DIGITAL IMAGE ANALYSIS OF CRACKS IN CONCRETE

By

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ABSTRACT

The image analysis technique for the automatic detection and quantification of cracks in concrete is described. The presence of cracks can significantly influence the mechanical and mass transport properties of concrete. Over the past 20 years, several techniques have been developed to detect and measure micro-cracks in concrete. This image analysis technique allows the assessment of the characteristics of the crack network in concrete. The technique of the image analysis is essentially a three-step process that includes the preparation of the samples, segmentation of the cracks, and the treatment of the collected data. The first procedure carried out in this study was the preparation of the concrete samples of the three different characteristics strength. The compressive strength of the samples was taken on 7 and 28 days. Image of cracks on the concrete samples were taken using digital camera and were analyzed using IDRISI sofware. The segmentation includes a treatment of the color image, thresholding on the gray level histogram and treatment of the binary images. The resulting images are then treated and finally the characteristic of the cracking pattern are determined.

ABSTRAK

Kaedah analisis imej untuk mengesan dan menganggarkan keretakan dalam konkrit diterangkan dalam kajian ini. Kehadiran retak dalam konkrit boleh mempengaruhi sifat mekanikal konkrit itu. Selama dua puluh tahun yang lalu, beberapa kaedah telah dihasilkan untuk mengesan dan mengukur keretakan dalam konkrit. Kaedah analisis imej ini membolehkan kita menilai atau mentafsir ciri jaringan keretakan dalam konkrit tersebut. Secara amnya kaedah ini mempunyai tiga langkah termasuklah penyediaan sampel konkrit, pembahagian (segmentation) keretakan dan juga pembetulan kepada data yang telah terhasil. Prosedur yang pertama sekali dijalankan ialah penyediaan sampel konkrit dengan 3 kekuatan ciri yang berbeza. Kekuatan mampatan sampel tersebut diuji pada hari ke-7 dan hari ke-28. Imej keretakan pada konkrit tersebut kemudian diambil dengan menggunakan kamera digital untuk dianalisa. Prosedur pembahagian (segmentation) termasuklah pembetulan terhadap imej bewarna, ‘thresholding’ ketas histogram dan pembetulan keatas imej binary. Imej yang terhasil akan dibaikpulih dan ciri-ciri bentuk retak akan ditentukan.

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CHAPTER 1

INTRODUCTION

1.0 PROBLEM STATEMENT

Concrete is a heterogeneous, multiphase material. On a macroscopic scale it is a mixture of cement paste and fine and coarse aggregates, with a range of sizes and shape. On a microscopic scale the cement paste itself is found to be heterogeneous, consisting of unreacted cores of cement grains, crystalline and amorphous hydration products, and porosity.

There are three types of cracks: plastic cracks, early-age thermal cracks, and drying shrinkage cracks. There exist also other types of non-structural cracks such as shear cracks, tension bending cracks and cracks at kicker joints. Concrete consist of aggregates (gravel and sand) embedded in cement paste matrix. When the cement paste matrix shrinks due to external or autogenously drying, stresses and micro cracks developed in a cement paste matrix when the shrinkage is internally restrained. Two types of internal restraints have been recognized. Firstly, the moisture and shrinkage gradient that cause drying is responsible for a so-called self-restraining effect of the drying specimen. Secondly the stiff aggregates restrain the matrix shrinkage. Cracks formation has a direct bearing on the overall performance of cementitious materials. The presences of pre-existing cracks (in the bulk matrix or at the paste-aggregate interfaces) influence the mechanical behavior of concrete. Development of a connected crack network contributes to the increase in the permeability and the diffusivity of concrete. This will lead to a reduction of its durability.

A lot of works on cracks and micro cracks in concrete have been published in a last few years. The aim of this work is to relate the cracks of concrete to its physical properties and to evaluate the cracks due to loading (shrinkage, creep, thermal action or mechanical loading). Several methods have been used to study the cracks and micro cracking of concrete. This includes acoustic emission, sonic testing, microscope technique with dye, mercury intrusion porosimetry, x-ray technique, optical and electron microscopy computerized tomography analyse, and halographic inteferometry. Some of these techniques are limited in their resolution, their sensitivity in defecting cracks or their ability to make observation over the large area. Other methods are incapable of examining the specimen while under load or they require special preparation of the specimen, which alter its behavior.

Two tools are necessary to characterize micro cracking: one for observation and one for quantitative analysis. Over the past 20 years, several techniques have been developed to detect and measure micro cracks in cement-based materials. Image analysis is an efficient tool to quantify the morphology of material. An image analysis is a technique that allows the detection of cracks in concrete. This technique was developed to assess the morphological characteristic of concrete. More over, it can help to understand the concrete behavior.

