A New Method Of Studying Of Different Types Of Fractures And Cracks In Concrete By Image Processing

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Abstract— **Fractures are produced from the propagation of cracks and structural weaknesses. Fractures may be transmitted in aggregates or in cement mortars or in the transition zone, which are diagrams of many internal and external concrete phenomena that are physically, chemically and mechanically exposed to the concrete. There are various methods for detecting fractures, but most are macroscopic, and because of the microscopic nature of the concrete structure, these investigations are not generally consistent with the actual concrete behavior. New and accurate technologies should be used to minimize the error in measuring and identifying fractures. In this research, fractures and cracks were detected with the principles of fracture mechanics and rock mechanics. Investigations are based on microscopic images of polished sections. Studies in the microscopic form allow access to the concrete microstructure, including the transition zone and micro-fractures. These images are inserted into MATLAB software for image processing to be precisely analyzed. Experiments have shown that the microscopic image processing can detect the intra-grain fractures and the type of cracking.**

Keywords—component; concrete construction ; micro-fractures ; polished-section ; image processing

I. INTRODUCTION

One of the most important features of concrete is its fractures. The first major study on concrete cracks and their fractures was done by Richard, Brandzag, and Brown (1928). In engineering studies, each of the created cracks can have different meanings and have a relationship with other characteristics of concrete such as compressive strength [1, 2]. In steel structures, there is a change in the shape of the structure and in fact, strains are a kind of warning to engineers to correct the structure. Concrete as a brittle material with low ductility has no sensible strain, so these cracks and fractures are the warning to engineers [3]. Ahmed Z. Bendimerad and his colleagues (2016) have investigated the risk of cracking and the relationship between these cracks and the amount of water in concrete in plastic shrinkage [4]. Lang Li and his colleagues (2018) have identified cracks in high-temperature concrete, and this study highlights the importance of cracks to identify concrete behaviors. The internal behavior of concrete has a great influence on its mechanical behavior [5]. These changes are usually predictable and identifiable with cracks. Man Zhou and his colleagues (2018) analyzed the cracks in the concrete mortar and in the internal structure of the concrete under stress. As they concluded, the type of loading and its amount can influence the type of cracks formed and furthermore, the type of crack created can be guessed by the type of loading. If there is an understanding of the types of fractures and cracks, the concrete can be analyzed from the fractures and its demands, strengths and weaknesses can be identified [6].

In this regard, fracture mechanics has been introduced in recent decades. Kaplan (1961) used the principles of linear fracture mechanics to investigate concrete cracks [7]. McGregor and Shah (1971) proved that the behavior of concrete in failure is nonlinear. So that the behavior of concrete earlier than its constituents tends to be nonlinear [8]. The reason for this behavior is also rooted in the transition zone. The area is structurally weak and consists of microscopic cracks which, as a result of its rapid expansion fail before the cement and aggregate, and as a result, the concrete enters the nonlinear phase [9, 10]. For this reason, scientists see fracture strength as a function of the adhesion forces between atoms. The study of micro-fractures, transition zone and interatomic adhesion force is clearly required by microscopic studies. Microscopic studies of concrete structure have been carried out in recent years [11]. Hua Huang and his colleagues (2019) studied the structure of lightweight concrete with normal weight concrete, the transition zone in concrete and the microstructure of concrete for comparison [12]. Bjorn Van Belleghem and his colleagues (2019) performed a comparison between traditional methods and microelectronic microanalysis in the determination of chloride axis perpendicular to self-healing concrete cracks [13]. These studies demonstrate the power of microscopic studies.

