FRACTURE TOUGHNESS OF RAILWAY TRACK MATERIAL USING FINITE ELEMENT ANALYSIS

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AWARD FOR DEGREE

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Railway track are used as way for carrying cargo or passengers from one place to another place. Nowadays, Malaysia still using the old railway line and accidents can happen at any time due to several factors, namely high density load of railroad rails, cracks due to vibration and friction wheel. Therefore, in this project the analysis is to prevent and predict the occurrence of harm or injury to passengers, and goods. The objective of this project is to determine the value of fracture toughness of railway track material using analytical solution. Finite element analysis is used to find the value of stress that has been used in analytical equation. The design of the model specimen drawn by Solidworks software and then imported into the Patran software to key in data such as load, material, element, and properties. Then, Nastran software is used as a solver and decision analysis model will be produced when the specimen is successful simulated. Comparisons are made between the simulation using finite element analysis and previous research. The result shows that the fracture toughness decreasing when the thickness is increasing. The average value of fracture toughness found was 39.02 MPa.√m. It is said to be plane strain fracture toughness.

ABSTRAK

Landasan rel keretapi digunakan sebagai laluan untuk membawa muatan atau penumpang dari suatu tempat ke tempat yang lain melalui laluan tertentu. Saat ini, Malaysia masih menggunakan laluan kereta api lama dan kemalangan boleh terjadi pada bila-bila masa saja disebabkan oleh beberapa faktor, iaitu beban yang tinggi pada rel kereta api, retak kerana getaran dan geseran pada roda. Oleh kerana itu, analisa ini adalah untuk mengelakkan berlakunya kerosakan atau kecederaan pada penumpang, dan barang-barang. Tujuan dari projek ini adalah untuk menentukan nilai ketangguhan retak menggunakan penyelesaian analitis. Analisis unsur terhingga digunakan untuk mencari nilai tekanan yang telah digunakan dalam persamaan analitis. Spesimen reka bentuk model dilukis dengan menggunakan perisisan Solidworks dan selepas itu dimasukan ke dalam perisian Patran untuk memasukkan data seperti beban, bahan, unsur, dan sifat. Kemudian, dengan menggunakan perisian Nastran untuk analisis dan model analisis keputusan akan dihasilkan ketika spesimen berjaya disimulasikan.Perbandingan dilakukan antara simulasi dengan menggunakan penyuluh dan penelitian terlebih dahulu. Keputusan kajian menunjukkan pada ketangguhan retak berkurang dengan ketebalan meningkat. Nilai rata-rata Ketangguhan retak ditemui adalah 39.02 MPa.√m. Hal ini dikatakan regangan bidang ketangguhan retak.

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LIST OF SYMBOLS

K_I	is the fracture toughness in MPa.√m
σ	is the applied stress in MPa
a	is the crack length in meters or inches
Y	geometry factor
P_Q	load, kN
S	span length
B	specimen thickness, mm
W	specimen width
$f\left(\frac{a}{w}\right)$	geometrical factor

LIST OF ABBREVIATIONS

ASTM	American Standard Testing Method
SENB	Single Edge Notch Bend
CT	Compact Tension
FEM	Finite Element Method
FEA	Finite Element Analysis

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Rail track network forms an essential part of the transportation system of a country and plays a vital role in its economy. It is responsible for transporting freight and bulk commodities between major cities, ports and industries, and carrying passengers, especially in urban areas. Hundreds of millions of dollars are spent each year for the construction and maintenance of rail tracks in large countries like the USA, Canada and Australia. The efficient and optimum use of these funds is a challenging task which demands innovative and cutting edge technologies in railway engineering. The efficiency and safety of a railway track, including passenger comfort, depends on the complex interaction of various system components in response to the cyclic wheel loading of various magnitudes and frequencies (Indraratna B. and Salim W.,2005).

Nevertheless, the annual frequency of accidents with people kills or seriously injured is strikingly high, and more than half of these accidents happen under circumstances that suggest suicide or attempted suicide. If rail workers' accidents are included in the figures, the incidence of serious accidents is around 100 per year - an average of about two death or disabilities per week on the railway lines, according to the Swedish National Railway Administration's latest statistics report (Banverket, 2004) as shown in Table 1.1.

Table 1.1: Number of accidents on the Swedish railways, including suicide or attempted suicide, from 1997 to 2003. Passenger accidents, including passage to or from trains at stations, train collision, and electric accidents are not included.

