Research on image analysis technology for determining alkali active component content of alkali in low-grade metamorphic rock based on deep learning

Haotian Zou,Qian Yang*, Yi Liu and Xiaoxiong Wang

Guizhou Hongxin Chuangda Engineering Inspection Consulting Co., Ltd., Guiyang City, Guizhou province, China
E-mai: manager@gzhxcd.com

Abstract. To accurately compare the alkali activity of aggregates, this paper proposes applying microscopic imaging and computer image analysis technology to calculate active mineral content in lithofacies examination and analyze its correlation with the rock aggregate expansion rate. The results show that SiO₂ is the main chemical component of metamorphic rocks, and its content is over 60%. Low-grade metamorphic rocks in Guizhou province are composed of sericite, feldspar, quartz, calcite, and other minerals. The active minerals are mainly microcrystal quartz and strain quartz, and their active interference color is different from other inactive minerals. Equipped with microscope imaging and computer image analysis technologies, computers can quantitatively and qualitatively estimate the active mineral content of rocks. Compared with the conventional lithofacies method, the results are more accurate, the acquisition parameters can be saved, and the analysis is faster. Furthermore, the calculation results of alkali active mineral content of rock correlate with the expansion rate measured by the rapid mortar bar method.

Keywords: image processing; Low-grade Metamorphic Rock; alkali activity; active mineral content

Alkali-Silica reaction (ASR) of concrete is one of the critical factors that cause expansion cracking damage and durability reduction of concrete[1~5]. Cracking damage will intensify over time, and
maintenance is difficult and expensive. With the increasingly strict requirements of engineering quality and safety in China, there is no tolerance for error in concrete quality and safety control in bridges, dams, and other projects. Therefore, how to avoid concrete cracking caused by ASR is a problem that cannot be overlooked. At present, the commonly used test methods for ASR in China can be divided into three categories: chemical method, rapid mortar bar method, and lithofacies method. The chemical method is known to experience significant interference by external factors and has low accuracy. As a test method for quantitative determination of alkali reactivity, the rapid mortar bar method is considered to have high accuracy and is more suitable for practical engineering data. However, some studies suggest that it is an accelerated reaction, and the results of different rocks are different. As a test method for qualitative judgment of alkali active reaction, the lithofacies method can directly observe whether there is alkali active mineral in the aggregate used. Still, it requires artificial visual or mathematical principles to estimate the percentage of active minerals in the sample area to further confirm the content of active minerals. In practice, the lithofacies and fast mortar bar methods are usually combined to judge ASR accurately.

This paper applies the combination of microscope imaging and computer image analysis technology to the lithofacies analysis, referred to as the computer image processing method. The feasibility of this method in the study of alkali active minerals is analyzed and evaluated.

1. Experimental program

1.1. Materials
Aggregates: Undifferenced sampling was carried out from the A and B quarry in the Jianrong area, the southeastern part of Guizhou province, 7 groups of A quarry, 5 groups of B quarry, with a total of 12 groups of samples. The chemical composition of the samples is shown in Table 1, and the X-ray Diffraction (XRD) pattern analysis is shown in Figure 1.

Cement: The cement is P·I 42.5 portland cement, and its chemical composition is shown in Table 1. The basic characteristics are shown in Table 2.