One of the problems in evaluating and studying microscopic images is the analysis of images by the naked eye. The analysis with the naked eye has many errors; the human eye is able to see only a limited portion of the electromagnetic spectrum and cannot analyze automatically. For this reason, computer vision processing has been a major effort by researchers and scientists over the last few years. There are various ways to process images, but they are usually macroscopic. J. Valença and his colleagues (2017) analyzed the cracks on concrete using image processing and laser scanning, which yielded a positive result from this study [14]. Sonali Bhowmik, and his colleagues (2019) attempted to use the DIC[1] method to describe the fracture process region. Other methods have been studied in the fracture process [15]. Qinglei Yu and his colleagues (2018) used X-rays and tomography studies to study the fracture process, which attempted to gain access to the transition zone [16]. Of course, these types of studies are usually costly and harmful to the environment and laboratory staff. Nowadays, processing methods have been used for studies on the surface of concrete structures and to more precisely study the growth of cracks on the concrete surface [17, 18, 19, 20, 21, 22, 23]. Yeon Lee et al. (2013) in addition to studies of the identification of concrete cracks using image processing, they were also able to calculate the volume of fractures [24]. Recent years studies have shown that this process has been an efficient one [25]. Yun Wang and his colleagues (2019) used image processing to detect concrete cracks in bridges [26]. J. Valença et al. (2012) studied the cracking properties using image processing [27]. Tomoyuki Yamaguchi et al. (2010) used image processing techniques to quickly identify large-scale concrete surface images. This study resulted in computation slowdown and speed increase. [28]. This shows that studies based on image processing techniques can increase detection speed and reduce computation speed while increasing accuracy, and apply this approach in high volume projects.

The purpose of this study is to analyze the microscopic images made of polished concrete sections, using image processing techniques and the science of rock mechanics and fracture mechanics and to determine the type of cracking in the sections.

II. METHODOLOGY

Image processing operations include initial processing to reduce noise, reduce or increase image contrast and sharpen the image. Then, subsequent steps such as segmenting the image into smaller areas and objects are taken to determine image splits, such as edge editing. In the end is the scientific understanding and recognition of the set of objects identified in the image. To process digital images, it must first be converted to digital information using an analog to digital converter. A set of colored or black and white dots together create an image.

One of the most important steps in image processing is edge detecting. Especially in the process of recognizing and identifying cracks in the concrete, accurate recognition of the edges of an image can be very important. There are usually several categories of edges in the image. There have been many studies of edge detection algorithms in recent decades. In fact, the reason for many reviews of edge detection is that more accurate detection of the edges within the image can help better understand the targets within the image. We not only want to get the edge of a specific target or multi-category edges in a single image, we but also want to know which category of each edge pixel belongs to [29]. This makes it easy to identify the lines of expansion of the cracks. The points at which the brightness of an image changes dramatically are called edge points. Depending on the number of edges forming the corner, T-, L-, X-, and Y-corners and other types are distinguished [30]. These types of corners will greatly help identify the type of cracks. In fact, from the definitions of the types of cracks created in concrete and the location of each type of cracks [3], the similarity of these edges to the types of cracks is quite clear.

[1] **Digital Image Correlation**

III. PROCESSING AND RESULTS

Preparation of concrete cubic sample

The test was performed on 6 cubic specimens prepared from a fixed soils source the specimens were placed in water under standard conditions immediately after manufacture under the same storage conditions and observing the by-laws for different periods [31].

Specimens A_1 and A_2 were immersed in water for 7 days, samples B_1 for 28 days and samples C_1, C_2 and C_3 for 42 days. The cement content is 350. The following are the general specifications of concrete samples.

TABLE 1. General Specifications of Concrete Samples

Sample number	Dimensions (cm)	Volume (cm^3)	Weight (kg)	Specific weight (kg/cm^3)	Gravel Weight (kg)	Sand Weight (kg)	Water (Cc)	W/C	storage time
A_1	15*15*15	3375	7540	2.23	7.8	10.2	2000	0.44	7
A_2	15*15*15	3375	7720	2.29	7.8	10.2	2000	0.44	7
B_1	15*15*15	3375	7640	2.26	6	12	2000	0.5	28
C_1	15*15*15	3375	7460	2.21	6	12	2000	0.44	42
C_2	15*15*15	3375	7585	2.25	6	12	2000	0.44	42
C_3	15*15*15	3375	7460	2.21	6	12	2000	0.5	42

Rock mechanic tests

Samples are extracted from water after expiration of the required time (7, 28 and 42 days) and dried in the sun for about 8 hours. The specimens are then weighed and then loaded [31].

