

A real-time approach toward the chemical quality control of rock material (Case study: Gravel mines in Semnan, Iran)

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Abstract

The quality of concrete is highly dependent on the characteristics of its aggregate, such as the size, minerals, and their chemical properties. Even a small amount of impurities, such as hydrated sulfates, chlorine (salt), and acidic pH of the rock material, can adversely affect the quality of the concrete. Thus, many national codes and standards are developed for testing, selecting, and employing the rock materials in concrete. For instance, Iranian standards 446, 449, 1702, 4978, 4984, 7174, and 8672¹ are currently serving this purpose. In the present research, a new real-time system was developed in order to replace the customary chemical analysis and size distribution tests. 20 samples were taken from two mines, selected by the Building Material Committee of Semnan Province, in order to determine the dissolved chlorine and sulfate, pH, density as well as size distribution. The new system is constituted of hydraulic jacks and a reservoir, designed to take samples from the conveyer in given time intervals. The samples were washed with distilled water and real-time analyses of dissolved chlorine and pH were performed. The results showed 85% agreement with the results from laboratory analyses. The correct classification rate (CCR) was 92% for 13 samples.

Keywords: *concrete mixture, dissolved chloride, pH; real-time analysis, rock material.*

1. Refers to Institute of Standards and Industrial Research of Iran in order to see these standards.

1. Introduction

ISO (1994) defines quality assurance as "the assembly of all planned and systematic actions necessary to provide adequate confidence that a product, process, or service will satisfy given quality requirements" and quality control as "the operational techniques and activities that are used to satisfy quality requirements" [1]. Some researchers suggested and proposed quality-control programs, majority of them are not internet or network oriented [2, 3].

Real time quality control is considered as a suitable approach to prevent unnecessary production and transportation costs. In mining, the raw materials are extracted from underground, thus, there is no prior knowledge of their quality. This creates undesirable problems in quality management of the raw material and the production process. To understand the behavior of the materials, one needs to have a solid knowledge of mineralogy of grains, porosity, texture, degree of freedom of the minerals, and wider range of other characteristics of the target matter. The quality control of minerals has been developed through the last decades and traditional methods have been replaced by more recent techniques which provide more accurate results in a faster and less expensive manner.

Digital image processing is one of the fast-growing, developing methods for quality control of minerals. The method is developing rapidly and currently is used in variety of industries and scientific projects. The curious reader could find more information in the literature including but not limited to [4-10].

Numerous studies were contacted to employ the digital image processing to classify as well as separation of minerals from tailings to feed the processing factories. Oestreich et al. (1995) conducted an experiment in order to identify and classify the minerals in the mining samples using color characteristics of the images [11]. Perez et al. (2000) identified the petrological composition of the minerals samples in the image based on the extraction and classification of color properties of the minerals [12]. Casali et al. (2001) performed a similar study to determine the crushability of rocks [13]. Aydemir et al. (2004) conducted another study to assess the soil properties based on morphology and the texture of the soil samples captured in digital

images [14]. Marmo and Amodio (2004) used the image of calcite rocks to identify and classify them based on grain size classification [15].

Donskoi and Clout (2006) reorganized hematite and goethite as well as their porous forms under the microscope by the textural properties according to different reflections of oxides and hydroxides [16]. They used a software to process the images which was based on textural properties of the image. The chemical components and atomic weight of hematite, goethite, and some more iron minerals were given to the software to be used as the default values. Thus, the software could predict the percentage of the minerals and their chemical components. Chatterjee (2006) designed a visual model which was able to be used in all parts of the mine to assess the chemical components of limestone and ironstone using the visual properties of crushed rocks [4]. Singh et al. (2010) could separate different layers of an iron mine in India based on the texture and color of the images which were taken 1 m from the samples [17]. Khorram et al., in two separate papers, classified limestone lithology's [18] and estimated limestone chemical components [19]. They have extracted features from limestone images and designed a Bayesian classifier in order to discriminate four limestone lithological classes. They have arrived to 74% accuracy as average of correct classification rate [18]. Then, they have used neural network as an estimator for chemical component estimation of limestone, which the results have been worthy of attention [19].