| Sample no. | SiO₂ | CaO | MgO | Al₂O₃ | Fe₂O₃ | SO₃ | K₂O | Na₂O |
|------------|------|-----|-----|-------|-------|-----|-----|------|
| A quarry 1 | 62.98 | 3.20 | 1.79 | 16.19 | 5.07  | 0.11| 2.07| 1.43 |
| 2          | 60.83 | 1.78 | 2.17 | 17.16 | 5.80  | 0.13| 2.53| 1.64 |
| 3          | 69.30 | 1.41 | 0.76 | 15.26 | 4.03  | 0.07| 1.98| 2.17 |
4  64.26  1.60  0.64  17.02  5.33  0.10  2.42  1.30  
5  63.42  2.72  1.52  17.15  5.55  0.06  2.64  1.50  
6  64.48  2.16  1.68  15.15  6.03  0.08  2.66  1.39  
7  51.85  11.96  1.56  14.08  4.90  0.08  2.22  1.10  
8  64.64  1.99  1.04  15.14  5.14  0.09  2.49  2.27  
9  64.94  1.72  1.43  15.47  4.64  0.12  2.07  1.93  
B quarry 10  66.00  1.82  1.30  15.33  4.18  0.07  2.06  2.04  
  11  65.51  1.63  1.49  14.80  4.89  0.09  2.00  2.14  
  12  66.23  1.89  1.32  14.91  4.23  0.14  1.96  2.00  
Cement 13  21.46  61.18  2.43  4.38  3.41  2.46  0.58  0.21  

Table 2. Basic characteristics of cement.

| Cement | Specific surface area/ (m²/kg) | Alkali content (by mass)/% | Setting time/min | Flexural strength/MPa | Compressive strength/MPa | Stability |
|--------|-------------------------------|---------------------------|-----------------|----------------------|------------------------|----------|
|        |                               |              | Initial | Final | 3d | 28d | 3d | 28d |      |          |          |
| P·I 42.5 | 345                           | 0.55         | 229    | 290   | 5.5 | 9.1 | 25.8 | 50.2 | Qualified |

(a) XRD pattern of sample 1  (b) XRD pattern of sample 8

**Figure 1.** X-ray Diffraction (XRD) patterns of samples from different yards.

It can be seen from Figure 1 that the values of the samples of the two stockyards reached a peak at the position of about 27 in the abscissa. Hence, the quartz content in the composition of the samples was relatively high followed by feldspar, calcite, and iron ore. However, the poor sensitivity of clay minerals and sericite to light mandates the samples be further tested with lithofacies analysis.
1.2. Experiment methods

1.2.1. Lithofacies method–Fast mortar bar method. According to the requirements of lithofacies method in Railway concrete TB/T 3275–2018\textsuperscript{[15]}, four pieces of each rock sample were selected and weighed to make sample slices to accommodate the variance in observation results caused by the change of observation area. Then, the lithofacies analysis of the slices was carried out to determine the active alkali minerals of the samples. The linear method was used to determine the content of active minerals in the slices, and the average percentage of alkali active minerals in the samples was calculated according to the standard equation (1).

\[\alpha = \frac{\sum_{i=1}^{n} b_i \alpha_i}{\sum_{i=1}^{n} b_i}, \quad n = 3 \sim 5\]  

(1)

In the equation:

\(\alpha\)—the average measure of alkali active minerals in samples and is expressed as a percentage (%);

\(b_i\)—the weight of the piece rock used to make the slice, in gram (g);

\(\alpha_i\)—the measure of alkali active minerals in the thin sections of slice was measured by polarizing microscope and expressed as a percentage (%);

\(n\)—Number of slices taken;

As per the requirements of the rapid mortar bar method in Railway concrete TB/T 3275–2018, the specimens were placed in 80°C, 1N NaOH solution after pre-curing and initial length measurement. A regular length measurement was employed in determining the length expansion rate of mortar specimens of 14 days of age.

The correlation coefficient was calculated between the average percentage content of alkali active minerals obtained by the lithofacies method and the corresponding expansion rate obtained by the rapid mortar bar method.

1.2.2. Computer image processing method–Fast mortar bar method. According to the requirements of lithofacies method in Railway concrete TB/T 3275–2018, four pieces with the same mass were selected for each rock sample and weighed to make the slices. Then, the lithofacies analysis of the slices was carried out to identify the alkali active minerals of the samples. Based on the different optical characteristics of the minerals in the slices under the orthogonal polarizing microscope, combined with microscope imaging and computer image analysis technology, the alkali active minerals were collected so that it can be used to analyze and calculate the percentage content of alkali active minerals in the total area of the image by “Image-ProPlus 6.0” software. Finally, the average percentage content of alkali active minerals in the samples was calculated by the standard equation (1).

