# The Distribution Analysis of Concrete Horizontal Surface Air Pores

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The main aim of this article was to determine blemishes of concrete surface as well as to perform the statistical analysis of pores distribution. The quality of the concrete surfaces in this research depended only on the form's materials that were as follows: wood impregnated with polymeric oil [WPO], wood covered with rubber [WCR], sawn timber [ST], metal [M] and plastic [P] formworks. Statistical analysis of the results was made. Following parameters of the obtained results were calculated: mean value, dispersion, standard deviation and the coefficient of variation. Also maximum and minimum values of experimental results are given. Intervals of the experimental results are provided for each specimen with the biggest possibility.

**Keywords:** *concrete surface quality, formwork, statistical analysis*.

## 1. Introduction

It is not easy to obtain that the formed concrete surface would be free of air pores, honeycombs and other blemishes. At the moment, the main solution for the removal of air bubbles from the surface of concrete is to use various repairing mortars. Unfortunately, they change the color of the natural concrete, this process requires an additional work load and, of course, it is not economic (Klovas and Dauksys 2011).

In the building industry, architects and building owners generally have strict requirements for the quality of concrete surface (Lemaire et al. 2005, Menard 1999). Usually, these requirements mainly concern flatness, tint and the absence of bugholes of concrete surface CIB Report (1973). The evaluation of concrete surface flatness generally does not pose a problem on the building site. However tint and the quantity of bugholes are factors, which often are being considered by the owners, architects and building contractors.

According to the guidelines of: ACI 309R (2005), ACI 116R (2000), ACI 309.1R (2008), the most important factors that influence the concrete surface quality are:

1. Failings at the projecting and building processes:
   - Sophisticated concrete laying due to the complicated form of the structure element;
   - Inappropriate assembly and maintenance of the formworks;
   - Inappropriate concrete mixture compositions;
   - Lack or over vibrated concrete mixture;
   - Inappropriate supervision of the concrete hardening process.
2. Failings due to the outdated building equipment.
3. Failings due to the inappropriate usage of building materials:
   - Undesirable usage of mineral and chemical admixtures;
   - Bad evaluation of different cement characteristics.
4. Influence of the aggressive environment.

Bugholes do not affect the structural integrity of concrete, but their presence causes delays in the production schedule due to the need for proper surface treatment before the structure is considered to be finished (Reading 1972, Shilstone 1979, Stamenkovic 1973).

Formworks are also very important factor for concrete surface quality. Scientists have conducted a research using two different types of formworks: controlled permeability (CP) and not permeable formworks. The results have shown that by using CP formworks the pore diameter (mm) of concrete surface has decreased up to 50 %, porosity (%) – up to 45 %, surface hardness (MPa) has increased up to 70 % and blow-hole ratio has decreased up to 90 % comparing with those concrete surfaces using five layer wood-based formworks (Coutinho 2001, Price 2000, Duggan 1992).

International Council for Building Research has provided main guidelines how the concrete may be defined referring the surface quality: (Heist et al. 2002)

- ROUGH class is provided for surfaces where there is no special requirement for finish;
- ORDINARY class applies to surfaces where appearance, whilst a minor factor, is still of some importance;