TABLE 2. Values of force applied to different samples

Sample number	Compressive force (Kg)	Area (cm^2)	Compressive strength (Kg/cm^2)
A_1	52000	225	231.11
A_2	76500	225	340.00
B_1	80800	225	359.11
C_1	76100	225	338.22
C_2	66800	225	296.89
C_3	80400	225	357.33

In uniaxial compressive testing in medium strength concrete at stresses below 50% there is no new crack breakage in the cement paste and the relationship between strain and stress will be almost linear but will continue with a stable crack system near coarse aggregates. As the stress increases, new cracks are created in the cement paste and broken by bonding the cracks to the structure. The failure angle is about 20 to 30 degrees relative to the load direction [31]. The following diagrams and angles of failure of sample C_1 can be seen:

Fig. 1. Fracture angle for sample C_1

Petrography

The specimens were placed in sample bags to be polished and thin sections prepared and transferred to Amir Kabir University Laboratory.

Many minerals in the samples are not macroscopically detectable. For this reason, more accurate and complete characterization should be examined microscopically. A suitable example for this purpose is one that has an abrasive surface, at least fracture, protrusion, and recess that is not affected by heat and mechanical changes. There are several methods for sample preparation of ores, all of which require careful sample selection, arrangement, molding and better adhesion. For this purpose, it is necessary to make fine samples of minerals and to study them with reflective light polarizing microscope. Reflective light microscopy (mineralogical) studies are essential for the detection of ore samples and are among the least expensive scientific study methods. For the study of minerals, the sample must be polished appropriately. The preparation of the polished sections is done in the following four steps:

1. Cutting 2. Molding 3. Abrasion 4. Polishing

a) Macroscopic image **b) Microscopic image**

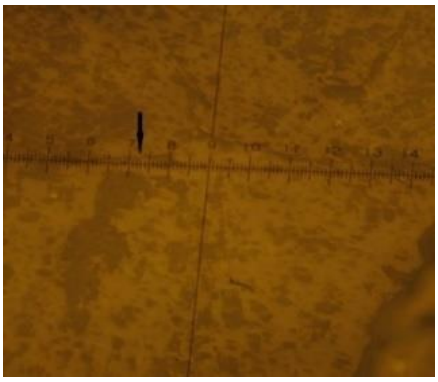
Fig. 2. Different components of aggregates used in concrete samples in a) macroscopic size that include of: 1- Aggregate mix 2- Extrusive igneous 3- Limestone 4- Metamorphic rock 5- Sandstone 6- Intrusive igneous 7- Chert 8- Tuff. And b) microscopic size

As can be seen from **Fig. 2**, the studied samples show different types of rocks such as igneous, sedimentary and metamorphic. In **Fig. 2**-a, the abundance of each type of rock is quite clear.

Part of the petrographic studies of 7, 28, and 42 days, samples taken in the form of polished sections and thin blades is given.

7-day samples:

a. Sample A_1:

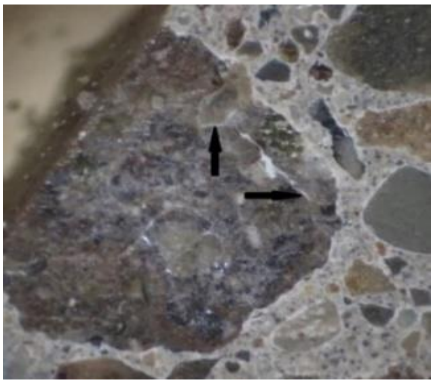


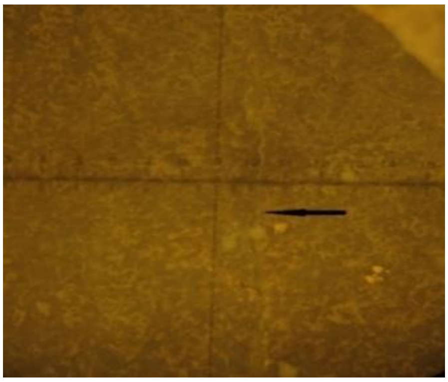
a b

Fig. 3. a) The image of suspected *basalt rock* in sample A_1 b) A view of the limited fracture of the aggregate fragment in sample A_1[2]

