AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Design and Production Engineering

Fracture Toughness Assessment for Steel Pipes Used in Gas Pipelines

A Thesis submitted in partial fulfillment of the requirements of the degree of

Master of Science in Mechanical Engineering

(Design and Production Engineering)

by

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Statement

This thesis is submitted in a partial fulfillment of Master of Science in Mechanical Engineering, specialization (Production Engineering), Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Thesis Summary

The current work is focused on studying the Fracture assessment of steels pipe with different grades. The research is divided into two parts. The first part is focused on determination of the fracture energy for materials used in natural gas pipelines. Double edge notch tension (DENT) samples with different ligament lengths of each pipe thickness were tested in tension to determine the fracture energy of each material. Increasing the pipe thickness increased the essential work of fracture. The results have a qualitative agreement with previous work.

The second part is studying the fracture toughness on full scale steel pipes under internal pressure with axial partially-through crack using two analytical methods Folin-Ciocalteu method (FC method) and Gauss–Seidel method (GS method). In this work, a comparison is made between results obtained from FC and GS methods. The GS is more conservative assessment method as it provides smaller crack depth (a) corresponding to (J_{cr}). In addition, Finite Element model was established to simulate the crack propagation in full scale pipe. Generally, Finite Element model is almost more conservative than the analytical methods and its results close to the experimental values.

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Nomenclature

LEFM	Linear Elastic Fracture Mechanics
EPFM	Elastic-Plastic Fracture Mechanics
K	The stress intensity factor
K_I	The stress intensity factor - mode I
K_C	Critical stress intensity factor = fracture toughness
K_{IC}	Plane strain fracture toughness - mode I (material property)
r and θ	Cylindrical polar coordinates of a point with respect to crack tip
$\sigma_{app.}$	The applied stress
h	Crack length
w	The specimen width
$f\left(\frac{h}{w}\right)$	Dimensionless parameter that depend on the geometries of the specimen and crack
P	Applied load
G	Energy release rate
J-Integral	Fracture toughness parameter for elastic-plastic material
$J_{el.}$	J - elastic
$J_{pl.}$	J - plastic
J-R curve	J resistance curve
J_c	The critical J-Integral value
CTOD	Crack Tip Opening Displacement
ρ	The length of the plastic zone
E	Modulus of elasticity
υ	Poisson’s ratio
SENB	Single edge notched bend specimen
CT	Compact tension specimen
T_i	Components of the traction vector
u_i	Displacement vector components
ds	Length increment along the contour Γ
EWF	Essential work of fracture method
DENT	Double Edge Notched Tension specimens
l	Sample nominal ligament length

t	Specimen thickness
W_F	Total work of fracture
W_e	Essential work of fracture
W_p	Non-essential work of fracture
w_F	Specific total work of fracture
w_e	Specific essential work of fracture
w_p	Specific non-essential work of fracture (plastic work per unit volume)
β	The shape factor associated with the volume of plastic deformation zone (it depends on the geometry of yield zone)
GE/EPRI method	General Electric/Electric Power Research Institute method
LBB.NRC method	Leak Before Break/Nuclear Regulatory Commission method
c	Half crack length of axial semi-elliptical part-through crack for full scale pipe
a	Crack depth of axial semi-elliptical part-through crack for full scale pipe
a_{cr}	Critical crack depth for full scale pipe
σ_h	The hoop stress for pipe
p	Pipe internal pressure
D	Pipe outer diameter
R	Pipe outer radius
M_F	A front-face correction on the stress intensity factor for the surface crack
$E_{(K)}$	Elliptical integral of the second kind
M_{TM}	The shell-curvature correction factor for a surface crack
M_T	Folias correction factor which include the effect of pipe curvature
σ_o	The yield stress of the material
ε_o	The strain corresponding to yield strength $\varepsilon_o = \frac{\sigma_o}{E}$
α, m	Material constants (Ramberg-Osgood parameters)
σ_n	The nominal stress
σ_{true}	True stress

σ	Engineering stress
ε_{true}	True strain
e	Engineering strain
k	Strength coefficient
n	Strain hardening exponent
r_p	Plastic zone size
P_{max}.	Fracture load of DENT sample
δ_c	Critical crack opening displacement
VHN	Vickers hardness number
PZS	Plastic zone size
σ_{max}	Maximum stress on sample
d	The process zone width of DENT sample
SEM	Scanning Electron Microscope
C	Plastic constraint factor
FEM	Finite Element Method
FC Method	The Folin–Ciocalteu method
GS Method	The Gauss–Seidel method

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