Ultrasonic tests of cement floors along their thickness with the use of exponential heads

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Abstract

The paper presents ultrasonic tests of cement floors that were carried out in order to show how big the heterogeneity of the compressive strength distribution along their thickness can be. The tested specimens were taken from floors that had a significantly large surface area, were made of good quality mortar produced on an industrial scale and were of various thicknesses. Special exponential heads with point contact with the specimen's surface were used for the tests. The correlative dependency between the velocity of the longitudinal ultrasonic wave and the compressive strength of mortars embedded in the tested floors was established. It was shown that the heterogeneity of the distribution of this strength along the thickness of the floors is significantly large. In the top zone, which is subjected to direct operational impacts, the compressive strength is definitely lower than that in the bottom and middle zones. The paper points out that this problem should not be underestimated with regards to floor durability. Suggestions for possible remedial actions were also provided.

1. Introduction

Cement floors are commonly used in the construction industry. They constitute the top finishing layer of concrete floors or are a substrate for a more precious flooring material [1]. The substrate for the floors can be made of concrete, but can also be styrofoam. Currently, floors are usually made of ready-made cement mortars that are produced industrially. They are primarily subjected to vertical operational loads and must therefore have an appropriate compressive strength. If the substrate is made of styrofoam, the floors must also have an adequate bending strength. Depending on the value of anticipated operational loads, type of substrate and operating conditions, the strength requirements are specified by a designer [2-4]. In practice, in order to check if the made floor meets the design requirements, small fragments of it are cut out and from these fragments beam specimens are obtained for bending and compressive strength tests.

Due to the fact that the cement floors are formed horizontally, differences in compressive strength along the direction of concreting are possible. The value of this strength in the top zone of the floor may adversely differ to the strength values in the middle and bottom zones, which was observed on the basis of laboratory tests by the authors of, among others [5-7]. The results obtained during classical destructive strength tests do not allow this phenomenon to be observed. Considering the fact that the top floor zone is subjected to direct operational impacts, knowledge about the compressive strength in this zone seems to be necessary with regards to the durability of the floors. This is especially important in the case when the cement floor is the final finishing layer of the floor.

This paper presents three newly made cement floors, out of which small fragments were cut out for tests that were carried out in order to signal the construction problem that is important for construction practice. The compressive strength along the thickness of the specimens obtained from the cut out sections of the floors was determined using the non-destructive ultrasonic method. Examinations of these specimens were also performed using the destructive method in accordance with [8]. The obtained results were compared and commented on.

2. Test methodology

The tests involved three newly made cement floors with an area of approximately 1500m^2 each. Their thicknesses were 40, 45 and 60 mm, respectively. They were made of cement mortars that were created from water mixed with dry mixes that are produced industrially. The granulation of the pebble aggregate in the mortars was in the range of 0-2 mm, and the slump of the mixes was in the range of 190-205 mm. The mortar was machine-laid, surface-vibrated and smoothed. According to the manufacturer's declaration, after 28 days of maturing the compressive strength and bending strength of the floors should be equal to 20MPa and 5MPa, respectively. The age of the tested floors was about 90 days. The 40 mm thick floor was marked with the digit I, the 45 mm thick floor was marked with the digit II digit and the 60 mm thick floor was marked with the digit III.

From each floor, fragments (Fig. 1) were cut out in six randomly selected places, which enabled at least six beam specimens of 160 mm long, 40 mm wide and with a height equal to the thickness of the floor to be obtained. Some of these specimens, in an amount of at least 3 out of each cut fragment of the floor, after being cut to a thickness of 40 mm, were subjected to ultrasonic tests with the use of special exponential heads with a frequency of 40 kHz and a point contact with the tested surface [9]. The design of these heads is described in detail in [5]. Ultrasonic tests were performed in the middle of the thickness of the specimens. Each specimen was tested in two places. Afterwards, the specimens were first subjected to bending tests (Fig. 1), and then half of the beams that were obtained after these tests were subjected to compression tests in accordance with [8]. In this way, more than 100 pairs of c_L – f_m results were obtained, where c_L is the velocity of the longitudinal ultrasonic wave and f_m is the compressive strength. These results were used to develop the correlative dependence of c_L – f_m. In turn, the remaining specimens were subjected to non-destructive ultrasonic tests in order to determine how the velocity of the longitudinal ultrasonic wave c_L changes along the direction of the concreting of the floors (along their thickness). For this purpose, measuring points were applied on the lateral surfaces of the specimens with a spacing of 5 mm in three rows, as illustrated in Figure 2.