- ELABORATE class applies to those with definite requirements for visual appearance;
- SPECIAL class applies to those calling for the highest standards of appearance.
- Guide to concrete construction (1994) provides the main surface blemishes that could be obtained after the concrete process.
- Blowholes (sometimes called bug holes) are individual rounded or irregular cavities that are formed against the formwork and become visible when it is stripped. Small blowholes (less than 10 mm.) tend to be approximately hemispherical while larger ones are irregular and often expose coarse aggregate particles. They tend to be more prevalent towards the top of concrete placement than at the bottom, due to the increased compaction and static head at the bottom layer of the pour. Blowholes are caused by the entrapment of air against the inside face of the formwork.
- Crazing or craze cracking (sometimes called as map cracking) is a network of fine random surface cracks spaced from 10 to 70 mm apart, dividing the surface up into irregular hexagonal areas. They are always most prominent then the surface has been wet and then dries off, leaving the damp cracks outlined against the dry surface. Crazing is caused by the shrinkage of the surface layer relative to the base concrete.
- Dusting. A dusting floor surface is marked by an accumulation of fine material requiring to be swept up after the floor has been used. Dusting of the surface is caused by the surface layer being weak and the matrix not properly bonding the fine aggregate particles (Suprenant and Malisch 1999).
- Flaking is where discrete pieces of the surface become detached leaving a rough indentation behind. The pieces are usually flat. Scaling should not be confused with flaking. Scaling is the delamination of the concrete surface when exposed to freeze-thaw cycles and although the appearance is similar, but the mechanism is different. Flaking is caused by inappropriate finishing techniques that seal the surface and trap the water which would otherwise have risen to the surface as bleed water (Suprenant and Malisch 1998).
- Honeycombing refers to voids in concrete caused by the mortar not filling the spaces between the coarse aggregate particles. It usually becomes apparent when the formwork is stripped, revealing a rough and stony concrete surface with air voids between the coarse aggregate. Honeycombing is caused either by the compaction not having been adequate to cause the mortar to fill the voids between the coarse aggregate, or by holes and gaps in the formwork allowing some of the mortar to drain out of the concrete.

The outcome of this article was to find how different formworks influence the quality of concrete surfaces.

## 2. Methods

JSC "Akmenes cementas" (Lithuania) Portland cement CEM II/A-LL 42.5 R was used for the test. Physical and mechanical properties of Portland cement CEM II/A-LL 42.5 R are given at the table 1.

Kvesu quarry sand with the fraction of 0/4, bulk density of 1550 kg/m$^3$ and fineness module of 1.67 was used as fine aggregate. 0/1 sand fraction ( $\rho = 1460$ kg/m$^3$, fineness module 2.37) was also used as fine aggregate. Gravel with the fraction of 4/16 and bulk density of 1327 kg/m$^3$ was used as coarse aggregate. Granulometric composition of aggregates is presented at table 2.

Concrete mixture composition, presented at table 3, was not designed, but selected according to the recommendations of reinforced concrete producers. Plasticizing admixture based on polycarboxylatether MURAPLAST FK 801.1 (MC-Bauchemie, Germany) was used with the solution density of 1.05 g/ml. The total dosage of admixture– MURAPLAST FK 801.1 was 1.4% of cement.

In addition, the pigment Bayferrox (Basf, Germany) was used for the test. Approximately 4% of pigment in respect to the mass of cement was added.

Also form release agent was used: Ortolan SEP 711 (MC-Bauchemie, Germany). During the research, dry aggregates were used for concrete mixtures. Cement and aggregates were dosed by weight while water and chemical admixture were dosed by volume. Chemical additives in the form of solutions were mixed with water and used in preparation of concrete mixture. Concrete mixture was mixed for 3 minutes in the laboratory in forced type concrete mixer.

***Table 1.*** *Physical and mechanical properties of Portland cement CEM II/A-LL 42.5 R*

| | |
|---|---|
| Specific surface area, m$^2$/kg | 410 |
| Particle density, kg /m$^3$ | 3050 |
| Normal consistency of cement paste, % | 26.5 |
| Initial setting time, min. | 195 |
| Compressive strength after 2 days / after 28 days, MPa | 27.1/54.0 |

***Table 2.*** *Granulometric composition of aggregates*

| Radius of the sieve's mesh, mm | The amount of poured out material, % | | |
|---|---|---|---|
| | Sand fraction 0/1 | Sand fraction 0/4 | Gravel fraction 4/16 |
| 16.0 | 100.00 | 100.00 | 98.80 |
| 8.0 | 100.00 | 100.00 | 42.10 |
| 4.0 | 100.00 | 95.10 | 4.30 |
| 2.0 | 99.80 | 81.80 | 1.00 |
| 1.0 | 99.10 | 54.60 | 0.52 |
| 0.500 | 77.40 | 12.40 | 0.44 |
| 0.250 | 2.20 | 0.70 | 0.36 |
| 0.125 | 0.50 | 0.30 | 0.32 |
| 0.000 | 0.00 | 0.00 | 0.00 |

