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# A Review of Effect of Mineral Admixtures on Appearance Quality of Fair-Faced Concrete and Techniques for Their Measurement

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**Abstract:** The appearance of fair-faced concrete is crucial, and it can be enhanced by incorporating an appropriate amount of mineral admixture. Different mineral admixtures have varying effects on the appearance quality of fair-faced concrete. For instance, the addition of fly ash helps control color differences and bubble formation on the concrete surface, while slag powder effectively controls its color and finish. In this review, the impact of using various mineral admixtures, such as silica fume, rice husk ash, limestone powder, and seashell powder, in fair-faced concrete on its appearance quality is examined. The effective combination of mineral admixtures made from industrial by-products or solid waste with fair-faced concrete can pave the way for new directions in the green and sustainable development of construction materials. This review also discusses the difficulties in objectively measuring the appearance quality of concrete and the various methods for the acquisition and evaluation of appearance images. New techniques for acquiring and evaluating information about concrete surfaces have been developed with advancements in image acquisition and processing technology. These techniques complement traditional manual inspection methods. The 3D Alicona system is advantageous for identifying air bubbles on concrete surfaces, the atomic-force microscope detects surface roughness, and the Orbital large-format scanner is ideal for use in large-scale engineering applications. Also, evaluation methods for different image processing software are presented in this article. This information offers a useful reference for future research and practical application.

**Keywords:** fair-faced concrete; mineral admixture; appearance quality; test and evaluate method

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## 1. Introduction

Fair-faced concrete is a specialized kind of concrete that is made in a single pour and without requiring any further finishing. Thus, fair-faced concrete significantly reduces resource consumption and eliminates much of the construction waste when compared to traditional building materials. Additionally, fair-faced concrete not only supports environmental protection, ecological preservation, and sustainable development but also has a distinctive heavy texture that lends itself to decorative applications [1]. Many international architects highly prefer fair-faced concrete due to its exquisite elegance and its ability to convey artistic and emotional expression [2–4]. Its appearance quality after forming is particularly noteworthy, making it as important as price/performance attributes and buildability [5].

One source of raw materials for fair-faced concrete, a type of green concrete, includes mineral admixtures derived from the secondary processing of industrial by-products or solid waste. In addition to commonly used industrial by-products such as fly ash, mineral powder, and silica fume, researchers have also experimented with using solid waste materials such as seashell powder and rice husk ash as raw materials for preparing fair-faced concrete. Shell processing is increasing globally, resulting in the creation of approximately 10 to 20 million tons of shell waste each year. The improper disposal of shell waste can lead to environmental hazards and pollution [6]. Nations with advanced agricultural industries produce substantial amounts of rice husk ash, and the proper disposal of this waste material is of the utmost concern. The utilization of seashell powder and rice husk ash as materials can help convert waste into valuable resources and create new opportunities for the sustainable advancement of fair-faced concrete.

The appearance quality of fair-faced concrete is primarily influenced by its components, especially various mineral admixtures. However, the non-standardized and unreasonable use of mineral admixtures can also affect its appearance quality [7], which in turn hinders the application of mineral admixtures in fair-faced concrete. Furthermore, there has been insufficient study and utilization of fair-faced concrete, and a comprehensive system for evaluating its appearance quality has not been developed. The manual measurement techniques commonly used at this stage have drawbacks, including a heavy workload and potential errors [8]. Therefore, many scholars have proposed the use of image processing technology for the semi-quantitative or quantitative analysis of the appearance quality of fair-faced concrete. This approach may benefit quality control and quantitative acceptance in real-world projects.

This article reviews the effects of various mineral admixtures on the appearance quality of fair-faced concrete under different dosages and mixing methods and discusses the corresponding influence mechanism. It also compares and analyzes the application of conventional measurement techniques and image processing techniques for the appearance quality of fair-faced concrete. Additionally, it presents an outlook for further research directions regarding the impact of mineral admixtures on the concrete's appearance quality and the techniques used to measure the appearance quality of fair-faced concrete. The article aims to provide a reference for future related research and application.

## 2. Effect of Mineral Admixtures on Appearance Quality of Fair-Faced Concrete

Fair-faced concrete, as a type of decorative concrete, has high requirements for its appearance quality [9], which is affected by the compactness and air content of the concrete itself [10]. Selecting reasonable types of mineral admixtures, using them correctly, and controlling their dosage can effectively improve cement-paste compaction and reduce air-bubble coverage on the concrete surface.

### *2.1. Single Mineral Admixture*

#### 2.1.1. Fly Ash

In the production processes for fair-faced concrete, fly ash is a frequently used mineral admixture. Fly ash particles are in the form of microbeads, which can play a lubricating role in the concrete mixing process, effectively improving the compatibility of the mix, thus enabling the concrete to fill the formwork better, and facilitating the dispersion of air bubbles, which to some extent reduces the appearance of color differences and the number of air bubbles in fair-faced concrete [11]. Meanwhile, compared to cement particles, fly-ash particles have a higher modulus of elasticity, which can be an aid in the inhibiting the shrinkage of cement paste [12]. In addition, fly ash also has a small internal specific surface area, which reduces the water adsorption capacity, thus effectively reducing the drying shrinkage of concrete and greatly improving the cracking resistance of fair-faced concrete [13]. Table 1 shows the effect of single-mixed fly ash on the appearance quality of fair-faced concrete.

**Table 1.** Effect of fly ash on the appearance quality of fair-faced concrete.

| Percent of Fly Ash % | Type | Water-to-Binder Ratio | Cementitious Material Content/(kg/m$^3$) | Testing Method | Appearance Quality | | Reference |
|---|---|---|---|---|---|---|---|
| | | | | | Surface Color Difference | Surface Bubbles | |
| 10 | I | 0.36 | 472 | Image analysis | Brightness 205.2, grey standard deviation 33.6 | Fewer bubbles | [14] |
| 15 | I | 0.36 | 472 | | Brightness 210.2, grey standard deviation 5.4 | Fewer bubbles | |
| 20 | I | 0.36 | 472 | | Brightness 207.4, grey standard deviation 10.1 | Showing a spongy texture | |
| 10 | II | 0.53 | 311 | Image analysis | Brightness 157.5, grey standard deviation 5.6 | Fewer bubbles | [15] |
| 15 | II | 0.53 | 311 | | Brightness 163.0, grey standard deviation 5.9 | Fewer bubbles | |
| 20 | II | 0.53 | 311 | | Brightness 159.2, grey standard deviation 6.9 | Many bubbles | |
| 10 | I | 0.53 | 377 | Image analysis | Brightness 163.6, grey standard deviation 5.3 | Fewer bubbles | [15] |
| 15 | I | 0.53 | 377 | | Brightness 167.4, grey standard deviation 5.4 | Fewer bubbles | |
| 20 | I | 0.57 | 377 | | Brightness 152.8, grey standard deviation 5.3 | Fewer bubbles | |
| 19 | I | 0.46 | 405 | Direct observation | Surface color is uniform | No bubbles | [16] |
| 19 | I | 0.32 | 555 | | Surface color is uniform | No bubbles | |

In their study, Jin et al. [14] discovered that the replacement of low (10–20%) cement admixtures with fly ash enhanced the appearance of fair-faced concrete by reducing surface bubbles and improving the appearance color differences. However, as the fly ash admixture increased, the appearance color differences also increased while the bubble area decreased. Similar conclusions were obtained by Li et al. [15]: the standard deviation of ashiness of fair-faced concrete admixed with 15% and 20% fly ash were 6.0 and 7.3, respectively. The reason for this is mainly because the production of fair-faced concrete is affected by the roller-ball action of fly ash, which improves the fluidity of the concrete and allows it to fill the molds evenly. Therefore, the surface area of air bubbles covering the concrete is significantly reduced. However, because fly ash is darker than cement in color, appearance color differences of the concrete gradually increases with the increase in the admixture amount. Microscopic analysis indicates that the inclusion of fly ash improves the hydration reaction and the secondary reaction with the cement hydrate product Ca $(OH)_2$, leading to the formation of needle columnar calcium alumina crystals during the curing process. As the needle columnar calcium alumina crystal structure develops, it becomes intertwined to form a dense crystalline network structure. This results in the hydration reaction products becoming more closely linked, leading to the densification of concrete and a reduction in the size of the various pores [17].

