ASPHALT CONCRETE DURABILITY UNDER THE COMBINED ACTIONS OF LOADING AND HOSTILE ENVIRONMENT

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ABSTRACT

Asphalt concrete surfaces are subjected to the combined effects of stress and exposure to liquid media. The lifetime or durability criterion is used as a measure of the characteristics of the destruction of asphalt concretes under such conditions. Our research method involves the determination of the lifetime of asphalt concrete under hostile conditions, from the application of the initial load to its destruction. Different media were used to provide the hostile environments: water, aqueous solutions of NaCl, HCl, and H2SO4, and a surfactant solution.

The wetting contact angles of the media at different substrates, and the bitumen adhesion to them, were determined in the given media.

The level of harshness of the medium in relation to the lifetime of asphalt concrete was determined as the ratio of the asphalt concrete lifetime in the given medium to that in air. The lifetime under a fixed load while subjected to the medium decreased more for media that wetted the substrate better. The lower the load (i.e., the longer the lifetime of the sample), the greater the destructive action of the medium.

The dependence of stability against the action of these hostile media on the bitumen viscosity and content and on the asphalt concrete composition is presented.

Keywords: asphalt, bitumen, stress, adhesion

1. INTRODUCTION

The assessment of the durability of pavements, road surfaces and materials is one of the most important tasks in solving the problems of the creation of "eternal" roads. In relation to asphalt concretes, such assessment is possible through cyclic tests of fatigue and rut formation. The results of these tests, expressed in the number of loading cycles before failure or the maximum allowable plastic deformation (rut depth), represent the direct lifetime characteristics. The values of the time from the loading to breaking of asphalt concrete under a constant load for the given stress conditions have the same physical meaning.

The values of the indexes of durability, having dimensions of time, are much more sensitive to the peculiarities of the composition and structure of the asphalt concrete and the test conditions than the indexes of strength and deformation (rut depth). Thus, when the temperature was changed from 20 °C to 50 °C, the lifetime of asphalt concrete under the action of a certain shear stress decreased by 190-200 times, and when the asphalt concrete based on bitumen with a penetration of 185×0.1 mm was replaced with one based on bitumen with a penetration of 78×0.1 mm, the lifetime decreased by 7-8 times. At the same time, the shear strength in the first case decreased by 3.5-5.5 times, and in the second case by 1.8-2.0 times [1].

In the rut formation tests, a temperature change from 50 °C to 60 °C led to a 2.2-fold increase in the rut, and the number of loading cycles before a rut of 5 % was reached changed 12-fold [2].

The number of cycles to failure (***N***) for the cyclic fatigue tests and the lifetime (***t***) for loading in a wide stress range obeys the power dependence predicted by A. Wöhler [3] under cyclic loading and that predicted by W.E.S. Turner under static loading [4]:

$N = K\sigma^{-b}$

$t = B\sigma^{-b}$

where ***B***, ***K*** and ***b*** are constant coefficient values.

In terms of asphalt concrete, this follows from the data of A. M. Goglidze, who studied the character of the development of deformation under the action of different stresses. The axial tension tests lasted between 1.66 and 6635 min (i.e., 4.6 days). The results of the data analysis [5] are presented in Figure 1. They show that the power dependence of asphalt concrete lifetime on the load is much more acceptable than the exponential function. This agrees well with the dependence of asphalt concrete strength on the speed of deformation or loading. The most important reason for such behaviour of asphalt concrete is the competition between the speed of mechanical influence and the relaxation time of the stress.