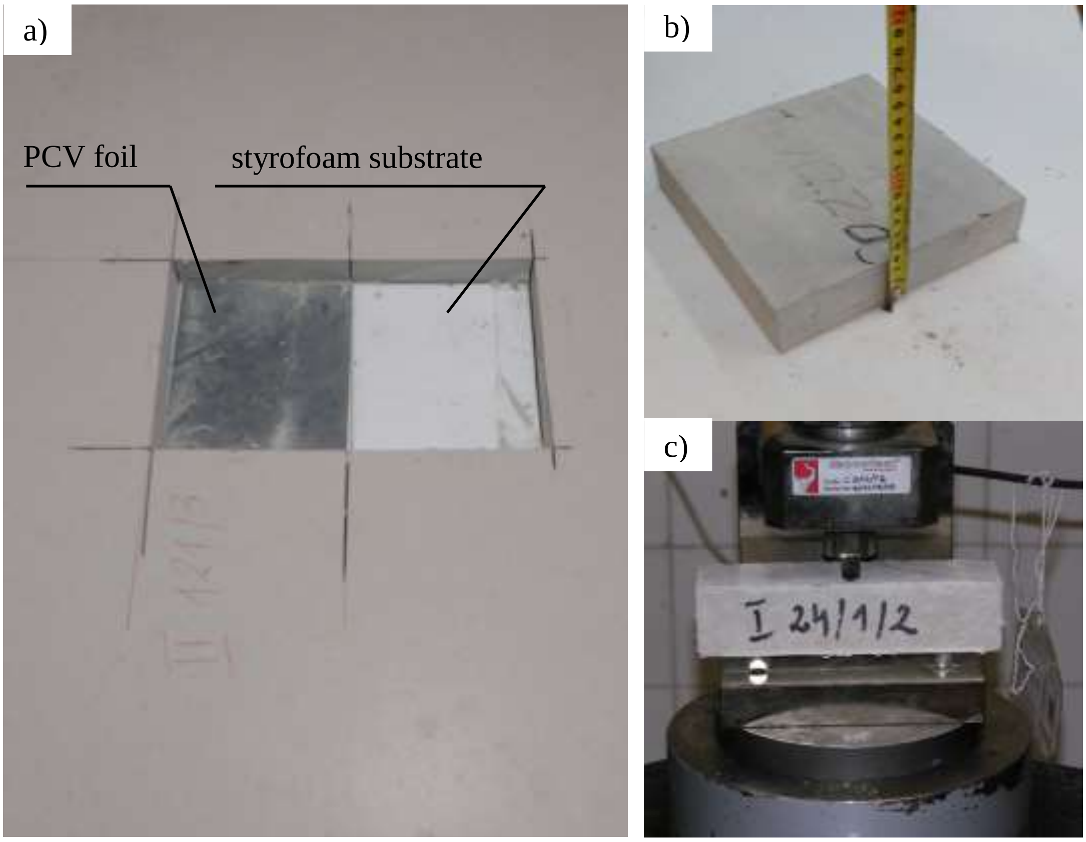

**Figure 1. Exemplary view of: a) floor after cutting out a fragment from it,
b) fragment of the cut out floor, c) beam specimen obtained from a cut out fragment and prepared for strength tests**

