Factors influencing the surface quality of architectural concrete

Y Tsimbalyuk¹, E Karpova²*, A Sedova³, and G Skripkiunas²

¹MC-Bauchemie, Taikos 135a, Kaunas, LT-51129, Lithuania
²Laboratory of Concrete Technologies, Institute of Building Materials, Vilnius Gediminas Technical University, Linkmenu 28, Vilnius, LT-08217, Lithuania.
³Department of Architecture, Kalashnikov Izhevsk State Technical University, Studencheskaya 7, Izhevsk, 426069, Russia

E-mail: ekaterina.karpova@vilniustech.lt

Abstract. Architectural concrete has wide opportunities to be used both for exteriors and interiors in different buildings. Architectural concrete is the type of concrete which is usually not subjected to finishing, therefore higher standards are declared for its surface quality. According to normative documents, architectural concrete needs to have a uniform colour tone, texture, minimal defects and porosity of the surface. The present research demonstrates the concrete surface quality obtained in the course of varying different factors such as the presence of stabilizing admixture, granulometry of aggregates, usage of fly ash and workability of the concrete mixture. In the course of the research, the testing of raw materials and concrete in the fresh and hardened state were performed according to standard methodologies. The assessment of concrete surface quality was provided through the analysis of concrete surface photo 50x50 cm size. Based on the experimental results, it can be stated that better quality of the concrete surface was obtained in case of usage of gravel with two fractions of 4/16 and 2/8 and fly ash in the dosage of 25 % cement weight in the presence of plasticizing and stabilizing admixtures. The concrete mixture with high workability showed better filling of formwork and mixture particles packing on the formwork surface which led to a better quality of the concrete surface.

1. Introduction

Today, many concrete elements require a good finish, especially in public buildings [1]. Architects and civil engineers more often prefer to use concrete as finishing material rather than a plaster finish. In this case the technique of using concrete surface refers us to stone buildings when the stone was used both as a construction and finishing material. The value of stone monuments is in its construction technique, the preservation of which impacts in higher heritage values and social acceptance. The use of concrete finish allows architects to create surfaces which look similar to the stone.

According to the concept of sustainable development, local activities have a major effect on the environment [3]. Hence, the preservation of vernacular materials promotes environmental pillar of sustainable development. Technically, the application of monolith concrete elements can produce an increase in building workability in comparison with stone structures. Architecturally, the depth of pores and the greater surface of concrete impacts in the creation of artificial stone material, which has similar aesthetic characteristics to vernacular materials. Through changing the size of pores, concrete surface can be made similar to different natural stones (Figure1a). While concrete surface can be
finished with texture (Figure 1b) similar to wooden planks, which can be easily archived through the use of wooden formwork (Figure 1c) or stone with a crushed surface for small concrete elements (see Figure 1d).

![Figure 1](image1.png)

**Figure 1.** Architectural concrete surfaces: concrete blocks as natural stones (a), facade concrete panels (b), concrete surface as wooden planks (c), concrete surface as stone crushed surface (d) (photo by Gintautas Skripkiunas).

The creation of modern concrete surfaces allows the construction of public and residential buildings looking similar to vernacular for a particular region in terms of their appearance which is made through the application of modern construction and design approach. For example, concrete with pores of 2 mm is able to make surface looking similar to sandstone which had been historically used in many European cities as construction and finishing material. Concrete allows avoiding natural stone limitations in terms of material choice and tooling [2].

![Figure 2](image2.png)

**Figure 2.** Concrete facade of residential building in Kaunas, Lithuania (photo by Rimvydas Moceikis).

Concrete which meets additional requirements to its surface can be classified as architectural concrete. Architectural concrete can be considered as concrete which is permanently exposed to view and therefore requires additional attention to the selection of the materials for concrete production, forming, placing and finishing [5]. The architectural concrete needs to have uniform colour tone and texture, minimal defects and porosity of the surface. The example of the residential building with the usage of architectural concrete is presented in Figure 2. Moreover, the international practice provides many successful cases of the architectural concrete use inside buildings (Figure 3).

Frequently in concreting, builders meet such surface defects as bugholes, water or paste loss, honeycombs, cold joints, efflorescence, cracking, aggregate transparency etc. [6-8]. Among surface defects, more significant attention is paid to surface voids and bugholes. Such defects are formed
when air and water bubbles entrap at the surface in the course of concrete placing [8, 9].

