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EFFECT OF OILING UP ON THE FAILURE OF CONCRETE DETERMINED BY ACOUSTIC EMISSION

J. HOŁA

Institute for Building Engineering
Wrocław Technical University
(Wybrzeże Wyspiańskiego 27, 50-370 Wrocław)

Results showing how the oiling up of concrete series, differing in their aggregate grading, affects their failure are presented. The acoustic emission was used in the test. The determined values of initiating stress, σ_i, and critical one σ_{cr}, in the oiled up concrete and the reference, unoiled up concrete prove that oiling up affects significantly the failure of the concrete. It has been found that the oiling up of concrete results in the reduction of the values of the initiating and critical stress compared to the values of these stresses in the reference unoiled concrete series. The tests have shown this reduction to be practically independent of the concrete's aggregate grading.

1. Introduction

There are frequent cases in industry that the floor and other structural components made of reinforced concrete become oiled up strongly by minearl oil leaking from the installations and production machines. It is commonly believed that mineral oils do not have a corrosive effect on concrete and reinforcing steel but they bring about changes in the physical and mechanical properties of concrete [1, 2, 3]. It has been established, for example, that oiling up has a negative effect on the compressive strength of concrete. A considerable oil-induced reduction in this strength is found when one examines and compares the strength of concrete specimens stored in oil with that of reference concrete specimens [2]. The few papers on this subject that have been published so far do not contain any test results which would allow one to formulate a definite opinion on the contribution of oiling up to the destructive processes that occur in the structure of concrete when it is loaded. This research problem has practically not been taken up yet, especially with respect to the determination of the effect of oiling up on the values of the initiating stress, σ_i, and the critical one σ_{cr}. The above stresses represent certain conventional levels of stress in loaded concrete; when they are reached characteristic phenomena associated with the appearance and the propagation of microcracks occur [4, 5, 6, 7, 8, 9]. According to

[5, 7, 8, 9], the intiating stress reaches values as high as the safe fatigue life of concrete and it can be defined as the lower limit of failure of concrete, whereas the critical stress is identified with the long-lasting strength of concrete [5, 6, 7, 8, 9].

One can expect that the oiling up of concrete should have a negative influence on the value of these stresses, particularly in the case of dynamic loads and shocks and other fatigue loads associated with technological processes or a changed function or purpose of a construction in which some structural components were oiled up in the past. The deep penetration of oil into the structure of concrete is undoubtedly easier when such loads occur. This phenomenon, in turn, contributes to the reduction of the concrete's cohesion and, as a result, to the observed loosening of its structure [1]. This fact seems to have more serious consequences in the case of porous concrete or concrete with a raised or high content of fine aggregate functions.

2. Description of tests

Three series of concrete — designated by the letter A, B and C — possessing similar compressive strength but differing sharply in the grading of the rounded aggregates, were tested. The sand point of the concrete A was 37.5%, that of the concrete B was 60%, whereas the concrete C had no gravel functions at all but 100% of sand. The compositions the same as in 10 of the particular concrete mixes from which the concrete series were made are given in Table 1. The tests were carried out on

Table 1. Compositions of the designed concrete mixes

Concrete mix composition	Designation of the mixes		
	A	B	C
Portland cement 35 from Górażdże Cement Plant [kg/m³]	321	350	469
Natural gravel [kg/m³]	1185	697	–
River sand [kg/m³]	711	1045	1480
Tap water [l]	178	194	257

100 × 100 × 100 mm cube specimens after 360 days. 24 specimens were made from each concrete mix. 12 of them were oiled up, whereas the other 12 ones served reference specimens. All the specimens after preparing were stored for 28 days in a climatic chamber at the air temperature of 18°C ± 1°C and relative humidity of 95% and then for the next 90 days in the laboratory at the air temperature of 18°C ± 3°C and relative humidity of about 65%. After this time, 12 specimens of each concrete batch, A, B, and C, were oiled up and labeled as series AO, BO and CO. The mineral oil Lux 10, having physical and chemical properties specified by the standard

PN-53/C-96085, was used. The specimens were oiled up by the following procedure. First, they were dried to a constant mass and then placed, by means of a cuvette, in a low pressure chamber in that the air temperature was 50°C. The specimens remained in the chamber for a period of about 24 hours under air pressure reduced to 0.006 MPa. Durign this time, the level of oil in the cuvette was raised gradually. Then the oiled up specimens were transferred to the laboratory and placed in a container with oil where they remained till the testing. The described treatment, by removing water and air from the pores and the capillaries of the concrete speeds up considerably the usually long-lasting process of complete oiling up of the concretes structure. The other concrete specimens were stored as reference specimens in the laboratory till the time of testing. They were labeled as series AL, BL and CL. Also $150 \times 150 \times 150$ mm specimens were made to determine the compressive strength of the tested series of concrete. They were stored in the same way as the $100 \times 100 \times 100$ mm specimens.

