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EFFICIENCY ANALYSIS OF THE DISC WORKING ELEMENT IN REFERENCE OF TREATMENT TECHNOLOGY OF CONCRETE SURFACE

The grow of interest in the significance of concrete surface of building constructions, floors, prefabricated elements etc. in warehouses, production rooms and road surface is currently being observed.

The purpose of concrete surface processing is the achievement of required, homogeneous and repeatable physical, mechanical and operational parameters of the surface. The parameters include: impact strength, grindability, stability of friction factor connected with smoothness or homogenous roughness.

The technological process of concrete surface placing is a process which is forced by the properties of a concrete mix which is being processed.

Standard process of concrete surface placing includes the following stages:

- placing elements for levelling,
- distribution of a concrete mix,
- levelling the concrete surface by means of surface finishing screeds,
- vacuum process and removing the excess of make-up water and cement wash from the surface by means of vacuum mats or by technology of removing aggressive cement wash,
- surface floating process,
- surface smoothing process,
- potential paint texturing,
- surface impregnation.

A concrete mix consists of: aggregate (of different fractions), cement, water, additives and it is a composed in the process of designing composition of concrete composites on the basis of hydraulic binding agents.

In the process of placing a concrete mix, the phenomenon of sedimentation occurs, which means partial separating and grouping aggregate fractions. This process causes displacement of the fraction with bigger grains into the lower part of a concrete mix. The fractions with lower granularity stay in the upper part. On the very surface, the cement wash gathers. This process is disadvantageous because it causes decreasing concrete surface layer resistance. The surface layer is particularly important because it is directly exposed to the influence of operating factors.

The decrease of concrete surface layer resistance is caused (as testing shows [1, 2]) by:

- displacement of coarse aggregate, which is the concrete framework, from the surface layer to the lower layer,
- substantial amount of fine aggregate, including sand with an excessive amount of water stays in the upper part. It increases the proportion of water to cement W/C badly influencing resistance parameter and impact strength,
- excess of water redundant for the process of cement hydrating, staying in a concrete mix causes the occurrence of empty places in the form of capillary tubes. It also causes the decrease of concrete resistance by the increase of absorbability and the decrease of freeze resistance,
- release of cement wash and its concentration on the surface causes the decrease of cement in the upper part which decreases concrete resistance and also causes microfractures on the surface facilitating damp penetration.

Mix susceptibility to sedimentation increases together with its fluidity and the time in which it is influenced after having been placed in a form. When mix fluidity is decreased, labour consumption during placing and further treatment increases.

As far as concrete surface exploiting is concerned the properties and their parameters for the surface layer directly exposed to abrasion, impacts and damp are very important.

As testing shows, the processes of surface treatment counteract the processes of decreasing resistance of operational parameters including the resistance of concrete surface layer.

Vacuum process causes suction of cement wash and make-up water from the surface layer. It decreases the occurrence of microfractures on the surface and decreases the amount of capillary tubes ie it improves concrete surface operational parameters.

The processes of floating as one of the technological operations causes surface levelling, giving it a homogenous texture, roughness, surface quality as well as final mixing and consolidation of the mix surface layer and closing capillary tubes which come from the surface consolidation process performed with surface finiszing screeds. Floating process also means rubbing enriching materials in the form of toppings into, which cause built into surface, permanent, structural connections with concrete.

1. Surface treatment by floating

Surface treatment by floating can be divided into the following stages:

- initial surface levelling and floating by a complete disk,
- final surface floating connected with rubbing additives into which increases abrasion resistance with using finishing disks.

Initial floating is performed by a complete disk and final floating by using working tools of different geometry resulting from parameters selection of disks treatment properties and from treated material properties. Final floating disks composed of four rectangles with straight or rounded corners, made of rustless steel are most commonly used.

Traditional, manual devices for floating are used in accordance with general, established movement programme with using chaotic scheme of local motion.