***Table 3.*** *Concrete mixture compositions*

| Materials | Measurement | Concrete mixture composition. Materials per 1m$^3$ concrete mixture |
|---|---|---|
| | | BA1 |
| Cement | kg | 293 |
| Water | l | 158 |
| Course aggregate, gravel - 4/16 | kg | 970 |
| Fine aggregate, sand - 0/4 | kg | 733 |
| Fine aggregate, sand - 0/1 | kg | 277 |
| Superplasticizer, Muraplast FK 801.1 (1.4 %) | l | 4.2 |
| Pigment, Bayferrox | kg | 11.7 |
| **Water and cement ratio** | – | **0.540** |

Five different formworks were used for this research: wood impregnated with polymeric oil [WPO]; wood covered with rubber [WCR]; sawn timber [ST]; plastic [P] and metal [M] forms. Some of them are presented at Fig. 1.

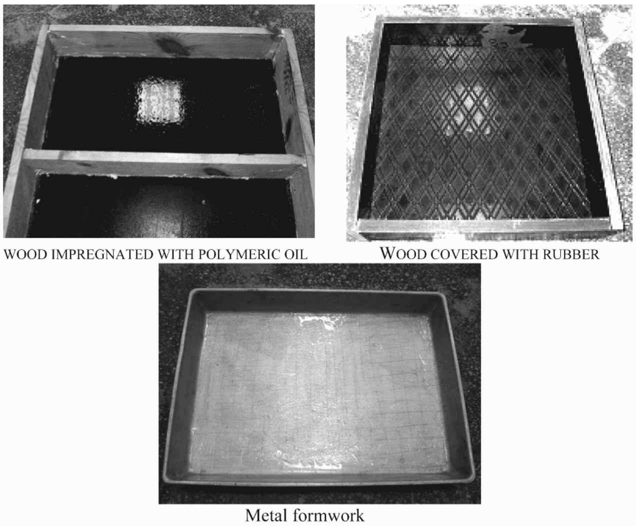



***Fig. 1.*** *Formworks that were used for the research*

Dimensions of the different formworks:

- Wood impregnated with polymeric oil [WPO]: 550 x 300 mm;
- Wood covered with rubber [WCR]: 400 x 400 mm;
- Sawn timber formwork [ST]: 600 x 300 mm;
- Plastic formwork [P]: 400 x 400 mm;
- Metal formwork [M]: 400 x 400 mm.

Concrete surface area of 300 x 300 mm was evaluated.

The irrigation corner of plywood using solvent-based form release agent was established. The test took 6 days in order to check the changing of an angle. The results are presented at table 4.

The main idea of this research was to conduct the test with the excessive amount of form release agent which was applied on the formwork. This is the most common mistake which is done by the building contractors, where the form release agent is sprayed on the formwork without removing the excessive amount.

The air content of concrete mixture was determined according to LST EN 12350-7 standard. Flow table test for concrete mixtures was conducted according to LST EN 12350-5:2009 standard and density of concrete mixtures – LST EN 12350-6. Technological properties of concrete mixture used in this research were established as follow: consistency of concrete mixture measured by flow table test rate (525 mm) – F4, air content of concrete mixture – 4.0 %, the density of concrete mixture – 2374 kg/m$^3$. The quantity of fine particles (not exceeding 0.25 mm) was 202.671 kg to 1m$^3$ of concrete mixture.

The parameters of vibration table: amplitude – 0.5 mm; frequency – 50 Hz. Environment conditions: 18 °C of temperature and 65 % of relative humidity. Vibration time was seven seconds.

