DETERMINATION OF FRACTURE STRAIN USING STRESS RELAXATION METHOD

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ABSTRACT

This project is a study on determination of fracture strain using stress relaxation method. The objectives of this project are to determine fracture strain of API X65 using stress relaxation method and to investigate the effect of true stress-strain data on failure initiation point. This project involves both analysis and experiment of the API X65 steel using tensile test and MSc Marc 2008 r1 software. This project will determine fracture of ductile material using stress relaxation method. For validation, simulated results using stress relaxation method are compared with the experimental data for API X65 steel. Advantages in the use of the stress relaxation method for practical used are discussed. The results show that good comparison between simulation and experimental results support the method of stress relaxation method.

ABSTRAK

Projek ini merupakan stu kajian pentuan ketegangan patah menggunakan kaedah kelonggaran tekanan. Objektif project ini adalah untuk menentukan ketegangan patah keluli API X65 menggunakan kaedah kelonggaran tekanan dan untuk menyiasat kesan perubahan data tegasan-tarikan sebenar pada titik permulaan kegagalan. Projek ini melibatkan kedua-dua analisis dan eksperimen keluli API X65 menggunakan ujian tegangan dan perisian MSc Marc 2008 r1. Projek ini akan menentukan patah bahan mulur menggunakan kaedah kelonggaran tekanan. Untuk pengesahan, keputusan simulasi menggunakan kaedah kelonggaran tekanan dibanding dengan data eksperimen untuk keluli API X65. Kelebihan dalam penggunaan kaedah kelonggaran tekanan untuk kegunaan praktikal akan dibincangkan. Hasilnya menunjukkan bahawa perbandingan yang baik antara simulasi dan keputusan eksperimen menyokong kaedah kaedah kelonggaran tekanan.

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LIST OF SYMBOL

mm	Milimiter
Mpa	Mega Pascal
E	Young Modulus
σ	Stress
e	Strain
UTS	Ultimate Tensile Strength
Y	Yield Strength
F	Force
%	Percent
Cu	Cuprum
H_2	Hydrogen
O_2	Oxygen
ε_E	Engineering Strain
ε_T	True Strain
σ_E	Engineering Stress
σ_T	True Stress
$\varepsilon_1=\varepsilon_2=\varepsilon_P$	Plastic Strain
σ_y	Yield Strength
K	Kelvin
m	Meter
GPa	Giga Pascal
kg	Kilogram

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineer
API	American Petroleum Institute
MS	Malaysian Standard
LPG	Liquefied Petroleum Gas
NG	Natural Gas
ANSI	American National Standards institute
SEM	Scanning Electron Microscope
FEA	Finite Element Analysis
FEM	Finite Element Method
WEDM	Wire-Cut Electrical Discharge Machining
CSV	Comma-Separated Values
BC	Boundary Conditions
RPM	Revolution Per Minute
CS	Cutting Speed
N	Spindle Speed
CW	Clock Wise
CCW	Counter Clock Wise
CNC	Computer Numerical Control
2-D	2 Dimensional
3-D	3 Dimensional

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain about the introduction of this project. The introduction must be clear before rub any project. This chapter will consist of project background, problem statement, objective and scope of study. All this information is important before furthering to the analysis and study later.

1.2 PROJECT BACKGROUND

This project will present a method to determine the value of fracture strain using finite element analysis based on the experimental value using tensile test. A procedure is given to determine the stress modified fracture strain as a function of the stress triaxiality from smooth and notched bar tensile test. Based on detailed finite element analysis, the result is compared with experimental data for smooth and notched bar tensile test. The material that will be use is API X65 steel. The validity of the approach is verified by comparing tensile test results with finite element analysis solutions obtained using modified true stress-strain curve.

1.3 PROBLEM STATEMENT

Tensile test is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. This will give cost to the manufacture to perform tensile test. With this project, the cost can be cut by using finite element analysis to determine the value of fracture strain. We can apply the real situation into the analysis using finite element method. This will help to have better quality control and also can predict the reaction of material without doing the real tensile test because it can be simulated in finite element analysis.

1.4 OBJECTIVES

For this project, the two main objectives are listed:

i. To determine fracture strain of API X65 using stress relaxation method.

ii. To investigate the effect of true stress-strain data on failure initiation point.

1.5 SCOPE OF STUDY

The scope of this project is to determine the value of fracture strain of API X65 using finite element analysis. The specimen will be in four different sizes that are smooth and three values of radius (R1.5, R3, and R6) of notched. This project will focus on API X65 as the material. This test will consist with two part that is usng tensile test and software that is MSC Marc 2008 r1 to simulate the tensile test. This simulation will consist of plastics and elastic deformation.