![Figure 3](image_url)

**Figure 3.** Home and studio of Pedro Reyes, Mexico City: interior. [4].

The methods of evaluation of concrete surface quality are still under development worldwide. However, there are some standards concerning the surface quality. Based on the annex to the Russian standard GOST 13015-2012, concrete surfaces classified into 7 categories (A1-A7) from the best to the worst one taking into account the biggest dimension of the blemishes, local rinses or hollows, the depth of cracks in concrete edge and their sum [10]. CIB Report No. 24 “Tolerances on blemishes of concrete” provides the estimation of surface quality through the comparison of samples with reference cards [11]. American standard ACI 309.2R-15 includes such category of surface quality as Rough, Ordinary, Elaborate and Special [12]. The similar and additional information about the classification of concrete surface quality described in the American standards ACI 301-16 and ACI 347R-14 as well [13, 14]. Recently issued Lithuanian standard “LST 2015:2020 Precast concrete product. Surface appearance characteristics and the methods for inspecting” classified the concrete surface quality into 3 categories (A-C), where C category is worst one [15]. This classification is made based on the number of blemishes per 1 m² of concrete surface. In addition to the methods of surface quality evaluation provided by standards, researchers work on the development of different digital image processing technologies to decrease or avoid manual labor-intensive evaluations and factors influenced by human eyes [16, 17].

To obtain concrete with high surface quality, it is necessary to pay attention to the properties of concrete including its type, composition, properties of the mixture (setting time, flowability, air content, bleeding, segregation) and quality of formworks, casting and curing [8]. As for concrete type, the number of research shows that the usage of self-compacting concrete and concrete with high workability is better to use in order to reach high surface quality [7, 8, 18]. The complex of concrete properties such as workability, bleeding, segregation, rheological parameters, amount of air in concrete mixture should be taken into account. J. Kwasny et al. established that an increase in yield stress increase the total content of surface air voids, especially with a size smaller than 1 mm [8].

Obviously, properties of concrete mixture should be managed by appropriate concrete compositions considering the water to cement ratio [8], type and granulometry of aggregates [19], features of fillers [18] etc. As for formwork and casting of concrete mixture, the following observations were obtained. Megid & Khayat established that permeable lined formwork improves the surface quality of concrete due to the effective escape of entrapped air/water and bleeding water [20]. Standard ACI 303R-12 highlights that impervious form surface of formworks will provide the more
uniform appearance of concrete surface. The same standard recommends the usage of the chemically active release agents for architectural concrete [5]. At the same time, it is important to take into consideration placement technique of concrete, methods of compaction, rate of casting, height from which placement of concrete is proceeding [8]. For example, Megid & Khayat observed that the increase in segregation risk and reduction of surface quality when concrete is poured into formwork with the height of more than 1 m [7].

The aim of the current research is to analyze how granulometry of aggregates, presence of stabilizer and application of fly ash affect the concrete surface quality.

2. Materials and methods

Portland cement without mineral additives CEM I 42.5R according to EN 197-1 was applied as a binder in the course of the research. Sand of fraction 0/4 and gravel of fractions 4/16 and 2/8 were used as a fine and coarse aggregates. Fine and coarse aggregates corresponded to the requirements of EN 12620. Mixing water was used in accordance with the requirements of EN 1008. Superplasticizer based on the polycarboxylate ether (PCE) with solution density 1.05 g/ml in the dosages 0.9-1.0 % cement weight was applied. The stabilizer was taken in the dosage of 0.4 % cement weight. Fly ash was applied as a mineral additive in the dosage of 25 % cement weight. 5 composition of concrete were mixed for surface quality testing (Table 1).

### Table 1. Concrete composition.

| Concrete composition | Fractions of coarse aggregate | Plasticizing admixture, % | Stabilizing admixture, % | Fly ash content, % |
|----------------------|-------------------------------|---------------------------|-------------------------|-------------------|
| 1                    | 4/16                          | 0.90                      | 0                       | 0                 |
| 2                    | 4/16                          | 0.90                      | 0.40                    | 0                 |
| 3                    | 4/16 and 2/8                  | 1.00                      | 0.40                    | 0                 |
| 4                    | 4/16 and 2/8                  | 1.00                      | 0.40                    | 25                |
| 5                    | 4/16 and 2/8                  | 1.00                      | 0.40                    | 25                |

For each concrete mixture the evaluation of concrete temperature, density, slump and air content was performed according to the corresponding chapters of EN 12350 (Table 2). The mixing of concrete mixture was performed in a plant and after that was transported to the construction site in a truck mixer. Concrete mixture was placed in the formwork with steel surface which was covered by mineral oil. The formwork was removed at 3 days age of concrete.

