# An Approach to Classify the Concrete Surface Using Digital Image Processing Combined with Fuzzy-logic Based System

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***Abstract-*** **This paper presents an expert system that was developed with the goal of classifying the surface finish of self-compacting concrete (SCC) precast elements. The classification concerns the presence of bugholes, which are imperfections that appear on a concrete surface after demoulding. The surface evaluation is based on digital images that are processed by an image analysis tool. This tool defines the parameters that will be evaluated by a fuzzy logic-based classification tool. The classification is based on a novel scale that considers the degree of treatment necessary to achieve proper surface finish. The proposed system was app lied to evaluate SCC precast elements. The results from the case study highlight the success of the proposed expert system in evaluating SCC finish. In addition, the system proved to be of great help when used for systematic analyses of the effect of mixture proportions.**

## 1. INTRODUCTION

Self-compacting concrete (SCC) is a high-performance concrete that can flow under its own weight so as to completely fill the formwork and self-consolidate without any mechanical vibration [1,2]. This type of concrete is specifically designed to achieve excellent deformability, low risk of blockage, and good stability, ensuring a high formwork filling capacity. SCC is considered a suitable material for the construction of structural members with high volumes of steel reinforcement because of its ability to easily flow in highly congested areas [3,4].

The use of SCC in precasting is rapidly developing in the construction industry, most likely due to the production process costs and the advantageous organizational nature of this material [4]. Nonetheless, it is important to consider that the production of SCC is more difficult than that of conventional concrete, and many parameters have to be considered to obtain a final product with acceptable quality for the intended purpose. One of the primary problems associated with precast concrete plants relates to the presence of bugholes on the concrete surface. Bugholes are imperfections or voids that appear on the concrete surface after demoulding. Even with the advanced construction methods and chemical admixtures of today, surface voids still persist [5]. The European guidelines for SCC [6] indicate that the appearance of bugholes is related to the presence of entrapped air, entrapped form oil, and/or entrapped water in the contact surface with the formwork. Also, the occurrence of bugholes is more pronounced in SCC mixtures with poor filling ability, poor passing ability, high viscosity or high yield stress, low slump-flow, and rapid slump-flow reduction. Although bugholes do not affect the structural integrity of concrete, their presence causes delays in the production schedule. These delays are due to the need for proper surface treatment before the structure is considered finished. As a result, the production cost is directly affected because the time to produce each concrete element is increased when cosmetic treatments are necessary. The first methods used to classify concrete surface quality were based on the manual counting and measuring of the diameter of bugholes, followed by the calculation of the percentage of holed areas on the surface [7,8]. This technique, however, was extremely laborious and incapable of representing the surface quality [9]. Therefore, this classification method was replaced with the one suggested by Thomson [7], who proposed that the analysis of concrete surface quality had to be based on the comparison of the actual surface to photographs of reference samples with different degrees of bughole coverage. An example of reference photos that are recommended by the Concrete International Board (CIB) [10] is illustrated in Fig. 1. This method, which uses the idea that was introduced by Thomson [7], is considered acceptable by the industry today. While simple in principle, the comparison with photographs of reference samples can be problematic due to the variability between different printed scales of the reference samples and the subjectivity of the human eye. Moreover, one surface can group together several types of bugholes such that the use of the reference becomes rather difficult and subjective [5,11].

In order to obtain a better evaluation of the concrete surface, an image processing and analysis tool is proposed in this work. According to Chermant [11] and Coster and Chermant [13], the use of image analysis is advantageous because it rapidly gives an objective result and in a way entirely automatically. Image analysis methods have been used successfully in several civil engineering areas of study, e.g., concrete surface crack monitoring and quantification [14], concrete bridge inspection and classification of radar images among others. An automated image analysis method for evaluating concrete surface finish was presented by Lemaire et al. [11]; however, this method takes into account the same parameter that was proved to be incapable of representing the essence of surface quality, i.e., percentage of holed areas on the surface. Also, Ozkul and Kucuk [5] designed an instrument for measuring bughole rating of concrete surfaces based on pressure differential method. Besides using a different technique, the surface classification still relied on the percentage of holed areas on the surface only. Therefore, it is noticeable that improvements are still necessary concerning the parameters to be used to numerically represent surface quality. In view of that, the use of two additional parameters for surface classification is proposed in this work.