In the present research, a different method was proposed for real-time chemical analysis of rock materials. In this method, the dissolved chloride and pH of the grain material were measured through wet analysis. For this purpose, a system consisted of the jack and the box was designed to take samples from conveyer in given time intervals. The sample was washed with distilled water and then the concentration of chloride and pH were measured.

2. Real-time sampler

A sampling system was designed as the following:

- A jack was placed in one side of the

conveyer. It was designed to periodically take a specific part of material from the conveyer to a cubic box in a given time interval (Fig. 1).

- A known volume of distilled water (based on the volume of the sample) is added and the mix is stirred by a stirrer simultaneously.
- In the next step, the solution is poured into another box (left box in Fig. 1).

- A pH meter and a chloride ion sensor were placed in the left box. These sensors are able to collect the required data in less than a minute (Fig. 2).
- In the last step, the left box is opened by another jack to drain water. The boxes are washed and prepared to take the next sample.

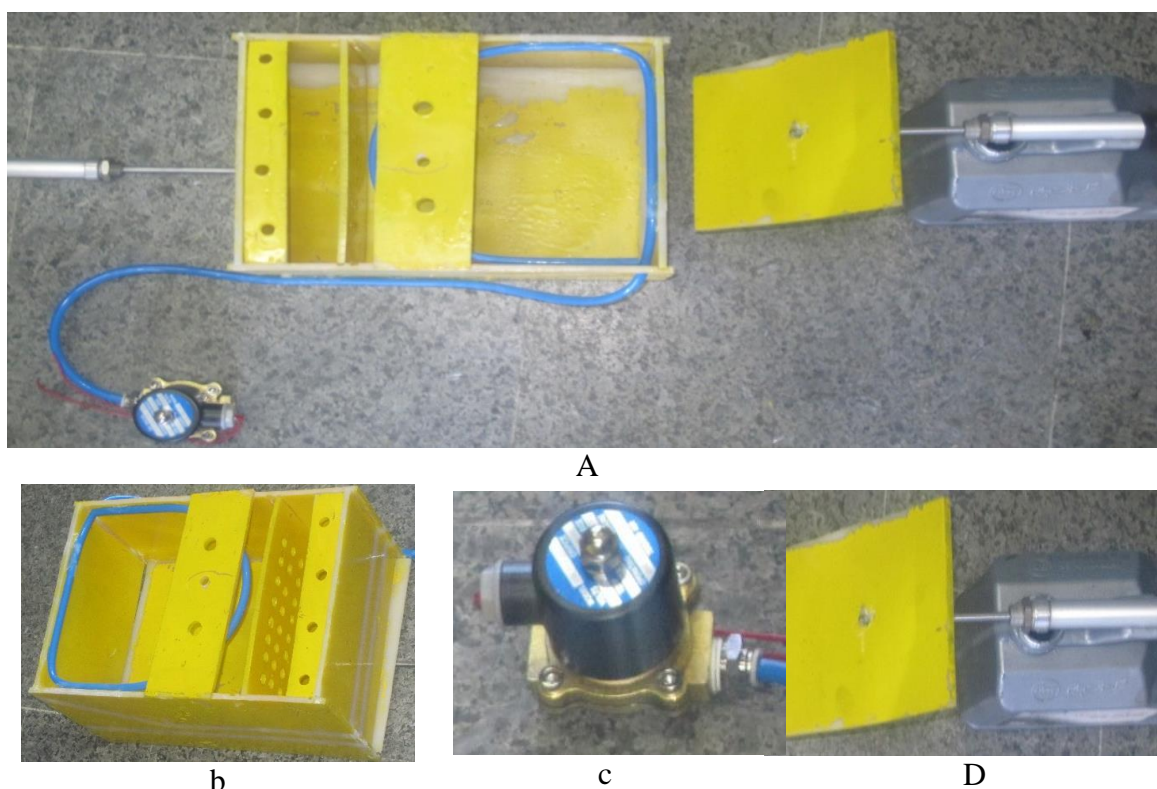


Fig. 1. a) The designed jack for sampling from the conveyer, b) Box, c) Water pump, d) Jack