1.1 OBJECTIVES

The main objectives of this project are:-

- To test the compressive strength of different characteristic concrete.
- To investigate the cracks and other defects in concrete using image analysis technique.
- To investigate the porosity and air void characteristic of cementitious materials.
- To identify the structure of concrete.

1.2 SCOPE OF ANALYSIS

Scope of analysis will be to prepare concrete sample in order to get the image of cracks. The ordinary Portland cement corresponding to ASTM Type I cement will used in all mixture proportions. The samples will be prepared in three different characteristics strength (fcu 15, fcu 30 and fcu 50) and will be tested on compressive strength on 7 and 28 days. After applying the loading, cracks may be formed on the concrete samples. The image of cracks will be captured to make the analysis.

An image analysis will be carried out for the detection of cracks on the concrete sample. This analysis includes the segmentation of cracks that will carry out on the gray level histogram and treatment of the binary image. The characteristic of cracks network will be presented.

CHAPTER 2

LITERATURE REVIEW

Image analysis is one of the tool to measure size, dispersion, orientation, shape, numbers, etc., of objects or components, and to evaluate the morphological changes under a process and/or a (temperature, stress, environment, etc.) solicitation (R.T. De Hoff et. al, 1968). In fact, today, image analysis includes several classes of tools: signal treatment, mathematical morphology (J. Serra, 1982), stereology, (Weibel ER, 1979), pattern recognition, and sometimes artificial intelligence (J.M. Chassery, 1988). The main objective of image analysis is (i) to obtain a measure or a sorting, which differs from some other activities in image science such as restoration, image correction, computer graphics or synthesis, and (ii) in some cases, if possible to accede to 3D parameters through measurements performed in 2D, using a stereological relationship. Stereology is a body of mathematical methods relating 3D parameters defining the structure to 2D measurements obtainable on sections of the structure (Weibel ER, 1979). Latest developments in microscopy and image processing techniques have facilitated efforts towards investigation of the concrete microstructure (D. St. John et. al, 1998). Image processing and analysis routines are also developed for removal of noise, distinction of micro cracks from voids, and detachment of connected micro cracks and voids in concrete micrographs.

Micro cracks define as cracks whose width is about few micrometers (<10μm). Whatever its origin (mechanical, physical, or chemical), the degradation of cement-based materials often results in initiation and the propagation of micro cracks. Over the past decade, numerous studies have clearly indicated that the presence of micro cracks can significantly influence the mechanical and mass transport properties of concrete (D.Ziegeldorf et. al, 1983). The subject is of considerable importance for engineers since crack formation has a direct bearing on the overall performance of cementitious materials. For instance, the presence of preexisting cracks (in the bulk matrix or at the paste-aggregate interfaces) has been found to significantly influence the mechanical behaviors of concretes (Mindess, S., et. al, 1982). Numerous studies have also clearly indicated that the development of a connected crack network contributes to increase the permeability and the diffusivity of concrete (Bier, T.A. et. al, 1989). Such an increase of the material transport properties is generally accompanied by a substantial reduction of its durability (Fagerlund, G. et. al, 1993). The optimization and/or the prediction of the material macroscopic properties therefore require the development of a reliable tool that is capable of quantifying the material micro structural characteristics.

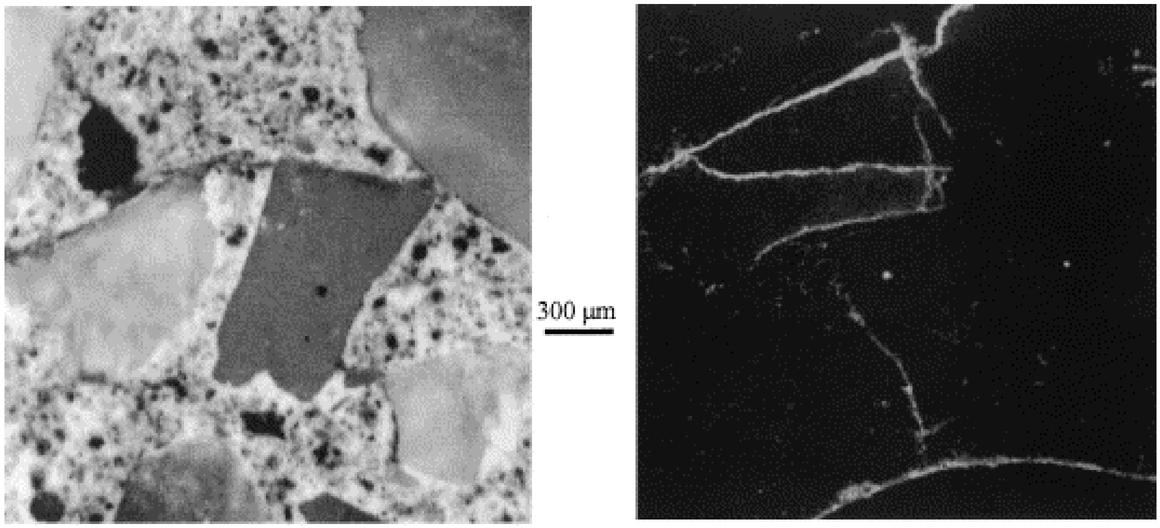
Although the process of cracks formation in cement-based composites is nowadays fairly well understood from a macroscopic point of view, the micro structural aspects of this phenomenon are much less documented. The limited information on the subjected might be attributed, to a great extent, to the fact that there exist actually very few techniques specifically developed to observe cracks in concretes. As all high surface area porous solids, cement-based materials are extremely moisture sensitive and tend to shrink and crack upon drying. Since they require drying the sample to certain degree, most classical microscopic observation techniques are not suited to study of crack in concrete. If they can be used for qualitative studies, these techniques cannot provide any reliable quantitative information on the crack formation process. (Hornain H. et. al, 1996)

