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DHAKA BANGLADESH

ORGANIZATION OF ISLAMIC COOPERATION (OIC)

Prediction of Fracture Behavior by Image Processing

A thesis submitted to the department of Mechanical and Chemical Engineering, (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for degree of Higher diploma in Mechanical Engineering.

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DECLERATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for award of any degree or diploma

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My excuses for any mistake that might occur in this report despite of my best efforts.

ABSTRACT

The failure of structure leads to the loss of money but more importantly, the loss of life. Failures occur for many reasons, including uncertainties in the loading or environment, defects in the materials, propagation of fractures, inadequacies in design, and deficiencies in construction or maintenance. Fracture is one of the most important factors that leads to the failure of the whole structure.

Many people have investigated the subject of fracture mechanics and proposed their solutions. Their solutions are based mainly on theories and experiments. In this thesis report a new way of investigating fracture behavior is studied by Matlab image processing. A simple Matlab code has been developed to detect cracks of a surface and to find the length of the cracks. Comparing the results of the code with the theoretical results given by Griffith the behavior of fracture has been predicted.

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CHAPTER 1

INTRODUCTION:

1.1: Fracture Mechanics:

Fracture mechanics is mechanics of solids containing planes of displacement discontinuities (cracks) with special attention to their growth. It is a failure theory that

1. determines material failure by energy criteria, possibly in conjunction with

strength (or yield) criteria

2. considers failure to be propagating throughout the structure rather than

simultaneous throughout the entire failure zone or surface.

1.2: Types of Fracture mechanics:

There are many types of Fracture mechanics, some of them are given below.

- Linear Elastic Fracture Mechanics
- Non-Linear Fracture Mechanics
- Dynamic Fracture Mechanics
- Experimental Fracture Mechanics

1.2.1: Linear Elastic Fracture Mechanics:

A large field of fracture mechanics uses concepts and theories in which linear elastic material behavior is an essential assumption. This is the case for Linear Elastic Fracture Mechanics (LEFM).

Prediction of crack growth can be based on an energy balance. The Griffith criterion states that ”crack growth will occur, when there is enough energy available to generate new crack surface.” The energy release rate is an essential quantity in energy balance criteria. The 6 resulting crack growth criterions is referred to as being global, because a rather large volume of material is considered. The crack growth criterion can also be based on the stress state at the crack tip. This stress field can be determined analytically. It is characterized by the stress intensity factor.

The resulting crack growth criterion is referred to as local, because attention is focused at a small material volume at the crack tip.

1.2.2: Non-Linear Fracture Mechanics:

When the plastic crack tip zone is too large, the stress and strain fields from LEFM are not valid any more. This is also the case when the material behavior is nonlinear elastic (e.g. in polymers and composites). Crack growth criteria can no longer be formulated with the stress intensity factor.

In *Elastic-Plastic Fracture Mechanics* (EPFM) or *Non-Linear Fracture Mechanics* (NLFM) criteria are derived, based on the *Crack Tip Opening Displacement*. Its calculation is possible using models of Irwin or Dugdale-Barenblatt for the crack tip zone.

1.2.3: Dynamic Fracture Mechanics:

It is important to predict whether a crack will grow or not. It is also essential to predict the speed and direction of its growth. Theories and methods for this purpose are the subject of *Dynamic Fracture Mechanics* (DFM).

1.2.4: Experimental Fracture Mechanics:

Detection of cracks is done by experimental techniques, ranging from simple and cheap to sophisticated and expensive. *Experimental Fracture Mechanics* (EFM) is about the use and development of hardware and procedures, not only for crack detection, but, moreover, for the accurate determination of its geometry and loading conditions.

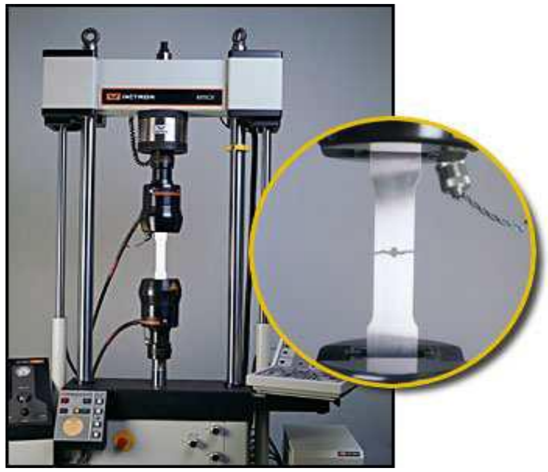

Fig. 1.1 Experimental Tensile Equipment

1.3: Fracture:

A **fracture** is the separation of an object or material into two, or more, pieces under the action of stress.

The fracture of a solid almost always occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops in this case perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation.

Fig.1.2 A wall crack

1.3.1: Crack Formation:

Prediction of crack growth can be based on an energy balance. The *Griffith criterion* states that ”crack growth will occur, when there is enough energy available to generate new crack surface.” The *energy release rate* is an essential quantity in energy balance criteria. The resulting crack growth criterion is referred to as being *global,* because a rather large volume of material is considered.

The crack growth criterion can also be based on the stress state at the crack tip. This stress field can be determined analytically. It is characterized by the *stress intensity factor*. The resulting crack growth criterion is referred to as *local*, because attention is focused at a small material volume at the crack tip.

The release of strain energy when crack extends provides the driving force for its growth. This increases with increase in applied stress. The more is the stress applied the more is the driving force for the crack propagation and hence it will be easier for the crack to propagate as the time passes.

The material also has the resistance to the crack propagation which depends upon the properties of the material and increases with the increase in the applied stress. The resistance force mainly depends upon the inter-molecular bonding of the material atoms/molecules. The stronger is the bonding, the more is the resistance force that will try to avoid the formation of the crack.

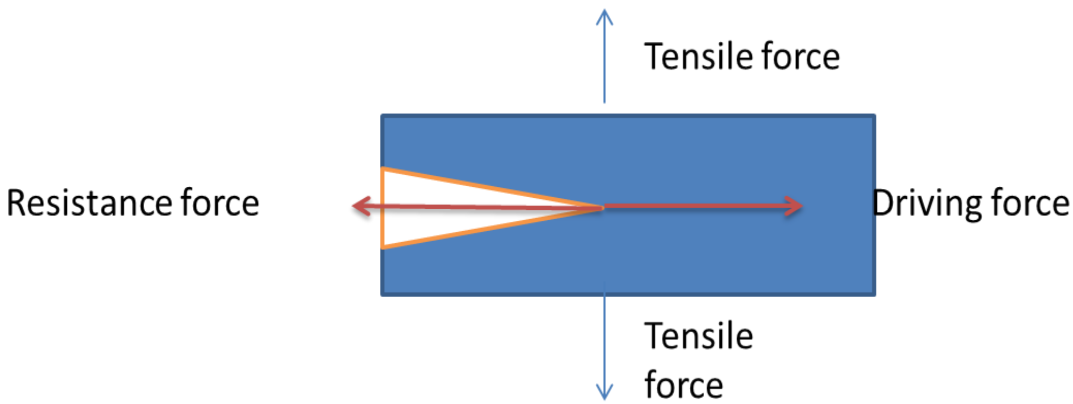

Fig. 1.3 Crack formations

1.3.2: Stress Distribution:

When a tensile force is applied stresses are developed inside the material. The stress distribution around a crack surface is not symmetrical. The stresses are concentrated at only one point that is the tip of the crack and all other surface of the crack is stress free. If the length of the crack is small, less amount of stresses will be concentrated at its tip but for crack having more length, most of stresses are concentrated at the tip. A crack with small length requires large amount of force for its propagation because the resistance for due properties of the material is more. This resistance force tries to stop the growth of the crack. A crack with large length requires small force for its propagation because the resistance force reduces as the crack length increases.

The figure shown below shows the distribution of stress around a crack.