The relationship between the average percentage content of alkali active minerals in the sample obtained by the computer image processing method and the corresponding expansion rate obtained by the fast mortar bar method in the aforementioned “lithofacies method–fast mortar bar method” is plotted, and the correlation coefficient is calculated.
2. Results and analyses

2.1. Lithofacies method–Fast mortar bar method
According to the standard, each sample was tested by the lithofacies method. Through the microscopic lithofacies analysis of the slice, the results show that the samples are regional metamorphic rocks, which are common greenschist facies in low P/T type. They are metamorphic from silty clay rock and have silty argillaceous palimpsest texture and tabular structure. This kind of rock's uniaxial saturated compressive strength has large variability and low softening coefficient, and the original rock is more acicular after crushing. However, the main mineral composition is not complex and has very little variability, if any. Combining XRD images and lithofacies images, it can be deduced that the main components are sericite, clay minerals, quartz, and the minor components are feldspar, calcite, opaque minerals. There is no dolomite. The alkali active reaction types are alkali-silica reactions, and there is no alkali carbonate reaction. Low-power imaging under an Orthogonal Microscope is shown in Figure 2.

![Image under orthogonal polarization.](image_url)

The optical characteristics of these minerals were analyzed under orthogonally polarized light[16–18]: sericite is a cryptocrystalline mineral with yellow-green color, which is formed by the feldspar sericitization, and some are directional distribution; the clay minerals are yellow and appear as mist filaments; the feldspar is mainly microcrystal plagioclase, which is a polysynthetic twin with a first-order off-white interference color; quartz is composed of two parts, most of which are microcrystal quartz, with some being strain quartz, yet all of which are first-order white interference colors, and the latter is heteromorphic crystal, and the lattice dislocation after strain will show wave extinction characteristics; calcite is a granular heteromorphic crystal with high-grade white interference color; the opaque minerals are limonite, and the color is black.

By analyzing the above optical characteristics, the six major constituent minerals can be distinguished under orthogonally polarized light. Firstly, sericite, clay mineral, and limonite have noticeable colors, which can be directly distinguished. Next, the standard thin sections were observed under the orthogonal polarizing microscope, and the quartz, feldspar, and calcite were compared. The quartz was white, the feldspar was grayish-white with a slightly turbid surface, and the calcite was pearl white. The three can be further distinguished from the crystal form and extinction type of minerals, the insertion of the gypsum board, and the observation under a polarizing microscope. A
comparison between plagioclase and quartz under orthogonal polarization is shown in Figure 3, and a comparison between calcite and quartz is shown in Figure 4.

![Figure 3. Plagioclase and quartz.](image)
![Figure 4. Calcite and quartz.](image)

The content of alkali active minerals in each slice was estimated by the linear method, and the average percentage content of alkali active minerals in the sample was calculated by the standard equation (1). The results are shown in Table 3.

| Sample no. | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Average percentage content/% | 8   | 10  | 8   | 10  | 8   | 7   | 7   | 10  | 10  | 11  | 11  | 8   |

Then, the rapid mortar bar test was carried out on each sample according to the specification, and the results are shown in Table 4.

| Sample no. | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Expansion rate of specimen/% | 0.158| 0.230| 0.212| 0.220| 0.183| 0.130| 0.314| 0.333| 0.328| 0.340| 0.262|

It can be seen from Table 4 that the expansion rate of 14d mortar specimens of each sample is greater than 0.1%, which has alkali silicate reaction activity. The relationship between the alkali active mineral content obtained by the lithofacies method in Table 3 and the expansion rate of mortar specimens in Table 4 is plotted. Finally, the correlation coefficient is calculated, as shown in Figure 5.
As shown in Figure 5, $R^2$ in the regression equation obtained by the lithofacies method–rapid mortar bar method is 0.7463, and the correlation coefficient R is 0.8639. Thus the expansion degree of mortar specimens made of samples as aggregates under an alkali environment is positively correlated with the content of alkali active minerals obtained from lithofacies analysis. The greater the content of alkali active minerals in the sample, the higher the expansion rate of the corresponding specimen.