The first quality of such a technique lies in its ability not to induce any cracks during the preparation of the samples. In that respect, any method that requires even the slightest drying should be set aside. The ideal technique should also be simple, economic, rapid and characterized by high resolution, i.e. that it should be able to detect very fine cracks. A good technique should permit the characterization of the initial state of the material with respect to cracking (Ringot et. al, 1987). According to this requirement, acoustic methods and laser speckles method, that can monitor crack propagation but cannot be used to determine the initial state of the material, do not qualify. Finally, the ideal method has to be easily coupled to an image analysis system in order to yield quantitative information. (Hornain H. et. al, 1996)

Over the past 20 years, several techniques have been developed to detect defects and measure micro cracks in cement-based materials. Darwin et al. (1995) proposed a new technique to detect and count micro cracks in neat cement paste sample. According to this approach, the hydrate cement paste samples are polished, impregnated with epoxy resin, and observed using a scanning electron microscope (SEM) in backscatter electron mode. Despite the good contrast obtained with this technique, the authors report that the reliability of the crack network characteristic determination is affected by variations in grey levels in the impregnated cracks. In backscatter imaging, the contrast between two phases depends on the ratio between their respective average atomic numbers; the grey levels in the crack area are directly influenced by the underlying and adjacent solid phases. A new image processing strategy is proposed to minimize the influence of this phenomenon on detection procedure. In contrast to the procedure of Darwin et al. that has been designed to investigate the material at the microscopic scale, this new technique operates at the mesoscopic scale. The technique is essentially a three-step process that includes the preparation of the sample, the automatic segmentation of micro cracks, and the qualitatively determination of the collected data. (Ammouche, A. et al., 2000).

2.0 MICROCRACKS DETECTION USING IMPREGNATION TECHNIQUES.

The objectives of specimen preparation for microscopic analysis are to provide a finely ground and polished surface which yield crisp images and sharp edges with good differentiation between the features of interest (micro cracks and voids in this study) and the body of concrete. Selection of a specimen preparation technique depends on the objects (features) of interest and the microscopy technique. For more than three decades, impregnation techniques have been used to assess the microstructure of concrete and to highlight the cracks and other defect including porosity and air bubble on the surface of the concrete. A dye-impregnation technique was developed to study the cracks in concrete. For fluorescent microscopy, the most common method of specimen preparation involves epoxy impregnation (H. Gran, 1995) that can highlight more porous areas of cement paste, but it is not effective in distinguishing cracks. Epoxy impregnation does not generally yield crisp boundaries and sharp contrast between micro cracks and air voids versus the body of concrete. To improve the epoxy impregnation, a fluorescent dye use in order to facilitate the detection of cracks (Knab, L.I. et. al, 1984). Although this technique offers interesting possibilities to investigate the microstructure and the air-void characteristics of cementitious materials (Slate, F.O. et. al, 1984), they usually require drying of the samples prior to the impregnation (Chatterji, S. et. al, 1981). In order to avoid the pre-drying of the samples, concrete specimens are immersed in fluorescent and ethanol solution for several days. The technique has been found to be well suited for study of cracks in concrete (Struble, L.J. et. al., 1989), and might even be used to determine the water /cement ratio of hydrated cement-based materials (Gran, H. Chr., 1995). Its main drawback is that it takes many days to prepare a sample. For the purpose of environmental scanning electron microscopy (ESEM) or conventional scanning electron microscopy (SEM), satisfactory results have been reported for concrete specimens impregnated with Wood's metal (K. Nemati et. al, 1998). This approach yields a desirable contrast between features of interest (micro cracks and voids) and the background but lead to incorrect diagnoses of concrete components (e.g., in the case of concrete damaged by delayed ettringite formation) (S. Marusin, 1995).



(A) (B)

Fig. 2.0 Microcracks in impregnated samples (magnification 40x). (A) Sample impregnated with red dye. (B) Sample impregnated with fluorescent solution.