Fig. 2. The digital shaker (right) and the ion-meter (left) used in the study for measurement of pH and the concentration of chlorine

According to Iranian concrete code (ABA) [19], the maximum dissolved chloride in water for concrete is as follows:

- For coarse rock material in concrete, the maximum dissolved chloride in water is up to 0.02%.
- For fine materials, the maximum dissolved chloride is limited to 0.04%.

Since the limit for dissolved chloride is quite small, digital image processing is not applicable and, thus, another approach was selected to determine the concentration of the ion.

3. Study area

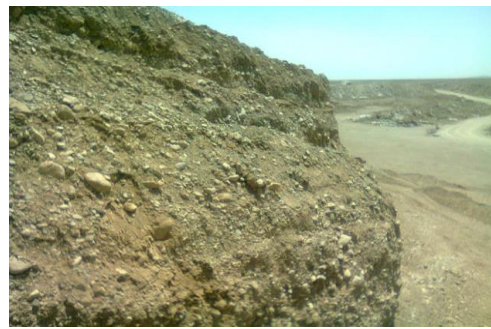
Two active river gravel and sand mines near Semnan city, where the main problems of rock

material are high chloride and pH, were selected for sampling. The problems are due to the development of clay and evaporative deposits in the area.

20 samples were collected from both mines. The samples weighed approximately 3 kg and the size range varied from fine to 5 cm (Fig. 3). Sampling periods from the conveyor have been 1 sample per 2 hours, and only four samples from conveyors in each mine have been taken. Other samples were taken from different deposits and depot in channel form (Fig. 3). After sample collection, they were analyzed with field instruments and crushed with Jaw crusher and sieved for lab tests.



Mine 1.



Mine 2.



Sampling from Mine 1.



Sampling from Mine 2.



Sampling from Mine 1.



Sampling from Mine 2.

Fig. 3. The general view from the mine and the sampling from the crushed rocks during the production

4. Results and Discussions

4.1. Sampler

The samples were analyzed in laboratory as well as by the designed system that uses industrial probs. The results are presented in Tables 1 and 2 for Mines 1 and 2, respectively. It should be mentioned that wet chemistry was used for analyzing the chlorine in the lab.

4.2. pH

The cross correlation of the pH results from Tables 1 and 2 are plotted in Figures 4, 5, and 6 for Mines 1, 2 and for both mines together,

respectively. As seen in the Tables and Figures, in the majority of the samples, lab pHs are higher than field pH. Therefore field pH-meter under-measures pH for about 0.1. Also, pH of the samples ranges from 8.5 to 10.5, thus, all samples were alkaline. This could be due to outcrops of various evaporate structures on the river path in the vicinity of Semnan City. As it is seen in Figure 6, the results are not mine dependent, and thus, they are generalizable. Therefore, the proposed methodology can be applied to any other mine.

Table 1. A comparison between the values measured for concentration of chlorine and pH in laboratory and by the industrial ion-meter and pH in the field (Mine 1)

Sample	Dissolved chlorine in water (%)		pH	
	Chemical Laboratory	Ion-meter	Laboratory	Field
1.1	0.063	0.057	10.01	9.95
1.2	0.053	0.042	10.10	10.00
1.3	0.05	0.052	9.95	9.90
1.4	0.34	0.31	8.81	8.63
1.5	0.024	0.028	9.30	8.83
1.6	0.045	0.048	8.87	8.86
1.7	0.041	0.039	10.31	10.40
1.8	0.032	0.030	10.75	10.35
1.9	0.048	0.044	9.48	9.10

Table 2. A comparison between the values measured for concentration of chlorine and pH in laboratory and by the industrial ion-meter and pH in the field (Mine 2)