Research has demonstrated that a high volume of fly ash can adversely affect the appearance quality of fair-faced concrete. According to a study by Reiner and Rens [18], when the fly ash admixture ranges from 40% to 70%, quality issues such as black spots and chalky materials can form on the concrete surface. Sun et al. [19] conducted research that indicates that when the fly ash admixture exceeds 50%, the concrete is prone to a bleeding phenomenon, which results in the quality of the concrete surface being adversely affected. According to the study by Puthipad et al. [20], large bubbles were also observed for concrete with a high admixture (40%) of fly ash. This is primarily caused by the conversion of nitrogen oxides in fly ash to gases, such as ammonia, in an alkaline environment, which occurs with an increase in fly ash contents. This results in more bubbles on the surface of the fair-faced concrete. Secondly, this may also be attributed to the spherical shape of the fly ash particles, which suggests that they have relatively less surface area to hold entrained bubbles in comparison to cement particles. Thus, the entrained bubbles can effortlessly move and come together [20]. In addition, Jiang et al. [21] found that fly ash quality has been shown to have a significant effect on appearance concrete quality. This is due to the fact that concrete exhibits a serious color difference when different types of fly ash containing different levels of floating black matter are used in its production [22]. Microstructural observations of the black-spot region on the fair-faced concrete surface were made by Strehlein and Schießl [23], who discovered that the black spots present in concrete are mostly comprised of fibrous C-S-H gel and needle-shaped ettringite. These spots also display a more densely intertwined structure when compared to the microstructure in unaffected areas. The research reveals that the inclusion of fly ash results in the local microstructure of the concrete becoming denser and the appearance of black spots with different shades on the surface. This could be attributed to the diverse reflective properties of light on the surface of the concrete [23]. Figure 1 shows the reason for the significant color difference in concrete with a single admixture of fly ash.

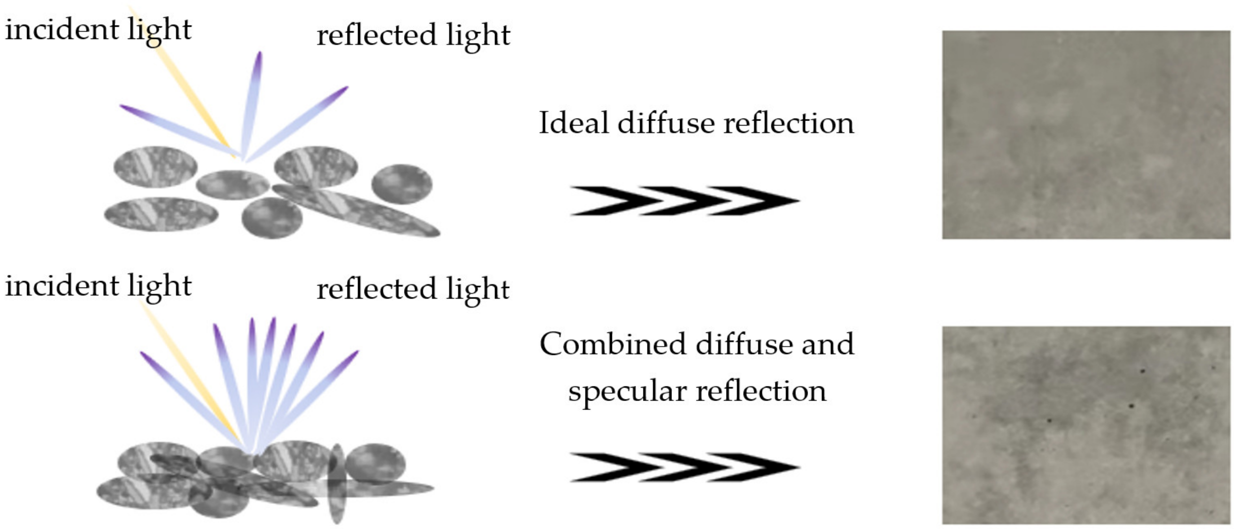



**Figure 1.** Causes of visible color difference in concrete with single admixture of fly ash.

To summarize, the quality of single-mixed fair-faced concrete made with fly ash is predominantly influenced by the quality of the ash and the mixing ratio. The inappropriate admixture of fly ash in fair-faced concrete can result in its appearance quality falling below standards. A suitable admixture of fly ash for preparing fair-faced concrete is approximately 15%, which helps to keep its appearance quality, color difference, and bubbles under better control.

#### 2.1.2. Slag Powder

Slag powder is a common material used in fair-faced concrete, and its effect on the appearance quality of concrete is shown in Figure 2. The color of fair-faced concrete is only minimally affected by the lighter shade of slag powder after it is formed. The addition of the appropriate amount of slag powder improves the particle gradation of cementitious materials, resulting in a more uniform and dense cementitious system [24]. At the same time, the original proportion of water used to fill the gaps between the particles of cementitious materials is reduced by the inclusion of slag powder to reduce the remaining water, which improves the fluidity of the paste, and the incorporation of slag powder raises the overall specific surface area of the cementitious materials, changing the amount of water covered by the cementitious material particles per unit volume, increasing the resistance to segregation of concrete [25]. Therefore, it has a positive effect on the improvement in the appearance quality of fair-faced concrete.

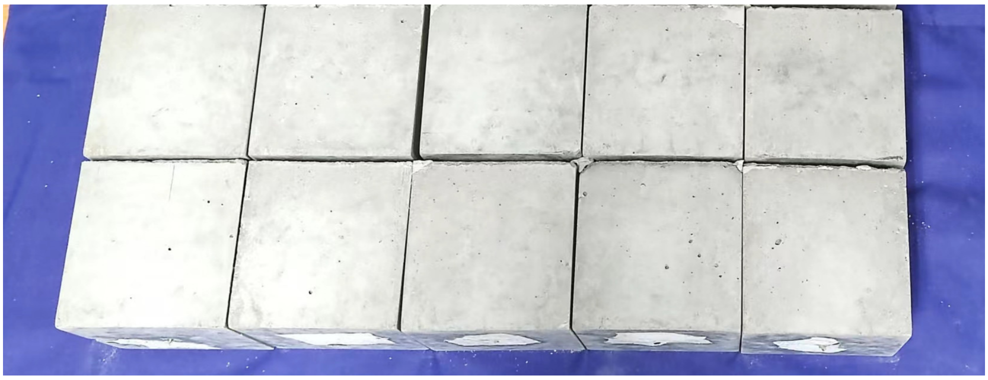


**Figure 2.** Appearance quality of concrete with single admixture of slag powder.

The addition of slag powders makes the surface of the concrete lighter in color, less discolored, and more aesthetically pleasing in appearance, particularly when the replacement rate exceeded 50%, as discovered by Arivalagan [26]. El-Hassan and Kianmehr also reached comparable conclusions in their study that found an increase of 0.07 in concrete surface albedo values to 0.52 when the slag powder admixture level was at 50% in comparison to normal concrete [27]. This is mainly attributable to the lighter color of the slag powder compared to cement, and as the concentration of admixture is raised, the surface color of the concrete gradually becomes white; secondly, slag powder admixture enhances the carbonation resistance of concrete, mitigating the undesirable effects such as color differences and black spots induced by the carbonation process.

However, Wawrzeńczyk et al. [28] found that when the dosage of slag powder was between 15% and 55%, the bubbles on the surface of concrete were not only large in number and diameter, but also increased in volume with the increase in slag powder dosage. The reason for this is that the slag powder improves the segregation resistance of concrete, but it also increases the viscosity of the cement paste, which leads to an increase in the gas content and causes large bubbles on the surface of concrete. From their microscopic analysis, the addition of mineral powder reduced the cement hydration products in the composite gel material, and at the same time consumed a large amount of calcium hydroxide, which led to a decrease in the alkalinity within the system; the amount used was insufficient to fully activate the slag powder's volcanic ash properties. Due to the small size of volcanic ash, and reaction products from adding slag powder, the particle size of the formed gel was small, which was not favorable for the bonding connection between the particles, thus forming a large number of connecting holes [29].

### 2.2. Compound Mineral Admixture

As research on fair-faced concrete deepens, it has been observed that, at times, a single mineral admixture may fail to meet its performance requirements [30]. Therefore, several scholars suggest employing different mineral admixtures in the appropriate proportion to mix into the fair-faced concrete to achieve better appearance quality, as shown in Figure 3. Compound mineral admixture is expected to address the inadequacies of single-mineral admixtures when used to produce fair-faced concrete, utilizing the respective advantages of each mineral admixture to achieve a superposition or overlapping effect.

#### 2.2.1. Compound Mixing of Fly Ash and Slag Powder

At present, many international scholars are studying fair-faced concrete, with most studying the preparation of fair-faced concrete through the mixing of fly ash and slag powder. Fair-faced concrete with the appropriate amount of fly ash and slag powder achieves a uniform color, its bubble area is small and there is no quality problem, as shown in Table 2.