The acoustic emission was used in conjunction with the quasi-axial compression test. The setup for measuring the acoustic emission was the same as in [8]. The specimens were compressed without friction at the contact with the pressure plates of the testing machine. This was achieved by grinding the surfaces of the specimens and lubricating them with cup grease. During the tests counts sum versus stress increment was recorded.

3. Results and analysis of the tests

The strength tests carried out on the $150 \times 150 \times 150$ mm specimens of the tested concrete series yielded mean compression strength values complied in Table 2. This Table contains also the total porosity values determined for the conrete series. The compressive strength of the oiled concrete series was found to be about 10% lower in comparison with those of the free of oil reference concrete.

Table 2. Mean compressive strength values determined using $150 \times 150 \times 150$ mm specimens after 90 and 360 days of curing and results of the overall porosity tests after 90 days of curing

Designation of concrete series	Mean compression strength R [MPa]		Overall porosity after 90 days P [%]
	90 days	360 days	
AL	42.30	44.30	13.02
BL	41.90	43.90	15.06
CL	38.30	40.10	16.28
AO	–	42.45	–
BO	–	42.00	–
CO	–	38.60	–

The acoustic emission results given in Fig. 1 show that the variation of the counts sum versus the increment in the absolute value of stress is similar for all the tested

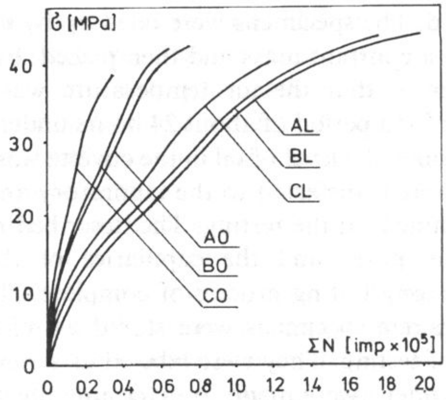

Fig. 1. The variation of the counts sum in the quasi-axially compressed oiled up concrete series AO, BO and CO and the unoiled up series AL, BL and CL as function of the increment in the absolute value of stress.

series of oiled and unoiled concrete. There are, however, marked differences between the values of this total both at the particular stress levels and during the whole process of destruction of the oiled and unoiled concrete. These differences grows the content of the fine aggregate in the concrete increases. For example, the counts sum recorded during the whole process of failure of the oiled concrete the AO series is about 2.65 times smaller than that of the AL ones and 3.60 times smaller for the CO concrete than for the CL one. This manifold reduction in the acoustic "activity" of the oiled concrete in comparison with the reference one can be attributed to the weaker cohesion and the loosening of the structure of the former concrete resulting from the oil penetration, this effect is reflected in the smaller amount of elastic strain energy released during the failure. The results of strength tests compiled in Table 2 corroborate the above statement. Also the damping of elastic waves by the oil filling the pores, capillaries and microcapillaries in the concrete contributes significantly to that reduction. The contribution of this factor certainly grows as the overall porosity of concrete increases. A qualitative analysis of the graphically recorded single acoustic pulses emitted during the destruction of the concrete seems to confirm the above interpretation of the reduced acoustic activity of the oiled concrete in comparison with the unoiled reference concrete. A comparison of such pulses recorded graphically for the concrete series AO and AL at the relative stress levels of 0.15, 0.40 and 0.90 σ/R is presented, as an example, in Fig. 2. It follows from this figure that the amplitude of signals is substantially lower and the duration of the signals is shorter or the oiled concrete than for the unoiled one.

To get a more complete picture of the changes in the failure of the oiled concrete series as compared with the reference concrete, the values of initiating stress σ_i and critical stress σ_{cr} in them were determined on the basis of the counts sum recorded during the destruction process. For this purposes, the intensity of this total versus stress increment was determined using the relation and description given in [11, 12]. Figures 3, 4, and 5 show how the intensity of the counts sum IN changes as a function