Fractures are observed in the **Fig. 3**-a, which may be igneous and possibly *basalt*. Dark *silicate rock* with fine-grained micro-cracks in the field, some of which are curved in shape, with healthy fragments of sedimentary type on the edges.

b. Sample A_2:





a b

Fig. 4. a) A view of the micro-cracks in *siliceous rock* (clastic type) in sample A_2 b) An overview of the overall fracture parallel to the upright web inside the aggregate in sample A_2[3]

In **Fig. 4**-a, in addition to this type of micro-crack, the edge of the piece and its contact surface with cement are also significant. And in **Fig. 4**-b, in addition to observing the fine-grained particles in the aggregates, especially the sand and sand dimensions, there is also a visible white micro-needle on the margins of the aggregate separating the aggregate from the cement. Another point is the presence of specific materials in the porous spaces.

28-day sample (sample B_1):

[2] Microscopic image of a polished cross section with a scale of 4 microns
[3] Microscopic image of a polished cross section with a scale of 4 microns

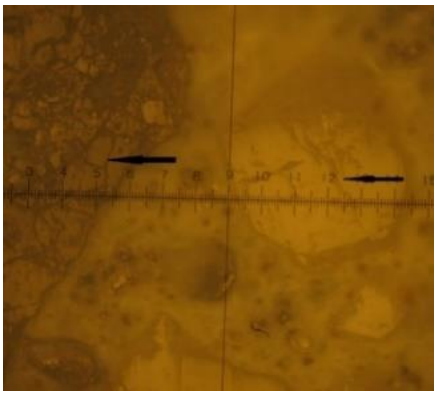


Fig. 5. An overview of the micro-carriers in large and small fragments in sample B_1[4]

According to microscopic studies, this sample contains gravel grain, type of pyroclastic and green tuff. Also calcareous components are other constituents of this sample. *Sandstone* fragments are varied and *sedimentary rock* fragments are visible among them.

In this example, around the aggregate the cement has been emptied, and there are also micro-cracks that are confined to the aggregate.

42-day samples:

a. Sample C_1:

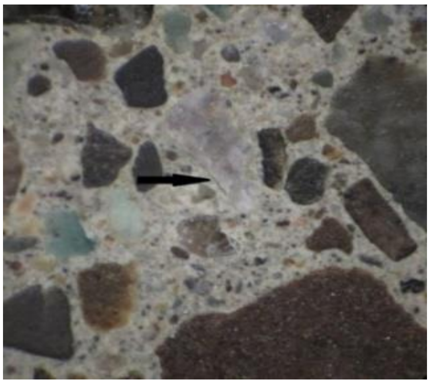
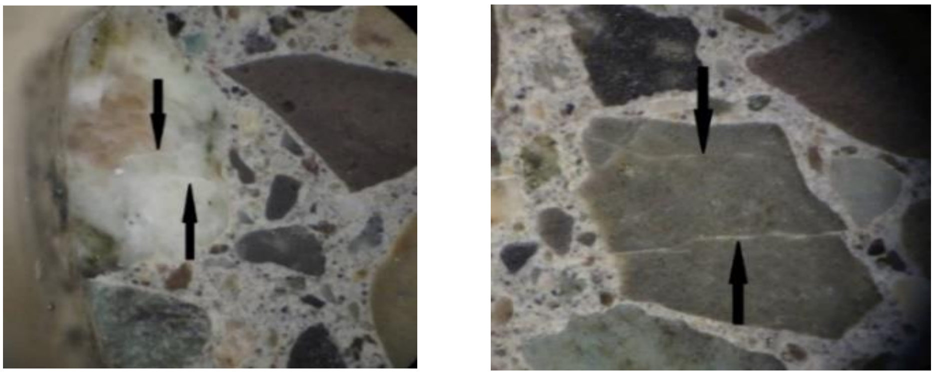


Fig. 6. A view of the micro-cracks in the central part of the field and the margin of the quartzite fragment in sample C_1

b. Sample C_2:



a **b**

Fig. 7. a) A view of the crystalline hidden aggregate fragment separated by two micro-cracks in sample C_2

b) An overview of the finite micro-crack in the *silica-quartzite* fragment in sample C_2

As it can be seen in the figure 7-b, the micro-carriers have not spread and are probably intrinsic.