	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Killed	96	71	73	69	83	80	76
Injured	27	13	22	39	34	14	19
Sum	123	84	95	108	117	94	95

Source: Wilson J.R. (2005)

The consequences of these accidents are extensive for everyone involved, including the train drivers, who risk experiencing at least one such fatal accident during their working life (Wilson J.R., 2005).

In Malaysia, the last 10 years was witnessed rapid development of rail based public transportation system especially in Kuala Lumpur, the capital of Malaysia and centre of Malaysia's economic activity. Kuala Lumpur's rail-based transit system consists of two Light Rail Transit lines (rapid transit), one monorail line, two commuter rail systems consisting four lines, and an airport rail link.

1.1.1 Light rail

There are three systems which are called light rail transits in Malaysia. Two are used in Kuala Lumpur to ferry paying passengers while the third is used at Kuala Lumpur International Airport to ferry passengers from the Main Terminal Building and the satellite building.

The two lines in Kuala Lumpur are the Kelana Jaya Line and the Ampang Line. The Kelana Jaya Line is a driver-less automatic system and is 29 km long, running between the northeastern suburbs of Kuala Lumpur and Petaling Jaya to the west of Kuala Lumpur. It is mostly elevated except for a 4km stretch where it goes underground and there is a short at-grade stretch. The Kelana Jaya Line was completely operational from June 1999. The older Ampang Line is 27 km and consists of two lines, running between the suburb of Sentul in the north of Kuala Lumpur, and Ampang in the east, as well as Sri Petaling in the south. Trains branch off to either Ampang or Sri Petaling at

Chan Sow Lin station about midway of both lines. The system is mostly at-grade outside the city, and elevated with it runs through the city. Unlike the trains on the Kelana Jaya Line, those on the Ampang Line have drivers. The line was completely opened on 1998.

The light rail system at Kuala Lumpur International Airport, called the Aerotrain, is a simple people-mover shuttle system running along two 1,286 m guiderails between the Main Terminal Building and Satellite Building. The two ends of the guiderails are elevated while the middle portion goes under the main airport taxiway. Each rail has a three-car automatic driver-less train.

1.1.2 Monorail

Malaysia's only monorail system is used for public transport in Kuala Lumpur. It is 8.6km long, running from Titiwangsa in the north of central Kuala Lumpur, to KL Sentral just to the south of the city center. It has 11 stations. The line consists of two parallel rails for most of the way except at the end stations where switches merge the two rails into a single rail before entering the station. The entire network is elevated. The system uses two-car trains which were manufactured in Malaysia. It is operated by KL Monorail Sdn Bhd.

There are proposals to construct monorails in Penang, Johor Bahru and Malacca but opposition has been vociferously expressed by Penang and Malacca residents concerned about the system being out of place in the historic downtown areas. Melaka has since focused on the less intrusive Aerorail. The federal administrative centre of Putrajaya was also supposed to have a monorail network and the main station and several metres of track have been built. However, the project has been postponed because of costs and the Malaysian government felt that it was not a priority project for the time being even though good public transportation would attract many Malaysians to re-locate to this new underpopulated city.

1.1.3 Keretapi Tanah Melayu Berhad

The main intercity passenger train operator is Keretapi Tanah Melayu Berhad (KTMB), a corporation owned by the Malaysian government. It operates KTM Intercity passenger trains on both main lines and the Bukit Mertajam-Butterworth branch

The other branch lines are either used for freight or not used at all, with the exception of the Kuala Lumpur-Port Klang and Batu Junction-Sentul stretch of the Batu Caves branch lines which are used for its commuter train service, KTM Komuter. The commuter service also uses the double-track and electrified portions of the West Coast Line between Rawang and Seremban. KTMB is also the main operator of freight trains in Malaysia.

Besides its own network, KTMB also operates trains on the Kerteh-Kuantan railway under contract with Petronas, the owner of the line. Although there has been no specific study on the impact of rail services in Kuala Lumpur, general observation indicate positive results. Since the introduction of Keretapi Tanah Melayu, followed by the two LRTs, ERT and KL monorail, Kuala Lumpur's road congestion has not worsened significantly, suggestion that rail based transit systems have contributed towards helping more people use public transport. Without urban rail services, Kuala Lumpur's traffic congestion would be much worse (Internet sited 2 March 2010, 11.52p.m).