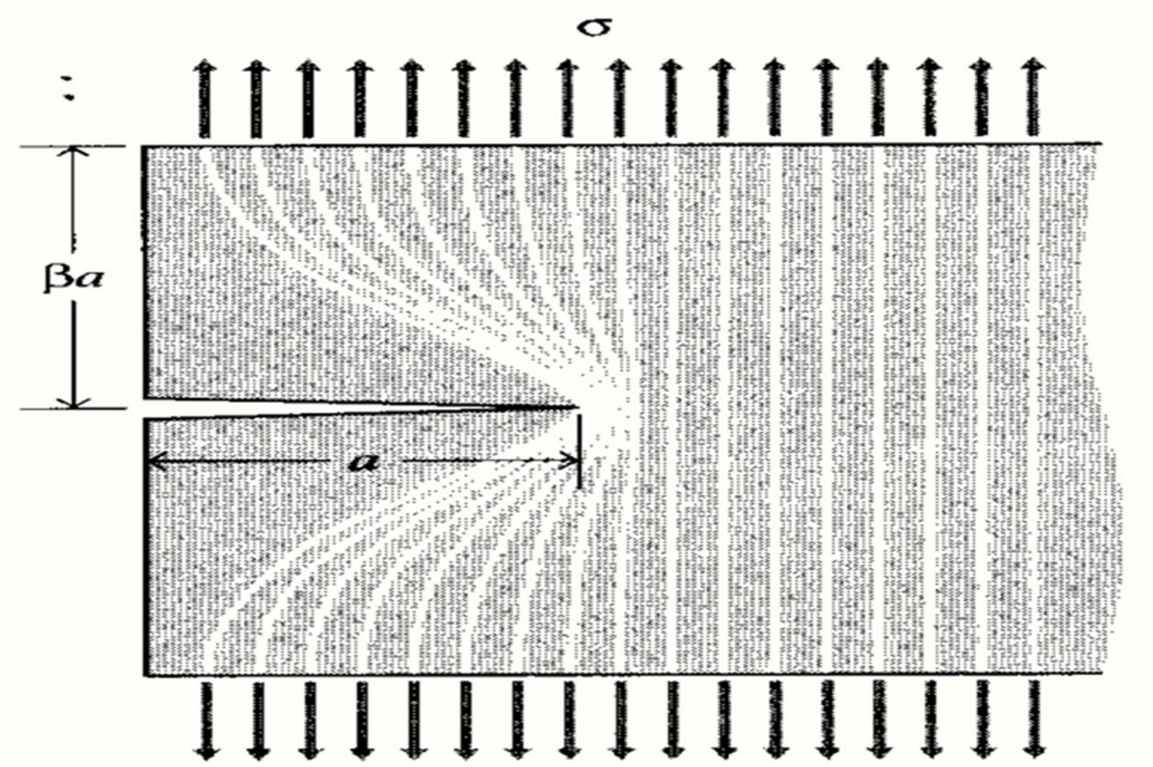

Fig. 1.4 Stress distribution around a crack surface

The figure is a material surface having a crack of length a. The height of the crack is βa . The material is subjected to a constant stress. We can see that the stresses are concentrated at the tip of the crack while the surface of the crack is stress free. We can also observe that the material surface is taking the whole effect of the applied stress.

1.3.3: Stress vs Crack length.

The stress required for Fracture to propagate is a very important parameter in understanding the behavior of Fracture. It depends upon many factor but most importantly it depends upon the length of the crack. Experimental results show that the stress required for crack to propagate depends mainly upon the length of the crack. The experimental results can be shown in the form of a graph. The graph is shown in the figure below.

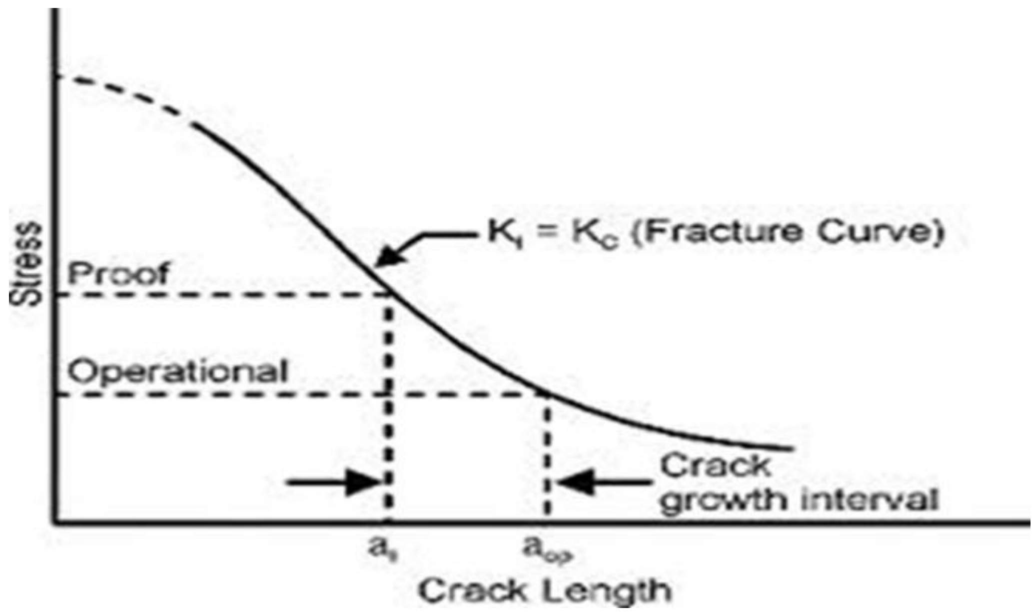

Fig. 1.5 Stress vs Crack length

From the figure we can see that the value of the stress required for Fracture propagation is highest when the length of the crack is zero i.e, when there is no crack than the stress required for fracture propagation is very large. As the length of the crack increases the value of stress required becomes small i.e, long crack require very small amount of stress for their propagation. But we should remember that there is a certain value of crack length below which crack will not propagate rapidly, that is known as the critical length of the crack. For a crack to propagate rapidly, its length must be greater than the critical length. The value of critical length of the crack depends upon many factors including the applied stress and most importantly the properties of the material. The value of critical length of crack is different for different materials.

1.4: Modes of Crack Opening:

There are three basic modes of crack Opening. The figure below shows the three basic modes of crack opening.

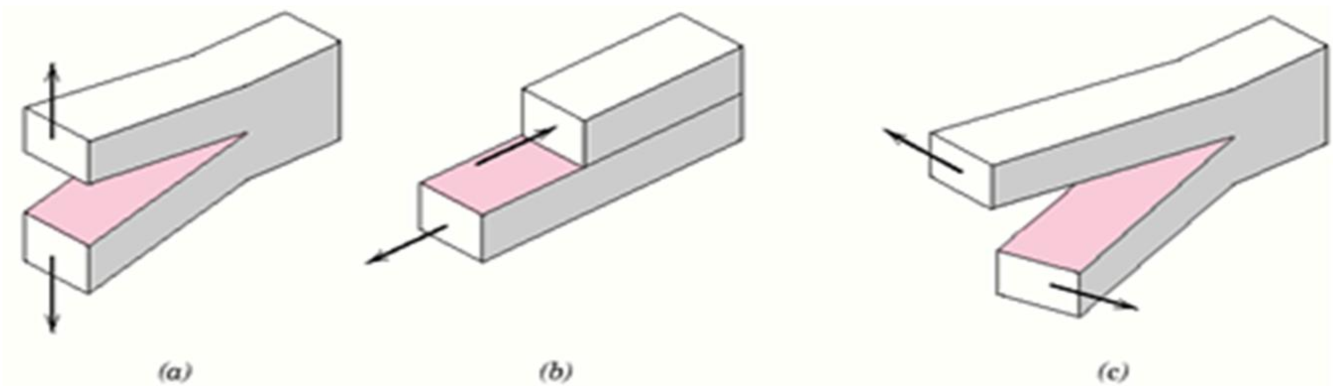

Fig. 1.6 Modes of Crack Opening

a) Opening mode b) Sliding mode c) Tearing mode

- First mode occurs due to tensile force. Crack surfaces are pulled apart in y-direction.
- Second mode occurs due to shear forces parallel to the crack surface. Crack surfaces slide over each other in x-direction.
- Third mode occurs due to shear force applied parallel to the front surface of the crack.

1.4.1: Opening Mode.