[4] **Microscopic image of a polished cross section with a scale of 4 microns**

c. Sample C_3:

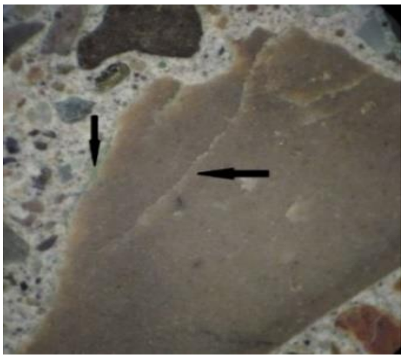


Fig. 8. A view of the gray-brown gravel grain fragment in sample C_3

In the background of this image, small cracks are observed and the left margin of the grain is visible in contact with the cement bounding. The total number of micro-cracks in this sample is lower than in the other samples.

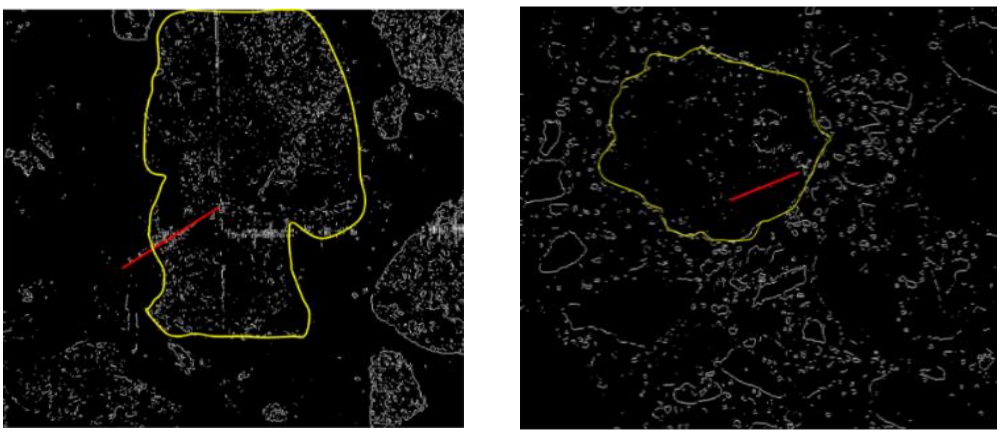
Image processing

The general way to do this is by calling the color shade to gray, and this shading allows the desired area of the mineral to be white and other minerals not favorable to the user with a black background. Then the desired user information such as cement minerals, cement degradation or setting rate is identified and displayed to the user. Since these studies all require coding, most of the modeling work is done in MATLAB software. For this purpose, the polished sections of the sample are selected and used in their code. Then, based on the desired properties, cement minerals can be identified.

Therefore, polished sections prepared from crushed samples by uniaxial strength testing using concrete petrographic studies (microscopic lithology) can be simplified and facilitated by image processing technique, which is an important step in the study of concrete fractures. For this purpose, the required samples should be prepared first and the resistance of each sample should be obtained. Afterwards, the broken pieces are sampled and sent to the laboratory for polished sections. In this study, we also try to photograph the broken specimens under the concrete breaker jack and examine these for the angle of fracture and existing cracks), Called by MATLAB software, and automated studies are performed by image processing. This study of fractures is done in three areas: aggregate, cement mortar and transition zone.