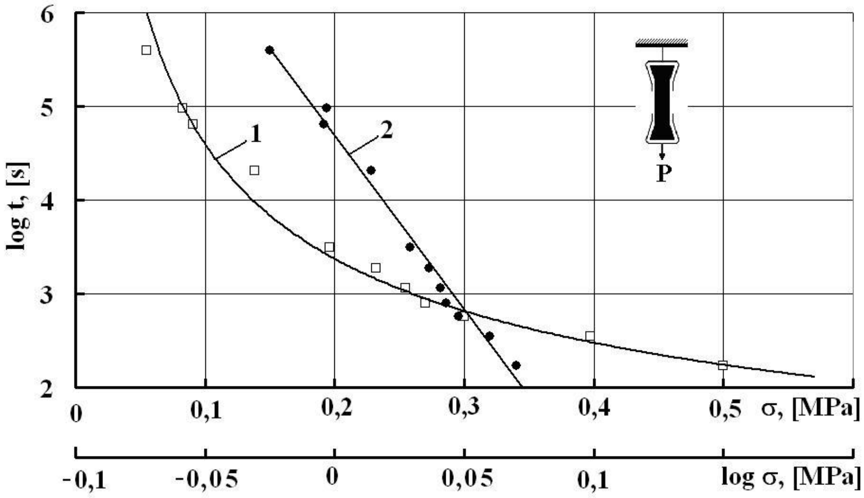

Figure 1: Presentation of the data of A. M. Goglidze in semilogarithmic (1) and logarithmic (2) coordinates

At the same time, the lifetime indexes of asphalt concrete, which are established only under the action of cyclic or static loading, do not reflect the particular conditions of its work in the road surface. Under real conditions, asphalt concretes coverings are subject to the action of water, solutions of various chemical substances (hostile liquid media), temperature, and other factors [6]. Thus, loading and hostile media act simultaneously on asphalt concrete surfaces. Such a combination is easily reproduced in laboratory tests on asphalt concretes by the static loading of samples in liquid environments.

In this research, we aimed to establish the laws governing the fracture of asphalt concrete under the simultaneous effects of different liquid aggressive media, and also the criteria for the evaluation of the stability under such conditions, which would be based on the lifetime of asphalt concrete specimens tested in hostile environments and in air.

2. RESULTS AND DISCUSSION

The experimental method consisted of the implementation of pure bending (Fig. 2) of asphalt concrete beams located in liquids under different loads. The determination of the lifetime under each load was carried out automatically within an error of up to 5 s. The experiments were conducted at a temperature of 21 °C. The mechanical load was implemented using six lever presses combined in a single setup. With the values of the stresses occurring in the samples and the corresponding lifetimes, the dependence shown in Figure 2 was found.

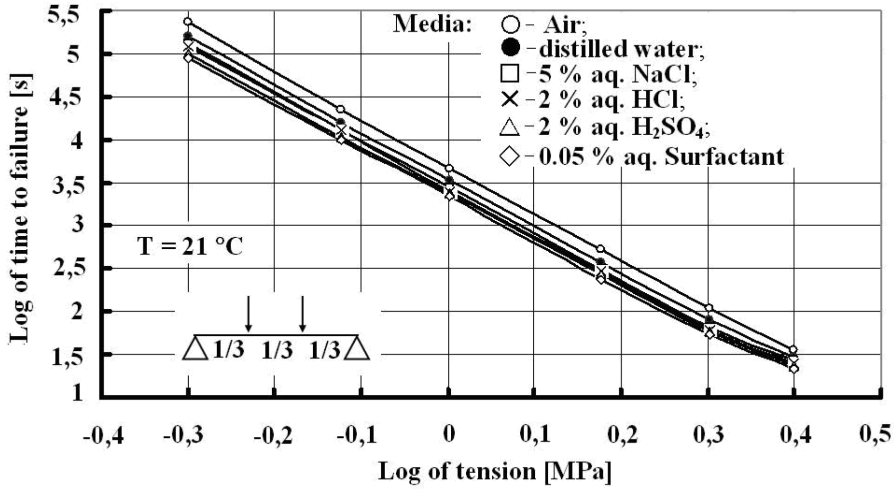

Figure 2: Dependence of time to failure on load for asphalt concrete of type "B" with 4.5% bitumen BND 60/90

The following media were taken as working environments: air, distilled water, aqueous solutions of rock salt (5 %), hydrochloric acid (2 %), and sulfuric acid (2 %), and the non-ionic surfactant OP-10 (polyoxyethylene ether of alkyl phenols) (0.05 %). The media investigated were chosen to represent real aggressive media encountered on roads: water as the main aggressive media as used in the method of M. Duriez'a; salt solutions that are widely applied as anti-ice agents; and acid solutions that are characteristic of industrial chemical liquids, waste water, and rainfall. A surfactant solution was employed to test the assumptions about wetting ability being the key factor in the process of bitumen delamination from the surface of the stone material (mineral aggregate) components of asphalt concrete.
The objects of study were mostly asphalts with 40 % rubble (based on bitumens of different penetrations obtained through oxidation of the same material).
On the basis of the preliminary studies the hypothesis was made that the extent of the action of the media is determined by its wetting ability in relation to the surfaces of rock materials and bitumens. The results presented in Table 1 show that the values of the contact angles for water and other media of hard substrates decrease on going from bitumen to marble and limestone, granite, quartz, and mica. The hydrocarbon content of bitumen ensures its practical hydrophobicity, while quartz and mica are ideally wetted because of their acidic nature. Marble and limestone are wetted much worse that granite. The same order is found for solutions of sodium salt and surfactants.