This mode occur due to application of Tensile load to a material surface. When tensile force is applied to a material it will induce tensile stress inside the material. The tensile stress is the main reason for crack formation and crack propagation. For crack formation stresses are concentrated around a region of the material in which crack is most likely to be formed. If a crack is already present at the surface of the material, the stress concentration will be most at the tip of the crack and the surface of the crack will be stress free.

1.4.4: Sliding Mode.

This mode of crack opening occurs due to application of shear force. The two crack surface slide over each other in opposite direction. When a shear force is applied to a material surface, different layers of the material try to come out of each other. If the bonding force between the layers of the material is homogenous then the layers with least bonding force cannot hold their together. Two layers slide over each other forming a cracked surface.

1.4.3: Tearing Mode.

This mode of crack opening also occurs due to application of shear force. The crack surfaces are torn apart in opposite direction due to the application of shear force. The mechanism of crack formation is the same as in the case of sliding mode.

1.5: Types of Fracture

The following are the types of fracture

- Brittle Fracture
- Ductile Fracture
- Tensile Fracture
- Shear Fracture
- Fatigue Fracture
- Cleavage Fracture

1.5.1: Brittle Fracture:

When a crack propagates, new free surface is generated, having a specific surface energy γ, which for solid materials is typically 1 [Jm−2]. This energy is provided by the external load and is also available as stored elastic energy. Not all available energy, however, is used for the generation of new crack surfaces. It is also transformed into other energies, like kinetic energy or dissipative heat. When a lot of available energy is used for crack growth, the fracture is said to be *brittle*.

The Brittle behavior of a material can be easily determined from the Tensile test. If we draw a stress vs. strain curve for a brittle material, it shows that the fracture occurs before reaching the plastic deformation region.

The stress vs. strain curve for a brittle material is shown in the figure below.

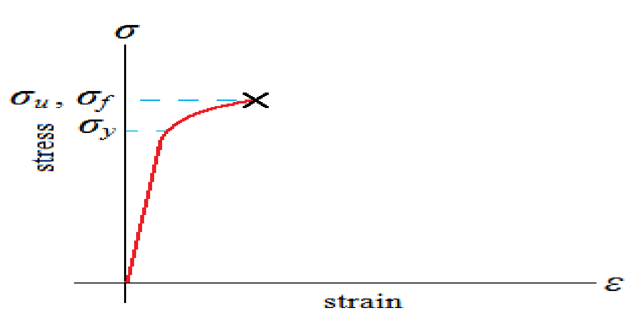

Fig 1.7 Stress vs. Strain Curve for a Brittle Material

1.5.2: Ductile Fracture:

When a crack propagates, new free surface is generated, having a specific surface energy γ, which for solid materials is typically 1 [Jm−2]. This energy is provided by the external load and is also available as stored elastic energy. Not all available energy, however, is used for the generation of new crack surfaces. It is also transformed into other energies, like kinetic energy or dissipative heat. When a lot of energy is transformed into other energies, mainly due to dissipative mechanisms, the fracture is indicated to be *ductile*.

The ductile behavior of a material can be determined by tensile test. If a stress vs. strain curve is drawn for a ductile material, we see that the material first goes through the plastic deformation region and then the fracture occurs.

The stress vs. strain curve for a ductile material is shown in the figure below.

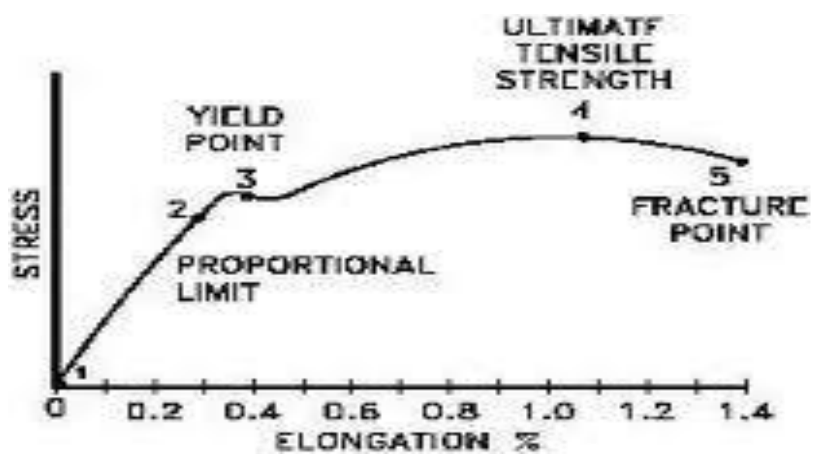

Fig. 1.8 Stress vs. Strain curve for Ductile material

1.5.3: Tensile Fracture

If a material specimen is subjected to a constant tensile force, the applied tensile force will try to tear the material specimen apart. The formation of the crack surface in a material under tensile force is according to the first mode of crack formation i.e., the Opening mode.

When a tensile force is applied to a material, stresses are developed inside the material. These stresses will be concentrated around the region in which crack is most likely to be formed . If there is already a crack present at the surface of the material then the stresses will be concentrated at the tip of the crack and the crack surface will be free of stress. This stress concentration is responsible for the propagation of the crack.

When crack length is small, less stress are concentrated at the tip of the crack and most are uniformly distributed inside the material. At this time more force is required for the propagation of crack and the crack has more resistance to its propagation. But when the length of the crack is more, then more stresses are concentrated at its tip and the crack has a very low resistance to its propagation. At this time the force required for the propagation of crack is very small and failure can happen at any time.

Typical example of a tensile crack is the formation of cracks in beams. When a beam is loaded, its upper surface is in compression and the lower surface is in tension. This means a tensile force acts at the lower surface of the beam. This tensile force is responsible for the formation of cracks in a beam.

The figure below shows the formation of cracks in a beam due to tensile force.

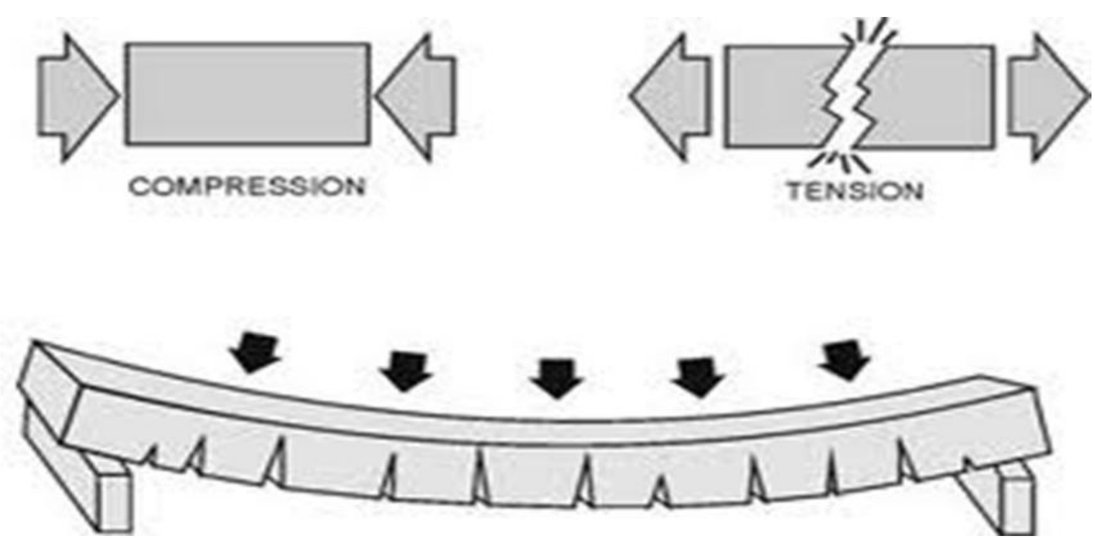

Fig. 1.9 Tensile Fracture in a Beam

1.5.4: Shear Fracture

The fracture that occurs due to application of shear force is known as shear fracture. The shear force tries to take one layer of the material out of the other. As a result the layers slide over each other and fracture occurs. Shear fracture in crystalline martials can be best explained on the basis of the crystal structure.