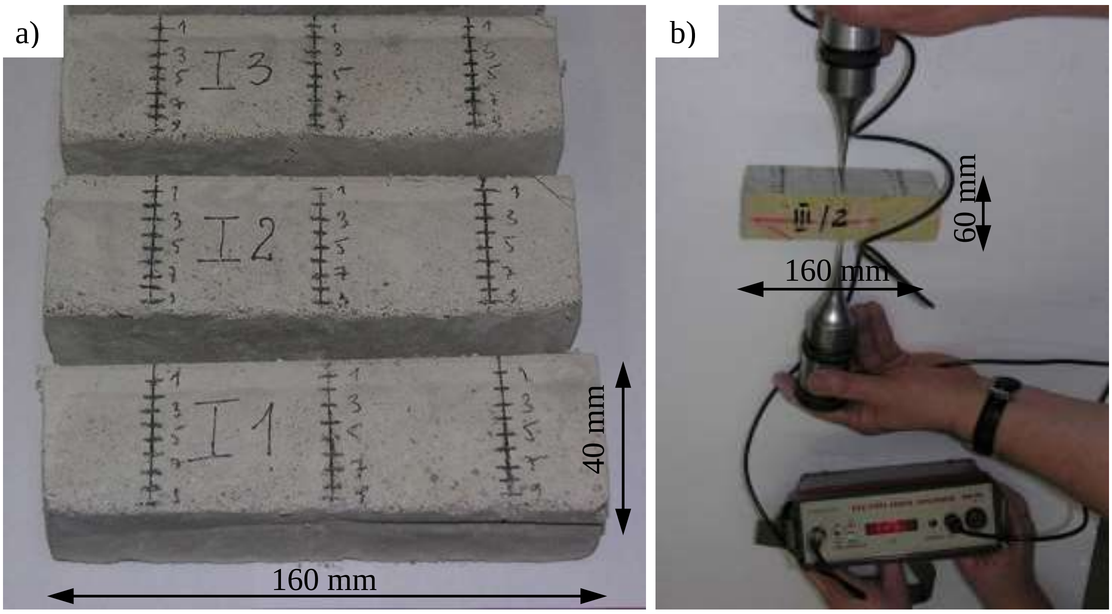

Figure 2. Exemplary view of: a) beam specimens of floor I prepared for ultrasonic tests, b) specimens of floor III tested along its thickness using the ultrasonic method

3. Test results and their analysis

As a result of the conducted tests, the correlative dependency between the velocity of the longitudinal ultrasonic wave c_L and the compressive strength of cement mortar f_m was developed for the tested floors. It was used to identify the value of compressive strength f_m of the mortar along the thickness of the tested floors (Fig. 3).

In contrast, Table 1 summarizes the average values of the compressive and bending strength obtained using the destructive method in accordance with [8], and also the strength declared by the manufacturer. When commenting on the results in Table 1, it should be noted that floor I has a lower compressive and bending strength than that declared by the mortar manufacturer, while floor II has a lower bending strength than that declared by the mortar manufacturer. There are no objections to the strength parameters of floor III.

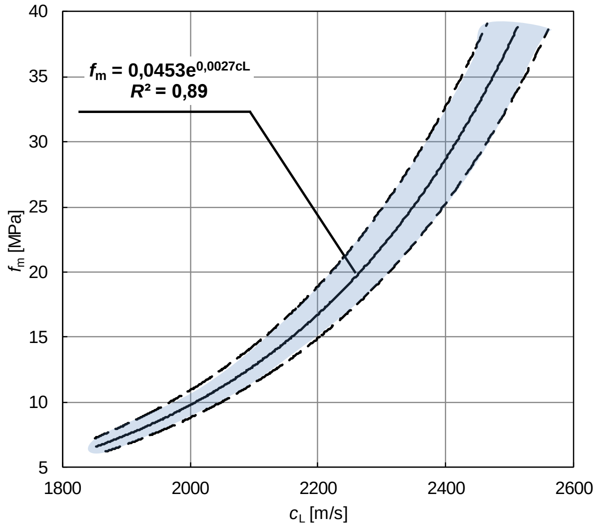

Figure 3. The dependency between the velocity of the longitudinal ultrasonic wave c_L and the compressive strength f_m of the cement mortar

Table 1. A comparison of the average values of compressive and bending strength obtained on the basis of tests in accordance with [8], and also the strength declared by the manufacturer

Summary of average values	Floor designation		
	I	II	III
Compressive strength f_{m1} [MPa]:			
- Obtained on the basis of tests	16.2	21.1	27.2
- Declared by the manufacturer	20.0	20.0	20.0
Bending strength [MPa]:			
- Obtained on the basis of tests	3.1	3.4	6.2
- Declared by the manufacturer	5.0	5.0	5.0

In turn, Figure 4 presents examples of ultrasonic test results, which show how the velocity of the longitudinal ultrasonic wave c_L changes along the thickness h of the specimens obtained from floors I (Fig. 4a) and III (Fig. 4b). This figure shows that the value of the velocity of the longitudinal ultrasonic wave successively decreases along the thickness. It is the highest in the bottom zone, and the lowest in the top zone of the tested specimens obtained from floors I and III.

