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METHODOLOGY OF INDICATING THE TROWELLING OPERATION START TIME ON THE CONCRETE MIX SURFACE

1. State of the art

Currently there is no known instrumental method allowing to identify the trowelling operation start time on the surface of concrete mix. Trowelling operation start time is closely related to concrete rheology and the process of concrete mix hardening. Concrete hardening process is usually described as a concrete shrinkage and a humidity gradient, caused by chemical binding of free water [1-8].

In case of irregular water distribution while concrete mix from which industrial floors are made, is treated, in spaces of porous structure, water constantly flows from more moisture areas to places where the moisture is lower. This phenomenon is called moisture conductivity. In some materials moisture conductivity is an external action and is connected with the concrete ability to bind water.

Series of experiments aiming to examine laws of physics, i.e. connected with water evaporation, have their contribution in explanation of this complex phenomenon, but the attempt to explore this area was only partially successful. Research conducted shows that in the initial period evaporation rate of water from concrete was the same as the evaporation rate of clean water. It means that in this period water evaporation from concrete was caused by liquid movement from the sample inside to the outside. It may be concluded that in concrete layers closer to the outer layer water migrates in form of steam. This phenomenon has a great influence on hardening of formed concrete mix and for the trowelling operation start time.

Water evaporation rate lowers at the end of the concrete drying process, it becomes smaller than the evaporation rate of clean water and tends to zero as the water content in concrete decreases. It is not possible to analyze all possible conditions in which concrete may be used, therefore it is impossible to characterize periods of time and specific areas in which a given moisture phase may occur. Because of that there was an attempt to build a device allowing to indicate trowelling operation start time.

Indication of the trowelling operation start time for hardening concrete has an influence on its qualitative features, e. g. concrete strength parameters and operating characteristics, such as surface abrasion. Too early start of the trowelling process will cause surface quality decrease, by shaping heterogenous evenness, which makes the surface disqualified, according to the requirements stated. Too early trowelling, in case of using concrete hardeners wiped into the upper concrete layer, may cause deep penetration of the hardener into the concrete structure, which causes defects on its surface (chips and micro-cracks). Missing out of the suitable time for trowelling causes that there is no possibility to use hardener, because it will not penetrate the concrete structure to the required depth. It decreases the concrete surface durability. The defects worsen the product's aesthetic values and results in the necessity of making further improvements, which constantly lowers the concrete quality.

Optimum trowelling action start time gives possibility to receive indiscrete and high-quality concrete surface. While analyzing solutions available and devices used for industrial floor making it was concluded that there is no device allowing to state clearly when the trowelling process of the hardening concrete mix should be started. In order to eliminate the subjective human factor, a device was designed and constructed, which is able to indicate the trowelling operation start time, with use of mechanical trowelling machine. The measurement is precise and may be made regardless of the weather conditions.

The subject for the research was to characterize the influence of trowelling operation start time on the quality of the concrete surface marked by the lowest surface waviness. The aim of the research was to establish an optimum trowelling operation start time marked by the sinking depth of a research board of a new device designed for effective evaluation of the changes in consistency of a hardening concrete.

Facing the problem connected with lack of a diagnostic device and aiming to eliminate workers' subjective opinions in a process of floor trowelling and the way of concrete hardener distribution, a special device was built whose task is to indicate trowelling operation start time for concrete surface. The device construction and operation principles were reported to the Polish Patent Office with the number PL387166(A1) [9]. Author's solution (device) is characterized by construction simplicity, which precisely and reliably measures changing features of concrete mix. It allows to indicate when the trowelling operation should be started, which influences the most important qualitative features of the concrete.

2. Examination of the trowelling start time

For each of the three samples with consistency V3 10 research areas were designated, with dimensions 3x3 m, which next were marked from 1A to 3J.

The way in which the research was conducted was based on reading of the results of research board sinking over time (mm). The measuring device was set on the surface after 20 minutes from the concrete mix formation, the results of sinking were measured. Immediately after making the reading of the results and their averaging the research area was floated with a trowelling machine with a circular disc, and next the effects of the trowelling were checked.

In the next research area the board sinking was measured and the second measurement was made after 25 minutes from the concrete mix formation, where next the area was trowelled and assessed. The readings were made after 30; 35; 40; 45; 50; 55; 60; 65 minutes, on the next research areas which were treated with the use of a full disc and for comparison - a circular disc.

The environmental temperature in a moment of concrete-mix composition was equal to 19°C, floor thickness was equal to 14 ±2 cm. For making samples there was used concrete mix with aggregate size less than 16 mm made on the basis of cement CEM III/A 32,5 LH/HSR, concrete category C20/25 exposure category XC3. Examination with the use of a device (Fig. 1) was made three times in three measuring points of a given floor for each 9 m^2 of the surface examined. In each place a reading of the measuring wheel sinking was made, the results of the measurements were averaged.

Fig. 1. Device for measuring of the changes in consistency properties on the surface of the formed concrete

Table 1 presents averaged results of the research of the trowelling start time. Research was conducted with 5 minute intervals.

In order to conduct a stylistic treatment the results were averaged and presented in Table 2.