When a crystalline material is loaded, dislocations will start to move through the lattice due to local shear stresses. Also the number of dislocations will increase. Because the internal structure is changed irreversibly, the macroscopic deformation is permanent (plastic). The dislocations will coalesce at grain boundaries and accumulate to make a void. These voids will grow and one or more of them will transfer in a macroscopic crack. One or more cracks may then grow and lead to failure. Because the origin and growth of cracks is provoked by shear stresses, this mechanism is referred to as *shearing*.

The example of shearing fracture is "wall Cracks". These cracks occur due to shear force. The load of the roof acts downward and the reaction force at the bottom of the wall acts upward creating a shearing action. Due to this shearing action the layers of the material of the wall slide over each other and give rise to the formation of shear cracks. The figure below shows one type of shear crack.

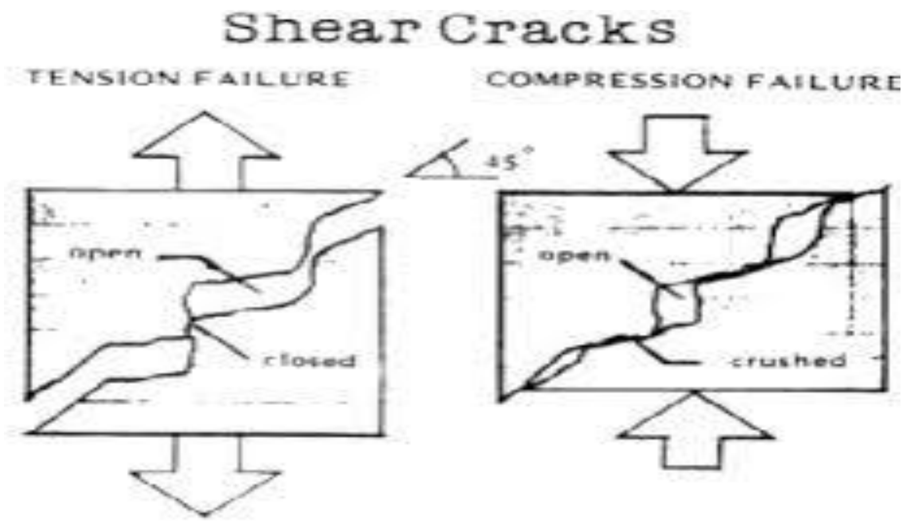

Fig. 1.10 Shear Fracture

1.5.5: Fatigue Cracks

This is probably the most important type of cracks. Because no one can estimate the exact time of failure of structures having Fatigue cracks. Even a very small crack under a very small time dependent load can cause the failure of whole structure suddenly.

This is a type of crack which is under the action of a time dependent load. When a crack is subjected to cyclic loading, the crack tip will travel a very short distance in each loading cycle, provided that the stress is high enough, but not too high to cause sudden global fracture. With the naked eye we can see a ’clam shell’ structure in the crack surface. Under a microscope ’striations’ can be seen, which mark the locations of the crack tip after each individual loading cycle.
This mechanism is referred to as *fatigue*. Because crack propagation is very small in each individual load cycle, a large number of cycles is needed before total failure occurs.

The figure below show a typical example of some components that work under fatigue. If the failure of these components occur, it will most probably be due to the fatigue crack propagation.

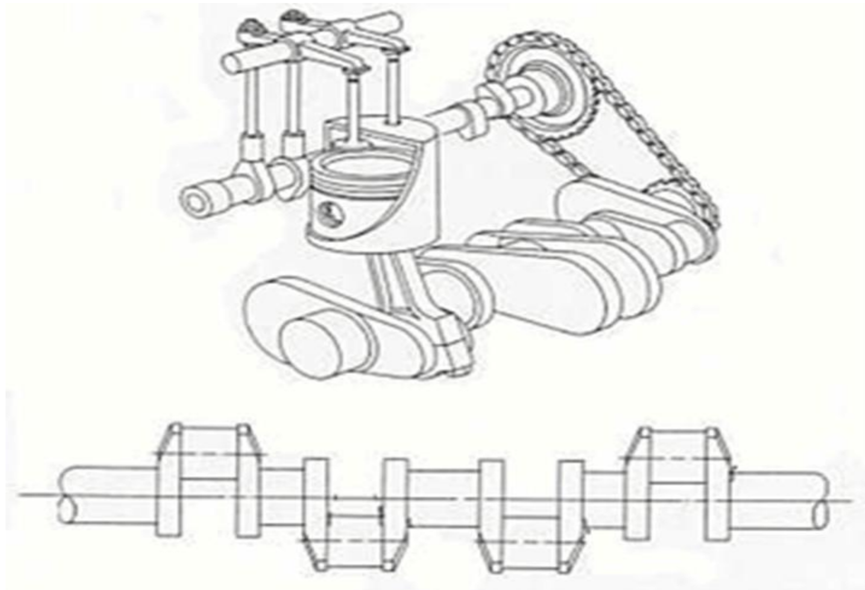

Fig. 1.11 Fatigue cracks in crankshaft

1.5.6: Cleavage Fracture:

When plastic deformation at the crack tip is prohibited, the crack can travel through grains by splitting atom bonds in lattice planes. This is called *intra- or trans-granular cleavage*. When the crack propagates along grain boundaries, it is referred to as *inter-granular cleavage*.

This cleavage fracture will prevail in materials with little or no closed-packed planes, having HCP or BCC crystal structure. It will also be observed when plastic deformation is prohibited due to low temperature or high strain rate. As will be described later, a three-dimensional stress state may also result in this mechanism.

Inter-granular cleavage will be found in materials with weak or damaged grain boundaries. The latter can be caused by environmental influences like hydrogen or high temperature. The crack surface has a 'shiny' appearance. The discontinuity of the lattice orientation in neighboring grains will lead to so-called cleavage step.

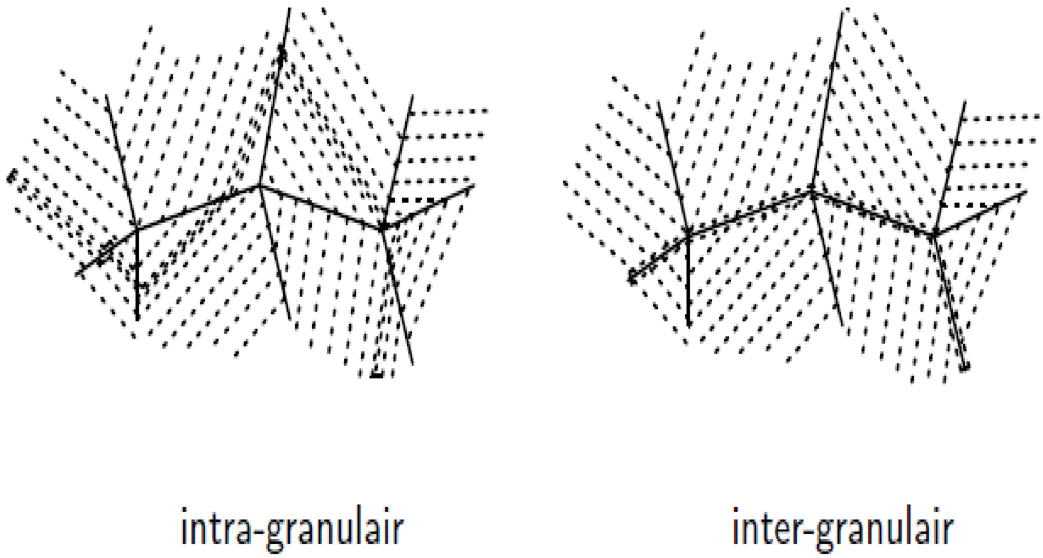

Fig. 1.12 Two types of cleavage Fracture

1.6: Experimental Techniques for Crack Detection.

To predict the behavior of a crack, it is essential to know its location, geometry and dimensions. Experiments have to be done to reveal these data.

Experimental techniques have been and are still being developed. Some of these procedures use physical phenomena to gather information about a crack. Other techniques strive towards visualization of the crack.

- Surface cracks
- Electrical Resistance
- X-rays
- Ultrasound
- Acoustic Emission

- Adhesion test

1.6.1: Surface cracks.