Table 1: Surface properties of hostile liquid media

Substrate	Contact angle (θ) in deg. of different surfaces in various media				
	Dist. water	Aqueous solutions			
		NaCl	HCl	H_2SO_4	Surfactant
Bitumen BND 40/60	88.8	80.9	61.6	57.7	34.4
Marble	64.6	63.1	-	-	33.8
Limestone	64.5	62.5	-	-	32.5
Granite	30.9	29.9	26.4	23.0	21.2
Quartz	16.2	14.0	12.1	10.1	9.3
Mica	16.5	12.2	15.4	14.6	7.2
Quartz glass	8.4	8.6	6.5	6.7	4.9
Surface tension (σ), mJ/m^2	72.59	72.90	70.01	69.00	28.17

In terms of the activity of the medium (according to the contact angle) the same tendency is observed for all the media: the lowest activity for water and salt solutions, a higher activity for acid solutions, and the highest activity for surfactant solutions (contact angle is the smallest on all substrates). This agrees well with the changes in the surface tensions of the media used (Table 1).
A natural consequence of such surface features of the media and substrates is the change in the adhesion of bitumen with them. The index of adhesion was determined from the proportion of surface covered with bitumen after holding in a medium for a given length of time (25 min) and at a given temperature (85 °C) [7]. The data presented in Table 2 show that the adhesion of bitumen with the substrate is greater when the wetting by the media is worse. This principle is confirmed for bitumens with different penetrations. The adhesion increases with increasing bitumen consistency. It is

highest on all substrates and in all media for bitumen with a penetration of 46×0.1 mm, and lowest for bitumen with a penetration of 269×0.1 mm.

Table 2: Adhesion of bitumens of different consistencies with mineral substrates in hostile media

Substrate	Adhesion (A) of bitumen with mineral surface in media, %				
	Dist. water	Aqueous solutions			
		NaCl	HCl	H_2SO_4	Surfactant
Penetration 46×0.1 mm					
Marble	100	100	-	-	91
Limestone	100	100	-	-	94
Granite	69	67	63	61	52
Quartz glass	47	46	44	45	36
Penetration 80×0.1 mm					
Marble	96	98	-	-	80
Limestone	100	100	-	-	83
Granite	62	61	60	58	45
Quartz glass	39	37	34	32	22
Penetration 143×0.1 mm					
Marble	92	90	-	-	65
Limestone	95	96	-	-	69
Granite	55	52	48	46	26
Quartz glass	29	26	24	23	7

The stabilities of the asphalt concretes were defined in terms of the lifetime to failure in different media under the same load, and the stability coefficient (K_a), which is the ratio of the lifetime in media (t_m) to that in air (t_a): $K_a = t_m / t_a$.

The changes in the lifetimes of asphalt concretes under loading in media can be reasonably well described by a power law. The contribution of the medium to the failure of the material is greater for smaller loads and longer lifetimes. Short lifetimes under loading do not allow the surface phenomena that occur in cracks and defects to take place. Also, the lifetime under loading follows the same order as that determined in the relationship between changes in contact angle of bitumens and substrates and in the relationship of the adhesion of bitumens with substrates in media: the smallest decrease in the shear strength factor is found in water, and the largest in the surfactant solution.

The resistance of asphalt concrete to the action of media is determined by the strength of the phase boundary between the bitumen and mineral material surface. The values of the adhesion with the surfaces of basic and acidic mineral materials show that carbonate rocks of all grades provide 31-38 % greater adhesion for bitumen than granite. At the same time, the decrease in penetration from 269×0.1 mm to 46×0.1 mm leads to a 15 % increase in the adhesion with granite in water and salt solutions, a 14-15 % increase in solutions of sulfuric and hydrochloric acid, and a 26 % increase in surfactant solution. In terms of the resistance to some media, carbonate rock materials are preferable. However, it is well known that their use is not advisable because of their poor durability.