IV. RESULT AND DISCUSSION

7-day Samples:



a b

Fig. 9. a) Micro-cracks identification at the polished section of sample A_1 b) Micro-cracks in polished section of sample A_2

The polished sections of the 7-day samples were studied. The results show the accuracy and efficiency of the study method.

28-day Sample:

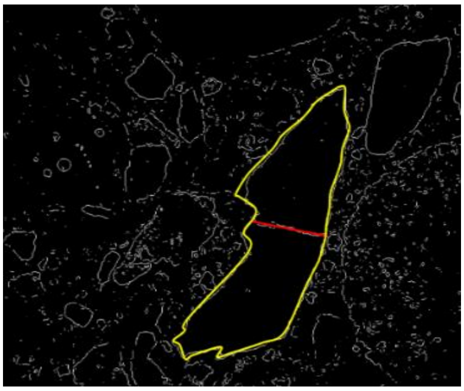
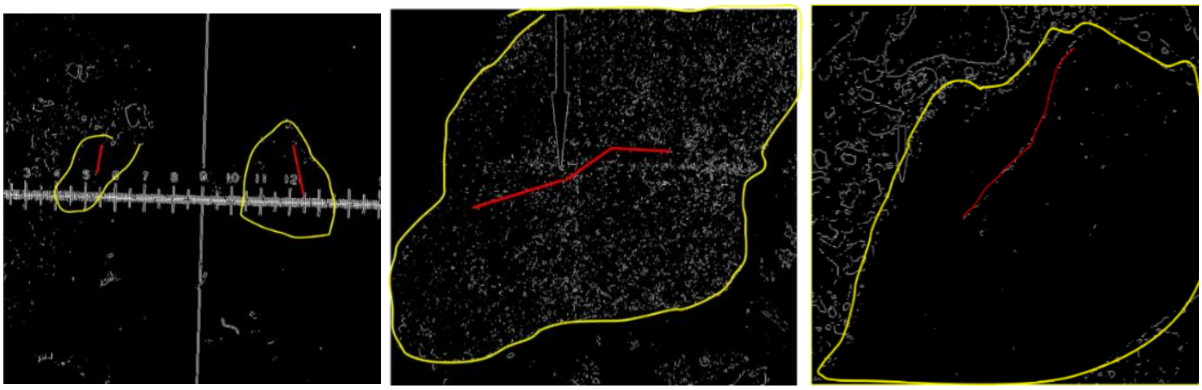


Fig. 10. Micro-cracks in the polished cross section of sample B_1

42-day Samples:



C_1 C_2 C_3

Fig. 11. Micro-cracks created in the polished cross-section of sample C_1, C_2, C_3

In addition to detecting cement minerals at this stage, the rate of cement degradation and cement bonding can be observed.

V. CONCLUSION

In this study 6 concrete samples were tested. The main purpose of this study was to make fracture investigation in concrete. There were, of course, other results as well as the main theme of the project. In general, the following results were obtained from this study:

- Resistance increases with increasing concrete retention days.
- As expected, the compressive strengths of the 28-day samples were higher than those of the 7-day samples.
- Concrete strength increased with increasing coarse-grained material (gravel).
- In samples with shorter days, fractures between cement paste and aggregates were higher than samples with longer retention days.
- Usually, most of the discontinuities and fractures between aggregates and cement pastes occur in areas where aggregates are cracked and be fractured during mixing of concrete or where cement retention is not performed well.
- Concrete petrographic studies can accurately identify the types of fractures present in concrete.
- Concerning aggregates, the use of different aggregates causes fractures between the aggregates and in the cement paste and does not have a good structural order.
- Intracellular fracture is completely separated by using image processing techniques.
- Micro-cracks and fractures can be more accurately identified by image processing techniques.
- Determining the boundaries of aggregates and cement paste can greatly help determine the type of fracture. Therefore, in this study it was observed that fractures were easily identified by separation of minerals and cement paste.
- By image processing techniques in addition to automatically study of fractures, can process the fractures, and the effects of each of the three fractures.

- The use of image processing techniques and extraction of features to study the fractures in concrete can increase the accuracy of petrographic studies of concrete.

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