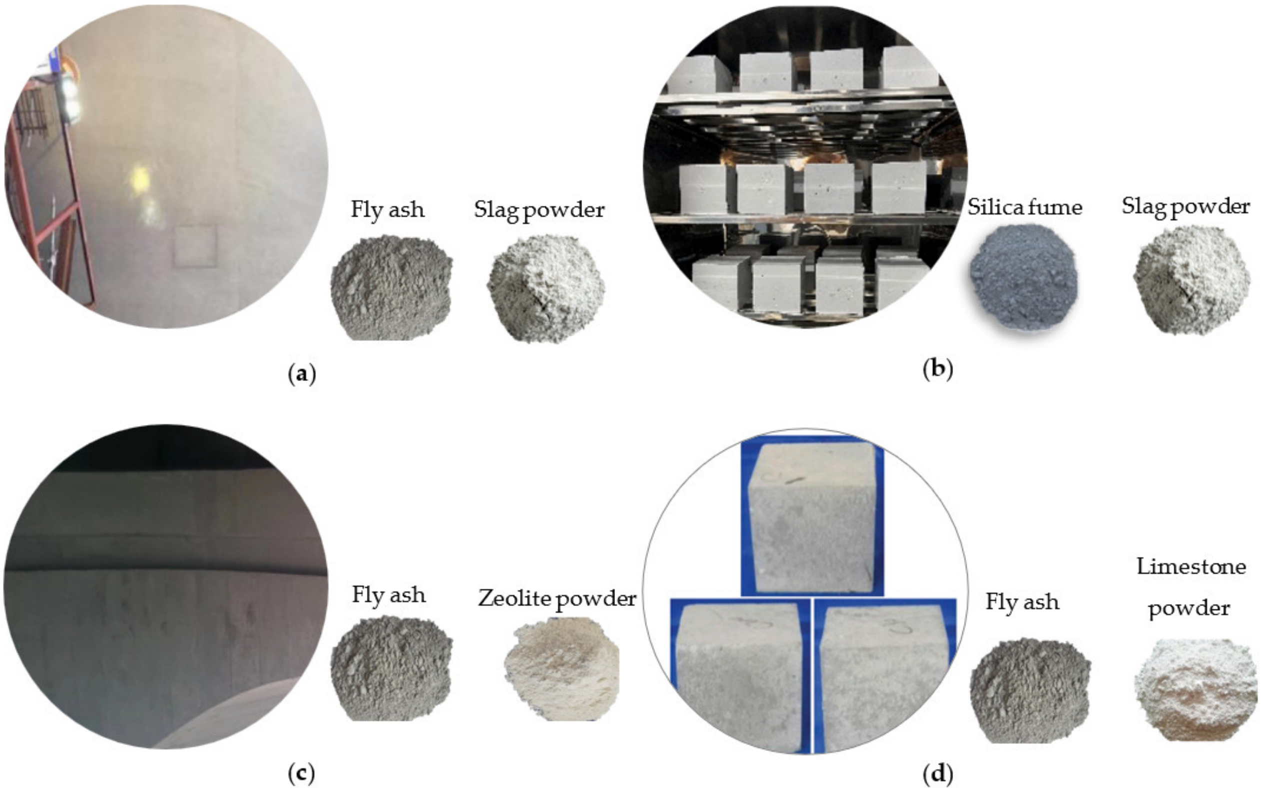



**Figure 3.** Appearance quality of fair-faced concrete with compound mineral admixtures: (**a**) Mixing of compound fly ash and slag powder [31] (Reprinted/adapted with permission from Ref. [31]. 2021, Elsevier); (**b**) mixing of compound silica fume and slag powder [32] (Reprinted/adapted with permission from Ref. [32]. 2023, Elsevier); (**c**) mixing of compound fly ash and zeolite powder; and (**d**) mixing of compound fly ash and limestone powder [33].

In the study of Wu et al., the impact of different proportions of fly ash and slag powder on the apparent concrete quality was investigated [31]. The authors found that the best quality fair-faced concrete was obtained with a mix of 20% fly ash and 25% slag powder. This mixture produced a uniform white coloring, reduced the diameter of surface bubbles, and minimized the accumulated area of bubbles; as a result, its surface was cleaner and smoother, having a roughness (RMS) of 3.79 nm as measured using Atomic Force Microscopy (AFM). According to Li et al. [34], the addition of 20% fly ash and 20% slag powder enhanced the surface properties of fair-faced concrete. This mix resulted in a low gray standard deviation (13.13) and a small surface pore area (13.50 mm$^2$). Shi et al. [35] formulated fair-faced concrete by compounding 10% fly ash and 17% slag powder and obtained similar results, with a standard deviation of chromatic aberration of only 1.85 and a surface porosity of 0.128%. The improved surface characteristics of fair-faced concrete can be attributed to the advantageous properties of slag powder and fly ash. While slag powder enhances the gloss of the surface, it also increases its paste viscosity and, hence, increases its internal gas content, which can lead to bubble formation. On the other hand, fly ash reduces paste viscosity, allowing the gas to escape, and minimizes the formation of bubbles. Therefore, a combination of fly ash and slag powder complement each other, resulting in an improved color appearance and reduced surface bubbles in the fair-faced concrete. However, Wu et al. [31] found that the surface of fair-faced concrete with 15% fly ash and 15% slag powder had a dull, uneven color, and large bubbles. In addition, the surface of fair-faced concrete with 25% fly ash and 25% slag powder also showed the quality problem of large air bubbles. In a study by Honglei [36], similar results were found, and the standard deviation of the ashiness of the fair-faced concrete with 25% fly ash and 25% slag powder was only 14.57. The dull color and poor consistency of the fair-faced concrete were mainly the result of the proportion of fly ash and slag powder, and inappropriate mixing. These two mineral additives, when combined, not only did not produce a composite effect, but also had a detrimental effect on the appearance color and overall homogeneity of the fair-faced concrete.

**Table 2.** Effect of a slag powder–fly ash composite system on the appearance quality of fair-faced concrete.

| Water-to-Binder Ratio | Cementitious Material Content/(kg/m$^3$) | Fly Ash/% | Slag Powder/% | Testing Method | Appearance Quality | | Reference |
|---|---|---|---|---|---|---|---|
| | | | | | Surface Chromatic Aberration | Surface Bubbles | |
| 0.42 | - | 15 | 15 | Direct observation | Even and dull color | Many bubbles | [31] |
| | | 15 | 20 | | Even and dull color | Fewer bubbles | |
| | | 15 | 25 | | Even and dull color | Fewer bubbles | |
| | | 20 | 25 | | Uniform and white color | No bubbles | |
| | | 25 | 25 | | Uniform and white color | Many bubbles | |
| 0.27 | 500 | 20 | 20 | Image analysis | Grey standard deviation 13.13 | Surface pore area of 13.50 mm$^2$ | [34] |
| 0.27 | 473 | 25 | 25 | Image analysis | Grey standard deviation 14.57 | No bubbles | [36] |
| 0.30 | 435 | 25 | 25 | | Grey standard deviation 13.53 | No bubbles | |
| 0.33 | 345 | 25 | 25 | | Grey standard deviation 13.75 | No bubbles | |
| 0.33 | 468 | 10 | 17 | Image analysis | Standard deviation of chromatic 1.86 | Surface porosity of 0.128 | [35] |
| 0.29 | 524 | 8 | 16 | | Standard deviation of chromatic 1.74 | Surface porosity of 0.125 | |
| 0.25 | 592 | 10 | 17 | | Standard deviation of chromatic 1.82 | Surface porosity of 0.124 | |
| 0.31 | 490 | 10 | 17 | Image analysis | Surface quality grade of 4 | The largest size that bubbles can reach is 8 mm. Surface porosity of 0.2 | [37] |
| 0.27 | 556 | 11 | 18 | | Surface quality grade of 3 | The largest size that bubbles can reach is from 4 to 8 mm. Surface porosity Less than 0.2 | |

### 2.2.2. Compound with Other Mineral Admixtures

Studies have shown that compounding other mineral admixtures can significantly improve the appearance quality of fair-faced concrete, as shown in Table 3.