Sample	Dissolved chlorine in water (%)		pH	
	Chemical Laboratory	Ion-meter	Laboratory	Field
2.1	0.013	0.016	10.21	10.20
2.2	0.015	---	10.77	---
2.3	0.019	0.017	9.04	9.33
2.4	0.022	0.03	10.21	9.92
2.5	0.027	0.03	9.60	9.66
2.6	0.025	0.025	9.38	9.98
2.7	0.020	0.015	10.41	10.27
2.8	0.018	---	9.15	---
2.9	0.017	---	8.96	---
2.10	0.026	0.03	10.03	9.85
2.11	0.023	---	10.03	---

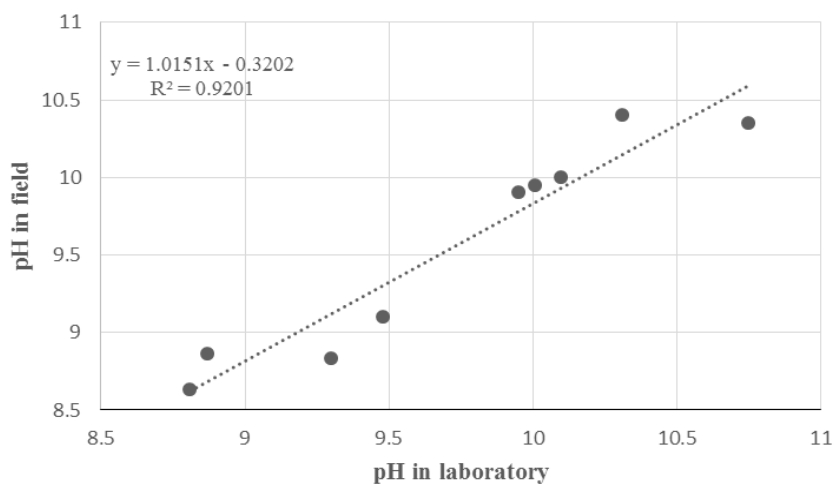


Fig. 4. Validation of the proposed method to measure pH for the samples from Mine 1

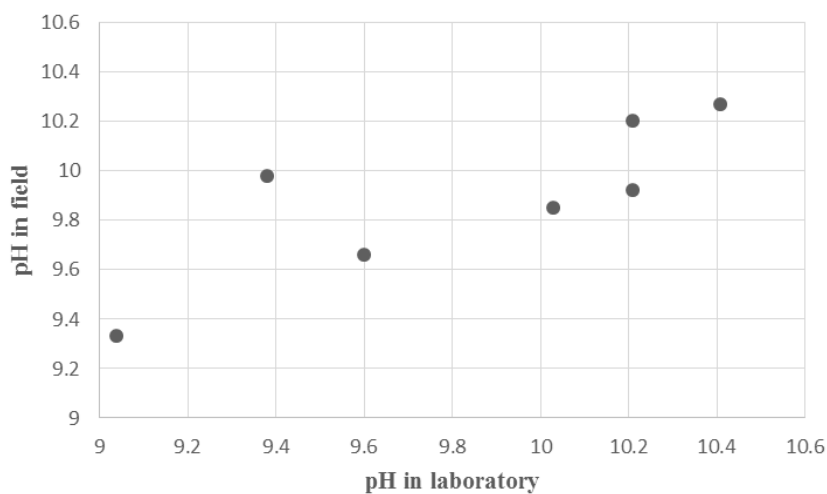


Fig. 5. Validation of the proposed method to measure pH for the samples from Mine 2