One of the simplest techniques to reveal surface cracks is based on dye penetration into The crack due to capillary flow of the dye. Although it can be applied easily and on-site, only surface cracks can be detected.

Other simple procedures are based on the observation of the disturbance of the magnetic or electric field, caused by a crack. Magnetic fields can be visualized with magnetic particles and electric fields by the use of inertances. Only cracks at or just below the surface can be detected in this way.

The figure below shows the detection of surface cracks with the help of simple technique of dye penetration

Fig.1.13 Dye Penetration in a stiffing cone of a turbine

1.6.2: Electrical resistance

A crack is a discontinuity in the material and as such diminishes the cross-sectional area. This may be associated with an increase of the electrical resistance, which can be measured for metallic materials and carbon composites.

1.6.3: X-ray

Direct visualization of a crack can be done using electromagnetic waves. X-rays are routinely used to control welds.

The figure below shows the use of the technique of X-ray to find cracks in a pipe with the help of robots.

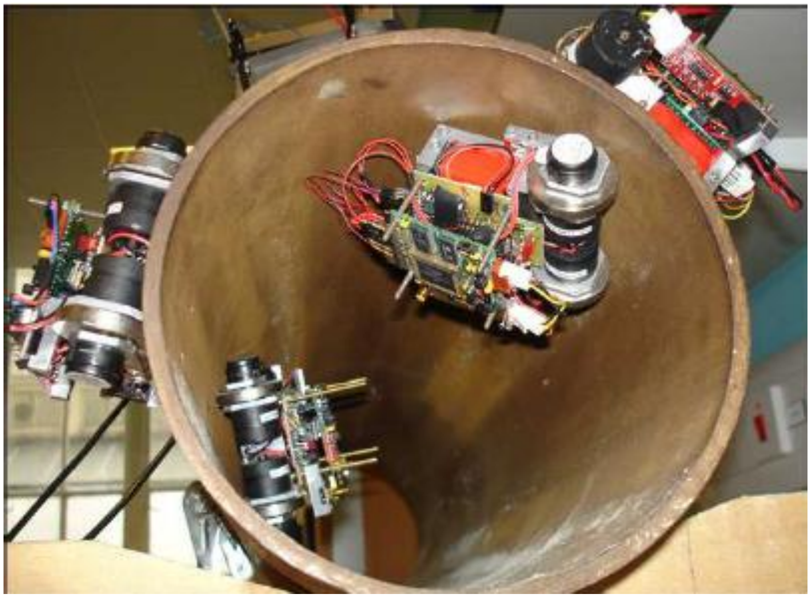

Fig.1.14: X-ray robots trying to find cracks on the surface of pipe

1.6.4: Ultrasound

Visualization is also possible with sound waves. This is based on the measurement of the distance over which a wave propagates from its source via the reflecting crack surface to a detector.

The figure below is a schematic diagram showing the use of ultrasound for detection of cracks on a surface.

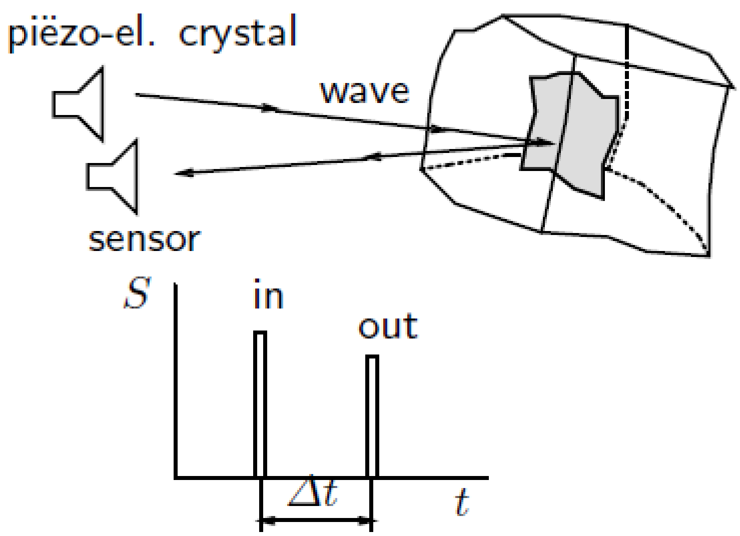

Fig. 1.15 Ultra sound crack detection

1.6.5: Acoustic emission

The release of energy in the material due to crack generation and propagation, results in sound waves (elastic stress waves), which can be detected at the surface. There is a correlation of their amplitude and frequency with failure phenomena inside the material. This *acoustic emission* (AE) is much used in laboratory experiments.

1.6.6: Adhesion tests

Many experimental techniques are used to determine adhesion strength of surface layers on a substrate. Some of them are illustrated below.

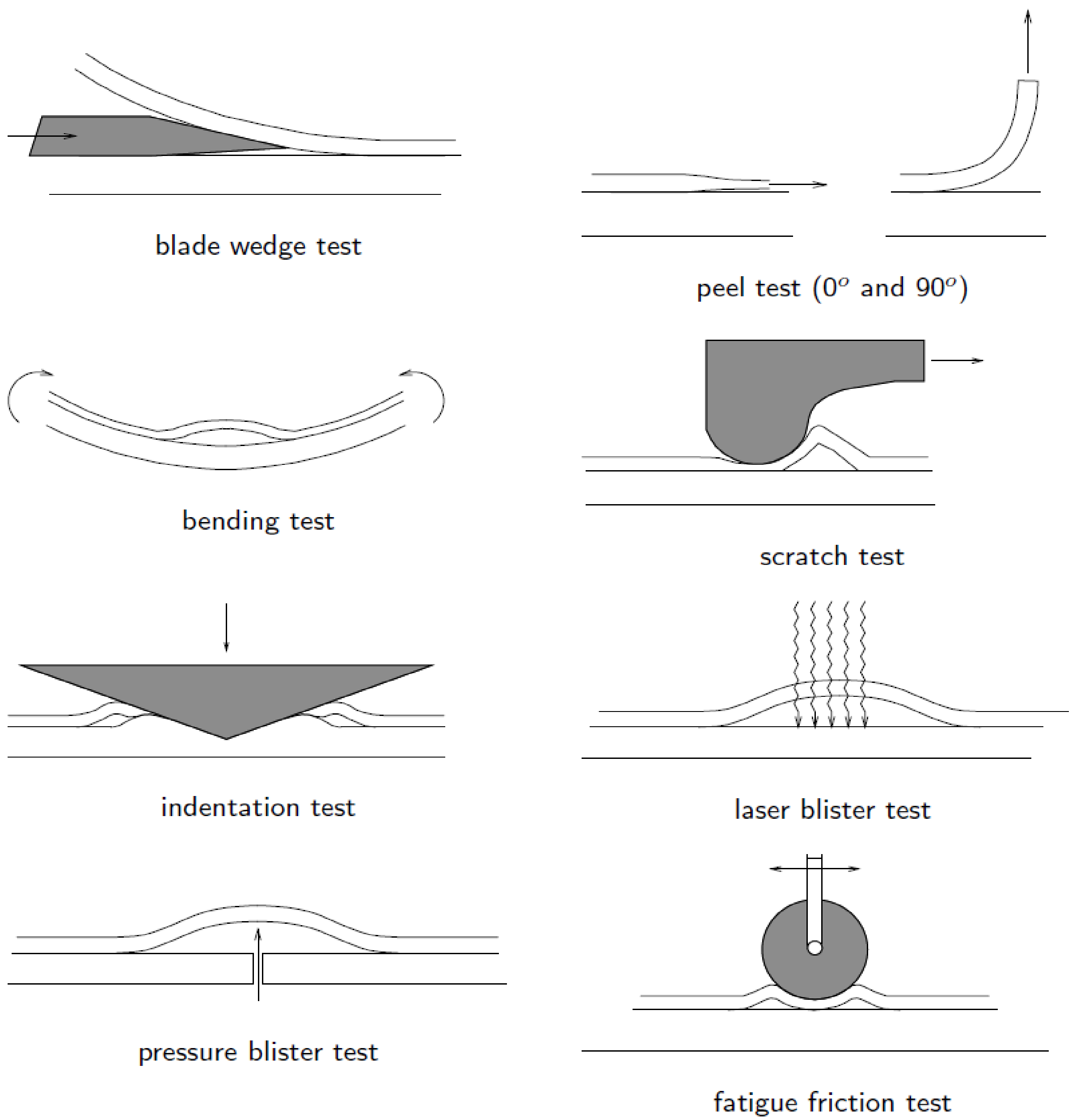

Fig. 1.16 Different type of adhesion test for crack detection

1.7: Girrifth's Experiment:

In 1921 Griffith determined experimentally the fracture stress σb of glass fibers as a function of their diameter. For d > 20 μm the bulk strength of 170 MPa was found. However, σb approached the theoretical strength of 14000 MPa in the limit of zero thickness.