**Table 3.** Effect of compounding other mineral admixtures on the appearance quality of fair-faced concrete.

| Water to Binder Ratio | Cementitious Material Content/(kg/m$^3$) | Mineral Admixture | Testing Method | Appearance Quality | | Reference |
|---|---|---|---|---|---|---|
| | | | | Surface Chromatic Aberration | Surface Bubbles | |
| 0.28 | 358 | 17% of slag powder and 11% of silica fume | Direct observation | Surface color is bright and uniform | Few bubbles and small | [32] |

**Table 3.** *Cont.*

| Water to Binder Ratio | Cementitious Material Content/(kg/m$^3$) | Mineral Admixture | Testing Method | Appearance Quality | | Reference |
|---|---|---|---|---|---|---|
| | | | | Surface Chromatic Aberration | Surface Bubbles | |
| 0.31 | 500 | 25% slag powder, 22.5% fly ash,10% seashell powder and 1% silica fume | Image analysis | Grey scale value 126 | Surface pore rate 231% | [38] |
| 0.31 | 500 | 20% slag powder, 25% fly ash,15% seashell powder and 2% silica fume | | Grey scale value 130 | Surface pore rate 73% | |
| 0.31 | 500 | 22.5% slag powder, 20% fly ash,5% seashell powder and 3% silica fume | | Grey scale value 127 | Surface pore rate 45% | |
| 0.27 | 450 | 10% limestone powder and 30% fly ash | Direct observation | Surface color is uniform and white | No bubbles | [33] |
| 0.27 | 450 | 20% limestone powder and 30% fly ash | | Surface color is uniform | No bubbles | |
| 0.27 | 450 | 30% limestone powder and 30% fly ash | | Surface color is not uniform | No bubbles | |
| 0.31 | 530 | 4% zeolite powder and 28% fly ash | Direct observation | White and clean surfaces | Fewer bubbles | [39] |
| 0.31 | 530 | 2% zeolite powder and 30% fly ash | | White and clean surfaces | Fewer bubbles | |
| 0.65 | 340 | 6% slag powder, 20% fly ash and 6% rice husk ash | Direct observation | Meet the requirements of fair-faced concrete | Meet the requirements of fair-faced concrete | [40] |

Liu et al. [32] found that concrete with 17% slag powder and 11% silica fume in the compound had good appearance quality, with bright, uniformly colored surfaces and minimal bubbles. In another study, Fu et al. [38] found that combining 20% slag powder, 25% fly ash, and 2% silica fume also resulted in the improved appearance quality of fair-faced concrete. The concrete surface displayed uniform color and possessed a gray scale value of 130, along with a surface pore rate of only 73%. Compared to fly ash and slag powder, silica fume has a smaller particle size. This smaller particle size helps optimize the particle gradation of cementitious materials in concrete, leading to improved micro filling and nucleation effects. As a result, a denser matrix is formed. In addition, silica fume exhibits higher volcanic ash activity, which means it has a greater reactivity. This high reactivity allows silica fume to generate a substantial amount of calcium silicate hydrate (C-S-H) gel, filling in the pores of the concrete. This filling of pores enhances the surface quality of the concrete [41]. Moreover, the addition of silica fume effectively inhibits the uplift of fly ash, and improves the surface color of concrete and enhances its mirror effect. The addition of silica fume and slag powder improved the concrete's ability to prevent bleeding and resist segregation. Furthermore, the ability of the concrete to remove air bubbles was increased. Nevertheless, for fair-faced concrete mixed with varying amounts of silica fume, there are noticeable differences in the appearance quality. For instance, Fu et al. [38] reported that fair-faced concrete made by mixing 22.5% fly ash, 25% slag powder, with 1% silica fume is poor, having a grey scale value of 126 and a surface pore rate of 231%. The complexity of mineral admixtures has led to numerous influencing factors and experimental quantities, making it challenging to achieve the satisfactory performance of fair-faced concrete.

In addition, due to the increasing shortage of fly ash resources, limestone powder is often used to replace fly ash to prepare fair-faced concrete. Limestone powder possesses properties such as a low density and a large specific surface area, which, when uniformly dispersed and added to cementitious materials, enhances the surface tension between the cementitious material and water, and boosts water retention in concrete. Consequently, it can improve the appearance quality of fair-faced concrete [42]. According to Shi et al. [33], using 10% limestone powder and 30% fly ash in the production of fair-faced concrete can result in a smooth surface with a consistent, vibrant color and the minimal uniform distribution of bubbles. Similarly, a study conducted using fair-faced concrete containing 20% limestone powder and 30% fly ash resulted in consistent outcomes regarding the visual quality of the product. Limestone powder, as an inert filler, has a smaller particle fineness than cement. This allows it to provide better micro-aggregate filling and water reduction effects, leading to improved concrete compactness and overall homogeneity of fair-faced concrete. This reduces the formation of surface bubbles [43]. Microscopic analysis shows that, since most of the limestone powder is in the form of smooth calcite, it provides good conditions for the nucleation and growth of C-S-H gel during the hydration process. Furthermore, calcite dissolved in water can provide sufficient carbonate ions for the hydration reaction of cement, which leads to an improvement in the reactivity of aluminate and the formation of more alumina carbonate to replace the alumina sulfate, which strengthens the interlocking with other hydration products, which improves the interlocking ability with other hydration products and further improves the densification of concrete. Secondly, limestone powder fills the interfacial transition zone between the cement matrix and the aggregate, providing higher bonding strength and reducing the porosity of the concrete due to its special texture and chemical properties [42].

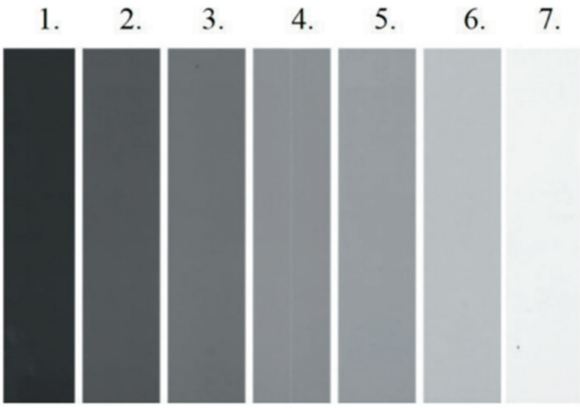
Apart from the common mineral admixtures mentioned earlier, some researchers have attempted to use additional mineral admixtures like zeolite powder, seashell powder, and rice husk ash. Gao [39] found that the surface of fair-faced concrete with 4% zeolite powder and 28% fly ash is clean and white, with fewer bubbles, which is better for achieving the decorative effect of fair-faced concrete. In addition, Fu et al. [38] investigated the feasibility of using fly ash, slag powder, $CaCO_3$-$TiO_2$ composites and seashell powder as mineral admixtures for fair-faced concrete. The findings indicate that seashell powder has a significant impact on the surface gray value of fair-faced concrete, and the concrete mixed with seashell powder is able to sustain its original look for a considerable period of time in the tropical coastal setting. In the process of creating an eco-friendly fair-faced concrete, Zhang et al. [40] added rice husk ash to the mixture. The research discovered that the visual quality of green fair-faced concrete using 6% slag powder, 20% fly ash, and 6% rice husk ash is similar to that of regular fair-faced concrete. As there is not enough research in this field, the impact mechanism of these mineral admixtures on the visual quality of fair-faced concrete remains unclear.

## 3. Techniques for Measuring Appearance Quality of Fair-Faced Concrete

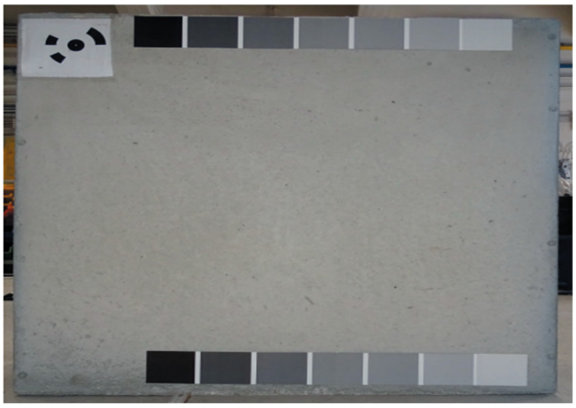
Currently, there are significant limitations in researching and applying fair-faced concrete, particularly in terms of measuring its appearance quality, which lacks a standardized method. Furthermore, the widely used acceptance standards for actual fair-faced concrete projects are primarily borrowed from plaster acceptance standards and, thus, have numerous limitations [44]. As a result, several researchers have attempted to enhance the measurement and evaluation methods for fair-faced concrete using novel technologies, for instance, by utilizing new tools for detecting appearance quality or applying image analysis methods for the quantitative or semi-quantitative analysis of its appearance quality.