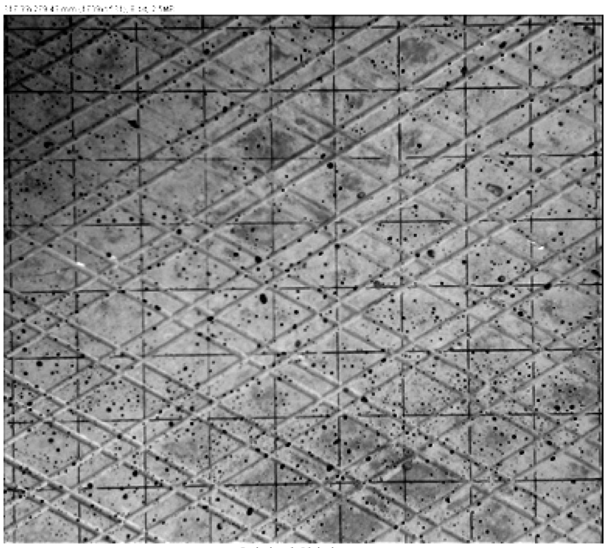
"ImageJ" method provides visual information about the quality of concrete surfaces in respect to the ratio between area of blemishes and whole specimen. All the photographs of this research were taken by the HTC HD2 with 5 megapixels camera. Photos were taken around 30 cm of distance.

"ImageJ" method:

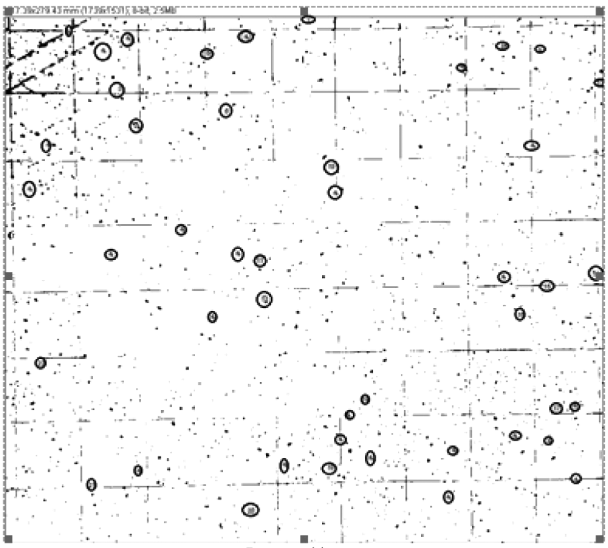
1. Image of the concrete surface is imported into the "ImageJ" program. In this research, images of around 900 cm$^2$ of area were analyzed;
2. Picture is set to the 8bit quality. This is done to highlight the blemishes of the surface (Fig. 2);
3. Image scale is set to the certain known dimension;
4. Image colors are changed into the black and white to highlight the blemishes of the surface;
5. The areas of surface blemishes are calculated.

***Table 4.*** *Irrigation corner of solvent-based form release agent*

| | | 24 h | | 48 h | | 72 h | | 96 h | | 120 h | | 144 h | | 168 h | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nr. | Form release agent | α | 90 – α | α | 90 – α | α | 90 – α | α | 90 – α | α | 90 – α | α | 90 – α | α | 90 – α |
| 1 | Solvent-based (excessive appl.) | 40 | 50 | 39 | 51 | 43 | 47 | 48 | 42 | 52 | 38 | 59 | 31 | 44 | 46 |



Original 8bit image

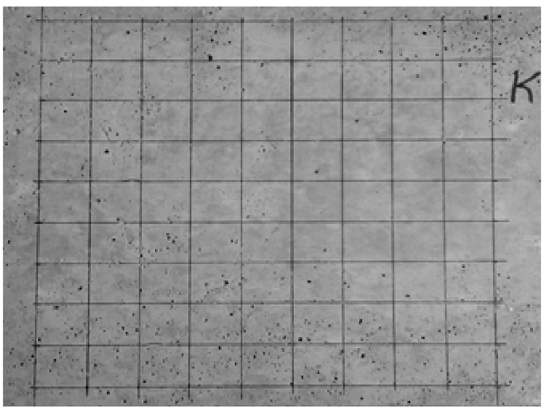


Processed image

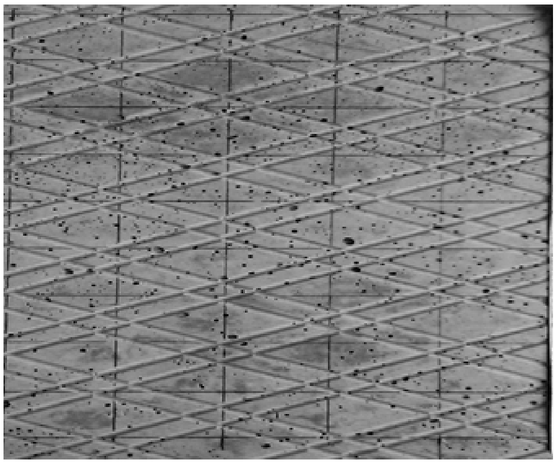
***Fig. 2.*** *Image transformation using "ImageJ" program*