Griffith new of the earlier (1913) work of Inglis [32], who calculated stress concentrations at circular holes in plates, being much higher than the nominal stress. He concluded that in his glass fibers such stress concentrations probably occurred around defects and caused the discrepancy between theoretical and experimental fracture stress. He reasoned that for glass fibers with smaller diameters, there was less volume and less chance for a defect to exist in the specimen. In the limit of zero volume there would be no defect and the theoretical strength would be found experimentally. Griffith published his work in 1921 and his paper [28] can be seen as the birth of Fracture Mechanics. It was shown in 1976 by Parratt, March en Gordon, that surface defects instead of volume defects were the cause for the limiting strength.

The ingenious insight that strength was highly influenced by defects has led to the shift of attention to the behavior of cracks and the formulation of crack growth criteria. Fracture Mechanics was born!

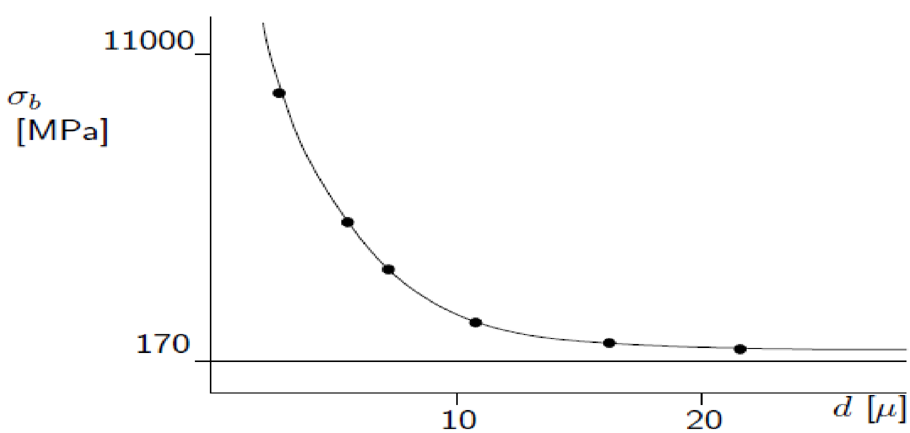

Fig. 1.17 Fracture strength of glass fibers in relation to their thickness.

1.7.1: Griffith's energy balance

It is now assumed that the available external and internal energy is transferred into surface energy. Dissipation and kinetic energy are neglected. This results in the so-called Griffith energy balance.

After division by the plate thickness B, the left-hand side of the equation is called the *energy release rate* G and the right-hand side the *crack resistance force* R, which equals 2γ, where γ is the surface energy of the material.

energy balance	$\frac{dU_e}{da} - \frac{dU_i}{da} = \frac{dU_a}{da}$	
energy release rate	$G = \frac{1}{B}\left(\frac{dU_e}{da} - \frac{dU_i}{da}\right)$	$[Jm^{-2}]$
crack resistance force	$R = \frac{1}{B}\left(\frac{dU_a}{da}\right) = 2\gamma$	$[Jm^{-2}]$
Griffith's crack criterion	$\boxed{G = R = 2\gamma}$	$[Jm^{-2}]$

According to Griffith's energy balance, a crack will grow, when the energy release rate equals the crack resistance force.

This is illustrated with the following example, where a plate is loaded in tension and fixed at its edges. An edge crack of length a is introduced in the plate. Because the edges are clamped, the reaction force, due to restraining, does not do any work, so in this case of *fixed grips* we have dUe = 0. The material volume, where elastic energy is released, is indicated as the shaded area around the crack. The released elastic energy is a quadratic function of the crack length a. The surface energy, which is associated with the crack surface is 2γa.
Both surface energy Ua and internal energy Ui are plotted as a function of the crack length. The initial crack length a is indicated in the figure and it must be concluded that for crack growth da, the increment in surface energy is higher than the available (decrease of) internal energy. This crack therefore cannot growth and is stable.

When we gradually increase the crack length, the crack becomes unstable at the length ac. In that case the crack growth criterion is just met (G = R). The increase of surface energy equals the decrease of the internal energy.

1.7.2: Griffith's Critical length of Cracks

We consider a crack of length 2a in an "infinite" plate with uniform thickness B [m]. The crack is loaded in mode I by a nominal stress σ [Nm−2], which is applied on edges at large distances from the crack.

Because the edges with the applied stress are at a far distance from the crack, their displacement will be very small when the crack length changes slightly. Therefore it is assumed that dUe = 0 during crack propagation. It is further assumed that the elastic energy in the elliptical area is released, when the crack with length a is introduced. The energy release rate and the crack resistance force can now be calculated. According to Griffith's energy balance, the applied stress σ and the crack length a are related. From this relation we can calculate the *Griffith stress* σgr and also the *critical crack length* ac.

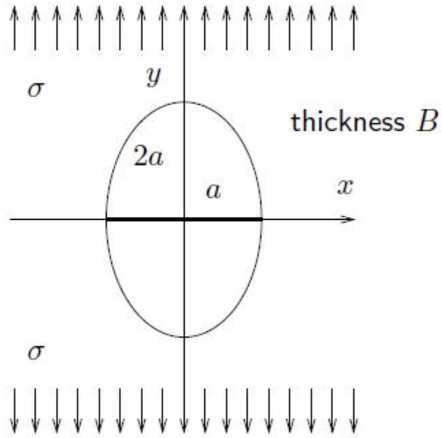

Fig. 4.3 : *Elliptical region, which is unloaded due to the central crack of length* $2a$.

$$U_i = 2\pi a^2 B \,\tfrac{1}{2}\frac{\sigma^2}{E} \qquad ; \qquad U_a = 4aB\,\gamma \qquad [\text{Nm} = \text{J}]$$

Griffith's energy balance $\quad (dU_e = 0)$

$$G = -\frac{1}{B}\left(\frac{dU_i}{da}\right) = \frac{1}{B}\left(\frac{dU_a}{da}\right) = R \quad \rightarrow \quad 2\pi a\frac{\sigma^2}{E} = 4\gamma \qquad [\text{Jm}^{-2}]$$

Griffith stress

$$\boxed{\sigma_{gr} = \sqrt{\frac{2\gamma E}{\pi a}}}$$

critical crack length

$$\boxed{a_c = \frac{2\gamma E}{\pi\sigma^2}}$$

Using this formula of critical length given by Girrifth and comparing with the length found in the image of a cracked surface we can find out the behavior of Fracture.

1.8: Problem Statement:

Cracks detection and propagation is a problem of great interest for many people and many have developed their theories for this cause. In this project I had been asked by the supervisor to find an easy way of detection of cracks and to predict the behavior of cracks. I had been asked to investigate the behavior of Fracture by Matlab image processing by developing a simple Matlab code for detection and for finding the length of the crack. I took help from the theory given by Girrifth. The theory of Girrifth is given below.

1.9: Objectives.

The objectives of the projects are

- To develop a Matlab code for the detection of cracks and to find the length of the crack.
- To compare the length of the crack with the critical length.
- And finally to predict the behavior of the crack i.e., to predict the time of crack propagation.