The decrease in lifetime of asphalt concrete is determined by the detachment of the bitumen film from the surface of the stone material by media penetrating to the interface between phases through defects in the film formed during the preparation of the mixture (poor mixing) and/or during sealing because of breaks in the film and the crushing of the stone materials. Defects in the film may be formed during exploitation under the influence of climate and transport. In addition, corrosive discontinuity is possible under the influence of some media (especially acids). Taking into account the narrow range of rocks used for the mineral aggregate and the opportunities provided by modern petrochemical technologies in regulating the adhesive properties of bitumen, in this work we investigate the influence of the bitumen consistency on the lifetime of asphalt concrete under loading in different media.

The dependences presented in Figure 3 show that the stability coefficient in all media under a stress of 0.5 MPa decreases on going from bitumen with a penetration of 46×0.1 mm to bitumen with a penetration of 269×0.1 mm. The degree of aggressiveness of the media toward asphalt concrete corresponds exactly with their aggressiveness in relation to the adhesion of bitumens with substrates, and shows the same order: water, NaCl solution, HCl, H_2SO_4, surfactant. The aggressiveness of all media increases with decreasing bitumen consistency. Thus, the differences between the stability coefficients in water and in sulfuric acid are 0.19, 0.22, 0.24, and 0.3 for bitumens with penetrations of 46×0.1, 80×0.1, 143×0.1, and 269×0.1 mm, respectively. The same tendency is observed for the other media.

The increase in the bitumen content of asphalt concrete decreases the air porosity and the proportion of bare bitumen surfaces of the stone materials in the asphalt concrete. This hampers the access of liquid media to the phase boundaries and increases the stability of the asphalt concrete in such media (Table 3). On increasing the bitumen content in asphalt concrete from 4 % to 4.5 % and then to 5 %, the stability coefficient in water under a stress of 1 MPa increases from 0.71 to 0.76 and 0.8, respectively. In sulfuric acid solution, it increases from 0.33 to 0.52 and 0.54, respectively, and in surfactant solution, from 0.28 to 0.49 and 0.50, respectively. Consequently, the likelihood of damage by the action of the media increases with the increasing air porosity of asphalt concrete that is available to the media. In this respect, insufficient compaction of asphalt concrete could also be problematic.

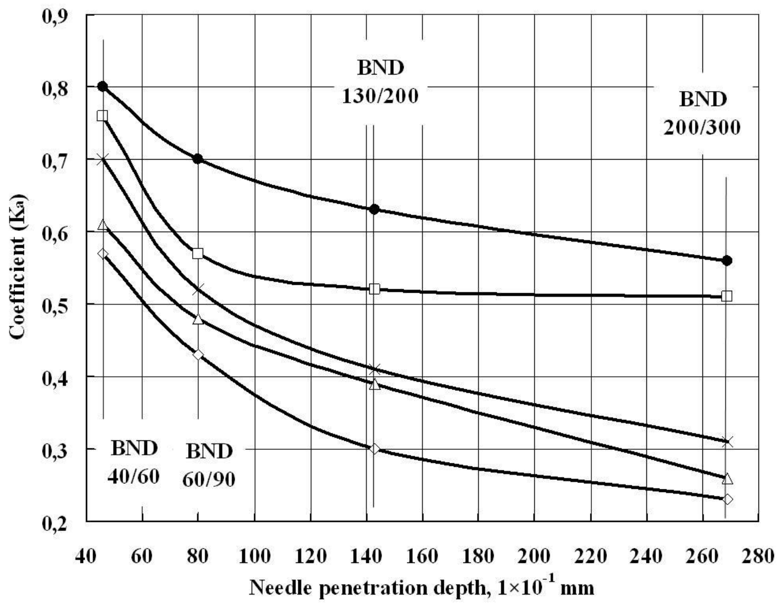

Figure 3: Dependence of stability coefficient in aggressive media (K_a) of asphalt concrete with 40 % mineral aggregate based on bitumens BND 40/60, BND 60/90, BND 130/200 and BND 200/300, under a stress of 0.50 MPa: ● – distilled water; aqueous solutions: □ – NaCl; × – HCl; △ – H_2SO_4; ◊– surfactant

Table 3: Effects of bitumen penetration on the failure of asphalt concrete in different media