## 3. Results

Concrete specimens were cured in different formworks for 7 days at temperature of 20±2 $^{o}$C. The appearance of the specimens is presented at Fig. 3.

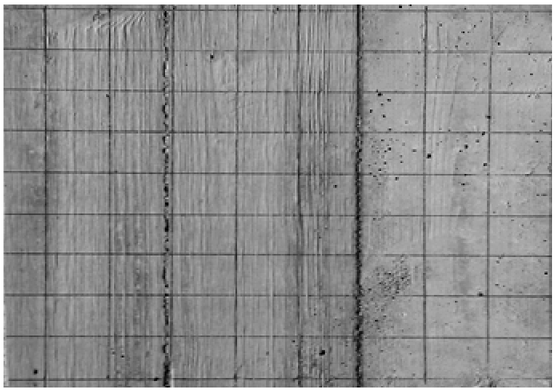



a) Concrete specimen cured in wood impregnated with polymeric oil formwork



b) Concrete specimen cured in wood covered with rubber formwork

c) Concrete specimen cured in metal formwork



d) Concrete specimen cured in saw timber formwork

e) Concrete specimen cured in plastic formwork

***Fig. 3.*** *The appearance of concrete specimens after the curing*

*Table 5.* *Statistical analysis of the experimental results*

| | Formworks | | | | |
|---|---|---|---|---|---|
| Parameters | WPO | WCR | ST | P | M |
| N | 59 | 106 | 12 | 45 | 70 |
| MV | 4.203 | 4.155 | 4.867 | 1.728 | 2.133 |
| D | 3.665 | 6.305 | 9.683 | 0.456 | 0.535 |
| SD | 1.914 | 2.511 | 3.105 | 0.675 | 0.732 |
| CV | 0.456 | 0.604 | 0.638 | 0.391 | 0.343 |
| MIN | 1.784 | 1.499 | 1.721 | 1.065 | 1.033 |
| MAX | 11.230 | 17.82 | 12.868 | 4.717 | 4.65 |
| RF/I | 0.322/ [3.157; 4.530) | 0.557/ [1.45; 3.50) | 0.500/ [3.95; 6.18) | 0.556/ [1.065; 1.627) | 0.314/ [1.54; 2.048) |

Statistical analysis of the results was made. Three casting with each formwork were performed. Computer programs “Mathcad 15” and “Excel 2010” were used. Following statistical parameters of blemishes area were calculated: mean value (MV), dispersion (D), standard deviation (SD) and the coefficient of variation (CV). Also maximum (MAX) and minimum (MIN) values of experimental results are given. The biggest relative frequency of experimental results is provided. The results of the statistical analysis are presented at table 5.

According to the information provided at table 5, the size of surface blemishes varies between 1.033 mm$^2$ (formwork – metal) to 17.82 mm$^2$ (formwork – wood covered with rubber). The biggest standard deviation (SD) of surface blemishes area is obtained by using formworks: sawn timber (ST) (SD = 3.105 mm$^2$) and wood covered with rubber (WCR) (SD = 2.511 mm$^2$). The most porous (N = 106) concrete surface is obtained by using wood covered with rubber formwork. The deviation of surface pores by size varied from 1.45 mm$^2$ to 3.50 mm$^2$. The smallest surface pore by size was 1.499 mm$^2$ and the biggest one – 17.82 mm$^2$. Rubber, as material, does not absorb the excessive oil, therefore many little pores appeared. The least porous (N = 12) surface was obtained by using saw timber formwork. The deviation of surface pores by size varied from 3.95 mm$^2$ to 6.18 mm$^2$. The smallest surface pore by size was 1.721 mm$^2$ and the biggest one – 12.868 mm$^2$. The reason could be that timber absorbed the excessive amount of form release oil. In those places where was the lack of oil, bigger surface blemishes appeared.