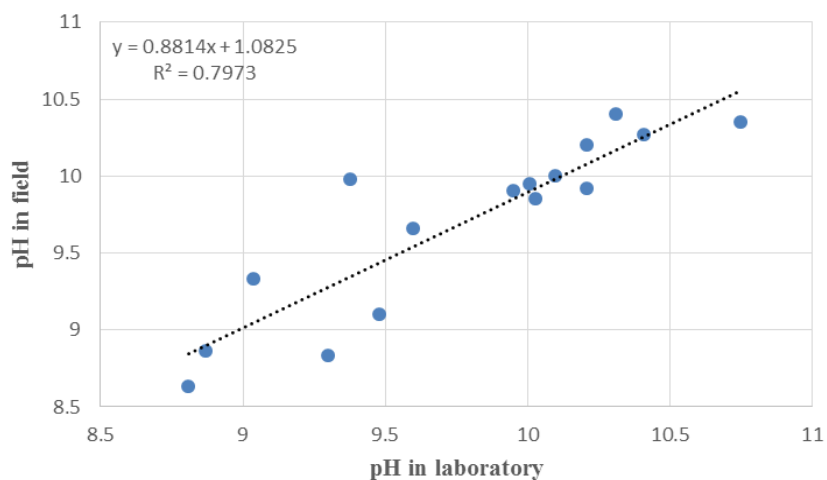


Fig. 6. Validation of the proposed method to measure pH for the samples from both mines

Since then alkaline pH is harmful to concrete, therefore, these samples do not meet the standards. It should be noted that although some samples were taken from the depot of washed crushed rocks, the problem of alkaline condition was not over even after washing (Tables 1 and 2). Since the city faces severe shortage of water resources, the continuous washing of material with clear water is not possible and usually miners recycle the water for washing without any treatment. In some cases, this process causes even augmentation of pH of the materials as seen in the Tables 1 and 2 in which pH in the depot of washed materials are maximum between the all samples.

5. Validation of the results of dissolved chloride

The cross correlation of the results from Tables 1 and 2 is plotted in Figures 7, 8, and 9 for Mines 1, 2, and data from both mines,

respectively. In Figures 7 and 9, one outlier data has been omitted to increase the visibility of error in other samples. As seen in the figures, the proposed approach for real time analysis provides reliable results. It seems better validation of the results in the first mine has been met, because the second mine is so bigger, and more variations between situations of samples has occurred in mine 2 and in data from both mines. Also, it can be seen in Figure 9 that these results are also generalizable. Therefore, the cross correlation supports the idea of applying the proposed methodology to any other mine.

To investigate the error of the method for the standard samples in terms of dissolved chloride, the cross correlation was plotted and standard threshold of dissolved chloride was shown (Figs. 10 and 11).

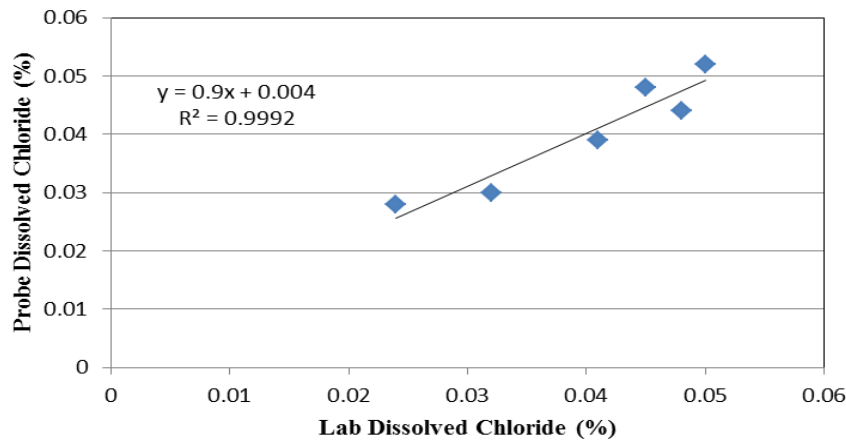


Fig. 7. Validation of the proposed method to measure chloride ion for the samples from Mine 1 after removing one sample with very high impurities