CHAPTER 2

LITERARTURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about tensile test, fracture strain, types of fracture, stress and strain, API X65, finite element analysis, and journals that have been done by current researchers. Besides that, the information about the software that has been used also included here. All this information is important before furthering to the analysis and study later.

2.2 STRESS AND STRAIN

During the tensile test samples of materials, stress-strain curve is a graphical representation between stress, derived from measuring the load applied to the sample, and strain, which is derived from measuring the deformation of the sample such as elongation, compression, or distortion. The slope of the stress-strain curve at any time is called the tangent modulus, slope of the linear elastic curve is a property used to characterize the materials and are known as Young’s modulus. The area under the curve known as the elastic modulus of resilience.

In general, stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on. If there is stress, there will be strain because stress causes strain. Putting pressure on an object is being causes it to stretch. Strain is a measure of how much an object is being stretched. Strain is related to change in dimensions and shape of a material. When a material is stretched the change in length and strain are positive. When it is compressed, the change in length and strain are negative. This conforms to the signs of stresses which would accompany these strains, tensile stresses being positive and compressive stresses negative. This definition refers to what are termed normal strains, which change the dimensions of a material but not its shape, in other words, angles do not change. In general, there are normal strains along three mutually perpendicular axes.

Stress-strain diagrams of various materials vary widely, and different tensile tests conducted on the same material may yield different results, depending upon the temperature of the specimen and the speed of the loading. It is possible, however, to distinguish some common characteristics among the stress-strain diagrams of various groups of materials divide into two broad categories on the basis of these characteristics, namely ductile materials and the brittle materials.

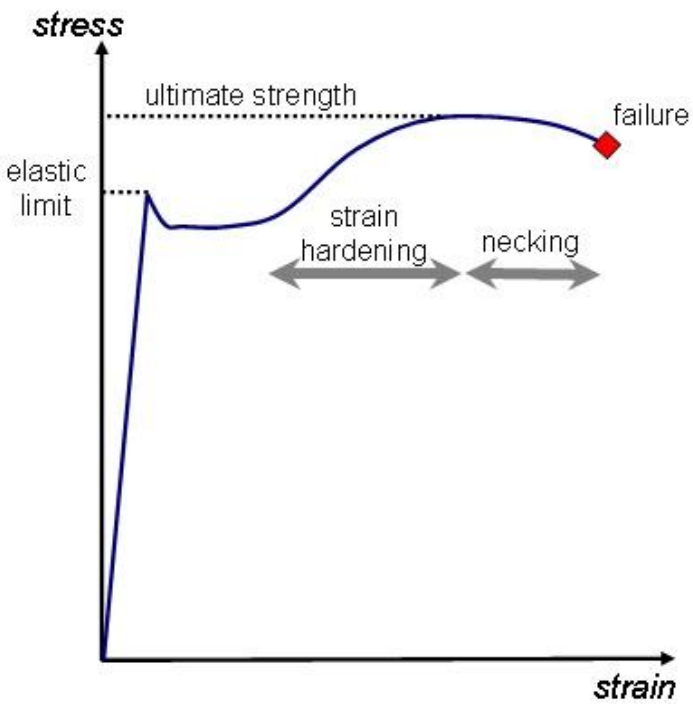

Figure 2.1: Stress-strain curve for mild steel

Source: Ling, (1996)

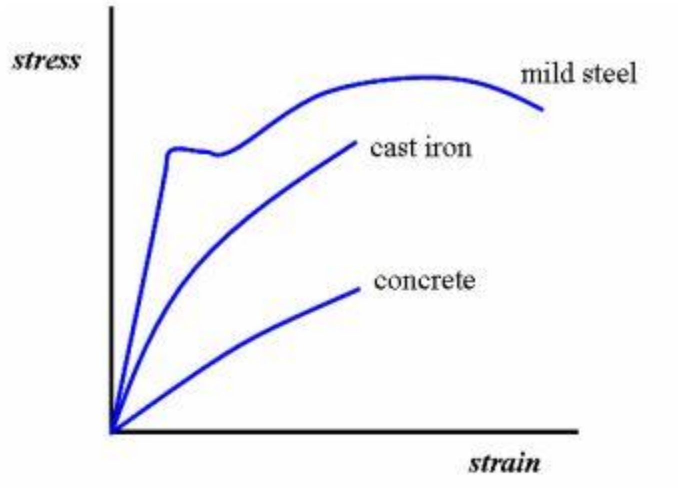

Figure 2.2: Stress-strain curve

Source: Ling, (1996)

2.2.1 Engineering Stress-Strain Curve

Engineering tension test is widely used to provide basic design information on the strength of materials and the acceptance tests for the specification of the materials. In the tension test specimens subjected to uniaxial tensile force which continues to increase while the elongation of specimens made simultaneous observations. The shape and magnitude of the stress-strain curve of a metal will depend on the composition, heat treatment, history or prior to plastic deformation, and strain rate, temperature, and the force applied during the test. Parameters used to describe the stress-strain curve of a metal, are tensile strength, yield strength or yield point, elongation percent and reduction area. Tensile strength and yield strength are strength parameter, while elongation percent and reduction area indicate ductility.