Chapter 2

Literature Review

In this project a research was conducted about the prediction of behavior of fracture with the help of Matlab software. There were two main goals of the project. One of them was to find a way of detecting cracks in a material that should be different from the traditional methods of cracks finding. The second goal was to predict the behavior of the cracks that has been detected. In order to complete both the goals of the project, Matlab Image Processing was chosen as the software by help of which fracture behavior can be predicted. A Matlab code was developed with the help of Matlab Image Processing for the detection of cracks in a material surface. Then another code was developed for finding the length of crack. That length could be compared with the critical length of the crack and then time of failure due to that particular crack could be predicted.

For detecting cracks of a surface and predicting their behavior, help was taken from the work of those who have done some research on this particular topic. A little detail of their work is given below.

Shawn Gowatski conducted a research for detection of crack in different type of material. According to him The inspection of welds on piping, pressure vessels, columns, etc. is a major priority for plant personnel. Traditional methods such as magnetic particle, dye penetrant, shear-wave ultrasonic, radiography, and vacuum box testing are useful but all have some limitations. Most techniques require extensive surface preparation for a successful inspection. Radiography requires the area to be evacuated during testing which causes scheduling conflicts during an outage.

The introduction of the Balanced Field Electromagnetic Technique (BFET) has made inspecting welds much easier with less unit preparation time. BFET is a scanning technology that detects cracking within 0.375” of the surface. The Balanced Field Electromagnetic Technique has inspected DA Tanks, Piping, Tube Stubs, Drums, Columns, Dryers, Heat Exchanger Shells, and other pressure vessels**.**

"ASNT crack detection Paper" by Shawn Gowatski.

In 2010 U. Hampel conducted a research for crack detection during load tests in civil engineering materials with digital closed range photogrammetry. According to him Methods of digital photogrammetry are qualified for automatically measuring of two- and three-dimensional fields of displacements, deformations and defects such as cracks on surfaces of test objects and structures during short and long time load tests in civil engineering material testing. The first part of the paper gives a short overview on some recent research projects employing digital closed range photogrammetry in a wide range of 2-D, 2.5-D and 3-D civil engineering material testing applications. The main part of the paper describes the developed algorithms for the detection, localization and width-determination of cracks during load tests of TRC-probes (Textile Reinforced Concrete). The paper presents the requirements/boundary conditions and the results for two different test setups, for tension (2.5D) and shear tests (3D). The detected minimum crack width is approx. 5 µm in a measurement area up to 240 mm x 100 mm.

"CRACK DETECTION DURING LOAD TESTS IN CIVIL ENGINEERING MATERIAL TESTING WITH DIGITAL CLOSED RANGE PHOTOGRAMMETRY – ALGORITHMS AND APPLICATIONS" by U.Hampel.

In August,2002 W. H. Whittmann conducted a research on the topic of "Crack formation and Fracture energy" according to him The crack path through composite materials such as concrete depends on the mechanical interaction of inclusions with the cement-based matrix. Fracture energy depends on the deviations of a real crack from an idealized crack plane. High strength means generally low ductility and increased risk for crack formation.

"Crack formation and fracture energy of normal and high strength concrete" by W. H. Wittmann.

Miguel Patricio and Robert M.M. Mattheij conducted a research program in which the analyzed the propagation of cracks. They used the conventional method of crack analysis like energy balance approach and equations of Elastic Fracture Mechanics. By using quasi-static analysis and equations of Dynamic Fracture Mechanics they developed simulation of crack propagation that gives the rate and the direction of crack propagation provided that some of the value of variables and constants used in those equations are known.

"Crack Propagation Analysis" by Miguel Patricio Robert M.M. Mathieu

The work of the above mentioned people provided valuable information for the completion of this project. In these researches emphasis have been given to find an easy, simple and cheap way of crack detection and prediction of fracture behavior. If we look at the research work conducted in this project we can say that this project has provided a guideline for finding an easy, simple and cheap way for crack detection by developing Matlab code. If this research continues, more efficient and easy way can be found for crack detection by developing more efficient Matlab codes and fracture behavior can be predicted more precisely.

CHAPTER 3

Matlab Image Processing

3.1: Matlab code for Crack Detection

With the help of Matlab Image Processing a code is developed for the detection of the cracks. The code is give below.

```
% clear all;
% close all;
I = imread('d:/dee.jpg');
I = rgb2gray(I);
f=figure;
imshow(I);
hy = fspecial('sobel');
hx = hy';
Iy = imfilter(double(I), hy, 'replicate');
Ix = imfilter(double(I), hx, 'replicate');
gradmag = sqrt(Ix.^2 + Iy.^2);
K=figure;
imshow(gradmag,[]);
```

3.1.1: Algorithm of Matlab Code:

The algorithm of the Matlab code is very simple and is given below.

- The program first reads the input image.
- It will convert the image to gray image.
- Using the fspecial function' solbel' it will detect the edges of the image.
- Filtering the x components of the image.
- Filtering the y components of the image.
- Combining both the x and y components of the image to get the required image.
- At the end, showing the image.

3.1.2: Flow diagram of the Matlab Code.

The figure below is the flow diagram of the Matlab code developed for detection of cracks from images.

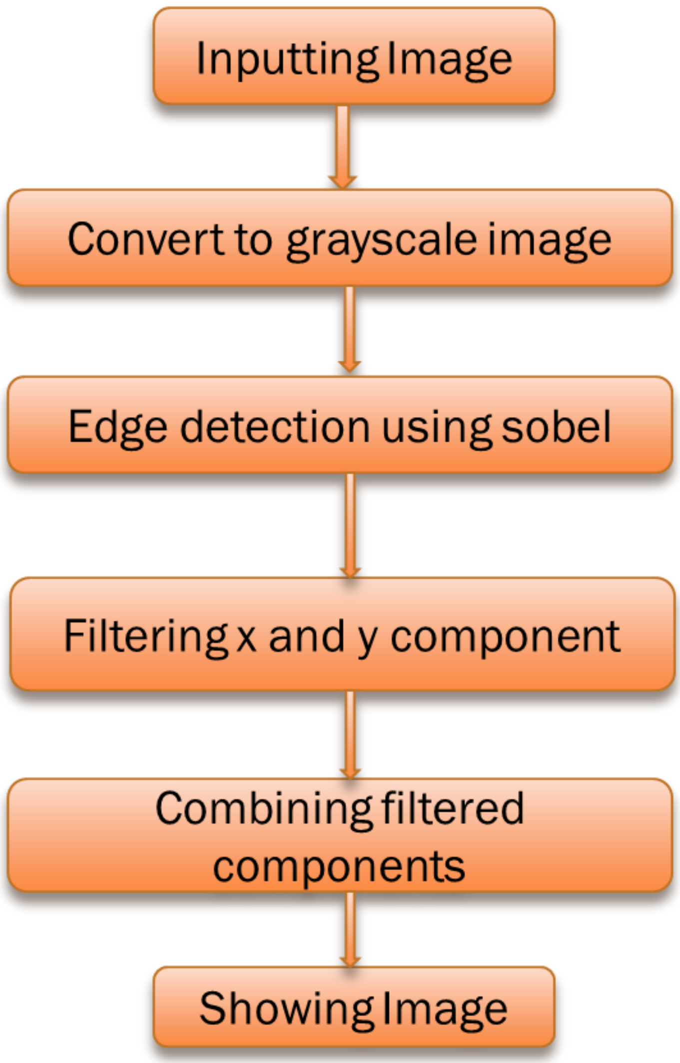

Fig. 3.3 Flow diagram of Matlab code for Detection of cracks

3.1.3: Explanation of Matlab Commands Used in the Code:

The explanation of all the Matlab commands that have been used in the above code is given below.

No.	Command	Explanation
1	Imread	This command is used for reading the input image from the user
2	rgb2rgay	This command is used for converting the rgb image to a gray image
3	fspecial('sobel')	This command is used for the detection of edges in the gray image
4	figure	This command is used for getting a blank figure in order to display an image on that
5	imfilter	This command is used for filtering the image i.e., to remove the small sized components from the image

Table. 3.1 Explanation of Matlab Commands used in the code for detection of cracks

3.1.4: Results of The Code:

Original Picture of the cracked surface:

The figure shown below is the picture of the cracked surface on which Matlab code was applied for the detection of cracks. We can see that the crack in the picture is not very clear and there are some other components that need to be filtered for getting a clear view of the crack. So we apply the Matlab code to this image and get the results.