TABLE 1

Results of board sinking research

Sample no	Time after concrete formation [min]	Research board sinking h_0 [mm]
1	2	3
1	A = 20	4.58
	B = 25	3.67
	C = 30	2.02
	D = 35	1.86
	E = 40	1.39
	F = 45	0.93
	G = 50	0.25
	H = 55	0.23
	I = 60	0.20
	J = 65	0.14
2	A = 20	4.09
	B = 25	3.07
	C = 30	2.07
	D = 35	1.70
	E = 40	1.56
	F = 45	1.32
	G = 50	0.87
	H = 55	0.82
	I = 60	0.80
	J = 65	0.73
3	A = 20	4.20
	B = 25	3.05
	C = 30	2.60
	D = 35	1.47
	E = 40	1.01
	F = 45	0.68
	G = 50	0.56
	H = 55	0.49
	I = 60	0.43
	J = 65	0.31

TABLE 2

Average results of the research board sinking

Research area	Time after concrete formation [min]	Average value of research board sinking [mm]
1	2	3
A	20	4.29
B	25	3.26
C	30	2.23
D	35	1.67
E	40	1.32
F	45	0.97
G	50	0.56
H	55	0.51
I	60	0.47
J	65	0.39

3. Estimation of trowelling start time expressed in relation to surface quality parameters evaluated after trowelling treatment

An optimum trowelling start time was expressed by the best result of the waviness marked as profile parameter F_l (waviness index) which is characterized by the value greater than roughness, smaller than the length of the sample portion, equal shape mistakes showing average distance from profile points to the reference level on the length of sample portion equal to 1.5 m, of every single research area from A to J. For the waviness examination there was used a construction RK3 from the Institute of Building and Material Technologies Processes, which makes measurements with accuracy ±0.52 mm. Wheels of the device imitate the movement of the vehicles, e.g. forklifts, and register surface irregularities, by measuring of the angle between the wheels and encoders.

Waviness results were stylistically treated and presented in a form of maximum deviation from the absolute horizontal level (for which the confidence intervals were calculated), $\overline{F_l}$ value with probability 95%, may be designated on the basis of the relation:

$$\overline{F_l} - t_\alpha \frac{\sigma}{\sqrt{n-1}} < F_l < \overline{F_l} + t_\alpha \frac{\sigma}{\sqrt{n-1}}$$

where:
F_l - surface waviness,
$\overline{F_l}$ - average waviness,

t_α - factor dependent on the amount of the analyses for a given research model, so-called small sample t_α = 2.08,

α - probability 0.05,

n - number of small sample examinations equal to 3,

σ - standard deviation ratio.

$$\sigma = \sqrt{\frac{\sum(F_{li} - \bar{F}_l)^2}{n-1}}$$

n – 1 - number of degrees of freedom.

While analyzing the results of the waviness measurement, presented in Table 3 and treatment quality level expressed by the treatment regularity function R_{RO} dependent on average waviness and standard deviation ratio, equal respectively to 90 and 10%, the function may have the following form:

$$R_{RO} = f(\bar{F}_l, \sigma) = 0{,}9\bar{F}_l + 0{,}1\sigma$$

Function minimum $R_{RO} = f(\bar{F}_l, \sigma)$ is the indicator of the lowest waviness, taking into account quality expressed in treatment regularity, at the same time in indicating the start time of the trowelling operations. Results of the average waviness, standard deviation and confidence interval with function $R_{RO} = f(\bar{F}_l, \sigma)$ are presented in Table 4.

TABLE 3

The results of the waviness measurements on the research areas in relation of the time to concrete mix placement

Time after concrete formation [min]	Research area	Sample 1	Sample 2	Sample 3
20	A	9.4	10.1	8.3
25	B	6.6	7.9	8.1
30	C	6.5	6.1	7.6
35	D	6.4	5.8	4.9
40	E	5.1	4.2	3.8
45	F	7.3	6.8	4.6
50	G	7.6	8.5	5.8
55	H	7.8	8.3	6.1
60	I	9.1	9.7	7.2
65	J	8.3	9.4	11.4

TABLE 4

Results of the regularity research for trowelling start time

Research area	Average waviness $\overline{F_l}$	Standard deviation σ	Confidence interval		Function $R_{RO} = F_l$
A	9.26	0.90	7.93	10.60	8.43
B	7.53	0.81	6.33	8.73	6.86
C	6.73	0.77	5.59	7.87	6.13
D	5.7	0.75	4.58	6.81	5.20
E	4.36	0.66	3.38	5.34	3.99
F	6.23	1.43	4.12	8.34	5.75
G	7.3	1.37	5.27	9.32	6.70
H	7.4	1.15	5.70	9.09	6.77
I	8.66	1.30	6.74	10.58	7.93
J	9.7	1.57	7.38	12.01	8.88

Analysis of the floor operational parameters, especially evenness, shows that the lowest waviness may be observed in samples from the area E. Average sample evenness was equal to 4.36 mm. According to Polish Norms an irregularity ≤ 5 mm on the length 2 m is allowed, which means that the floor surface was correctly trowelled.