2.2.2 True Stress –Strain Curve

The true stress-strain curves are based on instantaneous gage length and instantaneous cross-sectional area of the specimen. Therefore, the area under the curve is up to a specific strain is proportional to the energy required to create that level of strain or the energy absorbed ‘when that level of strain is imparted to a part. Because of that, true stress always rises in the plastic region.

During stress testing of a material sample, the stress–strain curve is a graphical representation of the relationship between stress, obtained from measuring the load applied on the sample, and strain, derived from measuring the deformation of the sample. The nature of the curve varies from material to material.

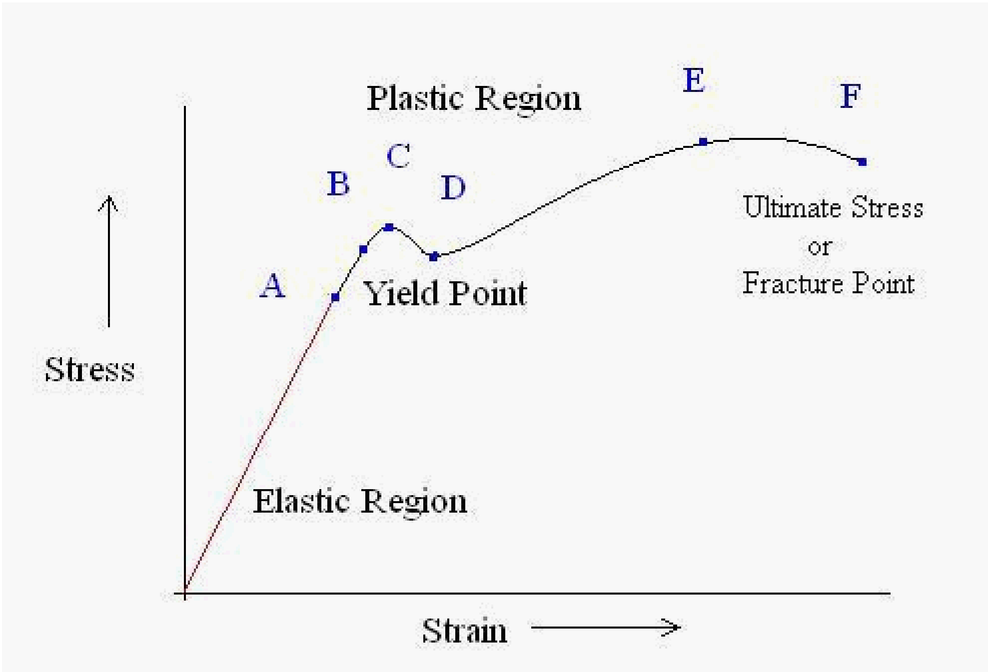

Figure 2.3 : Typical stress-strain curve

Source: Ling, (1996)

Point A: At origin, there is no initial stress or strain in the test piece. Up to point *A* Hooke's Law is obeyed according to which stress is directly proportional to strain. That's why the point *A* is also known as proportional limit. This straight line region is known as elastic region and the material can regain its original shape after removal of load.

Point B: The portion of the curve between *AB* is not a straight line and strain increases faster than stress at all points on the curve beyond point *A*. Point *B* is the point after which any continuous stress results in permanent, or inelastic deformation. Thus, point *B* is known as the elastic limit or yield point.

Point C & D: Beyond the point *B*, the material goes to the plastic stage till the point *C* is reached. At this point the cross- sectional area of the material starts decreasing and the stress decreases to point *D*. At point *D* the workpiece changes its length with a little or without any increase in stress up to point *E*.

Point E: Point *E* indicates the location of the value of the ultimate stress. The portion *DE* is called the yielding of the material at constant stress. From point *E* onwards, the strength of the material increases and requires more stress for deformation, until point *F* is reached.

Point F: A material is considered to have completely failed once it reaches the ultimate stress. The point of fracture, or the actual tearing of the material, does not occur until point *F*. The point *F* is also called ultimate point or fracture point.