2.2. Computer image processing method–Fast mortar bar method

The lithofacies analysis of each sample was carried out per test specifications. The content and structure of constituent unveiled by microscopic lithofacies analysis of the slice were consistent with those in the above “lithofacies method–rapid mortar bar method.”

The alkali active minerals were determined in accordance with that of the sample minerals using the lithofacies method. Firstly, it can be seen from the analysis that there are many minerals less than 5 μm in the slice, but most of them are sericite and clay minerals. Therefore, quartz and feldspar only account for a small fraction, and the influence of too small grain content on the calculation of component content is minimal. Secondly, according to the references, specifications, Chongxi Liu’s requirements for alkali active minerals and the region's characteristics, the alkali active minerals in this kind of samples are defined as 5 μm ~ 50 μm microcrystal quartz and strain quartz with wavy extinction.

The specific process of computer image processing method is as follows:

The first step was to collect the original image. Synchronous microscope and observation software were needed to ensure that images can be gathered during observation. Then, the slices were selected with low-power orthogonal polarization under representative areas, the original images were saved on the computer, as shown in Figure 6.
The second step is the preliminary collection of active minerals. Starting with the image analysis software, target active minerals were captured. Finally, the scale, analysis parameters, and acquisition threshold were set:

1. **Scale setting**: Set the appropriate scale, such as 100 μm and 50 μm scale.

2. **Analysis parameters**: Analysis parameters are set for area and particle size. The unit of particle size is “μm.” According to the requirements of active minerals in the test, the range of parameters is set to be 5 ~ 50.

3. **Acquisition threshold**: The color acquisition threshold is set. After comparing the analysis data for different threshold settings, the Hue-Saturation-Intensity (HSI) mode is selected, and the Intensity (I) value is set to 230 ~ 255 as the appropriate threshold setting.

Then, the captured images of the slice were analyzed: the “Count” function was used for the preliminary collection of active minerals, based on the lithofacies, mainly excluding sericite, clay minerals, limonite with apparent differences in color, and feldspar and quartz with less influence on mineral content below 5 μm of grain size. The initial image acquisition is shown in Figure 7, and the white area represents the active mineral revealed by the image.

![Figure 6. The original image.](image)

![Figure 7. Preliminary acquisition image.](image)

The third step was to capture the active minerals in detail. Here the computer observation software...
and image analysis software was used simultaneously. The extinction state of minerals was observed in detail by rotating the loading table, and the change of interference color of minerals was observed by inserting the gypsum board. Microscopic and computer imaging can further identify the strain quartz, feldspar, and calcite. Since quartz is a uniaxial crystal and feldspar is a biaxial crystal, the extinction angle is not used to determine whether there is alkali activity. As long as there is wavy extinction, it is regarded as alkali active minerals, as shown in Figure 8. At this time, with the “Draw/Merge Objects” function, the detailed acquisition of active minerals in the image after the previous analysis and processing was carried out, excluding feldspar, calcite, and other non-alkali active minerals, and adding strain quartz with large grain size, the detailed acquisition image was obtained, as shown in Figure 9. This step is an important combination of artificial intelligence, microscope imaging, and software recognition technology. After the analysis, the computer automatically calculates the data of active mineral content. The area percentage obtained was the percentage of the total area of active mineral that met the requirements of size and optical characteristics to the total image area.