The expert system proposed in this work consists of a combination of the developed image analysis method and the fuzzy logic based classification system. In contrast to current classification methods, the proposed expert system classifies the final aspect of concrete surfaces according to the degree of intervention necessary to achieve a proper surface finish. The system was applied in a case study focused on the classification of the surface appearance of precast elements produced with SCC.

## 2. EXPERT SYSTEM FOR CONCRETE SURFACE CLASSIFICATION

The proposed expert system intends to classify the surface appearance of concrete. The classification is based on a novel scale that takes into account the degree of intervention required to achieve a proper surface finish. Besides the percentage of bugholes area on the concrete surface, two additional parameters were taken into account to describe the surface quality of concrete in regard to the presence of bugholes. The expert system is divided in two parts: (i) image analysis tool and (ii) fuzzy logic-based classification tool. Its complete configuration

### 2.1. Input parameters

The concrete surface is prone to the appearance of bugholes. The higher the bugholes coverage on concrete surface, the higher the degree of intervention necessary to correct the surface before the structure is considered to be finished. Based on the CIB bughole scale (Fig. 1), it is likely that the ratio between the total area of bugholes (Ab), see Eq. (1), and the total area of the concrete surface (AS) is the most suitable parameter to classify the surface aspect. This parameter corresponds to the percentage of bugholes area on the concrete surface (AB ) and it is presented in Eq. (2)

$$A_b = \sum_{i=1}^{n} A_{r_i}, \quad (1)$$

$$A_B = \frac{A_b}{A_S}, \quad (2)$$

Where n is the total number of bugholes on the concrete surface and Ar is the area of each bughole. Surfaces with different values of AB are illustrated Notice that for all these surfaces the bugholes are considered as circles with constant diameter (£bh) and the total surface area (AS) is equal to (50 * 100) mm2.

The surfaces that are illustrated in Fig. 2 indicate, however, that AB cannot be used as a standalone parameter for surface classification. Although all the surfaces from Fig. 2 have similar A B values, it is clear that their surface aspect is not the same. While surfaces 1 and 2 would be considered of good quality with no further need for surface treatment, surfaces

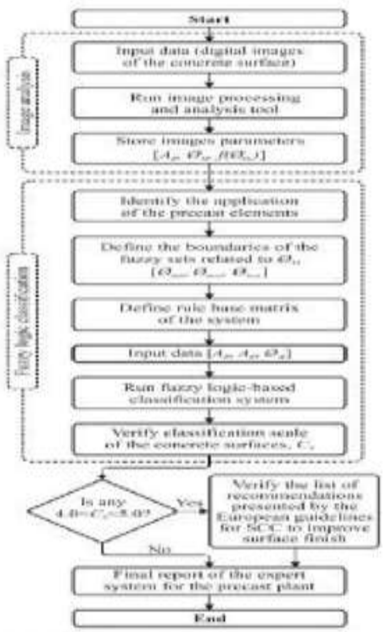
3–6 would have to be treated before being ready for delivery. Since these surfaces differ from each other in the bugholes diameter (£bh), it is then necessary to take such parameter into account for surface classification. For this reason, it was decided to consider the maximum bugholes diameter on the concrete surface (£M) as an additional parameter. Examples of surfaces with different values of £M are illustrated in Fig. 3a. These surfaces have AB value similar to the one from Fig. 2; however, the bugholes on those from Fig. 3a have a diameter range varying from 0.13 to 1.50 mm instead of a constant value. The comparison of the surfaces 7 and 8 (see Fig. 3a) indicates that an additional parameter is still needed. This is because, although different in aspect, both surfaces have similar values of AB and £M. In particular, surface 7 has few bugholes with large diameters and several bugholes with small diameters; whereas surface 8 has a higher number of bugholes with larger diameters, see Fig. 3a. Even with the same AB and £M values, it is again evident that surfaces 7 and 8 cannot be classified as having the same need for intervention. Although treatment is necessary in both cases, the degree of intervention on surface 8 is clearly higher than on surface 7 due to the higher number of bugholes with large diameters, leading to a higher impact in the entire production chain. Once AB and £M are not able to represent the distribution of bugholes with different diameters on the concrete surface, an additional information about the surface had to be considered. This information concerns the bughole size distribution curve (f(£bh)), which corresponds to a cumulative frequency curve of all bugholes on the concrete surface. The bughole size distribution curves for surfaces 7 and 8 are indicated in Fig. 3b. Based on the presented analysis, the percentage of bughole area (AB), the maximum bughole diameter size (£M), and the bughole size distribution curve (f(£bh)) were selected as the parameters that fully describe the final aspect of the concrete surface with regard to the presence of bugholes.