### *3.1. Conventional Assessment Techniques*

Published in 2004, the German Code of Practice on Fair-Faced Concrete [45] defines four specific categories and numerous subcategories, although it does not provide an assessment methodology. The Austrian standard has a classification that is less structured. To evaluate the quality of the exposed concrete's appearance, one can refer to the Guideline of Formed Concrete Surfaces [46], which provides evaluation criteria, and it can be evaluated subjectively by the human eye using the gray scale (Figure 4). This specification sets the maximum number of adjacent colors, allowing up to five consecutive colors for the lowest grade (FT1) and up to three consecutive colors for the highest grade (FT3). The current Chinese standard for fair-faced concrete includes quality standards that are measured and evaluated according to Table 4. To put it briefly, the appearance color and color difference of fair-faced concrete can be usually observed with the naked eye. Even though the naked eye has the ability to detect color differences in an objective and accurate way, the difference in the perception of colors can lead to an inconsistent evaluation of the uniformity of chromaticity and brightness for different colors [47]. The diameter and surface area of air bubbles in exposed concrete are typically calculated through manual ruler measurement and grid play. Surface cracks, on the other hand, are measured manually using a ruler or crack measuring instrument [48]. Even though these methods of manual measurement and statistics are more affordable and realistic, they are more demanding in terms of labor and time consumption in actual projects, and errors can occur due to both manual errors and random sampling errors.




(**a**)



(**b**)

**Figure 4.** Detection of appearance quality of concrete using gray charts based on Austrian guidelines: (**a**) grey color chart (includes seven consecutive color tones) according to the Austrian guideline; (**b**) image made of the F-3-1 sample [44].

**Table 4.** Testing standards for appearance quality indexes of fair-faced concrete in existing codes in China.

| Specification | Chromatic Aberration | | Surface Bubbles | | Surface Cracks | | Surface Quality | |
|---|---|---|---|---|---|---|---|---|
| | Requirements | Testing Method | Requirements | Testing Method | Requirements | Testing Method | Requirements | Testing Method |
| JGJ169-2009 [49] | Surface color is uniform | 5 m observation from concrete surface | Bubble dispersion | Area measurement | Width $\leq$ 0.2 mm | Measure with a ruler | No obvious signs of slurry leakage and runoff | Direct measurement |
| DB37/T5099-2017 [50] | Surface color is uniform | 4 m observation from concrete surface | Maximum bubble diameter $\leq$ 8 mm, depth $\leq$ 2 mm, and bubble area $\leq$ 20 cm$^2$/m$^2$ | Area measurement | Width < 0.15 mm Length $\leq$ 1000 mm | Measure with a ruler | No obvious signs of slurry leakage and runoff, no oil stains, and rust spots | Direct measurement |
| DB11/T464-2023 [51] | Surface color is uniform | 8 m observation from concrete surface | Maximum bubble $\leq$ 5 mm, depth $\leq$ 4 mm, and bubble area $\leq$ 6 cm$^2$/m$^2$ | Area measurement | Width $\leq$ 0.2 mm | Measure with a ruler | No contamination or stains | Direct measurement |

**Table 4.** *Cont.*

| Specification | Chromatic Aberration | | Surface Bubbles | | Surface Cracks | | Surface Quality | |
|---|---|---|---|---|---|---|---|---|
| | **Requirements** | **Testing Method** | **Requirements** | **Testing Method** | **Requirements** | **Testing Method** | **Requirements** | **Testing Method** |
| DL/T5306-2013 [52] | Surface color is uniform | 5 m observation from concrete surface | Maximum bubble diameter ≤ 8 mm, depth ≤ 2 mm, and bubble area ≤ 20 $cm^2/m^2$ | Area measurement | Width ≤ 0.2 mm length ≤ 1000 mm | Measure with a ruler | No obvious signs of slurry leakage and runoff | Direct measurement |
| DB36/T1009-2018 [53] | A small amount of chromatic aberration | 5 m observation from concrete surface | Bubbles dispersion, and no large area of bubbles | Direct measurement | Width ≤ 0.15 mm | Measure with a ruler | No obvious signs of slurry leakage and runoff, no oil stains, and rust spots | Direct measurement |

*3.2. Image Measurement Techniques*

With the advent of the informationization and digitalization era, digital image processing technology has been vigorously developed and widely applied in various fields. Many scholars have used digital image processing technology to measure the visual quality of concrete [54–56]. Shi et al. [35] summarized how to assess fair-faced concrete's appearance quality in four steps—image acquisition, grayscale processing, bubble analysis, and data evaluation—and pointed out that among the image processing techniques, the image acquisition stage is most easily influenced by outside factors and shooting conditions.

Currently, most visible images of fair-faced concrete are captured manually using a digital camera. However, this method has limitations such as a restricted shooting range and low efficiency. As a result, researchers have been exploring alternative acquisition technologies, as shown in Figure 5. Shyha et al. [57] proposed the use of a 3D Alicona system for image acquisition. This system, with a resolution of 40 nm, can provide comprehensive 3D information by scanning the X, Y, and Z coordinates of millions of points. The acquired data can be displayed in true color or as a wireframe model, enabling the accurate determination of the concrete surface's roughness, as well as the size and volume of surface bubbles. Shi et al. [35] employed a large-format orbital scanner to capture appearance images of fair-faced concrete and investigated the impact of various acquisition variables, including the acquisition height, tempo, accuracy, and environmental factors such as temperature, natural light angle and brightness, and ambient humidity. By reducing the discrepancy between the acquired and actual information, appropriate ranges for each factor were determined. Hallermann et al. [58] innovatively used drones to acquire appearance images of concrete and presented a case study by monitoring the state of an Unmanned Aerial System (UAS). They combined traditional inspection surveys with state-of-the-art photogrammetric computer vision techniques to develop a system for automated damage detection after the flight, simplifying the acquisition process.

Wu et al. [31] utilized an atomic-force microscope to evaluate the finished surfaces of fair-face concrete castings. They analyzed the average roughness values to assess the appearance quality of the fair-face concrete. Ozkul and Kucuk [59] designed a device that uses the differential pressure principle to determine air bubbles on concrete surfaces. The optimal skirt pattern for detecting cracks on the concrete surface was determined through theoretical calculations and practical fabrication considerations. In conclusion, while image acquisition technology can capture the appearance image of fair-faced concrete more accurately and conveniently, its application is not widespread due to its high technical cost.

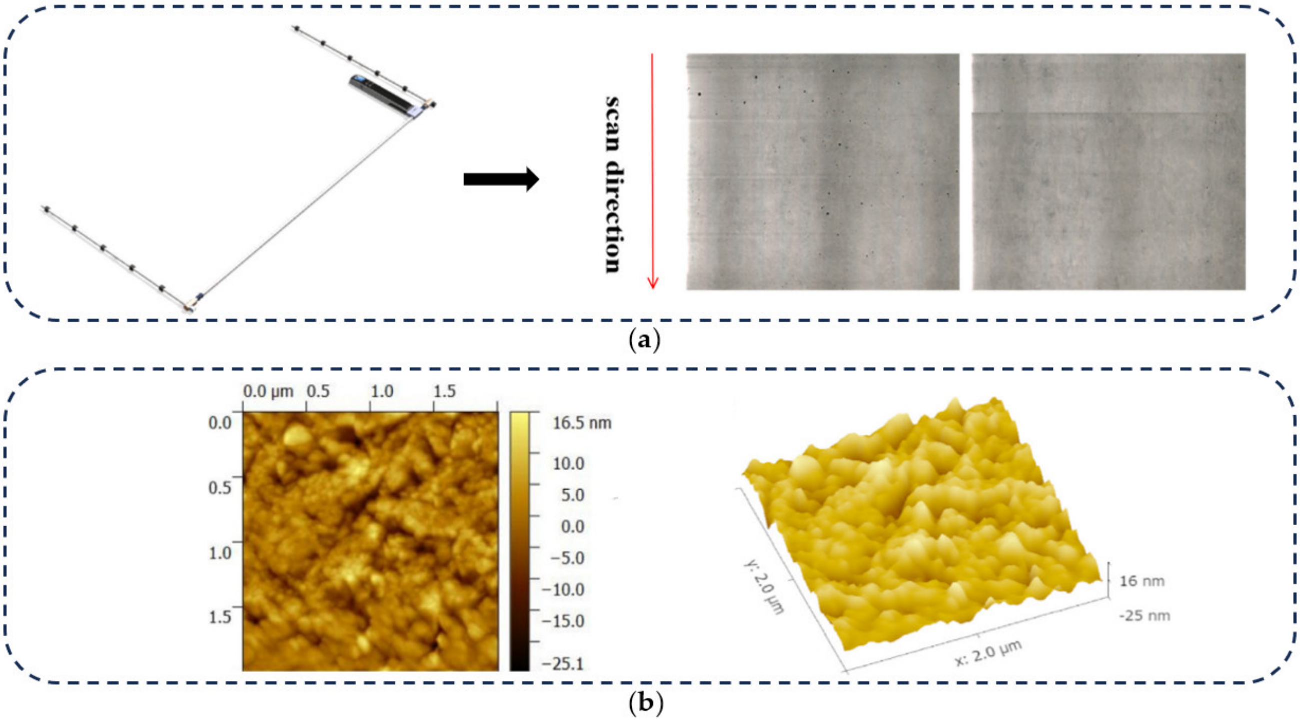



**Figure 5.** Measurement techniques for appearance quality of fair-faced concrete: (**a**) Orbital large-format scanner [35] (Reprinted/adapted with permission from Ref. [35]. 2023, Elsevier); (**b**) observation of the fair-faced concrete surface using an atomic-force microscope [31] (Reprinted/adapted with permission from Ref. [31]. 2021, Elsevier).