The disadvantage of such a method for floating process is unevenness of surface treated by a floating disk which causes:

- heterogeneity of resistance to operational conditions of treated surface,
- many defects causing necessity of local repairs performance,
- the increase of energy demand for floating process.

Literature analysis [1] shows that geometries of floating working tools have been constructed by first observing their behaviour in the operation process which was causing their construction modification in the way of evolution of machines and their working tools development. It is proven by the fact that in descriptions of their technical and technological abilities the parameters defining the effectiveness of the influence of such working tools on the treated surface are not given and this is the scope of the author's interest.

2. The quality assessment of surface treated by floating

The quality of treated surface is understood as its constant smoothness or roughness parameter describing the surface after the influence of a treatment element in surface every point.

High homogenous treatment quality enables reaching constant physical parameters of the whole surface.

Reaching particular physical and mechanical ie operational parameters might be assessed by the measurement of surface micro irregularities measured in the segment of 100 mm defined as **the average complete surface roughness R_a** which is defined as

$$R_a = \sqrt{\frac{2}{\pi}} H_{sk}$$

where

$$H_{sk} = \frac{\sqrt{(h_1 - H_o)^2 + \ldots + (h_n - H_o)^2}}{n}$$

The average arithmetic roughness

$$H_0 = \frac{h_1 + h_2 + \ldots + h_n}{n}$$

Concrete surface roughness might be defined by the following methods:

a) contact methods

– sand method
– Weingraber's needle apparatus
– one needle devices with digimatic indicators
– Podlich's profilograph

and

b) non-contact methods
– laser profilograph
– optoelectronic method developed in Department of Building Process Technology, Faculty of Civil Engineering, Czestochowa University of Technology.

Non-contact methods are currently being developed dynamically. They allow measurements of the average complete surface roughness R_a with high accuracy. On the basis of literature and practical experience, different concrete products require particular surface roughness values which are shown in Table 1.

TABLE 1

The classification of surface roughness requirements for prefabricated building products assessment [1]

Roughness class	Roughness mm	Basic length mm	Examplary products types
4 - sz	0.3÷0.6	100	Concrete floors inside and outside which undergo further treatment
3 - sz	0.6÷1.2	100	Inner surfaces in buildings as well as surfaces intended for painting and covering
2 - sz	1.2÷2.5	200	Surfaces intended for tiling
1 - sz	2.5÷5.0	200	Plates covered bituminously eg foundations surface

3. The analysis of surface floating process

The motion of a disk treating material surface (concrete mix) causes mixing material molecules under the treatment disk in a manner dependant on disk geometry and the influences of its movement kinematics. This effect is used in the processes of surface levelling, floating, smoothing, rubbing composite into to enrich the surface or in the process of hardened concrete grinding.

In case of a rotational disk, several motions join together. It is usually the composition of rectilinear, uniform, translational motion of the whole device and disk rotational motion around its axis.

Manual disk machines for surface floating are operated by means of a chaotic motion with orientation by visual assessment of the treated surface. Forward speed and motion path are changeable. Surface points are treated with different intensity. It causes non-uniformity of treated surface physical parameters which decreases its general quality. Such motion is not repeatable and difficult for modelling and mathematical analysis.

Performed analyses have shown that the most effective and repeatable method of operating a working tool in case of manual machines is uniform, rectilinear motion.

The physical parameter measured after performing the process of treating was the roughness of particular surface points. It has been shown that the higher treatment quality is, the lower coefficient of roughness standard deviation R_a measured on the measurement line perpendicular to a working tool path movement is.

A feature named geometrical effectiveness S_g has been chosen as the parameter of a working tool influence. The influence effectiveness S_g of a floating working tool in the process of surface treatment has been defined as the length of the contact line of friction surface defined on the complete axis of a disk cooperating with elementary treated surface.

Geometrical effectiveness of floating S_g in a particular point of treated surface is the length of contact line of this point with a working tool during the treatment.