Type of bitumen	Needle penetration depth at 25 °C, 1×10^{-4} m	Time to failure (s) and K_a in aggressive media				
		Air	Aqueous solutions			
			NaCl	HCl	H_2SO_4	Surfactant
BND 40/60	46	4.6×10^5	3.5×10^5	3.2×10^5	2.8×10^5	2.6×10^5
		K_a	0.76	0.70	0.61	0.57
BND 60/90	80	2.3×10^5	1.3×10^5	1.2×10^5	1.1×10^5	1.0×10^5
		K_a	0.57	0.52	0.48	0.43
BND 130/200	143	6.4×10^4	3.3×10^5	1.2×10^5	1.1×10^5	1.9×10^4
		K_a	0.52	0.41	0.39	0.30
BND 200/300	269	3.9×10^3	2.0×10^3	1.2×10^3	1.0×10^3	0.9×10^3
		K_a	0.51	0.31	0.26	0.23

The destructive effect of the media depends on the ambient temperature. This applies both to the coefficient of water resistance, determined according to the method of M. Duriez [8], and to the stability coefficient in media, determined by the method used here. On going from a temperature of 35 °C to 0 °C, the aggressive effects of all the media studied here not only slow down, but practically disappear (Fig. 4, Table 4), and the stability coefficient approaches unity. We can assume that this is connected with the increase in surface tension of the media with decreasing temperature. However, it is probable that, to a larger extent, this can be explained by the increase in the adhesive and cohesive links of the bitumen, with which the displacement effect of the media is not comparable. Also, with an increase in temperature to 35 °C, the values of the stability coefficient under a stress of 1.51 MPa decrease to 0.67 in water, 0.48 in NaCl solution, 0.4 in HCl solution, 0.35 in H_2SO_4 solution, and 0.3 in surfactant.

Table 4: Effects of temperature on the failure of asphalt concrete

Experiment temperature, °C	Time to failure of asphalt concrete (s) and K_a, in aggressive media under a stress of 1.51 MPa					
	Air	Distilled water	Aqueous solutions			
			NaCl	HCl	H_2SO_4	Surfactant
35	81	54	39	32	28	24
	K_a	0.67	0.48	0.40	0.35	0.30
21	1147	883	728	695	678	597
	K_a	0.80	0.76	0.70	0.61	0.57
10	16601	13682	13355	12346	12040	11094
	K_a	0.82	0.80	0.74	0.73	0.67