After acquisition, images are typically evaluated quantitatively or semi-quantitatively for appearance quality using image analysis techniques. Li et al. [34]. used Image-pro processing software to convert clear concrete images into grayscale and calculate the corresponding standard deviation of the grayscale image. The image grayscale standard deviation (STD) is a quantity used to reflect the degree of dispersion of the grayscale values on both sides of the image grayscale mean, as shown in Equation (1). This value is calculated based on the gray value of each pixel in the captured image and the gray-level mean. The gray value can be calculated from Equation (2). The gray value is a specification that reflects image chromatic aberration. The porosity of the clear concrete area was calculated using the Image-Pro Plus automated measuring function. And Shi et al. [35] also used image processing software to gray-scale and binarize the obtained pictures of the appearance of fair-faced concrete, and quantitatively characterize the appearance quality of concrete based on the obtained gray-scale average and Standard Deviation from Design. The Standard Deviation from Design (SDD) can be calculated from Equation (3).

The STD can be calculated using Equation (1):

$$\mathrm{STD} = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\mathrm{Gray}\,(i,j) - \overline{\mathrm{Gray}}\right)^2}{M \times N}}, \quad (1)$$

where STD is the standard deviation of the image gray level; M is the total number of rows of the image; N is the total number of columns of the image; $\mathrm{Gray}(i,j)$ is the gray level of each pixel point of the captured image; and $\overline{\mathrm{Gray}}$ is the average gray level of the image.

Gray can be calculated using Equation (2):

$$\mathrm{Gray} = 0.299 \times R + 0.587 \times G + 0.114 \times B, \quad (2)$$

where Gray is the grayscale intensity, and R, G, and B represent the intensity of the red, green, and blue components in the color images, respectively.

The SDD can be calculated using Equation (3):

$$\mathrm{SDD} = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\mathrm{Gray}\,(i,j) - G_R\right)^2}{M \times N}}, \tag{3}$$

where M represents the total number of rows of image pixels; N represents the total number of columns of image pixels; $\mathrm{Gray}(i,j)$ is the gray level of each pixel point of the captured image; and $G_R$ represents the gray value of the designed color in the RAL color card.

In addition, Jacek Kwasny et al. [60] used a popular image processing application (Adobe Photoshop CS4) (Adobe Systems Incorporated, San Jose, America) to process digital images. First, the captured digital photographs were cropped. Then, the original photographs were converted to binary images using image processing, and the surface bubbles in the figure were marked in white. Then, noise was removed using the processing function of the software. Finally, the surface bubble area was calculated by removing the total area of the test image with the white coverage area. Silva and Štemberk [8] proposed a new approach to image processing. They first used filters to eliminate noise effects and then applied an image contrast enhancement algorithm and function to optimize image segmentation. The segmented image was used to determine the roughness parameter of the concrete surface by locking the aspect ratio and performing calculations. Wei et al. [61] presented a novel image processing technique that combines the application of deep convolutional neural networks (DCNNs) to detect air bubbles in images of concrete surfaces. The technique involves first using image processing software to highlight the features of the bubbles on the concrete surface. Then, the DCNN automatically detects the bubbles in the image. To enhance the model's capabilities, an initial module consisting of multiple convolution and maximum pooling operations is incorporated into the network.

A multi-scale structured data algorithm for fair-faced concrete was proposed by Yao et al. [62]. Over 2000 images of fair-faced concrete samples were collected to create a database for identifying color-difference features using a convolutional neural network framework, as shown in Figure 6. The ratio of the area of stains on the surface of the concrete versus the total area of all the samples, as measured using ImageJ software based on the standard color cards, was employed by Klovas et al. [63] as an indicator of color difference when evaluating concrete. The ratio mentioned above was also used as an indicator of color difference when evaluating concrete by Guillaume Lemaire et al. [64]. They additionally evaluated the distribution of color differences and porosity on concrete surfaces by simulating images with a brightness of L* (D65) using a standard light source.

In summary, scholars commonly use image analysis technology to evaluate the appearance quality of fair-faced concrete. The process typically involves pre-processing the collected images, such as enhancing and denoising them. Grayscale processing is then applied to extract key parameters, such as grayscale standard deviation. Finally, a threshold is determined to extract evaluation data on features like air bubbles, cracks, and color differences. Image processing technology can assist researchers in evaluating the appearance quality of fair-faced concrete comprehensively, accurately, and objectively. However, due to variations in image acquisition technology, software, and algorithms, different scholars using image analysis technology may establish differing systems for evaluating appearance quality.

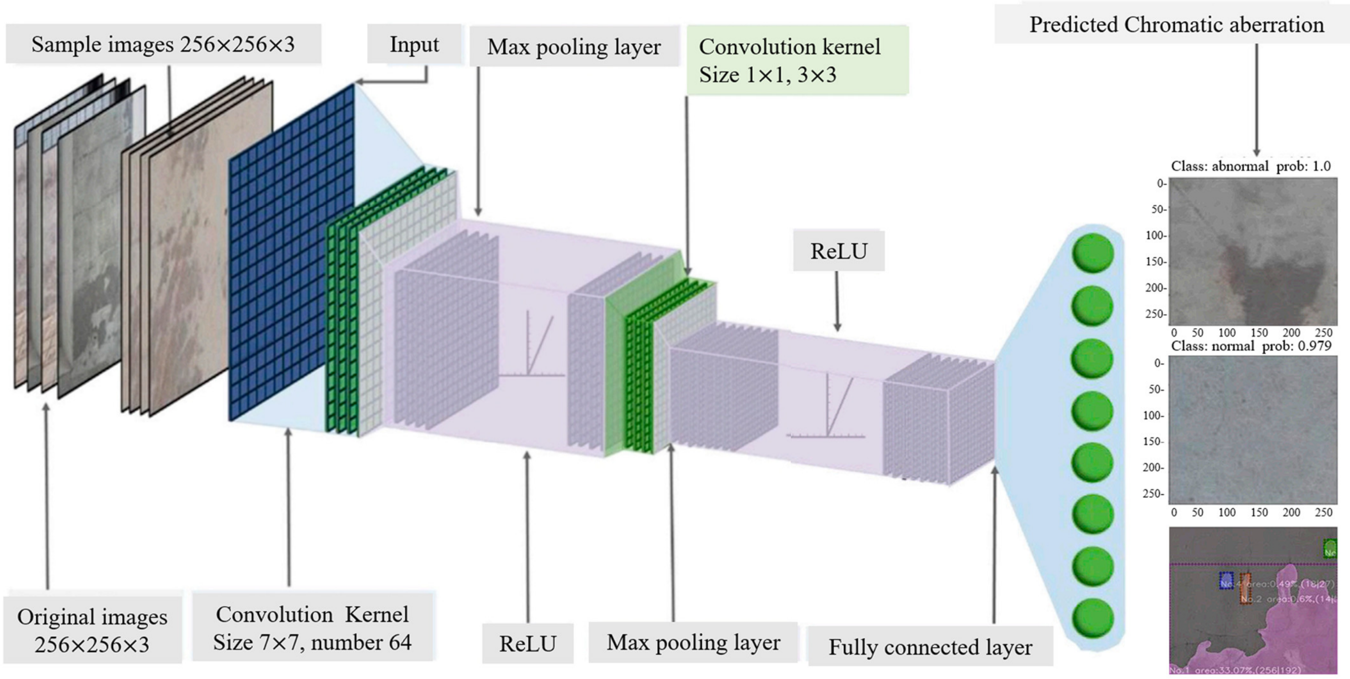



**Figure 6.** The training process of the quantitative analysis of colorimetric samples [62].

## 4. Conclusions and Outlook

This review offers an extensive examination of the impact that mineral admixtures have on the appearance quality of fair-faced concrete and the various types of appearance-quality measurement techniques. This review is a summary of the relevant literature, with the following specific conclusions and outlook:

1. A large body of research has demonstrated that the appropriate and prudent application of mineral admixtures is an effective strategy to enhance the visible quality of fair-faced concrete. The appearance quality is greatly influenced by the type and quantity of mineral admixtures used.
2. When using single-mixed fly ash to prepare fair-faced concrete, its appropriate mixing amount is about 15%, at which time its appearance quality, color difference and bubbles are better controlled, but too large or too small an amount of fly ash, on the contrary, will have a negative effect on the appearance quality. In addition, there are differences in the abilities of different qualities of fly ash to improve the appearance quality of fair-faced concrete.
3. The single mixing of slag powder does not promote improve the appearance quality of fair-faced concrete, although the addition of slag powder to fair-faced concrete for color and gloss enhancement improves it to some extent. However, it can also create air bubbles on the surface that affect the appearance quality of the surface and, therefore, its compliance with the standard.
4. A compound-mixing-mineral admixture has a superposition effect that, compared with single mixing, can better improve the appearance quality of fair-faced concrete; the combination of fly ash and slag powder in compound mixing is more effective in meeting the appearance quality requirements. In addition, the compound mixing of silica fume and limestone powder also has a beneficial effect on the appearance quality of fair-faced concrete. However, due to the complexity of the action mechanism of the mineral admixture in the compound mixing system, the type, dosage, and proportion of compound mineral admixture in fair-faced concrete have high requirements.
5. Existing research has shown that image processing technology is very suitable for evaluating the appearance quality of fair-faced concrete, but at present there is no unified method and related evaluation system.

6. The influence and mechanism of the superimposed effect of a compound mineral admixture on the appearance quality of fair-faced concrete can be thoroughly investigated to expand the application of the mineral admixture.
7. The application of image processing technology in the evaluation of the appearance quality of fair-faced concrete can be optimized, and relevant specifications and indicators can be established at the same time.

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## References


1. Liu, Y. Practical Analysis on the Integration of Fair-faced Concrete Decorative Elements into Modern Interior Design. *J. Landsc. Res.* **2020**, *12*, 9–12.
2. Mesquita, B.; Boiger, M.; De Leersnyder, J. The cultural construction of emotions. *Curr. Opin. Psychol.* **2016**, *8*, 31–36. [CrossRef] [PubMed]
3. Ribeiro, C.M.; Xavier, D.J. A função revelante da arquitetura religiosa moderna em São Paulo: O concreto aparente dos templos religiosos e sua simbólica do Sagrado. *Rever Rev. Estud. Relig.* **2019**, *19*, 25–41. [CrossRef]
4. Coburn, A.; Kardan, O.; Kotabe, H.; Steinberg, J.; Hout, M.C.; Robbins, A.; MacDonald, J.; Hayn-Leichsenring, G.; Berman, M.G. Psychological responses to natural patterns in architecture. *J. Environ. Psychol.* **2019**, *62*, 133–145. [CrossRef]
5. Yoshitake, I.; Maeda, T.; Hieda, M. Image analysis for the detection and quantification of concrete bugholes in a tunnel lining. *Case Stud. Constr. Mater.* **2018**, *8*, 116–130. [CrossRef]
6. Bamigboye, G.O.; Nworgu, A.T.; Odetoyan, A.O.; Kareem, M.; Enabulele, D.O.; Bassey, D.E. Sustainable use of seashells as binder in concrete production: Prospect and challenges. *J. Build. Eng.* **2021**, *34*, 101864. [CrossRef]
7. Dey, S.; Kumar, V.V.P.; Goud, K.R.; Basha, S.K.J. State of art review on self compacting concrete using mineral admixtures. *J. Build. Pathol. Rehabil.* **2021**, *6*, 18. [CrossRef]
8. Da Silva, W.R.L.; Štemberk, P. Expert system applied for classifying self-compacting concrete surface finish. *Adv. Eng. Softw.* **2013**, *64*, 47–61. [CrossRef]
9. Silva, C.d.; Coelho, F.; de Brito, J.; Silvestre, J.; Pereira, C. Inspection, diagnosis, and repair system for architectural concrete surfaces. *J. Perform. Constr. Facil.* **2017**, *31*, 04017035. [CrossRef]
10. Károlyfi, K. The effect of saturation degree of cement paste on fair-faced concrete surfaces. *Epa. J. Silic. Based Compos. Mater.* **2017**, *69*, 55–58. [CrossRef]
11. Liu, B.; Yang, T.; Xie, Y. Factors influencing bugholes on concrete surface analyzed by image processing technology. *Constr. Build. Mater.* **2017**, *153*, 897–907. [CrossRef]
12. Douglas, E.; Bilodeau, A.; Malhotra, V. Properties and durability of alkali-activated slag concrete. *Mater. J.* **1992**, *89*, 509–516.
13. Nath, P.; Sarker, P. Effect of fly ash on the durability properties of high strength concrete. *Procedia Eng.* **2011**, *14*, 1149–1156. [CrossRef]
14. Jin, L.H.; Ma, X.L.; Li, X.K. Experimental Study on Basic Properties of Fair-Faced Concrete for Urban Bridge. *Appl. Mech. Mater.* **2013**, *438–439*, 1156–1159. [CrossRef]
15. Li, X.K.; Ma, X.L.; Zhang, X.Y. Experimental study on mix proportion of fair-faced concrete for urban bridge. *Adv. Mater. Res.* **2012**, *450*, 383–386. [CrossRef]
16. Zhang, X.Y.; Ma, X.L.; Jin, L.H.; Li, X.K. Simulated Environment Test on Weather Fastness of Fair-Faced Concrete for Urban Bridge. *Appl. Mech. Mater.* **2013**, *438–439*, 1150–1155. [CrossRef]
17. Luan, C.; Wu, Z.; Han, Z.; Gao, X.; Zhou, Z.; Du, P.; Wu, F.; Du, S.; Huang, Y. The effects of calcium content of fly ash on hydration and microstructure of ultra-high performance concrete (UHPC). *J. Clean. Prod.* **2023**, *415*, 137735. [CrossRef]
18. Reiner, M.; Rens, K. High-volume fly ash concrete: Analysis and application. *Pract. Period. Struct. Des. Constr.* **2006**, *11*, 58–64. [CrossRef]
19. Sun, Z.; Young, C. Bleeding of SCC pastes with fly ash and GGBFS replacement. *J. Sustain. Cem.-Based Mater.* **2014**, *3*, 220–229. [CrossRef]
20. Puthipad, N.; Ouchi, M.; Attachaiyawuth, A. Effects of fly ash, mixing procedure and type of air-entraining agent on coalescence of entrained air bubbles in mortar of self-compacting concrete at fresh state. *Constr. Build. Mater.* **2018**, *180*, 437–444. [CrossRef]