2.1 IMAGE ANALYSIS ALGORITHMS

2.1.1 Segmentation

Segmentation is a process through which the image is partitioned into meaningful regions based only on the intensity of the pixels. To assess the characteristics of the crack network, it is necessary to convert the image (that may contain up to 256 possible grey levels) into a binary image. When segmentation is applied, the pixels that defining the defects are assigned a value 1 and the background pixels are given a value of 0. The pixels values can be presented by a single bit signaling a true or false situation (e.g., micro crack or not). Segmentation by brightness thresholding is the simplest approach where a contrast gray level is used as the threshold value; therefore, it is widely used to convert a gray scale image to binary (black and white) images.

2.1.2 Thresholding

There are two threshold methods (manual and automatic) and three different types of thresholding (by factorization, entropy, moment) (M. Coster et. al, 2001). From the automation point of view, manual (interactive) thresholding is not applicable due to the large variations in gray-scale level between images; therefore, a comparative study is generally performed to check the possibility of using automatic (in lieu of manual) thresholding and also to determine the suitable auto-threshold type for particular circumstances (Parviz Soroushian et. al, 2003). The automatic thresholding methods present numerous advantages over the manual procedure. They can easily account for any variation in the contrast between two successive images originating from the same sample (or originating from two samples of the same mixture) (J.C. Russ, 1990). These variations are generally related to the heterogeneous nature of the material. They can also be induced by the sample preparation operations (Ammouche, A. et al., 2000).

2.1.3 Shape and edge corrections

Shape and edge correction are the algorithms used to treated the resulting image and extract the micro cracks. Micro cracks and air voids are key micro structural features of concrete that have different effects on engineering properties. The shape of objects is recognized in complex ways by our visual system. Experience has shown the need of an additional criterion based on the shape of the objects to eliminate particles that are not micro cracks. Cracks can be individual objects with an elongated shape but in most cases arranged into a connected network (Ammouche, A. et al., 2000). Instead of using numerical values, human being's eyes rotate objects to the same orientation before making comparisons and distinguishing different objects. A particularly interesting and revealing characteristic of the visual matching of patterns occurs when similar objects are viewed in different orientations. The length of time required to make a decision as to whether objects are the same is directly proportional to their angular deviation (J. Russ, 1992). The proposed approach, however, distinguishes micro cracks from voids quantitatively, based on distinct aspects of their geometry. The various objects that have been selected on the basis of the previous criterion may be parts of particles that look like micro cracks but actually not. This happens for objects partially masked by the edge of the images. During the treatment of the image, it is assumed that an object with the azimuth counterclockwise of its greatest projected breadth (Feret's diameter) belonging to [-10º, +10º] when cutting a horizontal edge or belonging to [80º, 100º] when cutting a vertical edge is not a microcrack. This criterion was established and experimentally verified in many cases), obviously it must be carefully used when analyzing new unknown materials (Ammouche A., 1999).