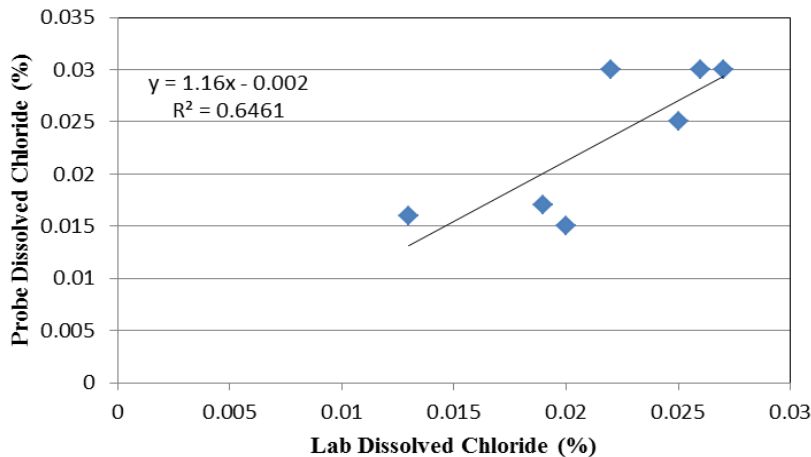


Fig. 8. Validation of the proposed method to measure chloride ion for the samples from Mine 2

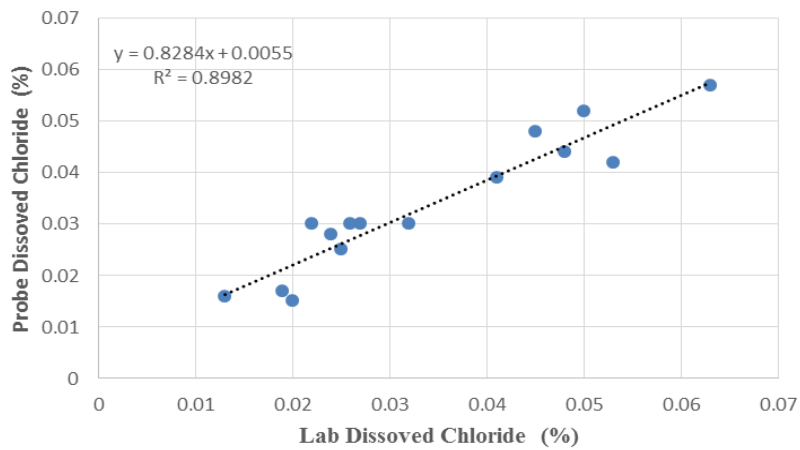


Fig. 9. Validation of the proposed method to measure chloride ion for the samples from both mines

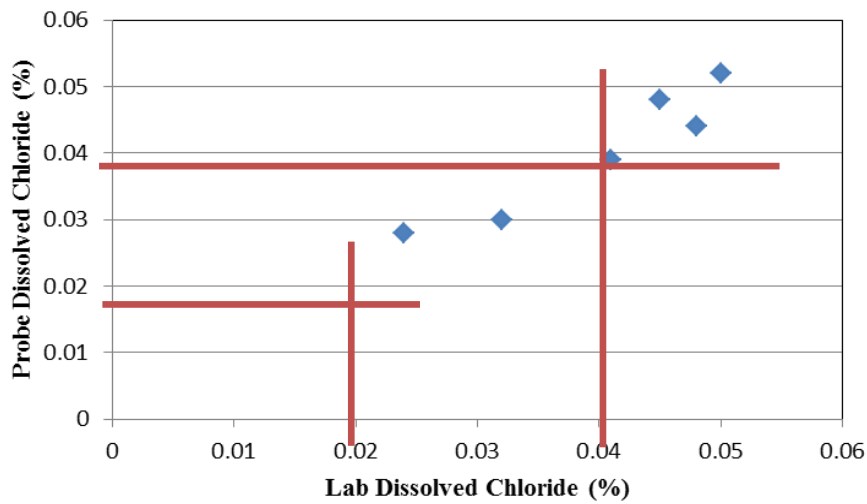


Fig. 10. Validation of the proposed method for separation of the samples with standard chloride ion in Mine 1 (according to ABA)