![Figure 8. Observation of strain quartz. Figure 9. Detail acquisition images.](image)

In the fourth step, the percentage content of alkali active minerals of different slices in the same sample was calculated according to equation (1). The average percentage content of alkali active minerals of the sample was obtained. Then, with respect to the above test process, each sample was tested to obtain the final results of each, shown in Table 5. The detailed acquisition images of the slices are shown in Figure 10.

**Table 5.** Average percentage content of alkali active minerals in samples (computer image processing method).

| Sample no. | Slice no. | Active mineral \(/(10^{-3}\times \text{mm}^2)\) | Observation area \(/(10^{-3}\times \text{mm}^2)\) | Percentage content/% | Average percentage content/% |
|------------|-----------|-------------------------------------------|-----------------------------------------------|---------------------|-----------------------------|
| 1          | 1-1       | 63.6831                                   | 1658.3172                                    | 3.840               |                              |
|            | 1-2       | 8.3962                                    | 414.5793                                     | 2.025               |                              |
|            | 1-3       | 19.0661                                   | 414.5793                                     | 4.599               |                              |
|            | 1-4       | 17.5491                                   | 414.5793                                     | 4.233               |                              |
|            | 2-1       | 23.1850                                   | 1658.3172                                    | 1.398               | 3.674                        |
|            | 2-2       | 74.4517                                   | 1658.3172                                    | 4.490               |                              |
|            | 2-3       | 3.6853                                    | 414.5793                                     | 0.889               |                              |
|            | 2-4       | 35.8775                                   | 414.5793                                     | 8.654               | 3.858                        |
|   |   |   |   |   |
|---|---|---|---|---|
| 3 | 3-1 | 78.9893 | 1658.3172 | 4.763 |
|   | 3-2 | 65.0836 | 1658.3172 | 3.925 |
|   | 3-3 | 5.5589 | 414.5793 | 1.341 |
|   | 3-4 | 10.7961 | 414.5793 | 2.604 |
| 4 | 4-1 | 33.6702 | 1658.3172 | 2.030 |
|   | 4-2 | 33.2844 | 1658.3172 | 2.007 |
|   | 4-3 | 18.8086 | 1658.3172 | 1.134 |
|   | 4-4 | 9.5096 | 414.5793 | 2.294 |
| 5 | 5-1 | 83.9718 | 1658.3172 | 5.064 |
|   | 5-2 | 69.2426 | 1658.3172 | 4.175 |
|   | 5-3 | 85.8396 | 1658.3172 | 5.176 |
|   | 5-4 | 2.3848 | 414.5793 | 0.575 |
| 6 | 6-1 | 29.0857 | 1658.3172 | 1.754 |
|   | 6-2 | 33.0774 | 1658.3172 | 1.995 |
|   | 6-3 | 34.3863 | 1658.3172 | 2.074 |
|   | 6-4 | 5.4118 | 414.5793 | 1.305 |
| 7 | 7-1 | 60.6246 | 1658.3172 | 3.656 |
|   | 7-2 | 21.0507 | 1658.3172 | 1.269 |
|   | 7-3 | 2.2746 | 414.5793 | 0.549 |
|   | 7-4 | 3.4464 | 414.5793 | 0.831 |
| 8 | 8-1 | 123.9150 | 1658.3172 | 7.472 |
|   | 8-2 | 17.4247 | 414.5793 | 4.203 |
|   | 8-3 | 17.4554 | 414.5793 | 4.210 |
|   | 8-4 | 46.3409 | 414.5793 | 11.178 |
| 9 | 9-1 | 77.7537 | 1658.3172 | 4.689 |
|   | 9-2 | 48.2143 | 414.5793 | 11.630 |
|   | 9-3 | 43.6616 | 414.5793 | 10.532 |
|   | 9-4 | 4.4735 | 414.5793 | 1.079 |
| 10 | 10-1 | 70.0839 | 1658.3172 | 4.226 |
|   | 10-2 | 51.5316 | 414.5793 | 12.430 |
|   | 10-3 | 28.4087 | 414.5793 | 6.852 |
|   | 10-4 | 7.2656 | 414.5793 | 1.753 |
| 11 | 11-1 | 118.1606 | 1658.3172 | 7.125 |
|   | 11-2 | 16.5119 | 414.5793 | 3.983 |
|   | 11-3 | 38.4071 | 414.5793 | 9.264 |
|   | 11-4 | 9.7794 | 414.5793 | 2.359 |
| 12 | 12-1 | 107.5723 | 1658.3172 | 6.487 |
|   | 12-2 | 3.9927 | 414.5793 | 0.963 |
|   | 12-3 | 20.1448 | 414.5793 | 4.859 |
|   | 12-4 | 10.7702 | 414.5793 | 2.598 |
(a). slice 1–1. (b). slice 2–2. (c). slice 3–2.