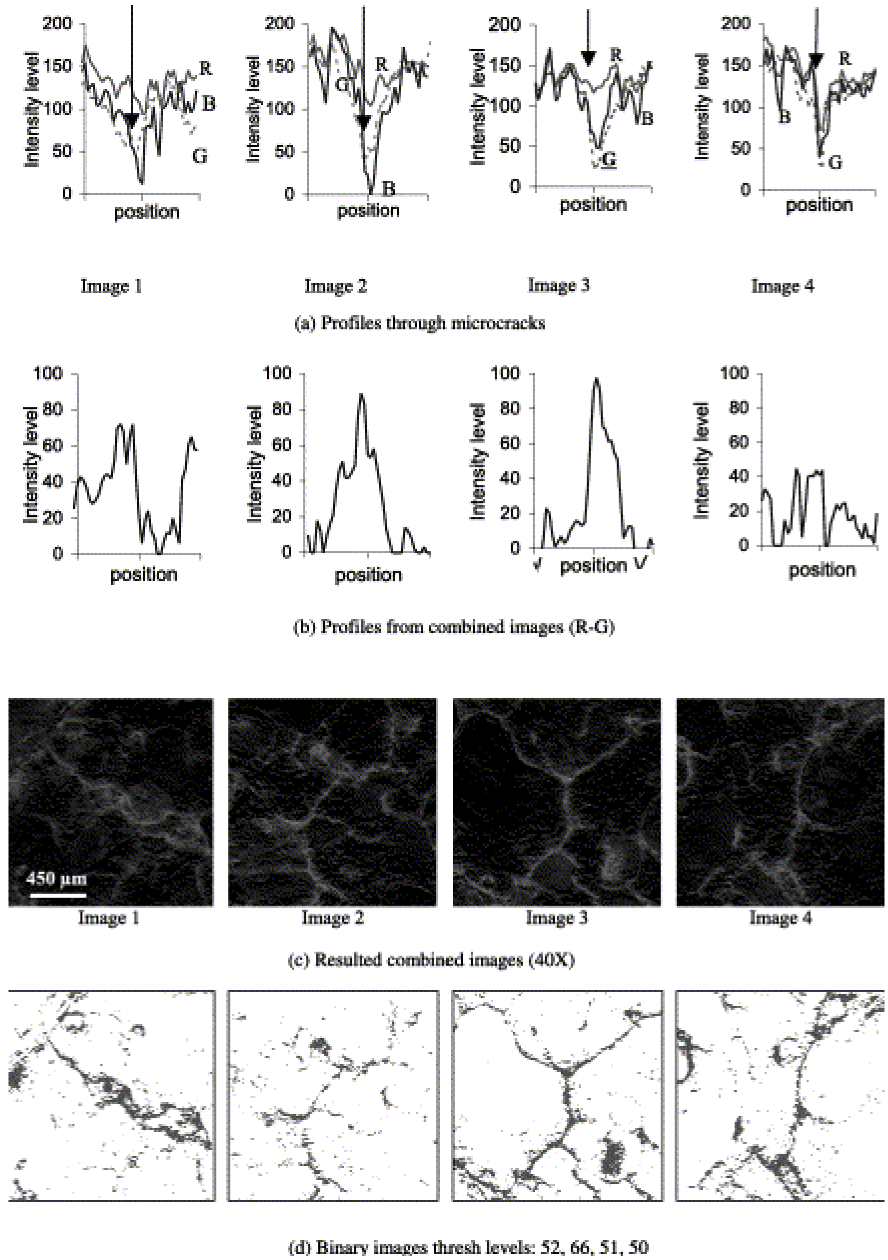
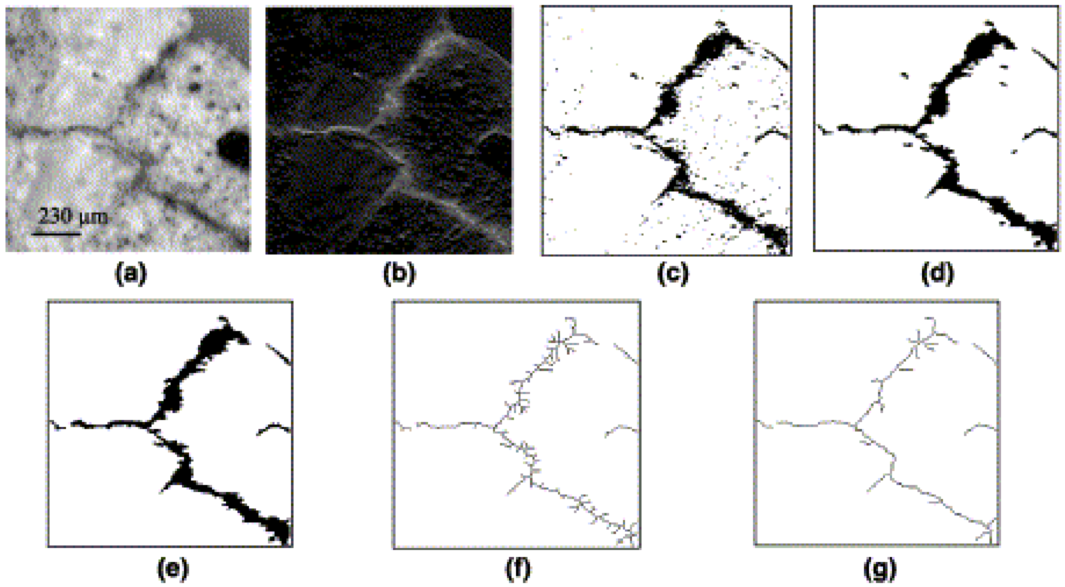
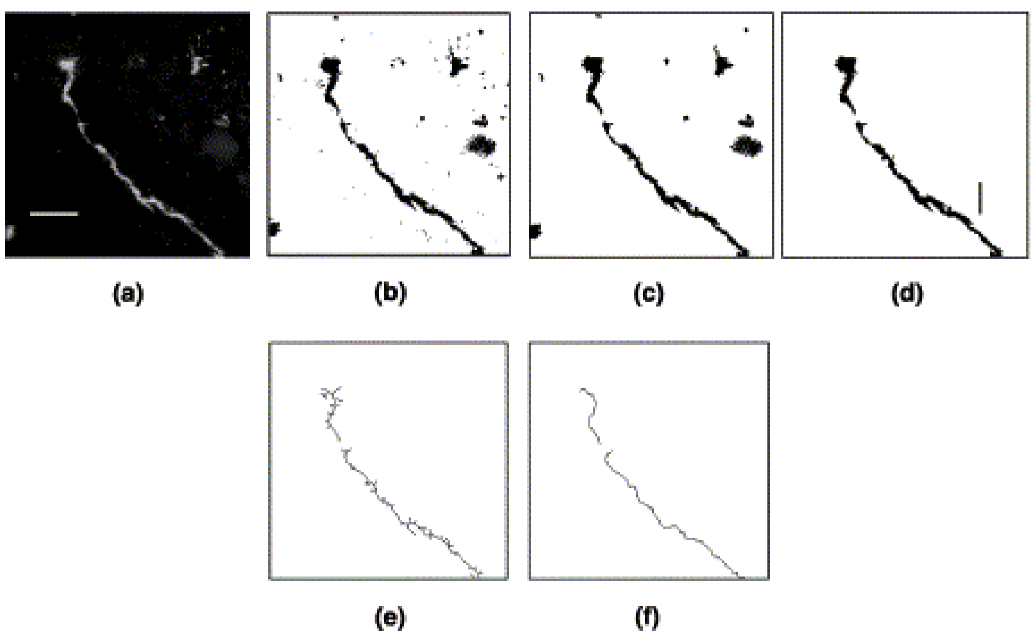