1.2 BACKGROUND OF STUDY PROBLEM

There is a worldwide trend to use more computer simulation during the development phase of new vehicle or product, in order to improve structural behavior and decrease the incident and to know the lifespan of a material that can withstand. Accurate finite element model must be generated in order to predict the system structural behavior and to allow fast optimization process. This work shows the FAE procedure applied to rail track material.

Finite element analysis (FEA) consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

1.3 PROJECT OBJECTIVES

The research is focus on:-

a) To determine the value of fracture toughness (K_c) of railway track material using analytical solution.
b) To determine the value of stress by using the finite element analysis.
c) To compare the value of fracture toughness with previous research.

1.4 PROBLEM STATEMENT

Nowadays, many of accidents with people kill or seriously injured is because of rail track railway, not follow the rules, natural disasters and etcetera. So, in this project the analysis is to fix the problem using the finite element analysis software to find the value of fracture toughness of railway track material. While the causes of train accidents are numerous, the most common ones involve mechanical failure, maintenance problems, human error, structural defects, and old and improperly maintained tracks.

1.5 SCOPE OF PROJECTS

This project focused on Finite Element Analysis method by using the software analysis, Patran, Nastran and Solidworks software to determine the value of fracture toughness K_{IC}. The material used at the track railway is mild steel. The Solidworks are used to design the specimen and import to Patran and Nastran. In Patran and Nastran, the model analysis was used to get the data about the fracture toughness of railway track material. Analysis in this project focus on single edge notch bends (SENB) specimen. The dimensions used in the software is followed the previous research as the comparison.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A fracture is the (local) separation of an object or material into two, or more, pieces under the action of stress. The word fracture is often applied to bones of living creatures, or to crystals or crystalline materials, such as gemstones or metal. Sometimes, in crystalline materials, individual crystals fracture without the body actually separating into two or more pieces. Depending on the substance which is fractured, a fracture reduces strength (most substances) or inhibits transmission of light (optical crystals). A detailed understanding of how fracture occurs in materials may be assisted by the study of fracture mechanics.

2.2 FRACTURE DUCTILITY

The initiated local fracture will continue to propagate. The extent of fracture propagation varies according to the "brittleness" of the material. The fracturing processes can be classified in three categories. Once initiated, the localized fracture will continue to grow rapidly across the specimen without further increase in a, or fracture toughness, *K* (Liu. H.W.1983). It is very brittle (Figure 2.1a).

The localized fracture will continue to grow to a sizable extent in a rapid manner while (T, and ***K*** drop. After the initial fracture, it needs to increase ***K*** in order to continue to grow further (Liu. H.W.1983) (Figure 2.1b).

If fracture initiation is caused by brittle particles and if the brittle particles are small and far apart, once the local fracture is initiated, it needs a considerable amount of plastic deformation to grow across the regions between particles. A crack grows primarily by the process of plastic deformation. This material is ductile and tough (Figure 2.1c).

Fracture is initiated in the interior in the plane strain region, and the initial fracturing process will stop when the crack is out of the zone of triaxial state of tension.

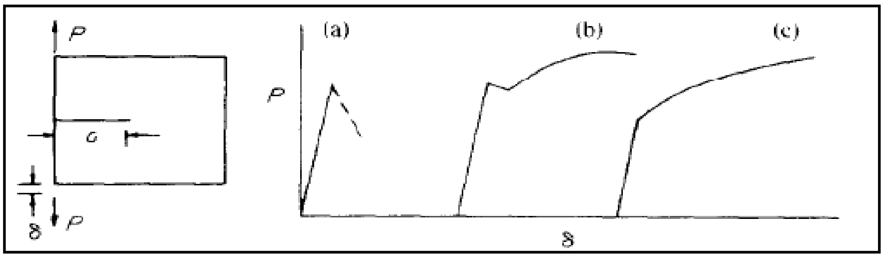

Figure 2.1: Schematic diagrams of load versus load point displacement showing difference in fracture ductility (Liu. H.W., 1983).

The maximum tensile stress, σ_{max}, could be the parameter that controls fracture initiation in the case of brittle particles, the nucleated crack may then propagate rapidly for a clear definition of $\boldsymbol{K_I}$, as shown in Figure 2.1(a) and 2.1(b). In this case, $\boldsymbol{K_{Ic}}$ might be correlated with σ max. On the other hand, if the particles are small and far apart, the nucleated minute local fractures will grow by a mechanism which needs a great deal of plastic deformation. If $\boldsymbol{K_{Ic}}$ is defined by a specific amount of crack growth, primarily by a mechanism of plastic deformation, $\boldsymbol{K_{Ic}}$ will be correlated better with the effective plastic strain, ϵ^p. If a crack propagates by the shear-off process between the ductile matrix and hard second phase, then the maximum shear strain should be used.