2.2. Image analysis tool

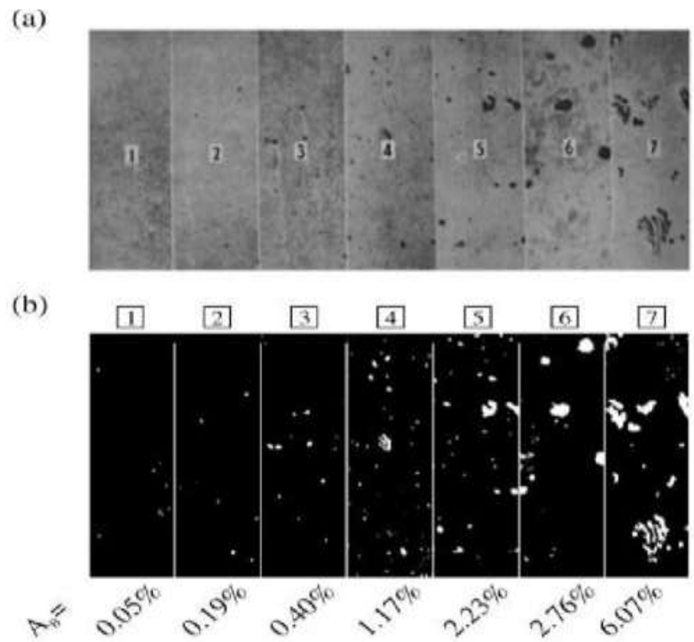
The pseudo-algorithm of the developed image analysis method is shown in Table 1 and described along these lines. Initially, a Wiener's filter is used to reduce the noise caused by the presence of blemishes on the concrete surface; for further details regarding this filter and its application refer to [24,25]. Next, the image contrast is enhanced by using a bottom-hat filtering, i.e., a morphological filter, and a contrast adjustment function, which provides optimized results when image segmentation is applied. These steps were necessary because the primary analyses that were performed during the implementation of the imaging algorithm have shown that the boundaries of bugholes with diameters of greater than 7.50 mm could not be properly detected. Such effect is likely caused by the lack of contrast between the bughole boundary and its surrounding area. The use of filtering and segmentation for image analysis is recommended by Coster and Chermant [13], who presents a comprehensive review about image analysis techniques for civil engineering materials. Subsequently, the segmented image is remounted, and the input parameters that will be used to determine the surface aspect are computed. An example of a concrete surface and the detail of the output from the image analysis tool are depicted in Fig. 5. A variation of the presented method was successfully applied for the evaluation of concrete porosity based on backscattered and optical image analysis; for further details refer to Silva et al. [26]. The percentage of bughole area (AB) is calculated by the sum of the area of individual bugholes (Ar ) that were detected by the image analysis tool divided by the total area that is evaluated. To compute £bh , the proposed tool first determines the area of each bughole (Ar), and then the diameter of the circle with equivalent area (£(Ar )). Finally, f(£bh ) is calculated based on the bughole diameter (£bh ) and the number of bugholes. Notice that the relation between pixel and area in mm 2 has to be established to determine Ar , AB ,£M, £bh, and f(£bh). For that, a linear grid with known dimensions is marked on the concrete surface to be used as reference scale.