Geometrical effectiveness S_g of a rotating and moving disk with working tools might be defined as the function of three variables: forward speed, rotational speed and disk geometry which is expressed by the dependence:

$$S_g = f(V_p, \omega_o, B)$$

where:

V_p - disk forward speed,

ω_o - disk rotational speed,

B - parameters connected with working tools geometry and their arrangement.

4. The dependence of surface roughness R_a on treatment geometrical effectiveness S_g

Treated surface roughness depends on geometrical effectiveness of floating by a working tool which has been presented in Figure 1.

The analysis of data presented in Figure 1 shows that the increase of geometrical effectiveness in the process of floating causes the decrease of roughness R_a to minimum value and then its increase.

It is particularly visible for mix consistency 15 s measured in apparatus (Ve-Be) where the fast roughness increase occurs when passing through minimum happens. Liquid or semi-liquid mixes are particularly sensitive to too long influence of a working tool.

Planned surface roughness might be achieved by defining required geometrical effectiveness of the working tool influence.

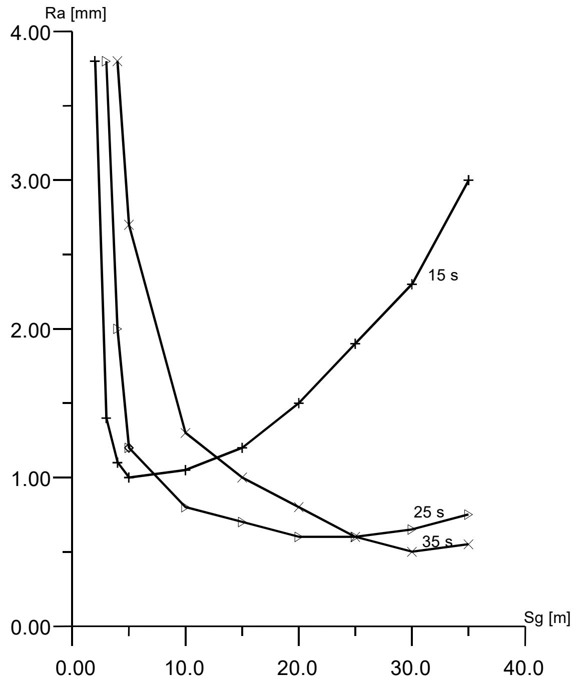

Fig. 1. The dependence of geometrical effectiveness of floating by a working tool on the surface roughness index R_a for different consistencies of a concrete mix [2, 3]

5. Surface treatment kinematics in the process of floating

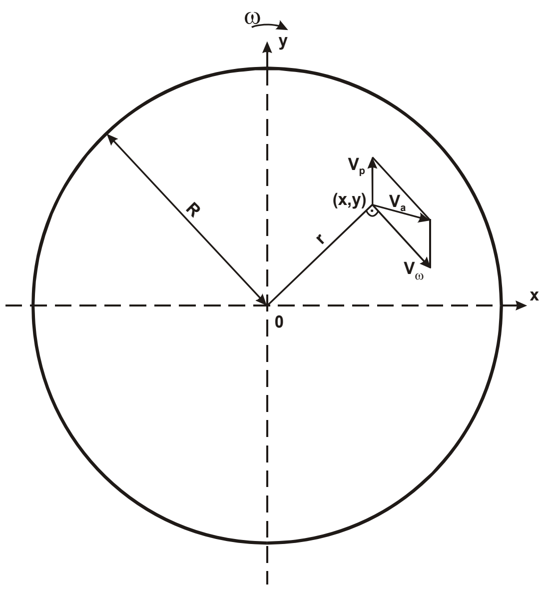

Fig. 2. Resultant speed vector V_a as the sum of forward speed V_p and circumferential speed V_o for disk surface points