Fig. 2.1 Profiles through micro cracks and resulting binary images.



Sample impregnated with red dye

(a) : original color image ; (b) pretreated image, (c) binary image after thresholding ; (d) image cleaning (e) shape analysis ; (f) Skeleton; (g) Skeleton after pruning of size 10



Sample impregnated with fluorescent dye

(a) : original color image ; (b) binary image after thresholding; (c) cleaned image ; (d) image after shape analysis; (e) Skeleton; idealized thin lines ; (f) Skeleton after pruning of size 10

Fig. 2.2 Major steps of image analysis algorithm.

2.2 SUMMARY

Automated quantitative microstructural analysis of concrete microcracks and voids systems requires proper selection of image processing operations complemented with appropriate sample preparation techniques which highlight microcracks and voids against the body of the concrete. A technique for the quantification of micro cracks in concrete includes (1) an experimental process during which samples are impregnated without inducing any spurious microcracking and (2) a set of image analysis algorithms that enable one to determine the crack pattern characteristics of a given sample and to map the defects. Various tests run as part of the development of the method have shown that the image analysis algorithms are reliable and lead to reproducible results. The measurement can be qualitatively as well as quantitatively compared for several magnifications.

CHAPTER 3

METHODOLOGY

Image analysis is a three-step process which includes the preparation of the samples, segmentation of the cracks and the treatment of binary image.

3.0 CONCRETE SAMPLES PREPARATION

The first thing that is important in this part is preparation of the concrete samples sized 100x100x100mm regarding to the design mix. Three different types of characteristic strength (fcu) were used: 15, 30, and 50. The ordinary Portland cement was used in all mixture proportions. The superplasticizer was used in the Fcu 50 mix to reduce the water binder ratio. The steps in preparing the concrete samples are shown below:

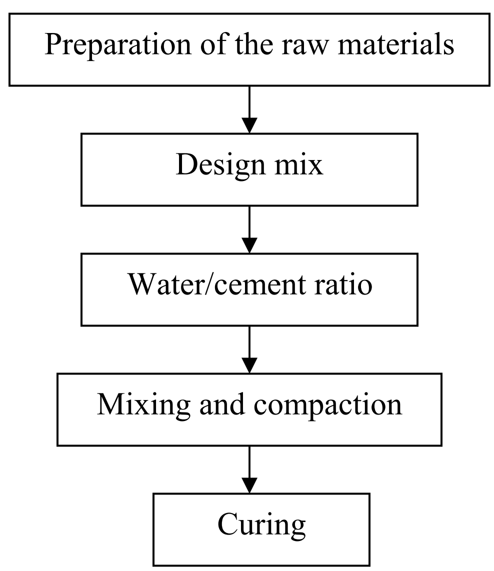


Fig. 3.0 Steps in preparing the concrete samples

The main elements used in preparing the concrete samples are:

1. Portland cement
2. Water
3. Aggregates (fine and coarse)
4. Admixture

3.0.1 Raw materials

The ordinary Portland cement corresponding to ASTM Type I cement was used in all mixture proportions. This type of cement is excellent most widely used. This cement produces reaction when mixing with water. The hydrolysis and hydration reactions then will produce component that will bind the aggregates together and improves the aggregates-cement interface.

Water is important component in concrete mixing. The water present will give chemical reaction in the concrete mixing. The hydration process needs water to react properly. Water also acts as binding agent to paste the aggregates with cement which in the right amount will produce high strength concrete. Any water with pH of 6 to 8 is suitable for use in mixing.

Fine and coarse aggregates were used in preparing the concrete. Sands were used as the fine aggregate with the sized limit about 0.07mm or a little less. The coarse aggregate with the maximum size of 20mm were used.

Superplasticizer admixture was used in mixing the fcu 50concrete. The purpose of using this admixture is to reduce the volume of mixing water and water/cement ratio or water/binder ratio in order to increase concrete strength and to enhance the durability.