21. Jiang, X.; Zhang, Y.; Xiao, R.; Polaczyk, P.; Zhang, M.; Hu, W.; Bai, Y.; Huang, B. A comparative study on geopolymers synthesized by different classes of fly ash after exposure to elevated temperatures. *J. Clean. Prod.* **2020**, *270*, 122500. [CrossRef]
22. Zhang, R.; Guo, F.; Xia, Y.; Tan, J.; Xing, Y.; Gui, X. Recovering unburned carbon from gasification fly ash using saline water. *Waste Manag.* **2019**, *98*, 29–36. [CrossRef] [PubMed]
23. Strehlein, D.; Schießl, P. Dark discoloration of fair-face concrete surfaces-transport and crystallization in hardening concrete. *J. Adv. Concr. Technol.* **2008**, *6*, 409–418. [CrossRef]
24. Ling, T.-C.; Poon, C.-S. Feasible use of large volumes of GGBS in 100% recycled glass architectural mortar. *Cem. Concr. Compos.* **2014**, *53*, 350–356. [CrossRef]
25. Amran, M.; Murali, G.; Khalid, N.H.A.; Fediuk, R.; Ozbakkaloglu, T.; Lee, Y.H.; Haruna, S.; Lee, Y.Y. Slag uses in making an ecofriendly and sustainable concrete: A review. *Constr. Build. Mater.* **2021**, *272*, 121942. [CrossRef]
26. Arivalagan, S. Sustainable studies on concrete with GGBS as a replacement material in cement. *Jordan J. Civ. Eng.* **2014**, *8*, 263–270.
27. El-Hassan, H.; Kianmehr, P. Pervious concrete pavement incorporating GGBS to alleviate pavement runoff and improve urban sustainability. *Road Mater. Pavement Des.* **2018**, *19*, 167–181. [CrossRef]
28. Wawrzeńczyk, J.; Molendowska, A.; Juszczak, T. Scaling resistance and air void characteristics in concrete containing ggbs. *Arch. Civ. Eng.* **2016**, *62*, 181–192. [CrossRef]
29. Zhao, J.; Li, Z.; Wang, D.; Yan, P.; Luo, L.; Zhang, H.; Zhang, H.; Gu, X. Hydration superposition effect and mechanism of steel slag powder and granulated blast furnace slag powder. *Constr. Build. Mater.* **2023**, *366*, 130101. [CrossRef]
30. Dong, J.; Liu, H. The Charm of Concrete--Research on the Artistic Expression of Concrete in Architectural Design. *Int. J. Simul.—Syst. Sci. Technol.* **2016**, *17*, 1–10.
31. Wu, M.; Xiong, X.; Shen, W.; Huo, X.; Xu, G.; Zhang, B.; Li, J.; Zhang, W. Material design and engineering application of Fair-faced self-compacting concrete. *Constr. Build. Mater.* **2021**, *300*, 123992. [CrossRef]
32. Liu, Q.; Liao, Z.; Xiong, Y.; Liu, Z.; Zhang, W. Effect of imitation fair-faced curing and protective coating on the durability of concrete. *J. Build. Eng.* **2023**, *63*, 105540. [CrossRef]
33. Shi, J.; Zhang, F.; Zhuang, J.; Wu, Z.; Chen, R.; Li, H. Study on the Influence of SAP on Properties of White Fair-Faced Concrete with Limestone Powder. *Adv. Mater. Sci. Eng.* **2023**, *2023*, 4994299. [CrossRef]
34. Li, W.; Jiang, T.; Jin, R.; Xu, Y. Optimization of the preparation process of Fair-Faced concrete incorporating recycled aggregates. *Constr. Build. Mater.* **2022**, *326*, 126908. [CrossRef]
35. Shi, J.; Qian, C.; Hao, Z. Effects of equipment parameters, ambient parameters and concrete surface moisture on the acquisition of fair-faced concrete appearance quality information. *J. Build. Eng.* **2023**, *72*, 106476. [CrossRef]
36. Honglei, C.; Zuquan, J.; Penggang, W.; Jianhong, W.; Jian, L. Comprehensive resistance of fair-faced concrete suffering from sulfate attack under marine environments. *Constr. Build. Mater.* **2021**, *277*, 122312. [CrossRef]
37. Zhang, J.; Qian, C.; Chen, Y. Robustness interval of apparent air bubbles of fair-faced concrete. In Proceedings of the IOP Conference Series: Materials Science and Engineering, Chennai, India, 16–17 September 2020; p. 012061.
38. Fu, X.; Li, Y.; Lin, C.; Meng, Y.; Yue, Q.; Liu, H. Strength, durability and appearance of low-carbon fair-faced concrete containing multiple mineral admixtures. *Constr. Build. Mater.* **2023**, *392*, 131838. [CrossRef]
39. Gao, C. Development and Application of High-performance Self-compacting Fair-faced Finish Concrete under Complex Conditions. *Adv. Mater. Res.* **2011**, *163–167*, 4604–4611. [CrossRef]
40. Zhang, T.; Fang, G.; Chen, H.; Cui, W. Experimental study on mix proportion of green environmental protection type three-doped fair-faced concrete. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Surakarta, Indonesia, 24–25 August 2021; p. 012045.
41. Liao, J.; Zeng, J.-J.; Zhuge, Y.; Zheng, Y.; Ma, G.; Zhang, L. FRP-Confined Concrete Columns with a Stress Reduction-Recovery Behavior: A State-of-the-art Review, Design Recommendations and Model Assessments. *Compos. Struct.* **2023**, *321*, 117313. [CrossRef]
42. Wang, D.; Shi, C.; Farzadnia, N.; Shi, Z.; Jia, H. A review on effects of limestone powder on the properties of concrete. *Constr. Build. Mater.* **2018**, *192*, 153–166. [CrossRef]
43. Liu, S.; Yan, P. Effect of limestone powder on microstructure of concrete. *J. Wuhan Univ. Technol.-Mater. Sci. Ed.* **2010**, *25*, 328–331. [CrossRef]
44. Károlyfi, K.A.; Papp, F.; Horváth, A. Digital image processing method for evaluation of discoloration on fairfaced concrete surfaces. *Építöanyag J. Silic. Based Compos. Mater.* **2022**, *74*, 67–70.
45. Bundesverband der Deutschen Zementindustrie EV. *Merkblatt Sichtbeton*; Deutscher Beton- und Bautechnik-Verein EV: Berlin, Germany, Fassung August 2004; p. 52.
46. für Beton, Ö.V. *Und Bautechnik (ÖVBB), Sichtbeton—Geschalte Betonflächen*; Österreichische Vereinigung für Beton-und Bautechnik: Wien, Austria, 2002.
47. Kelber, A. Colour in the eye of the beholder: Receptor sensitivities and neural circuits underlying colour opponency and colour perception. *Curr. Opin. Neurobiol.* **2016**, *41*, 106–112. [CrossRef] [PubMed]
48. Wei, F.; Yao, G.; Yang, Y.; Sun, Y. Instance-level recognition and quantification for concrete surface bughole based on deep learning. *Autom. Constr.* **2019**, *107*, 102920. [CrossRef]
49. *JGJ 169-2009*; Technical Specification for Fair-Faced Concrete Construction. China Architecture and Building Press: Beijing, China, 2009.

50. *DB37/T 5099-2017*; Technical Specification for Fair-Faced Concrete Construction of Urban Rail Transit. Shandong Provincial Department of Housing and Urban-Rural Development: Beijing, China, 2017.
51. *DB11/T 464-2023*; Technical Specification for Architectural Concrete Construction. Beijing Municipal Administration of Market Supervision: Beijing, China, 2023.
52. *DL/T 5306-2013*; Specifications for Fair-Faced Concrete Construction of Hydroelectric and Hydraulic Engineering. China Electric Power Press: Beijing, China, 2013.
53. *DB36/T 1009-2018*; Technical Specification for Construction of Super Wide Concrete Box Girder of Hybrid Girder Cable-Stayed Bridge. Jiangxi Provincial Bureau of Quality and Technical Supervision: Nanchang, China, 2018.
54. Liu, B.; Yang, T. Image analysis for detection of bugholes on concrete surface. *Constr. Build. Mater.* **2017**, *137*, 432–440. [CrossRef]
55. Gamil, Y. Machine learning in concrete technology: A review of current researches, trends, and applications. *Front. Built Environ.* **2023**, *9*, 1145591. [CrossRef]
56. Valikhani, A.; Jaberi Jahromi, A.; Pouyanfar, S.; Mantawy, I.M.; Azizinamini, A. Machine learning and image processing approaches for estimating concrete surface roughness using basic cameras. *Comput. Aided Civ. Infrastruct. Eng.* **2021**, *36*, 213–226. [CrossRef]
57. Shyha, I.; Richardson, A.; Coventry, K.; Ponton, H. Mould release technologies with regard to concrete surface finish. *Mag. Concr. Res.* **2016**, *68*, 87–98. [CrossRef]
58. Hallermann, N.; Morgenthal, G.; Rodehorst, V. Unmanned aerial systems (uas)–case studies of vision based monitoring of ageing structures. In Proceedings of the International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE), Berlin, Germany, 15–17 September 2015; pp. 15–17.
59. Ozkul, T.; Kucuk, I. Design and optimization of an instrument for measuring bughole rating of concrete surfaces. *J. Frankl. Inst.* **2011**, *348*, 1377–1392. [CrossRef]
60. Kwasny, J.; Sonebi, M.; Plasse, J.; Amziane, S. Influence of rheology on the quality of surface finish of cement-based mortars. *Constr. Build. Mater.* **2015**, *89*, 102–109. [CrossRef]
61. Wei, W.; Ding, L.; Luo, H.; Li, C.; Li, G. Automated bughole detection and quality performance assessment of concrete using image processing and deep convolutional neural networks. *Constr. Build. Mater.* **2021**, *281*, 122576. [CrossRef]
62. Yao, G.; Sun, W.; Yang, Y.; Sun, Y.; Xu, L.; Zhou, J. Chromatic aberration identification of fair-faced concrete research based on multi-scale lightweight structured data algorithm. *Front. Mater.* **2022**, *9*, 851555. [CrossRef]
63. Klovas, A.; DAUKŠYS, M. The evaluation methods of decorative concrete horizontal surfaces quality. *Mater. Sci.* **2013**, *19*, 343–348. [CrossRef]
64. Lemaire, G.; Escadeillas, G.; Ringot, E. Evaluating concrete surfaces using an image analysis process. *Constr. Build. Mater.* **2005**, *19*, 604–611. [CrossRef]