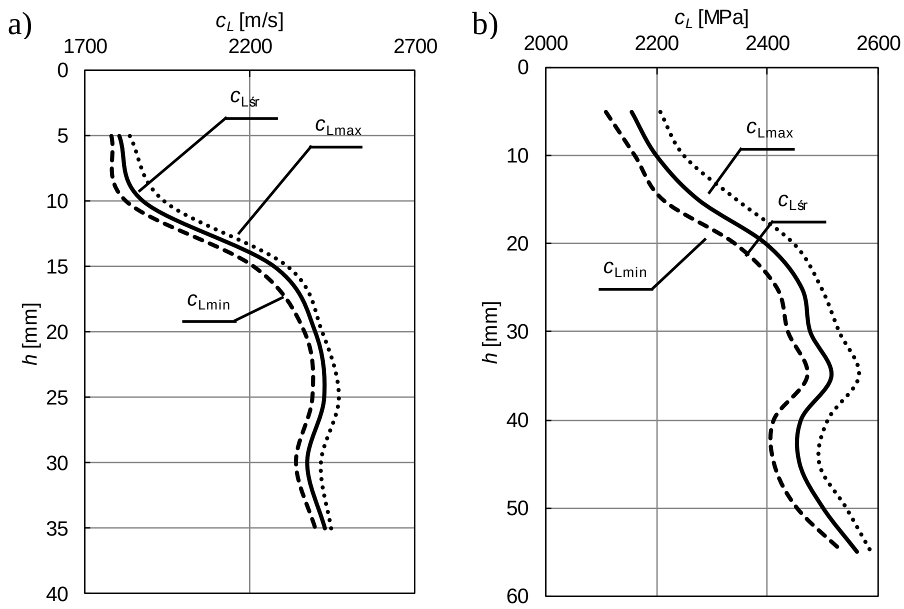

Figure 4. The velocity of the longitudinal ultrasonic wave c_L along the thickness *h* of the specimens obtained from floors: a) I, b) III

In contrast, Figure 5 shows the course of compressive strength f_m of cement mortar along the thickness *h* of the tested specimens. From Figure 5 it is clear that for all the three tested cement floors, the value of compressive strength f_m decreases successively along their thicknesses and is the lowest in the top zone. In floor I, the compressive strength ranges from about 6 MPa in the top zone to about 28 MPa in the bottom zone. On the other hand, the compressive strength in floor II is equal to about 14 MPa in the top zone and to about 35 MPa in the bottom zone, while in floor III it is equal to about 12 MPa in the top zone and to almost 40 MPa in the bottom zone. For comparative purposes, the average compressive strength f_{m1}, which is declared by the manufacturer, is shown in the form of a vertical line in Figure 5 and is equal to 20 MPa for all the tested floors. Due to this it is possible to read, starting from the top surface, to what depth the compressive strength f_m is lower than the strength f_{m1} declared by the manufacturer. As can be seen, the thickness of this zone in the case of the tested floors is considerable and ranges from 13 mm to 16 mm. For better readability, this zone is marked in blue in Figure 5.

When omitting the answer to the question of why in the case of all the three floors the average compressive strength determined on the basis of destructive tests deviates from the strength declared by the manufacturer, it is worth considering why such large differences occurred along the thickness. These differences should be seen, among others, in the adverse effect of aggregate sedimentation, insufficient thickening of the top floor zone or bleeding that occurs during too excessive smoothing of the top surface [10].