3.0.2 Water/cement ratio

The suitable water cement ratio is required to produce a given mean compressive strength. It is important that the water/cement ratio selected on the basis of strength is satisfactory also for the durability requirements.

3.0.3 Mixing and compaction

The mixing operation consist essentially of rotation of stirring, the objective being to coat the surface of all aggregates particles with cement paste, and to blend all the ingredients of concrete into a uniform mass. This uniformity must not be disturbed by the process of discharging from the mixer. The operations of placing and compacting are interdependent and are carried out almost simultaneously. The process of compacting concrete by vibration consists essentially of the elimination of entrapped air and forcing the particles into a closer configuration. Both compaction by hand and compaction by vibration can produce good quality concrete with the right mix and workmanship. Non-uniform compaction can occur due to inadequate vibration or over-vibration which causes segregation. Vibration need at least two minutes time to get good compaction.

3.0.4 Curing

The objective of curing at normal temperature is to keep concrete saturated, or as nearly saturated. The necessity for curing arises from the fact that hydration of cement can take place only in water-filled capillaries. This is why loss of water by evaporation from the capillaries must be prevented. Once the concrete has set, wet curing was provided by keeping the concrete in contact with water. This was achieved by flooding (ponding) where the concretes were immersed in the water for 7 and 28 days.

3.0.5 Compression test

A compression test determines behavior of materials under crushing loads. The specimen is compressed and deformation at various loads is recorded. The objective of this test is to determine the concrete compression strength. The apparatus used for this test should be robust and can stand certain loading, uniform, and no vibrating. Samples that not immersed in water should be immersed at least for five minutes. The surface of the concretes and machine plates should be cleaned. The samples position should be right on the plate and the loading should touch the concrete samples. Continuous loading in the rate of 0.2 N/ (mm^2.s) until 0.4 N/ (mm^2.s) are given until the samples fail. Maximum loading on the cubes are taken.

3.0.6 Concrete mix design

Mix design is the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties, notably workability, strength and durability.

For concrete fcu 15;

Material	Quantity
Cement (OPC)	250 kg/m^3
Coarse aggregate	1092 kg/m^3
Fine Aggregate	858 kg/m^3
Water	190 kg/m^3
Water/cement ratio	0.76

Table 3.0 Concrete mix design of fcu 15 concrete

For concrete fcu 30;

Material	Quantity
Cement (OPC)	400 kg/m^3
Coarse aggregate	846 kg/m^3
Fine Aggregate	954 kg/m^3
Water	190 kg/m^3
Water/cement ratio	0.56

Table 3.1 Concrete mix design of fcu 30 concrete

For concrete fcu 50;

Material	Quantity
Cement (OPC)	440 kg/m^3
Coarse aggregate	580 kg/m^3
Fine Aggregate	1180 kg/m^3
Water	190 kg/m^3
Water/cement ratio	0.43

Table 3.2 Concrete mix design of fcu 50 concrete

3.1 IMAGE ANALYSIS

3.1.1 Image analysis technique

The technique is essentially a three-step process that includes the preparation of the sample, the automatic segmentation of cracks, and the mathematical treatment of the collected data. IDRISI software was used to make the image analysis procedures.

Firstly, the procedure involves the acquisition from the 3.2 mega pixels color images using digital camera. The images of concrete cubes with cracks on it were taken using that digital camera.

Secondly, the step carries the image analysis algorithms that consist of segmentation. In order to perform optimum image segmentation, it is fundamental interest to first analyze the intensity level distributions of the three RGB planes, profile across images and additionally to measure some particular profile through cracks. The segmentation of cracks consists in recognizing them from the images. In the past, this operation was done by hand from photographs but some researches made attempts at using image analysis for this purpose. The usual stages of such a treatment are:

- Combination of the RGB components into one image in the case of color acquisition
- Filtering; for avoiding over-segmentation
- Binarisation
- Shape analysis and elimination of non-cracks objects
- Skeletonisation

At the end of the binary image treatment, cracks looks like a curved and branched thin lines. The characteristic of cracks network are quantitatively determined. This technique enables the user to draw maps of the sample crack network over an area. Results obtained for undamaged and mechanically loaded samples are presented. Below is the steps involve in image procedure.