Therefore, availability of a method similar in principle to (Zhang and Li, 1994) approach but much simpler is highly desirable. A power law is often used to represent the whole flow curve, for instance , where *K* and *n* are empirical constants determined from known true stress-strain data before necking.

Modern FEA programs do not require input of the uniaxial true stress-strain function in analytical form. It is entered numerically as ordered pairs taken from experimental data and the power law or any other function in analytical form are not necessary for curve fitting the measured true stress-strain data before necking. The power law may be useful for extrapolation of the true stress-strain curve beyond necking (Ling, 1996).

True stress–strain curves can be obtained using tensile (Bridgman, 1952; Cabezas and Celentano, 2004; Koc and Stok, 2004; Komori, 2002; Mirone, 2004;

Zhang, 1995; Zhang et al., 1999), compression, ball indentation, punch, torsion, and notch tensile tests. Haddadi et al. (2006) and Bouvier et al. (2006) studied the anisotropic behaviors of sheet metals under large plastic deformations using the simple shear test. Most of these methods obtain true stress–strain relations only for strains less than 0.5. However, the maximum strain often exceeds 1.0 in bulk metal forming, such as in forging, extrusion, and rolling. Sometimes it reaches 3.0 in multi-stage automatic cold forging, the so-called cold-former forging used to produce fasteners.

Recently, many researchers have tried to obtain true stress–strain curves using finite element methods, see e.g. (Cabezas and Celentano, 2004; Campitelli et al., 2004; Choi et al., 1997; Husain et al., 2004; Isselin et al., 2006; Lee et al., 2005; Mirone, 2004; Nayebi et al., 2002; Springmann and Kuna, 2005). In a tensile test, the true strain reaches its maximum value at the smallest cross-section in the necked region, and it may exceed 1.5 just before a ductile material fractures. Therefore, one should be able to obtain the flow stress of materials at a large strain if finite element methods are used to predict the localized deformation behavior during a tensile test. A few researchers have attempted to obtain the flow stress at a large strain using simulation and experimental approaches, but these applications have been quite limited, see e.g. (Cabezas and Celentano, 2004; Mirone, 2004).

2.2.3 Comparison Of Engineering And True Stress-Strain Curves

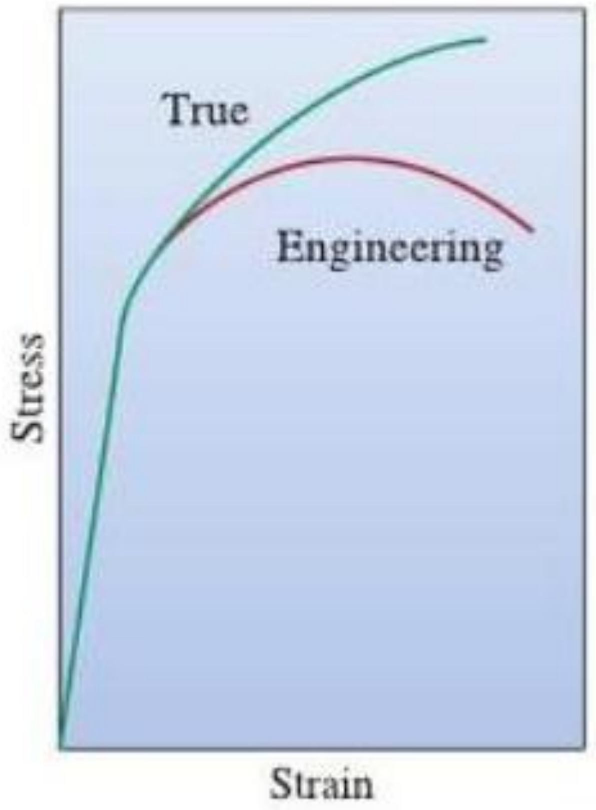

Figure 2.4: Graf of engineering and true stress strain curve

Source: C.K. Oh, (2011)

2.3 FRACTURE STRAIN

From detailed elastic-plastic FE analyses with the large geometry change option, accurate values of stress and strain components can be determined at every stage of deformation. By combining such information with notched bar tensile test results, a ductile failure criterion in terms of the equivalent strain to failure as a function of the stress triaxiality can established. Before proceeding, it should be noted that stress and strain are defined only at appoint.

Different positions with notched bar can be chose, which lead to different failure criteria. One possible approach is to develop a failure criterion based on stress and strain at the location where the failure is most likely to initiate, which corresponds to the site with the highest stress triaxiality and strain or with the highest damage. Another interesting approach is based on average stress and strain over the minimum section. Although the former approach is more plausible, the latter approach could offer some advantages in practical application to defect assessment.