The establishment of surface pores quantity helps to evaluate the concrete quality more accurately. In nowadays, in Lithuania only old standard GOST 13015.0-83 is being used, where the evaluation factor is the size of blemishes, but there is nothing about the quantity of surface defects.

## 4. Conclusions

1. Open sourced computer program “ImageJ” can be used for the evaluation of concrete surface quality by calculating the quantity and establishing the dimensions of blowholes, air pores and honeycombs.

2. The most porous concrete surface is obtained by using wood covered with rubber formwork (N = 106). The excessive amount of form release agent was not cleaned from the surface of the formwork and the surface material did not absorb it.

3. The least porous concrete surface is obtained by using sawn timber formwork (N = 12). At this case, the excessive amount of form release agent was absorbed by the timber.

4. The smallest concrete surface pores are obtained by using formwork covered with plastic (referring the distribution of the pores), on the other hand, the biggest pores are obtained by using formwork with the rubber surface material.

## References


ACI 309R. Guide of Consolidation of Concrete. 2005. ACI Committee 309, technical committee document 309R-05 2005, 35.

ACI 116R. Cement and Concrete Terminology. 2000. American Concrete Institute. 2000, 73.

ACI 309.1R. Behavior of Fresh Concrete During Vibration. 2008. ACI Committee 309, technical committee document 309. 1R-08. 2008, 18.

CIB Report no. 24, commission W29. 1973. Tolerances on blemishes of concrete, 1973.

Coutinho, J. S. The Effect of Controlled Permeability Formwork (CPF) on white concrete. 2001. ACI Materials Journal. Vol. 98. No. 2. 2001, 148–171.

Duggan, T. Enhancing Concrete Durability Using Controlled Permeability Formworks. 1992. 17th Conference on Our World in Concrete and Structures. Singapure, August 1992: pp. 57–62.

Klovas, A., Daukšys., M. 2011. Apdailinio betono paviršiaus kokybė ir defektai // Statyba ir architektūra: jaunųjų mokslininkų konferencijos pranešimų medžiaga / Kauno technologijos universitetas. Kaunas: Technologija, 2011. ISBN 9786090202555, 99–108. [Quality and defects of the decorative concrete surface // Civil engineering and architecture: conference of the young scientists, proceedings

/ Kaunas university of Technology. Kaunas: Technology, 2011. ISBN 9786090202555, 99–108]

Lemaire, G., Escadeillas ,G., Ringot, E. 2005. Evaluating concrete surfaces using an image analysis process. Construction and Building Materials 19 2005, 604 – 611. http://dx.doi.org/10.1016/j.conbuildmat.2005.01.025

Menard, J. P. 1999. La qualite pour tous les usages. Construction Moderne 101 1999, 12. [Quality of all uses. Construction Modern 101. 1999, 12.

Price, W. F. Controlled Permeability Formwork. 2000. CIRIA Report C511. 2000, 102.

Reading, T. J. The Bug Hole Problem. 1972 ACI Journal, Proceedings V. 69, No. 22, Nov. 1972, 165–177.

Stamenkovic, H. Surface Voids Can Be Controlled. 1973. Concrete Construction, V. 18, No. 12, Dec. 1973, 597–598.

Suprenant, B. A., Malisch, W. R. 1998. Diagnosing slab delamination. Concrete construction January, February and March,1998.

Suprenant, B. A., Malisch, W. R. 1999. Sealing effects of finishing tools. Concrete construction September 1999, 39–43.

Shilstone, J. M. Surface Blemishes in Formed Concrete.1979. Concrete construction, V. 24, No. 11, Nov. 1979, 719 and 765.

Heist, T. C., Kaden, R. A., Martin, R., Meza P. Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117-90) 2002. Reported by ACI Committee 117. 2002.

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