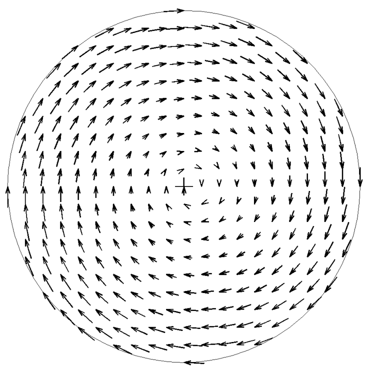

Fig. 3. Vector field of disk absolute speed V_a for forward speed V_p = 0.1m/s and rotational speed w = 7.54 rad/s

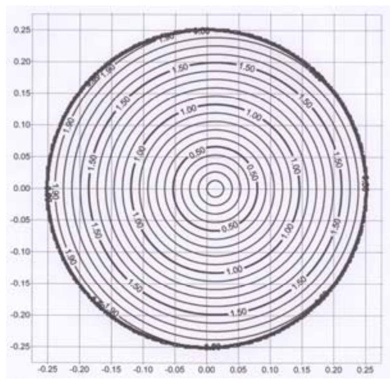

Fig. 4. Disk absolute speed isolines V_a for forward speed V_p = 0.1 m/s and rotational speed w = 7.54 rad/s

The average geometrical effectiveness for a complete disk might be defined by the formula:

$$\overline{S} = a\,\frac{\omega \cdot R^2}{V_p}$$

where:
V_p - disk forward speed,
ω - disk rotational speed,
R - floating disk radius,
A - proportionality coefficient assumed as 1.05.
Geometrical effectiveness of floating after one, complete disk pass through a line perpendicular to movement path for a complete disk moving by means of a uniform, translational, rectilinear motion with a simultaneous uniform, rotational motion has values presented in Figure 5.

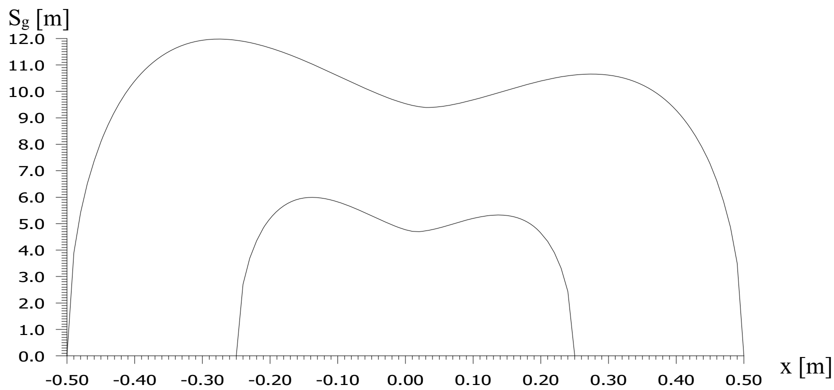

Fig. 5. Chart of geometrical effectiveness for forward speed V_p = 0.1m/s and rotational speed ω = 7.54 rad/s R = 0.25 m and for a disk with R = 0.5 m sustaining the relation $\omega R/V_p$ gives proportional chart [4]

6. Floating process modelling by using a computer programme SIM

The effectiveness of working tools influence has been defined by using a computer simulation model which uses Euler's method with a steady time step for defining geometrical effectiveness value and distribution.

Simulation task is defined as three data blocks:

– working tool geometry might be defined by summing or subtracting simple figures, such as a circle, an arc, a polygon,
– motion path defined by a curve consisting of segments, arcs, circles with defined forward and rotational speed or summing two paths (reciprocating motion),
– sensors as points in which the value of geometrical effectiveness is calculated.

Modelling result is:

– geometrical effectiveness value for each defined sensor,
– standard deviation index defining the influence uniformity,
– calculated optimal cover plate of motion paths for maximum influence uniformity of a working tool on treated surface.

In order to increase the influence effectiveness of a floating tool, the change of disk motion path has been programmed according to Figure 6. Local, chaotic motion has been replaced by parallel, rectilinear paths with cover plates. Cover plate size has been selected to increase the influence uniformity on the surface basic measurement line.