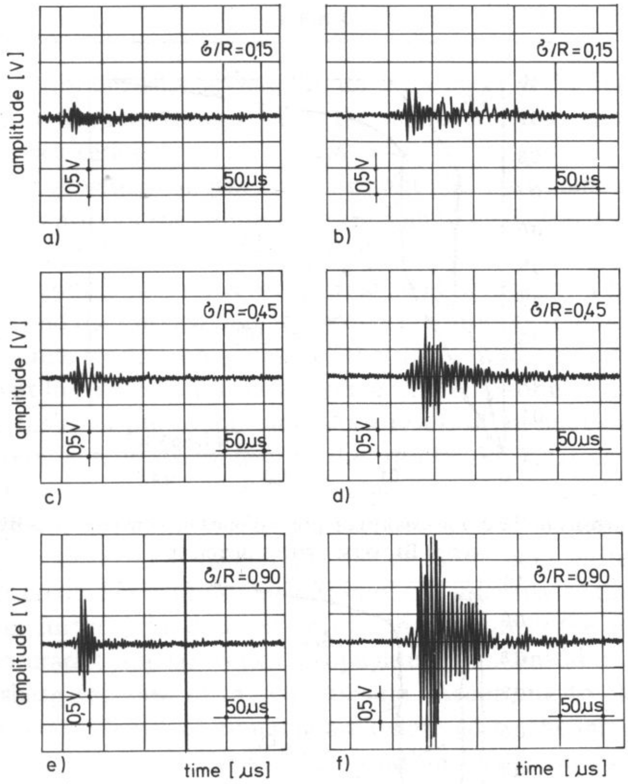

Fig. 2. Graphic recordings of the acoustic emission pulses: a, c, e — in oiled up concrete series AO; b, d, f in the unoiled up concrete series AL.

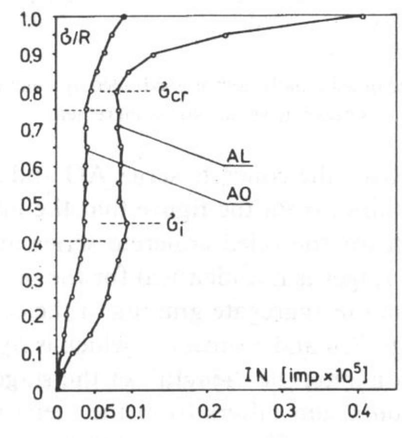

Fig. 3. Counts sum intensity in the quasi-axially compressed oiled up concrete series AO and the unoiled up series AL versus stress increment.

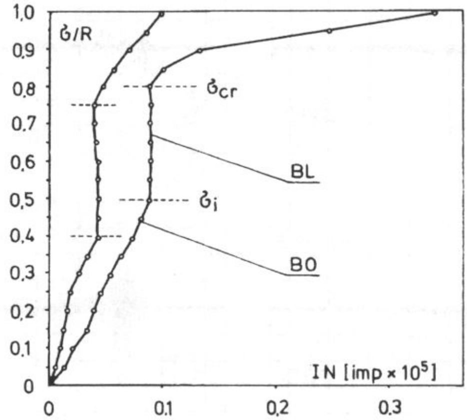

Fig. 4. Counts sum intensity in the quasi-axially compressed oiled up concrete series BO and the unoiled up series BL versus stress increment.

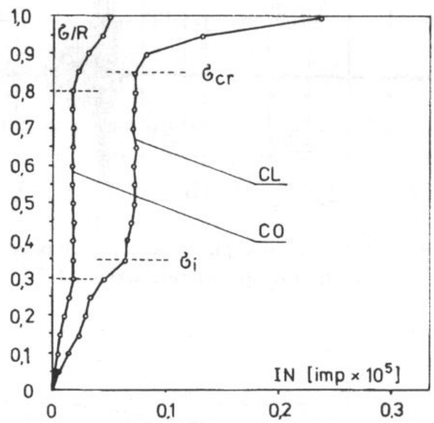

Fig. 5. Counts sum intensity in the quasi-axially compressed oiled up concrete series CO and the unoiled up series CL versus stress increment.

of the stress increment σ/R for the concrete series AO and AL, BO and BL, and CO and CL, respectively. It follows from the figure that the intensity of the counts sum varies in three stages both for the oiled concrete series and the unoiled ones. The "length" of the individual stages is not identical for the tested concrete series and, as shown in [10], it depends on the aggregate grading of the concrete. An analysis of the test results presented in Figs. 3, 4 and 5 shows — which is significant — that for all the tested series of the oiled concrete, the "length" of the stages of constant, stable and rapid increment in the counts sum differs from the "length" of these stages for the unoiled reference concrete series. The stage of the constant increment of acoustic emission in the oiled concrete series is always "shorter" than that in the reference concrete series, no matter what the content of the fine aggregate in the concrete. The greatest difference in the "length" of this stage appear for the concrete series BO and

BL with a 60% content of fine aggregate. In turn, the stage of the abrupt increment in the counts sum is always "longer" for the oiled concrete series than for the comparable reference series.

