6. Particle size distribution of suspended particles in seawater after underwater electrode cutting.

Predominant fraction of microparticles (Q3(x)), %	Fraction (x), µm	Sum of fractions, %	Particle size composition of samples, %*				
			1	2	3	4	5
10	1.8	16.0	2.3	1.8	1.5	1.6	2.0
20	5.1	23.2	5.3	4.5	3.7	4.9	7.2

30	9.1	21.0	9.0	7.8	7.0	9.4	12.6
40	161.7	182.5	13.5	13.5	11.2	18.5	751.8
50	784.9	7.1	696.2	803.9	751.6	817.9	855.1
60	895.4	3.1	858.7	902.9	870.0	909.8	935.6
70	984.1	2.0	959.9	989.3	964.6	993.6	1013.3
80	1082.5	1.4	1064.9	1087.0	1066.1	1089.9	1104.6
90	1221	1.1	1208.2	1223.5	1206.5	1225.3	1241.8

* Numbers from 1 to 5 indicate the sampling repetitions.

Table 6 shows the results of the determination of the complex composition of the suspended particle fraction after underwater cutting with electrodes, where it is observed that the predominant 30 % fraction includes 9.1 µm particles (PM10) which are hazardous for the environment.

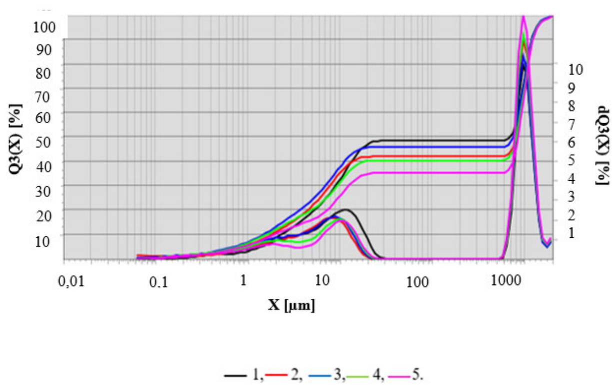

Fig. 6. Cumulative curve of particle size distribution of suspended particles after underwater electrode cutting.

Figure 6 shows the cumulative particle size distribution curve of suspended particles after underwater welding, which is a visualization of the mathematical model of the measurement results in Analysette 22 NanoTec plus (Fritsch). The cumulative curve shows peak values of 9.1 µm microparticles in all samples with a predominant particle fraction of 30 %.

When comparing the results of underwater welding and cutting (Tables 5-6) obtained with Arcair size electrodes, it is found that for underwater cutting and welding, the predominant 30 % fraction contains almost the same particle size of 9.1-9.8 µm. When considering the predominant 40 % particle fraction, it can be assumed that for cutting, suspended particles with a fraction size of 161.7 µm are less hazardous than welding particles with a fraction size of 12.1 µm. If we compare welding methods, it is obvious that wire welding releases 2 times more microparticles into the environment than electrode welding, and it is found that the cutting process releases less microparticles into the environment than the welding process.