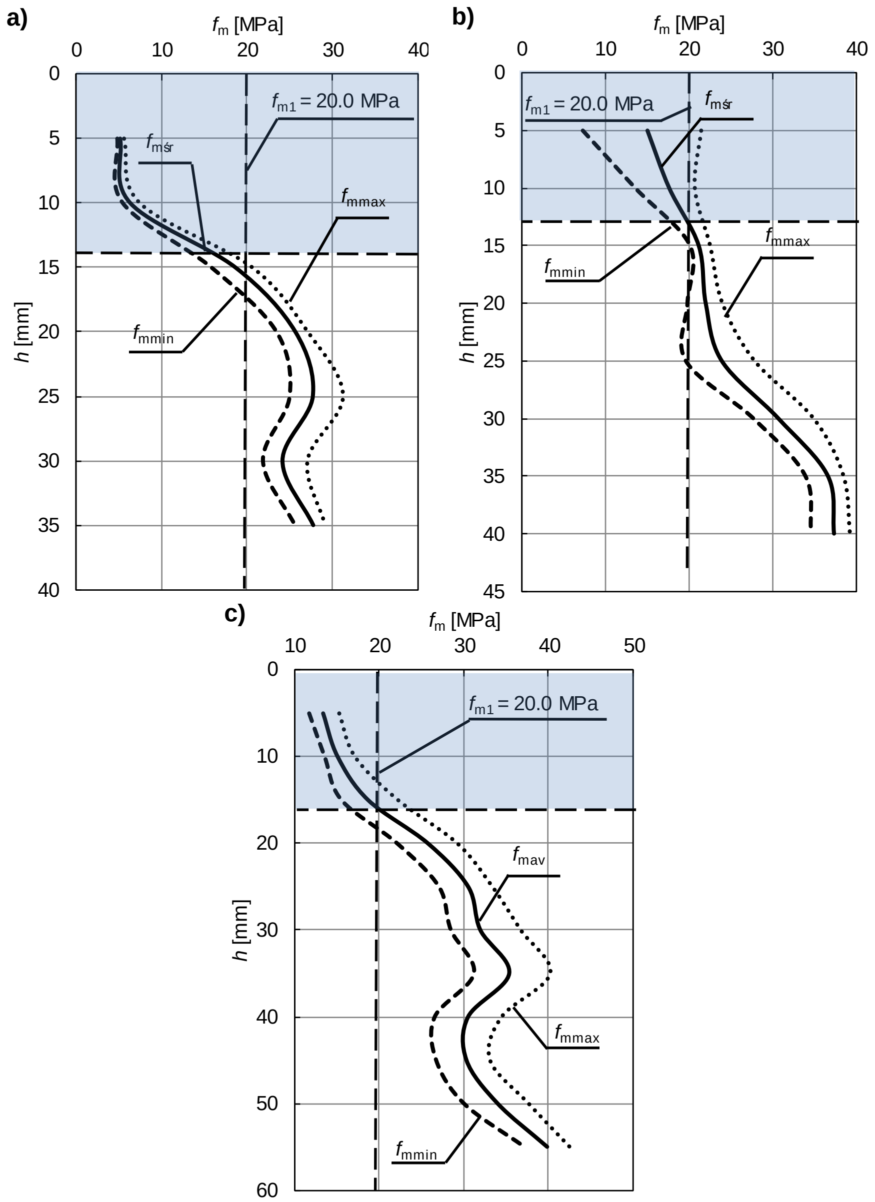

Figure 5. The course of compressive strength f_m of cement mortar along the thickness h of the specimens taken from floors: a) I, b) II, c) III

4. Summary

The ultrasonic tests of the compressive strength of cement floors along their thickness that were presented in the paper showed that in all the examined cases this strength is not the same in the individual zones of the floors, namely: the lowest is in the top zone, the highest is in the bottom zone, while in the middle zone it is close to the compressive strength that is assessed in a destructive manner. Differences in the strength of individual zones are so significant that this problem should not be trivialized in practice when considering floor durability.

Taking into account the obtained tests results, it seems reasonable, for control purposes, to conduct in construction practice strength tests of floors along their thicknesses, especially when the top zone, which is the weakest regarding compressive strength, is subjected to direct operational impact. It can also be concluded that some remedial actions should be considered, not only at the stage of designing floors, but also at the stage of their implementation, which would prevent or at least significantly minimalize the problem that was shown in the study. In the authors' opinion, these activities should include: designing floors made from self-compacting cement mortars, increasing the strength class of cement mortar and modifying the top floor zone e.g. by hardening.

References

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