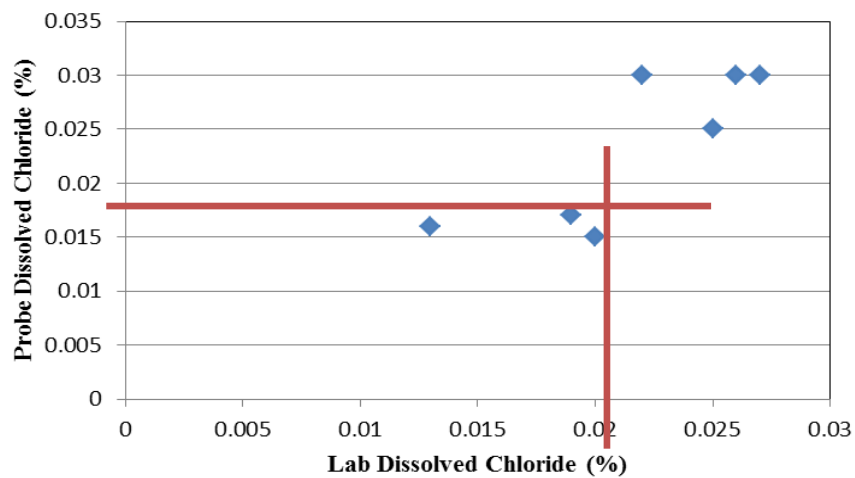


Fig. 11. Validation of the proposed method for separation of the samples with standard chloride ion in Mine 2 (according to ABA)

As seen in Figure 10, all samples have more than 0.02% chloride. Since this was recognized correctly by the designed system in all samples, the accuracy of the proposed method could be considered to be 100%. It should be mentioned that as seen in Figure 3, some samples were of coarse material, thus, these type of material in Mine 1 are not standard in terms of dissolved chloride.

It could also be concluded from Figure 10 that the dissolved chloride in four out of six samples were more than 0.04%. The designed system could identify three of them that make the accuracy of the method up to 75% for this case. From the industrial point of view, dissolved chloride of material from Mine 1 is generally more than standard limit; therefore, it is necessary to employ a washing system for the rock material. However, the material in the current shape is not recommended for concrete mixture.

Figure 11 shows that all samples from Mine 2 have dissolved chloride less than 0.04% which was correctly determined by the proposed system in all samples. For this case, the accuracy of the method is 100%. It should be noticed that, from industrial point of view, the fine materials from Mine 2 are standard in terms of dissolved chloride.

Dissolved chloride in four out of seven samples was more than 0.02% and the rest were below that, which was correctly measured by the system (Fig. 11). The system has 100% accuracy for this case as well. Dissolved chloride in rock material from Mine 2 is in a range that can meet the standards, although, use of these materials for concrete mixture is not recommended without extreme care.

7. Conclusions

This research was conducted to design a real time quality control system for river rock material for concrete production. The investigations showed that the chemical quality control of sand and rocks is not possible by digital image processing due to very small standard limits for impurities in rock materials. The standard limits could be as low as 0.02% and 0.04% for coarse and fine materials, respectively, according to ABA, which are way below the resolutions available for digital image processing. A new system

was designed and manufactured which consisted of jacks and boxes. The samples were taken in given time intervals and placed in a box where pH and dissolved chloride are measured by related probes.

The results reported by the system were compared with the laboratory analyses results that showed the accuracy of the designed system up to 100% for most cases. In other words, the designed system is capable of classification of the materials in terms of pH and dissolved chloride. The system has undergone a field test in two mines and among all the samples, only one defected sample was not recognized.

Since the conventional methods are based on expensive and time consuming laboratory tests, in majority of cases, the results are available only when the final product is already in the market; in this case, when the concrete is produced. Nevertheless, even if the laboratory tests show that the materials are not suitable for concrete mixture, this is not helpful to the final product. The proposed system is able to provide reliable quality control for the material as well as issuing a warning to prevent the release of low quality material to the market.

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