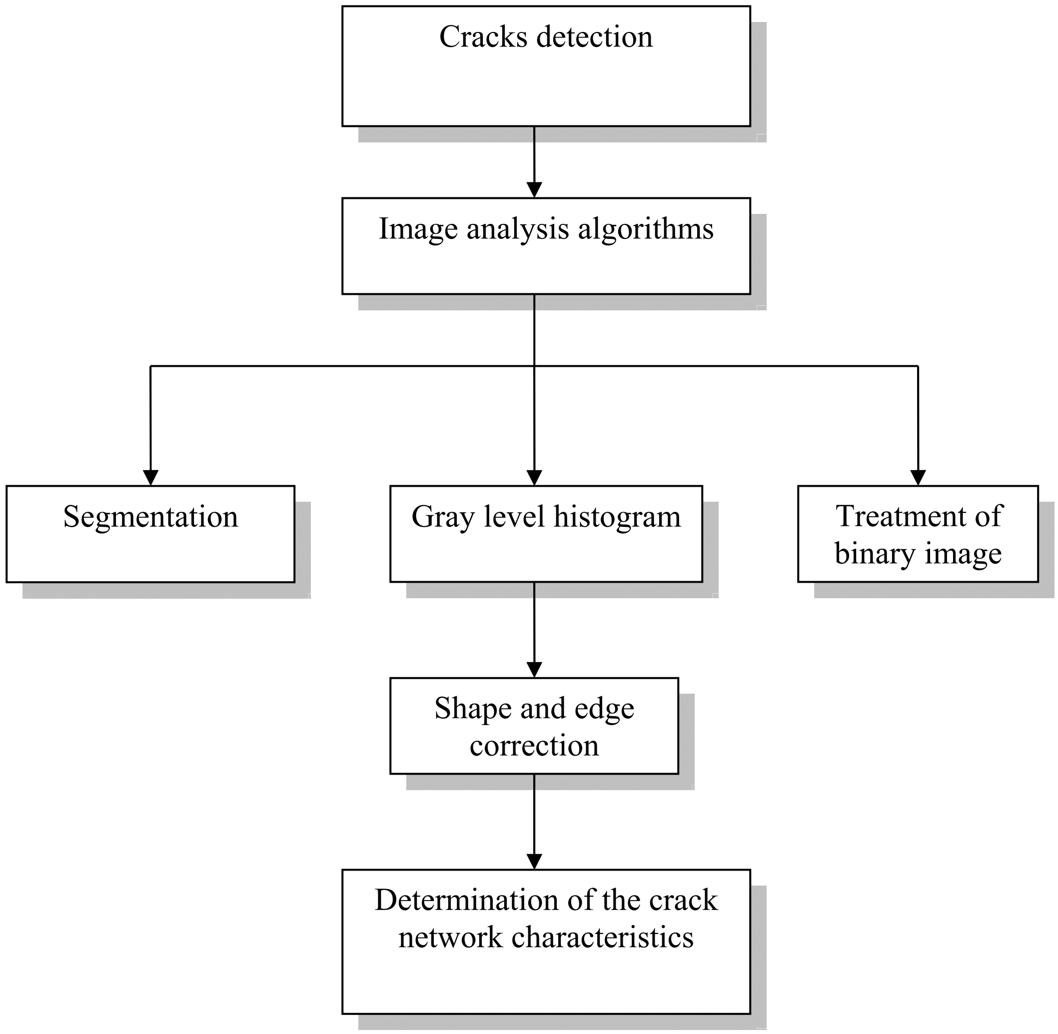


Fig. 3.1 Steps in image analysis procedure

3.1.2 Sets of cracks images

Fig. 3.2 fcu = 15, 7 days (7d15)

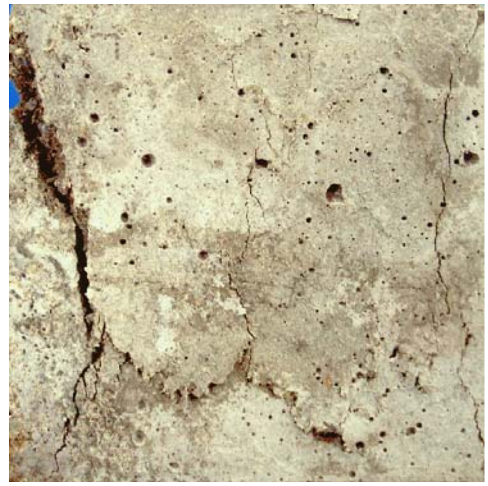


Fig. 3.3 fcu = 15, 28 days (28d15)

Fig 3.4 fcu = 30, 28 days (28d30)

Fig. 3.5 fcu = 50, 7 days (7d50)

Fig. 3.6 fcu = 50, 28 days (28d50)

3.1.3 Program module

Firstly, the RGB file images have to be converting into TIF file image. Then this file image was import into Idrisi32 software.

- **Conversion of RGB24 files**

- The conversion to and from TIF passes through the BMP format. Therefore, error messages may indicate an error in conversion to BMP rather than TIF.
- Only byte binary or RGB24 data type images are supported for conversion from IDRISI to TIF. If the values in your image are integers between 0-256, use CONVERT to change to Byte binary. If the values are integers beyond 0-256 or are real numbers, then use STRETCH and stretch to 256 or fewer levels, then convert if necessary.