The stress levels at which the stages of constant and stable and stable and abrupt increment in the intensity of the counts sum are demarcated clearly correspond to the initiating stress σ_i, and the critical one, σ_{cr} in the concrete. The three-stage course of the intensity of the counts sum reflects the three-stage character of the failure of both the oiled concrete and the unoiled one. It is worth mentioning that, according to [6, 9], the failure of concrete starts with a stage of the stable initiation of microcracks that have their origin at the material formation stage. An indication of this is the constant growth in the intensity of the counts sum. As a result of an increase in the load, the failure of concrete enters the stage of the stable propagation of cracks. The microcracks that appeared at the first stage propagate now and new stable microcracks develop, particularly due to the destruction of the adhesion of the aggregate grains to the cement paste and that of the cement paste itself [6, 9]. An indication of this condition is the stabilization of the intensity of the counts sum. As the load increases further, the destruction of concrete enters the stage catastrophic failure, i.e. wide cracks appear which propagate in an unstable manner. This is indicated by a sharp increase in the counts sum. According to [4, 5, 6, 7, 8], the particular stages in the failure of concrete are delimited by the initiating stresses, σ_i, and the critical ones σ_{cr}, respectively. The variation in the values of these stresses determined by the acoustic emission method, for all the tested oiled and unoiled concrete series, versus the percentage of fine aggregate is illustrated in Fig. 6. These values also have been marked in Figs. 3, 4 and 5.

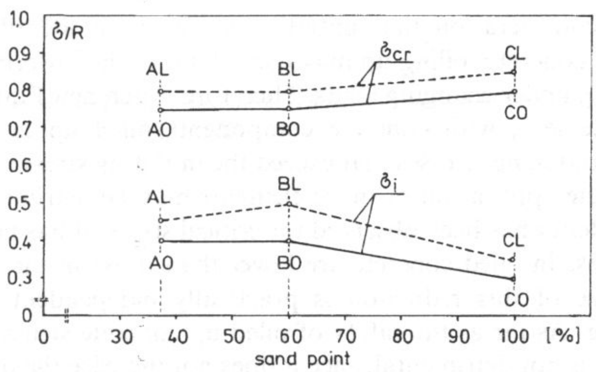

Fig. 6. The variation of the values of the initial stress and the critical stress in the tested oiled up and the unoiled up concrete versus fine aggregate percentage.

It follows from Fig. 6 that the oiling up of concrete affects significantly the values of both the initiating and critical stresses no matter what the fine aggregate content in the concrete. And so, the values of the initiating stress in all the tested series of oiled concrete turned out to be lower than those of this stress in the unoiled reference concrete series. This means that the $0-\sigma_i$ interval has narrowed in the case of the oiled concrete. It is worth while noting that a similar narrowiong of this interval observed in the case of concrete saturated with water [13, 14]. Thus, the failure of such concrete enters the second stage which is characterized, among other things, by the stable development of microcracks at the smaller effort of the material than in the case of the unoiled concrete. This allows one to conclude that oiled concrete has a shorter safe fatigue life than unoiled concrete, no matter what grading had the aggregate used for its making. A similar tendency has been observed in the case of the critical stresses. The oiling up of concrete also leads to the reduction in the values of these stresses. As afar as the safety of the concrete structures which have become oiled up is concerned, that is not a negative phenomenon. The problem is that when the values of the critical stress are high the cracks appear in the concrete suddenly and they are usually wide as observed by the authors of papers [15, 16]. This means that no warning signs precede the destruction of the concrete. One can conclude that there is no such danger in the case of oiled concrete.

4. Conclusion

By using the method of acoustic emission it has been shown that oiling up affects significantly the course of failure of compressed concrete. This is reflected in the value of the intiating stresss, σ_i, and critical one σ_{cr}, that delimit the particular stages of the destruction of the concrete. Generally, for all the tested series of oiled concrete a reduction in the values of the initiating stress in comparison with the values of the corresponding stress in the unoiled up concrete the reference series has been observed. The largest reduction is observed for the BO series concrete with a 60% fine aggregate content.

Taking into consideration that initiating stress, σ_i, is identified with the safe fatigue life of the concrete, oiling up may contribute to the lowering of the safety of structures working under changing loads. Therefore, when new functions or purposes of a structure element, with concrete components oiled up in the past, involve changing loads producing stresses that exceed the initiating stress value characteristic of the concrete, the application of those elements may be detrimental.

A similar tendency has been observed for critical stress. It has been found that the values of this stress in oiled concrete are lower than those in the reference, unoiled concrete. The size of this reduction is practically independent of the concrete's aggregate grading. As far as the safety of oiled up concrete structures is concerned, this phenomenon is not detrimental since it does not increase the danger of a sudden failure not preceded by any warning signs.

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