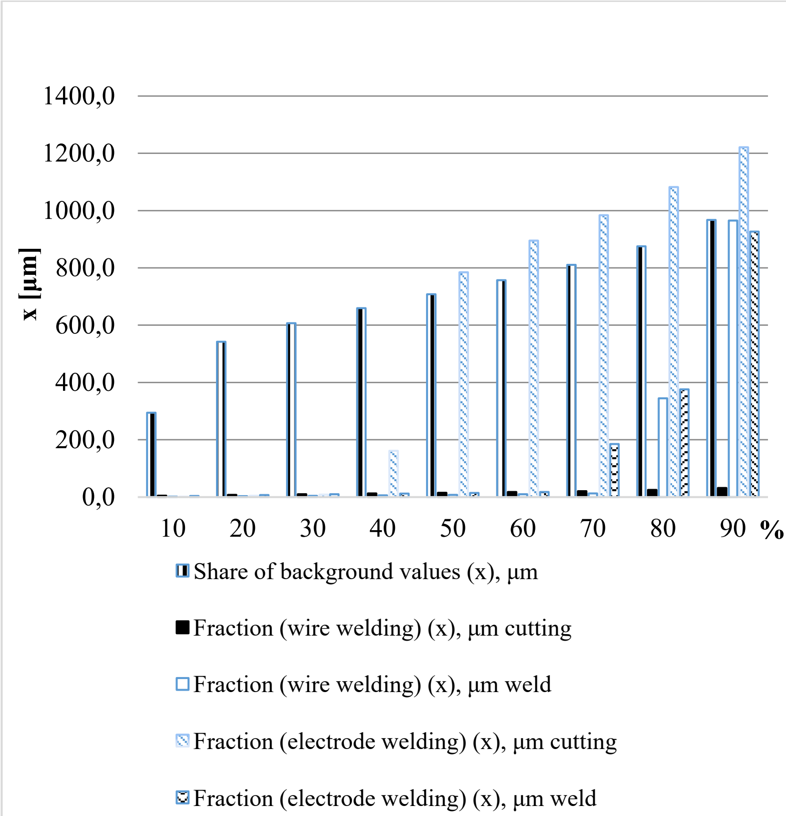

Fig. 7. Comparative histogram of particle size distribution before and after welding and wire cutting.

The comparative histogram of the results of measurements of particle size distribution of suspended particles in Figure 7 shows that under anthropogenic impact mainly hazardous substances with the sizes less than 10 µm are emitted during underwater welding, whereas no such particles are observed at background indicators.

It can be seen that underwater seawater wire welding shows a predominant particle emission (60 %) up to 9.9 µm (PM10). In underwater cutting in seawater, the emission of a predominant fraction of particles (30%) up to 10.2 microns (PM10) is observed. According to the results, it is found that underwater welding exceeds the hazardous fraction of particles (PM10) twice compared to underwater cutting. Particles up to 960 µm are encountered, which are the aggregations of primary particles with finer fractions obtained by natural coagulation process. Russian Federation and many other countries have adopted standards and protective equipment for welders, which regulate emissions into the atmospheric air [8]. Norms on particle discharges into the marine environment from these technological processes have not been developed. Technogenic activities such as underwater welding and cutting are a source of particles that are extremely hazardous to human health and the environment (Figure 1-4, Table 1-4). In order to develop a regulatory framework for emissions, data are needed to develop threshold concentrations and values based on an assessment of the toxicological impact of anthropogenic particles from underwater welding on marine organisms.

Based on the data obtained, we can definitely conclude that such type of work as underwater welding, being a contributor of PM10 fractions to the air of Vladivostok, is the main criterion that worsens the quality of life of its residents. In connection with the implementation of the state program "Energy Efficiency, Development of Gas Supply and Energy in Primorsky Krai" for 2020-2027, the amount of fine dust emitted into the atmosphere will only increase, and the environmental situation in this city, accordingly, can only worsen.

4 Conclusion

According to the results of the study it is shown that during underwater cutting in seawater from the Sea of Japan particles with a diameter of less than 10 μm occur in a fraction of 30 %. During underwater welding in seawater the predominant 60 % fraction contains particles with a diameter of less than 9.9 μm. In the study of water without anthropogenic impact, no particles with a diameter of less than 10 μm were found. The presence of particles of the smallest fractions of PM1-PM10 was detected in anthropogenic processes such as underwater welding and cutting. Wire welding releases 2 times more microparticles into the environment than electrode welding. The cutting process releases less microparticles into the environment than the welding process.

The level of microparticles quantity can have a negative impact on representatives of marine life and affect the sustainability of marine ecosystems. It should also be noted that the study of the particle size distribution in seawater after underwater welding will allow further modeling of biogeochemical processes for operational monitoring under anthropogenic impact on the marine environment. Based on the obtained data, it will be possible in the future to develop compensatory measures and recommendations aimed at maintaining the balance stability of marine ecosystems under increasing anthropogenic load associated with the development of offshore shelves and laying of infrastructure communications for the transportation of hydrocarbons.

The work with these samples will be continued in the field of assessment of toxicological impact of particulate matter on living test objects, namely on representatives of marine biota and hydrobionts. These are the species that are exposed to anthropogenic particles from underwater welding, which can have toxicological effects on living organisms [17].

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