0	138012	137954	137932	137891	137877	137671
	K_a	1.0	1.0	1.0	1.0	1.0

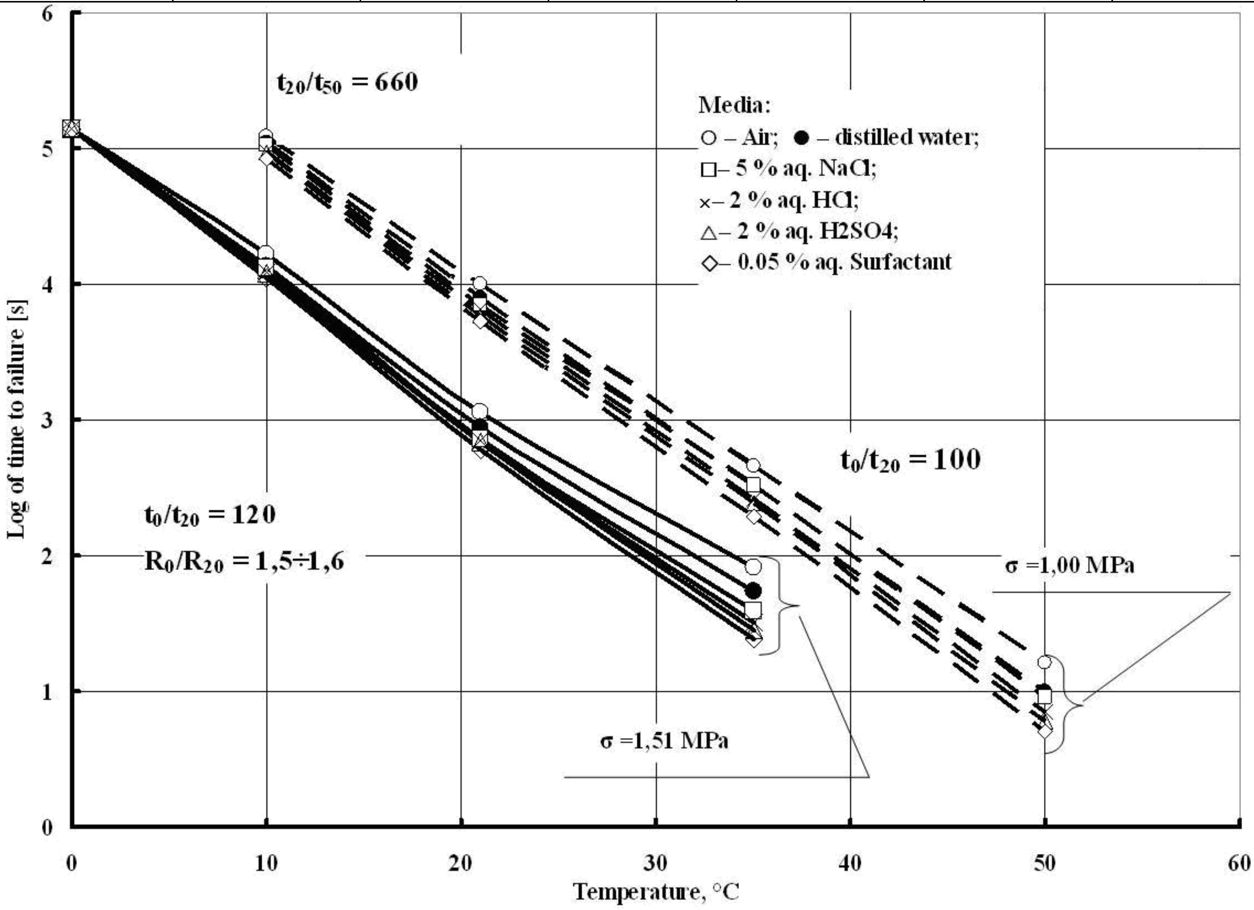

Figure 4: Dependence of time to failure of asphalt concrete with 40 % mineral aggregate and 5.0 % bitumen BND 40/60 on ambient temperature

Increasing the temperature from 20 °C to 50 °C under a tension of 1 MPa causes a decrease in the lifetime of asphalt concrete in air by a factor of 660, and increasing the temperature from 0 °C to 20 °C causes an increase in the lifetime by a factor of 120. The ratio of the indexes of compressive strength at these temperatures is in the range 3-4. For the most aggressive medium, the surfactant solution, the ratio of lifetimes at 0 and 20 °C is 230.
For the practical application of the stability coefficient of asphalt concretes under the simultaneous actions of loading and hostile liquid media and for the obtainment of comparable results, it is advisable to establish a uniform level of stress under a normalized deformation rate.

3. CONCLUSIONS

The lifetime of asphalt concrete under constant loading is extremely sensitive to the temperature, loading, type of working environment, and bitumen content and consistency. This time may be interpreted as an indicator of the static endurance or durability of asphalt concrete.
The lifetime of asphalt concrete is directly related to the wettability of the medium in relation to bitumen and the surface of the stone material, and also to the stability (adhesion) of the bitumen film on the surface of the stone material in the given medium. The better the medium wets the substrate and the lower the adhesion of the bitumen to the substrate in the medium, the lower the lifetime. The media are placed in the following order according to the degree of their impact on the lifetime: water, aqueous salt solutions, hydrochloric and sulfuric acid solutions, and surfactant solutions. The surfactant solution, having virtually no chemical effect on the interphase region (bitumen – mineral aggregate surface), results in the swiftest destruction of asphalt concrete under pressure because of its high wetting ability.
The lower the stress caused by the applied load, and accordingly, the lower the rate of crack development, the greater the influence of the medium on the durability of the asphalt concrete. The destructive action of the medium is determined by the relationship between the rate of destruction (crack formation) and the rate of wetting of the internal surfaces of the asphalt concrete, and also the rate of penetration of the medium through the continuous bitumen film on the surface of the rock materials or through technological defects in the film.
The development of an evaluation method for the stability of asphalt concretes in aggressive liquid media requires the establishment of an appropriate stress level which would both ensure the full participation of the media in the

destruction process and minimize the test time in which an acceptable practical value of the coefficient proposed in this work could be obtained.

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