Fig. 3.1 Original Image of a cracked surface

After applying the code:

After applying the code developed in Matlab we get the image in this form. In this figure we can see that the crack of the surface is now very clear as compared to the origional picture. Thus cracks can be easily detected by applying the above Matlab Image Processing Code developed in this project.

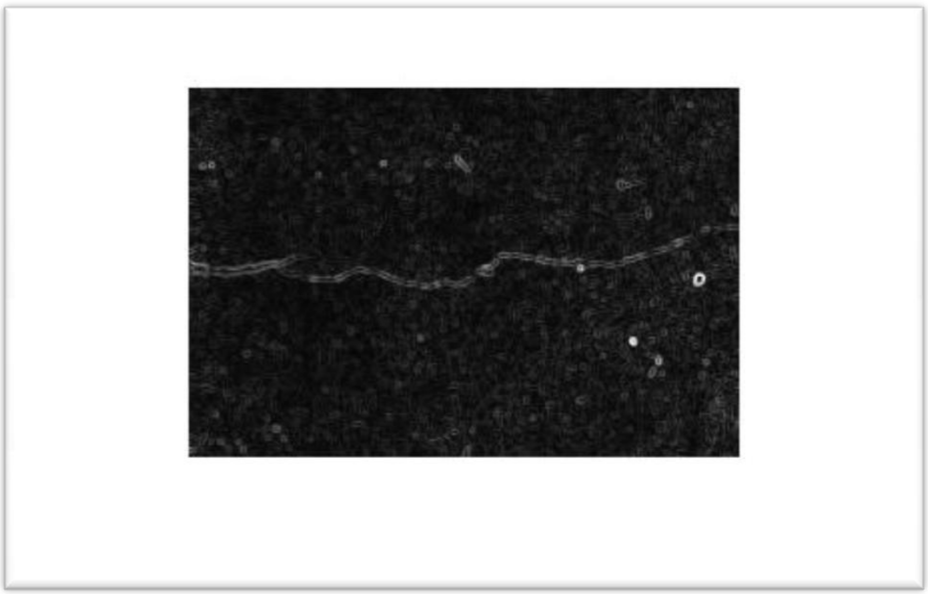

Fig. 3.2 Image After applying Matlab code

Another Example:

Here is another example of the application of Matlab code for detection of cracks.

Original Picture:

After applying Matlab Image Processing Code:

Fig. 3.4 Example of Applying Matlab code to a cracked image

3.2: Matlab Code for Finding the Length of Crack

In Matlab, a code is developed that is used for finding the length of the cracks from pictures.

The code is given below

```
% clear all

% close all

i=imread('input image location');

figure;

imshow(i);

bw=im2bw(i);

figure;

imshow(bw);

cc=bwconncomp(bw);

bl=bwlabel(bw);

crack_length=bwdist(bl);

crack_length
```

3.2.1: Algorithm of the Code.

The algorithm of the program is very simple and is given below

- Reading the input image.
- Converting the image to binary image.
- Finding the connected components of the binary image.
- Labeling the connected components of the binary image.
- Using the distance transform to find the length of the connected components.
- Length of the connected components gives the length of the crack.
- Finally we get the length of the crack in the form of a matrix.

3.2.2: Flow Diagram of the Code.

The figure below is the flow diagram of the Matlab code that is used for finding the length of the crack from images.

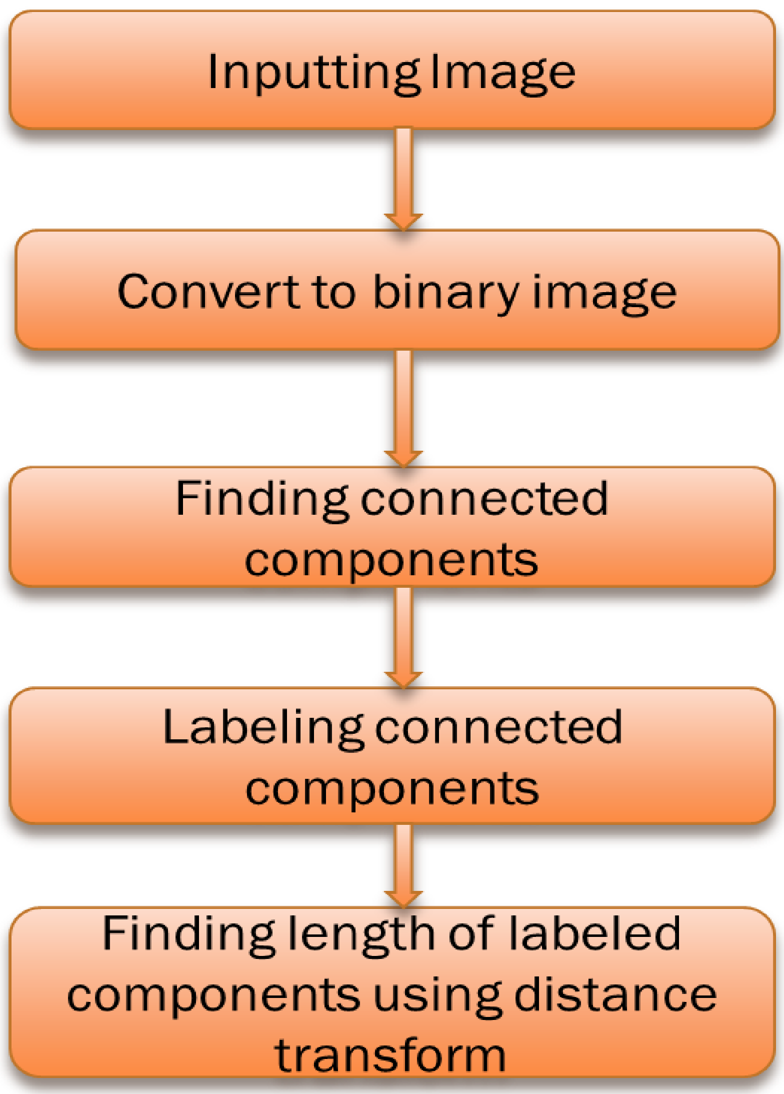

Fig. 3.5 Flow diagram of Matlab Code for finding length of crack

3.2.3: Explanation of Matlab Commands Used:

Here is the explanation of Matlab Commands that have been used in the code for finding the length of the cracks from images.

No.	Command	Explanation
1	imread	This command is used to read the input image
2	imshow	This command is used to show the image on the screen
3	im2bw	This command is used to convert the image to binary image
4	bwconneccomp	This command is used to find all the connected components of the binary image
5	bwlabel	This command is used to label all the connected components of the binary image
6	bwdist	This command is used to find the distance of all the connected components of the binary image

Table. 3.2 Explanation of Matlab commands used in the code for finding the length of crack

3.2.4: Results:

When we apply the code to the image for which the length is required to be found we find the length of all the connected components of the binary image. This length is in the form of a matrix. By converting this matrix to a simple integer we can find the exact length of the crack from an image.

After getting the length of the crack from the above code, we can compare this length with critical length of the crack and conclude following results.

1. If crack length is smaller than critical length the crack is stable and will not propagate as far as the applied stress is constant.
2. If crack length is equal to the critical length, a very slight in applied stress will cause the crack to propagate.
3. If crack length is greater than the critical length, the crack is unstable and will propagate continuously and can cause failure at any time.

3.3: Conclusion:

The following points can be concluded from the research work that was conducted for the completion of this project.

- Cracks can be detected very easily with the help of the code developed in this project.
- Method of crack detection found in the project is very easy i.e. We just need to write the location of the image having crack in the code.
- Many other methods of finding cracks have been developed by different people e.g. use of ultrasounds, use of X-Rays, Electrical Resistance method, Magnetic field method etc. but all these methods are complicated and expensive. The method of crack detection developed in this project is very cheap. We just need an image of the cracked surface and Matlab Toolbox.
- The length of crack can be easily found out by applying the code developed in this project and fracture behavior can be predicted by comparing with critical length of the crack.

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