2.4 PLANE STRESS

Plane stress is defined to be a state of stress in which the normal stress, σ_z, and the shear stress, σ_{xz} and σ_{yz}, directed perpendicular to the *x-y* plane are assumed to be zero. The geometry of the body is essential that one of the plate with one dimension much smaller than the others. The loads are applied uniformly over the thickness of the plate as shown. The plane stress condition is the simplest form of behavior for continuum structures and represents situations frequently encountered in practice.

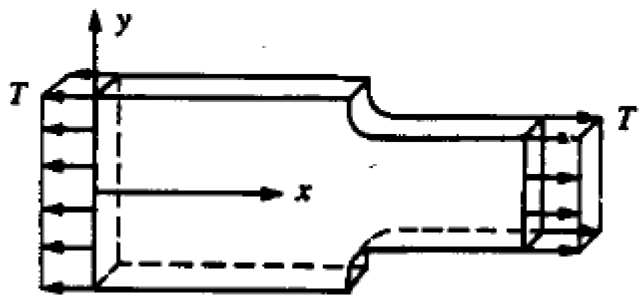

Figure 2.5: Plate with fillet

Source: Choung and Cho, (2008)

2.5 PLANE STRAIN

Plane strain is defined to be a state of strain which the strain normal to the *x*-*y* plane, ε_z, and the shear strain γ_{xz} and γ_{yz}, are assumed to be zero. In plane strain, one deals with a situation in which the dimension of the structure in one direction, say the *z*-coordinate direction, is very large in comparison with the dimensions of the structure in the other two directions (*x*-and *y*-coordinate axes), the geometry of the body is essentially that of prismatic cylinder with one dimension much larger than the others. The applied forces act in the *x*-*y* plane and do not vary in the *z* direction. For example, the loads are uniformly distributed with respect to the large dimension and act perpendicular to it. Some important practical applications of this representation occur in the analysis of bars and rollers compressed by forces normal to their cross section are amenable to analysis in this way.

2.6 DUCTILE FRACTURE

In ductile fracture, extensive plastic deformation (necking) occurs prior to fracture. Breach of the terms of major failure of the ductile fracture reflects ductile materials loaded in the tension difficult. Instead of cracking, the material will pull apart. In this case, there is slow diffusion and absorption of large amounts of energy before breaking. Many ductile metals, in particular materials with high purity, can sustain very large deformation or strain before fracture under favorable loading condition and environmental condition. At room temperature, pure iron can undergo deformation up to 100% strain before breaking, while high carbon steel cannot maintain 3% strain.

Because of the ductile fracture involves a degree of high plastic deformation, fracture behavior of the crack propagates as a model on the basic of change. Some of the energy of the stress concentration at the crack tip is dissipated by plastic deformation before crack propagates. The characteristics of ductile fracture are there is permanent deformation at the tip of the advancing crack that leaves distinct patterns in SEM images. As with brittle fractures, the surface of a ductile fracture tends to be perpendicular to the principal tensile stress, although other components of stress can be factors. In ductile, crystalline metals and ceramics it is microscopically resolved shear stress that is operating to expand the tip of the crack. There also has to be a lot of energy available to extend the crack.

2.7 BRITTLE FRACTURE

In brittle fracture, no apparent plastic deformation takes place before fracture. In brittle crystalline materials, fracture can occur by cleavage as the result of tensile stress acting normal to crystallographic planes with low bonding. In amorphous solids, by contrast, the lack of crystalline structure results in a conchoidal fracture, with cracks proceeding normal to the applied tension.

Some characteristics of brittle fracture are there is no gross, permanent deformation of the material. The surface of the brittle fracture tends to be perpendicular to the principal tensile stress although other components of stress can be factor. Besides that, characteristic crack advance markings frequently point to where the fracture originated. The path of the crack also follow depends on the material's structure. In metals, transgranular and intergranular cleavage are important. Cleavage shows up clearly in the SEM.

2.8 MATERIALS PROPERTIES OF PIPELINE

2.8.1 Materials

A summary of the relevant properties of these materials is given in Table 2.1. To make a complete economic assessment of the various competitive materials taking into account all the factors enumerated above is a matter of extreme complexity, verging on the impossible. Adequate data on service conditions may not be available and even if the initial conditions can be specified fairly precisely, they may subsequently change in an unpredictable manner. Estimates of the probability of satisfactory behavior for the various materials will have to be made. First costs must be balanced against subsequent costs of maintenance, repair and replacement and loss of revenue due to outage. The calculations need to include assumptions about