### Table 2. Fresh concrete properties.

| Concrete composition | Temperature, °C | Density, kg/m³ | Slump / Flow, mm | Air content, % |
|----------------------|-----------------|----------------|------------------|---------------|
| 1                    | 6.8             | 2339           | 230 / -          | 2.2           |
| 2                    | 7.4             | 2343           | 220 / -          | 1.7           |
| 3                    | 9.0             | 2306           | 240 / -          | 2.7           |
| 4                    | 10.3            | 2431           | 210 / -          | 1.4           |
| 5                    | 6.2             | 2431           | - / 525          | 3.1           |

Evaluation of concrete surface quality was provided through the analysis of photo of 50x50cm size.

3. Results and discussion

Figure 4 presents the quality of concrete surface with and without the application of stabilizing admixture. It can be seen that concrete surface presented in Figure 4b is slightly better than the surface
in Figure 4a. However, even with the application of stabilizer the surface possesses by recesses of different diameters and depth. Also the colour of the surfaces in both pictures is not homogeneous.

In the next stage of the experiment, the concrete with a different granulometry of gravel was prepared. Figure 4a, b demonstrates the concrete surface with the usage of gravel with a fraction of 4/16 whereas Figure 4c shows the concrete surface in case of the usage of gravel with two fractions 4/16 and 2/8. It can be seen that concrete surface in Figure 4c has less caverns and more equal colour, but some pores and recesses are still visible.

Addition of fly ash in the dosage of 25 % cement weight leads to the concrete surface with equal colour and absence of caverns and less number of pores in comparison with surfaces presented in Figure 4. Figure 5 demonstrates the concrete surface quality with the application of fly ash.

![Figure 4](image1.png)

**Figure 4.** Concrete surface of the sample without stabilizer (a), with stabilizer (b) and with gravel of fractions 4/16 and 2/8 (c).

The improvement of concrete consistency for 5th concrete composition leads to the high workability of concrete with a flow of 525 mm. The surface quality for 5th concrete composition (Figure 5b) possesses by homogeneous colour and less number of pores in comparison with surface presented in Figure 5a.
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**Figure 5.** Concrete surface with 25 % cement weight of fly ash (a), with 25 % cement weight of fly ash and high workability (b).

Based on the obtained images of concrete surfaces and evaluation of the number of lumps and recesses, the surface quality of concrete was classified according to LST 2015:2020 [15]. The results of the evaluation and assignment of the surface quality category are presented in Table 3.

**Table 3.** Evaluation and assignment of concrete surface category according to LST 2015:2020.

| Concrete composition | Quantity of lumps in 1m$^3$ concrete surface | Quantity of recesses in 1m$^3$ concrete surface | Category by LST 2015:2020 |
|----------------------|---------------------------------------------|-------------------------------------------------|--------------------------|
|                      | d = 2-5 mm                                   | d ≥ 5 mm                                        |                          |
| 1                    | 0                                            | 1372                                            | 260                      | -                        |
| 2                    | 0                                            | 1124                                            | 196                      | -                        |
| 3                    | 0                                            | 772                                             | 140                      | -                        |
| 4                    | 0                                            | 132                                             | 16                       | B                        |
| 5                    | 0                                            | 108                                             | 0                        | A                        |

5th concrete composition with high workability leads to better surface quality. Improved concrete consistency simplifies the concrete placement, provides better filling of formwork and better mixture particles packing on the formwork surface.

**4. Summary**

Architectural concrete has wide opportunities to be used both for exteriors and interiors in different buildings. Whereas, the surfaces made of architectural concrete have high aesthetic characteristics, they apply additional requirements to the quality of finish, which contribute to the perception of such surfaces. The architectural concrete has to possess by the uniform colour tone, texture, minimal defects and porosity of the surface.

In the course of the research the high concrete surface quality was reached in case of application of high workability concrete with coarse aggregates of special granulometry (gravel of fractions 4/16 and 2/8), sufficient content of fines (fly ash in the dosage 25 % cement weight), plasticizing and stabilizing admixtures. In this case the absence of lumps and a small content of recesses in 1m$^3$ of concrete were observed.

The concrete composition with high workability showed better surface quality in comparison with other considered concrete compositions. Improved consistency of concrete mixture simplified the concreting and provided better mixture particles packing on the formwork surface. Grinded dolomite, sand, granite and others fine particles can be used along with fly ash in order to ensure the better stability of concrete with high workability.
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