Once a crack starts to grow, the crack will continue to propagate as the applied stress is increased (Liu. H.W., 1983). As a crack grows, the crack shifts its fracture surface from mode I to a combination of modes I, II, and III as shown in Figure 2.2. The stable crack growth is the result of a series of successive local fractures, as the crack changes from mode I to a combination of modes I, II and III accompanied by the decrease in the principle tensile stress and an increase of fracture ductility (Liu. H.W., 1983).

2.3 FRACTURE TOUGHNESS

Fracture toughness is an indication of the amount of stress required to propagate a preexisting flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component (Sajuri Z., 2009). Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof (Sajuri Z., 2009). Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics (LEFM) approach to design critical components (Sajuri Z., 2009). This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture.

A parameter called the stress-intensity factor, K_{Ic} is used to determine the fracture toughness of most materials. A Roman numeral subscript indicates the mode of fracture and the three modes of fracture are illustrated in the image to the right. Mode I fracture is the condition in which the crack plane is normal to the direction of largest tensile loading. This is the most commonly encountered mode and, therefore, for the remainder of the material we will consider K_I.

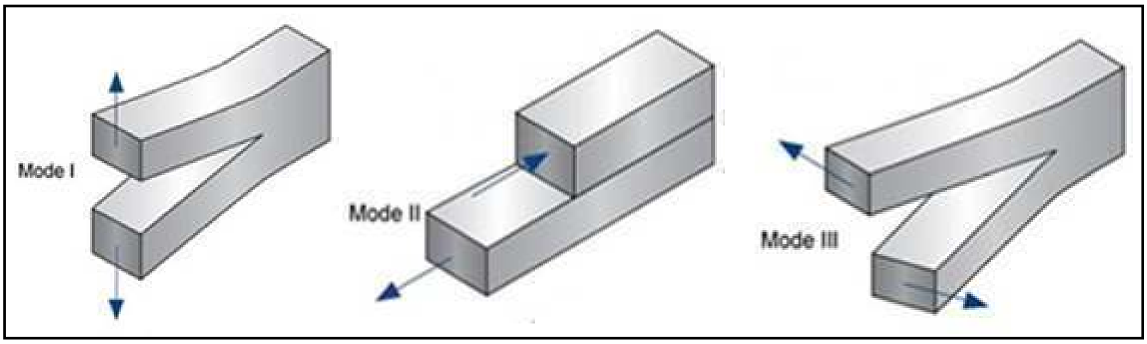

Figure 2.2: Type mode of fracture (Sajuri Z. 2009)

The stress intensity factor is a function of loading, crack size, and structural geometry. The stress intensity factor may be represented by the following equation as shown as follow

$$K_I = \sigma\sqrt{\pi a}\ Y \tag{2.1}$$

where	K_I	is the fracture toughness in MPa.√m
	σ	is the applied stress in MPa
	a	is the crack length in meters or inches
	Y	geometry factor

2.3.1 Role of Material Thickness

Figure 2.3 show that the specimens having standard proportions but different absolute size produce different values for K_I. This results because the stress states adjacent to the flaw changes with the specimen thickness (B) until the thickness exceeds some critical dimension. Once the thickness exceeds the critical dimension, the value of K_I becomes relatively constant and this value, K_{Ic} , is a true material property which is called the plane-strain fracture toughness. The relationship between stress intensity, K_I, and fracture toughness, K_{Ic}, is similar to the relationship between stress and tensile stress. The stress intensity, K_I, represents the level of "stress" at the tip of the crack and the fracture toughness, K_{Ic}, is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. As the stress intensity factor reaches the K_{Ic} value, unstable fracture occurs. As with a material's other mechanical properties, K_{Ic} is commonly reported in reference books and other sources.

2.3.2 Plane Strain and Stress

When a material with a crack is loaded in tension, the materials develop plastic strains as the yield stress is exceeded in the region near the crack tip. Material within the crack tip stress field, situated close to a free surface, can deform laterally (in the z-direction of the image) because there can be no stresses normal to the free surface. The