7. Conditions providing maximum uniformity of the influence

Geometrical effectiveness is not symmetrical to rotation centre for a disk moving by means of uniform, rectilinear motion V_p and by rotational, uniform motion ω at the same time. It is caused by the direction change of peripheral speed vector on the left and right side of the disk. As far as maximum uniformity of a disk influence is concerned, it is important for the obtained charts to be as close to a horizontal straight line as possible which guarantees a stable value of geometrical effectiveness of a working tool influence.

8. The importance and defining a coefficient of a cover from the left and right side of a working tool pass

Charts for a single pass at the ends of a influence border of a floating disk have zero values and they increase differently depending on geometry which is applied. Natural procedure is to select suitable cover plates from the left and right side of the influence zone. To achieve the lowest deviation from the average influence effectiveness by summing influence in the floating process with one disk and cover plates pass, cover plates are specially selected. This rule is presented in Figure 6. Cover plate width in figure from the left side is marked as a, and from the right side as b. Using a cover plate during a machine work means leading the next disk path

to partially cover the surface treated in the previous path. This coverage is equal to cover plate width. It is presented on the diagram in the upper part of Figure 6.
Selecting cover plate size should be performed on account of obtaining the most advantageous influence uniformity in the whole surface treatment process.
In cover plate zones summing influence effects during following passes of a working tool takes place.

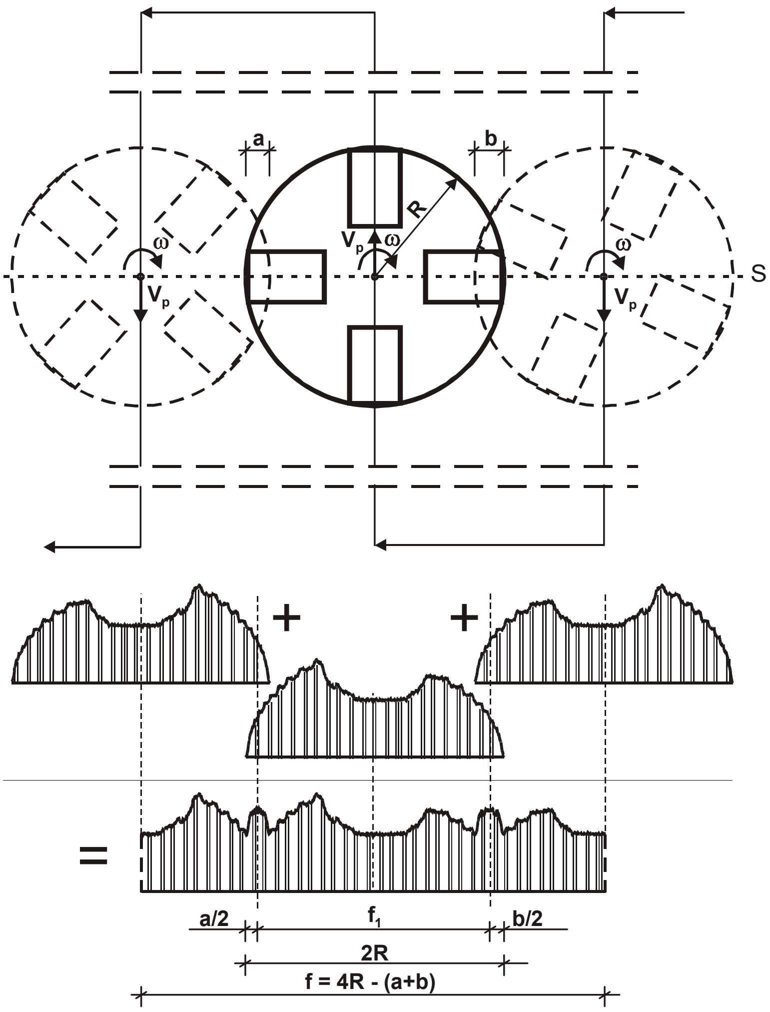

Fig. 6. Surface treatment by a working tool according to work scheme with partial treatment zone overlaps during following passes

The repeatable part of the influence effectiveness is marked as *f* in the picture and the length is equal to four disk radii minus the sum of cover plates length from both sides.