(d). slice 4–2. (e). slice 5–2. (f). slice 6–2.

(g). slice 7–2. (h). slice 8–1. (i). slice 9–1.

(j). slice 10–1. (k). slice 11–1. (l). slice 12–1.

**Figure 10.** The detailed acquisition images of the slices.

The relationship between the alkali active mineral content obtained by the computer image processing method in Table 5 and the expansion rate of mortar specimens in Table 4 is plotted. The correlation coefficient is calculated, as shown in Figure 11.
As shown in Figure 11, $R^2$ in the regression equation obtained by the computer image processing method–Rapid mortar bar method is 0.7816. The correlation coefficient $R$ is 0.8841, a strong correlation higher than $R^2 = 0.7463$ was obtained by the lithofacies method–rapid mortar bar method. Furthermore, there exist a positive correlation between the expansion degree of the specimen made of samples and the content of alkali active minerals obtained by the computer image processing method. The greater the content of alkali active minerals in the sample, the higher the corresponding expansion rate of the specimen.

Figure 11. Relation diagram of computer image processing method and rapid mortar bar method.

2.3. Methods Feasibility analysis and significance

The conventional lithofacies method is heavily reliant on personal experience and mathematical calculation in quantitative analysis. The content of alkali active minerals is also different in the quantitative assessment of the same slice by different people. When quantitative judgment is carried out on different slices by same person, if the slice is complicated, it is easy to have disunity on the judgment criteria of alkali active minerals. In addition, there will be some problems such as the omission of active minerals, slow analysis speed, and workload leading to manual calculation errors.

The computer image processing method relies on the computer for analysis and judgment under the specified conditions in the quantitative analysis. There is a unified reference standard for alkali active minerals in the same slice and different slices. The calculation results are stable, without leakage and manual calculation error. The acquisition parameters can be saved, and the analysis is faster. At the same time, through the threshold adjustment of collection parameters, combined with manual calibration to supplement and remove specific minerals, the collection results are more accurate.

It can be seen from Figure 5 and Figure 11 that $R^2 = 0.7463$, obtained by the lithofacies method–rapid mortar bar method, and $R^2 = 0.7816$, obtained by computer image processing method–rapid mortar bar method, both exhibited a strong positive correlation. In contrast, comparing correlation coefficients of the two methods to that of the conventional lithofacies method, a larger value was obtained for the former than was observed in the latter. Thus, serving as a verification basis for the
feasibility of the computer image processing method–rapid mortar bar and lithofacies method–rapid mortar bar method.

In conclusion, compared with the traditional lithofacies method, the computer image processing method has the advantages of better analysis conditions, more standardized reference standards, and more accurate results in quantitative analysis. Therefore, it can be used as a progressive method of traditional lithofacies analysis to evaluate the alkali activity of aggregates.

3. Conclusion

(1) This paper introduces a method to analyze the content of alkali active minerals in rocks. The microscope imaging and computer image analysis technology are combined to the lithofacies analysis, and the content of alkali active minerals is objectively and accurately calculated.

(2) The protolites in this study are regional metamorphic rocks with low P/T type greenschist facies, and the alkali active minerals are microcrystalline quartz and strain quartz.