Remaining samples represent greater surface irregularity, which was caused by too early or too late beginning of the trowelling operation. It was directly connected with the surface evenness.

Results of the function relation R_{RO} are presented in Figure 2.

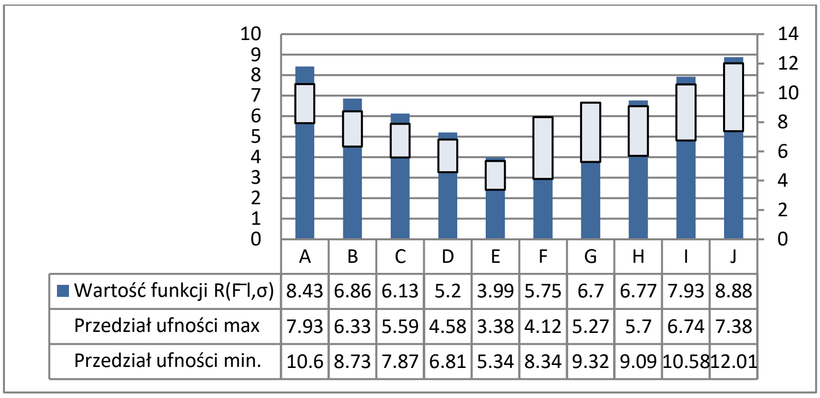

Fig. 2. Diagram presenting the value of a function R for research areas from A to J

Optimum trowelling operation start time may occur for areas reaching the minimum value of the function R_{RO}. In order to find the function minimum value, the results for the function R_{RO} were used together with the sinking value h_0 for research areas A-J.

In order to evaluate effectiveness of the new construction of a circular operating element, waviness evaluation was made after treating by a new disc construction for which waviness measurements were made with the use of RK3 device and presented in Table 5.

TABLE 5

Results of waviness and research board sinking for areas trowelled with use of a circular disc

Research areas	Average value of research board sinking h_0 [mm]	Average waviness $\overline{F_l}$
1	2	3
A	4.29	9.26
B	3.26	7.53
C	2.23	6.73
D	1.67	5.7
E	1.32	4,36
F	0.97	6.23
G	0.56	7.3
H	0.51	7.4
I	0.47	8.66
J	0.39	9.7

On the basis of the research conducted average trowelling operation start time for a given concrete mix with consistency value V3 may be expressed in a form of a sinking parameter equal to **1.32 ±0.005** mm. Sinking of the research board in concrete mix corresponds to the time **40 ±2** minutes from mixture hardening. Results of the recommended technological parameters were measured with the use of RK3 device. For trowelling operations a start time for concrete consistency V3 was presented in Table 6.

TABLE 6

Recommended technological parameters indicated with the use of RK3 device measuring the trowelling operation start time for concrete mix with consistency value V3

Trowelling operation start time t_0 [min]	Research board sinking h_0 [mm]	Remarks
Early	>1.49	unsuitable
Suitable	1.15-1.49	suitable
Late	<1.15	unsuitable

Using the described method of trowelling start time indicating for concrete mix consistency V3 a calibration of the remaining consistency types was made. Results of the use of Ve-Be method are presented in Table 7.

TABLE 7

Recommended technological parameters indicating the start time of trowelling operation for standard concrete mix consistency values determined with the use of Ve-Be device

Consistency Ve-Be [s]		Start time t_0 [min]	Research board sinking h_0 [mm]	Remarks
V1	wet > 28	< 20	< 0.5	A great number of defects appear
V2	thick-plastic 27÷14	30÷35	0.5	Proper waviness index
V3	plastic 13÷7	40÷45	1.40	Proper treatment, possibility of obtaining of a high waviness index
V4	semi-fluid ≤ 6	50÷55	2.30	Low waviness index
V5	liquid	60÷65	3.20	Unsuitable waviness index

Conclusion

For the first time an important technological measurement parameter in a process of concrete surface treatment was nominated. It is called waviness level parameter and it allows to increase quality of the final product. Quality measurements analyzed give important package of knowledge allowing to increase exploitation security and construction durability of a new-formed concrete floor surface.

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Abstract

The article presents technology used in making industrial floors and research connected with testing and calibration of the device for concrete trowelling start time measurements. The method allows to determine the start time of mash operations which result in improvment in the quality of the concrete surface expressed by its evennes. The method eliminated the workers subjective assessment and determines the precise starting point of machining operations.

Metodyka określania czasu rozpoczęcia operacji zacierania powierzchni mieszanki betonowej

Streszczenie

W artykule została przedstawiona technologia wykonania posadzek przemysłowych, a także badanie związane z testem oraz skalowaniem aparatu do badania czasu rozpoczęcia operacji zacierania. Metoda pozwala na wyznaczenie czasu rozpoczęcia operacji zacierania skutkującej podniesieniem jakości powierzchni betonowej wyrażonej jej równością. Metoda wyeliminowała subiektywną ocenę pracowników wykonujących posadzką przemysłową - oraz określa w precyzyjny sposób moment rozpoczęcia operacji obróbczych.