The chart of the influence effectiveness with the presented work scheme on any line length might be obtained by cyclic repeating a repeatable part from the left and right side.
Surface quality indexes will be reliable for the whole surface when they are measured or calculated for a basic segment with f or f_1 length in direction perpendicular to disk motion path.

Identical indexes values as for the repeatable length f might be obtained by measuring on f_1 length according to the picture. It is caused by the fact that the left side which is 2R long and the right side, 2R-b long divided by the direction line of the disk central motion path is symmetrical to its middle point.
Calculation amount for simulation programmes might be decreased or a measurement line length might be shortened this way.

9. The assessment criterion of geometrical effectiveness uniformity

Standard deviation from the expected value of the geometrical effectiveness of influence S_g is assumed as a **comparative criterion** defining uniformity of the geometrical effectiveness of influence for systems with the same average effectiveness.

In case of comparing geometry of different expected values standard deviation coefficient is used.
The influence of a floating disk is more uniform for lower values of the abovementioned parameters.

The average geometrical effectiveness along the examined segment with the length L on which n measurements within the same distance $L/(n-1)$ are performed and values $S_{g1} \ldots S_{gn}$ are successively obtained, is defined by the dependence:

$$\overline{S_g} = \frac{\frac{1}{2}S_{g1} + \sum_{i=2}^{n-1} S_{gi} + \frac{1}{2}S_{gn}}{n-1}$$

Standard deviation of the influence geometrical effectiveness S_g is defined by formula:

$$\sigma = \sqrt{\sum_{i=1}^{n} (S_{gi} - \overline{S_g})^2 \, p_i}$$

where:
S_{gi} - geometrical effectiveness test value in particular point,
$\overline{S_g}$ - expected value of geometrical effectiveness,
p_i - probability of a particular sample occurrence.

In case of analyzing data along a representative repeatable basic segment with the length L on which we perform n measurements within the same distance $L/(n-1)$ the formula for a standard deviation is as follows:

$$\sigma = \sqrt{\frac{\frac{1}{2}(S_{g1} - \overline{S_g})^2 + \sum_{i=2}^{n-1}(S_{gi} - \overline{S_g})^2 + \frac{1}{2}(S_{gn} - \overline{S_g})^2}{n-1}}$$

Standard deviation index is better for comparing characteristics of tools with different average value of an examined parameter.
In general form the formula is

$$\varepsilon = \frac{\sigma}{\overline{S_g}}$$

A developed version of the formula for analyzing data defined on a measurement segment is:

$$\varepsilon = \sqrt{\frac{\frac{1}{2}(S_{g1} - \overline{S_g})^2 + \sum_{i=2}^{n-1}(S_{gi} - \overline{S_g})^2 + \frac{1}{2}(S_{gn} - \overline{S_g})^2}{\overline{S_g}^2 (n-1)}}$$

Conclusions

The floating process analysis allows:

- showing the dependence of floated concrete surface quality on a uniformity index of a disk influence,
- improvement of physical and mechanical features of concrete mix products for example by increasing surface compression strength and abrasion resistance,
- thanks to applying disks of optimal geometrical parameters for working tools or an optimal movement path, the quality and durability improvement as well as the decrease of costs connected with treated surfaces maintenance might be achieved without any additional investment outlays.

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Abstract

The article contains the theoretical bases of the analyses process floating causes and grinding concrete surface. The particular attention has been paid to quality factors of processing determined by roughness uniformity of processed surface.

Streszczenie

Artykuł zawiera teoretyczne podstawy analizy procesu zacierania i szlifowania powierzchni betonowych. Szczególną uwagę zwrócono na parametry jakości obróbki określonej równomiernością szorstkości obrabianej powierzchni.