(3) The traditional lithofacies method relies too much on personal experience judgment and mathematical principle calculation. On the other hand, the computer image processing method has the advantages of objective and reasonable analysis conditions, accurate data results, preservation of acquisition parameters, and fast analysis.

(4) The alkali active mineral content calculated by the computer image processing method has a good positive correlation with the expansion rate measured by the rapid mortar bar method, $R^2 = 0.7816$, which is feasible.

Reference

[1] Broekmans M A T M 2012 Deleterious reactions of aggregate with alkalis in concrete Reviews in Mineralogy & Geochemistry. 74 279-364.

[2] Šťastná A, Šachlová S and Pertold Z 2015 Factors affecting alkali-reactivity of quartz-rich metamorphic rocks: Qualitative vs. quantitative microscopy Engineering Geology. 187 1-9.

[3] Bulteel D, Rafai N and Degrugilliers P 2004 Petrography study on altered flint aggregate by alkali–silica reaction Materials Characterization. 53 141-154

[4] Fournier B 2000 Alkali-aggregate reaction in concrete: a review of basic concepts and engineering implications Canadian Journal of Civil Engineering. 27 167-191.

[5] Yang Qian, Jiang Zhengwu and Zhang Bingbingbing 2019 The alkali activity characteristics and inhibition measures of metamorphic rock aggregates Journal of Building Materials. 22 104-111.

[6] Lu Duyou, Xu Zhongzi and Lu Yinong 1998 Review of ASR alkali activity test methods for aggregates Journal of Nanjing University of Chemical Technology (Natural Science Edition). 2 87-93.

[7] Jiang Yuchuan, Wang Qing, Wang Yang 2017 Summary of test methods and evaluation of alkali aggregate reaction China Building Materials Science and Technology. 26 1-5.
[8] Berube M A and Fournier B 1993 Canadian experience with testing for alkali aggregate reaction reactivity in concrete Cement Concrete and Composite. 15 27-47.

[9] Wang Jing, Li Guhua and Zhou Junjie 2012 Research on test method of alkali activity of concrete Building Science. 28 98-100.

[10] Xu Zhongzi, Shen Yang and Lu Duyou 1998 Main parameters of the new detection method for alkali activity of siliceous aggregates Journal of Nanjing University of Chemical Technology (Natural Science Edition). 2 2-8.

[11] American Society of Testing Materials 2008 ASTM C1293-08b (West Conshohocken: ASTM International).

[12] Lu Duyou, Xu Zhongzi and Lu Yinong 2008 Limitations and improvements for alkali aggregate reactivity measurement with Accelerated Mortar Bar Test Journal of Nanjing University of Technology (Natural Science edition). 2 98-104.

[13] Oberhoster R E and Davies G 1986 An accelerated method for testing the potential alkali reactivity of siliceous aggregates Cement and Concrete Research. 16 181-9.

[14] Mo Xiangyin, Yu Chenjie and Xu Zhongzi 2001 Mineralogical characteristics and alkali activity of aggregate Concrete and Cement Products. 6 3-6.

[15] Ministry of Railways of the People’s Republic of China 2018, Railway Concrete(Beijing : National Railway Administration) pp30-32.

[16] Lu Fengxiang and Sang Longkang 2002 Petrology(Beijing:Geological Publishing House) pp 1-401.

[17] Zeng Guangze, Zhu Yunhai and Ye Delong 2017 Crystal optics and optical mineralogy (Wuhan : China University of Geosciences Press) pp 1-306.

[18] Zhao Jingsong, Tang Hongming and Lei Bianjun 2013 Research foundation of mineral rock slice (Beijing:Petroleum Industry Press) pp 1-220.

[19] Liu Chongxi and Wen Ziyun 1995 Alkali-aggregate reaction of concrete (Guangzhou : South China University of Technology Press) pp 174-197.