2.3. Fuzzy logic-based classification tool

The fuzzy logic-based classification tool aims to classify concrete surfaces in regard to the presence of bugholes. In particular, the system allows for the user to define a set of verbal rules (ifthenrules) that will be used for the proposed classification. Because these rules are purely based on the user's expertise, limited by production process tolerances, the system simulates the human subjectivity to classify the final aspect of the concrete surface. Each rule takes into account the input parameters that were discussed in Section 2.1 , i.e., AB ,£M , and f(£bh). Antecedent part of the established if-then rules. Next, the outputs from the rules are aggregated to compute the output of the system, which corresponds to a classification score of the concrete surface. The approaches that were taken into account to design the fuzzy sets related to each input parameter are discussed as follows. further, the novel classification scale, rule base, guidelines to define the rule base, and inference engine of the system are also introduced.




Proposed expert system applied for classifying concrete surface finish.




**Pseudo-algorithm of the image analysis method.**

```
For each board image do
    Calculate relationship between pixel and area in mm²
    Convert image to grayscale
    Filter image using Wiener Filter
    Segment image
    For each image segment do
    Improve the contrast
    Transform image to binary image
    Find holes boundaries
    End for
    Remount binary image
    Fill the holes in binary image
    Calculate the area of each hole (A_r) using the relationship
    between pixel and area in mm²
    Compute A_B, ∅_M, ∅_bh, and f(∅_bh)
    Plot graphics
End for
```

## 3. APPLICATION OF THE PROPOSED EXPERT SYSTEM

The proposed expert system was applied in a case study of a Brazilian precast concrete plant. Besides quality control, the application focuses on the optimization of the final surface appearance of precast elements produced with SCC. For that, an experimental investigation of six SCC mixtures and two types of form release agents was performed. The concrete surface appearance was analyzed using digital images that were taken from concrete board 1* 0.30* 0.08 m (length width thickness).

These images were then inserted in the expert system, which calculated the classification score of the concrete surfaces from all investigated mixtures and pointed out those with optimized results.

## 4. RESULT

Summary of results from the proposed expert system.

| Surface | $A_B$ (%) | $A_E$ (%) | $\varnothing_M$ (mm) | $C_S$ (−) | Rank |
|---|---|---|---|---|---|
| $C_1A_1$ | 0.68 | 10.1 | 14.2 | 3.11 | 8 |
| $C_2A_1$ | 1.81 | 12.7 | 14.8 | 4.01 | 11 |
| $C_3A_1$ | 0.10 | 23.1 | 5.50 | 1.44 | 3 |
| $C_4A_1$ | 0.23 | 15.5 | 8.40 | 2.53 | 6 |
| $C_5A_1$ | 0.01 | 50.0 | 2.50 | 1.33 | 1 |
| $C_6A_1$ | 0.73 | 12.1 | 12.8 | 3.20 | 9 |
| $C_1A_2$ | 1.03 | 12.6 | 11.9 | 3.75 | 10 |
| $C_2A_2$ | 1.67 | 13.5 | 12.7 | 4.50 | 12 |
| $C_3A_2$ | 0.10 | 21.9 | 5.80 | 1.44 | 4 |
| $C_4A_2$ | 0.11 | 28.7 | 4.40 | 1.45 | 5 |
| $C_5A_2$ | 0.10 | 45.8 | 2.80 | 1.36 | 2 |
| $C_6A_2$ | 0.75 | 15.4 | 9.20 | 3.09 | 7 |

Control of SCC surface finish. Based on the obtained results the following conclusion can be drawn. The developed image analysis tool allowed for a more objective evaluation of the surface finish when compared to contemporary methods such as the CIB bughole scale. Moreover, the use of three input parameters, in particular, percentage of bughole area (AB), maximum bughole size diameter (£M), and bughole size distribution curve (f(£bh)), was crucial to achieve a proper classification of surfaces with different aspects. Furthermore, the fuzzy logic-based classification tool, which is based on a novel scale, was effective in classifying the concrete surface depending on the degree of treatment required to the evaluated surface. Also, the flexibility of the rule base arises as an advantageous feature, because it allows the system to be used in various applications depending on the production process criteria. The system proved suitable for optimization when systematically used in experimental investigations. Such feature, in combination with the flexibility of the rule base, makes the proposed expert system interesting to the concrete industry, in special to precast concrete plants. For the studied case, the SCC mixture that presented the best results (C3 ) allowed for a reduction of 3.5% in the production cost when compared to the currently used mixture (C1).

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