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Numerical and experimental investigation of mode I cracking of asphalt concrete using semi-circular bending test

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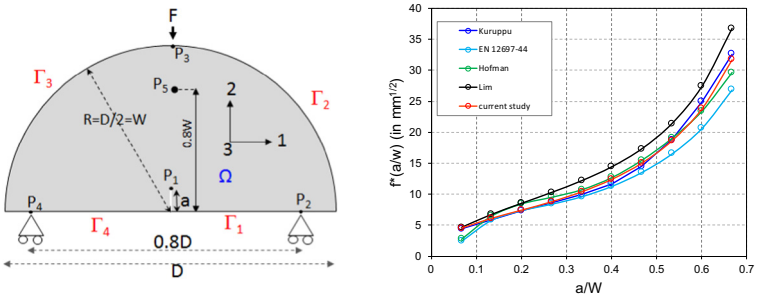
HIGHLIGHTS

- Geometrical factor $f(a/w)$ assessment procedure for SCB is presented in detail.
- Influence of Poisson' ratio is analyzed.
- 2D and 3D effects are investigated.
- Effects of temperature, loading rate and RA are studied through ANOVA.

GRAPHICAL ABSTRACT



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ABSTRACT

Mode I fracture toughness (K_{Ic}) assessment procedure is presented in this study for semi-circular bend configuration. The geometrical factor f(a/w) is determined through 2D and 3D FEM simulations assuming linear elastic behavior. Parametric analyses have been done to evaluate the sensitivity of f(a/w) to the Poisson's ratio (ν), specimen thickness (t) and position of the Gauss points where the vertical displacements are computed. The FEM analysis shows that f(a/w) is more sensitive to ν in plane strain condition (thick specimens) than plane stress condition (thin specimen). Moreover, f(a/w) decreases slightly when "t" increases from 15 to 75 mm. In addition, f(a/w) evaluated from 3D FEM is slightly higher than that obtained in 2D configuration. The results also show that f(a/w) decreases when the position of the Gauss point is chosen far from the crack tip. Full factorial experimental program has been designed to evaluate the potential influence of: reclaimed asphalt (RA) content, loading rate and temperature on the fracture toughness (K_{Ic}) and the total fracture energy (W_f). The results show that the influent parameters on the K_{Ic} can be ranked from the most important to the least one as follows: loading rate, temperature and RA content. They also show that temperature is the most influent parameter on W_f, while the loading rate is the least influent one. K_{Ic} and W_f results have been modeled by polynomial functions.

1. Introduction

Several fracture test configurations have been developed to investigate the fracture toughness of asphalt mixtures. In most tests the specimen is notched to initiate the cracking. Today, the most common test configurations are:

- the single edge notched bend beam (SENB) subjected to three or four-point bending test [1–3],
- the modified indirect tension (IDT) test [4],
- the disc shape compact tension (DCT) test [5],
- the semi circular bend (SCB) test [6–13].

These test configurations allow measuring at least mode I cracking and some of them can be modified to evaluate mixed mode I/II fracture. The advantages and drawbacks of these test

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Nomenclature

a	crack length, m
A_{lig}	area of the ligament, m^2
a/w	relative crack length
ANOVA Analysis of variance	
C	compliance, Nm^{-1}
D	specimen diameter, m
DoF	degree of freedom
E, E'	stiffness modulus, MPa
e_i	square of errors between model and experiment
f(a/w)	dimensionless geometrical factor
f*(a/w)	dimensional geometrical factor, $mm^{1/2}$
F_0	nominal or applied load, N
F_{max}	maximum load at failure, N
FEM	finite element method
G	energy release rate, $J.m^{-2}$
G_f	fracture energy, Jm^{-2}
k	stiffness, $m.N^{-1}$
K_{Ic}	fracture toughness, $N.mm^{-3/2}$
LEFM	linear elastic fracture mechanics
LA	Los Angeles property, %
LR	loading rate, $mm.min^{-1}$
m	number of test results
M_{DE}	Microdeval property, %
n	surface normal vector
PMB	Polymer modified bitumen
R	radius of the specimen, m
RA	Reclaimed asphalt
SCB	semi circular bend
Seq-SS	Sequential sum of square
SSE	Sum of square of error
t	specimen thickness, mm
T	temperature °C
u	displacement field, mm
w	specimen width, mm
W_f	work of failure, N.m
Greek symbols	
ν	Poisson's ratio
σ	stress tensor, MPa
σ_0	nominal stress, MPa
σ_{max}	maximum stress at failure, MPa
ε	strain tensor
ρ	density, $kg.m^{-3}$
Ω	whole domain
Γ	domain border
λ, μ	Lamé coefficients
I	Identity matrix
∇	gradient operator
∇.	divergence operator

configurations have been analysed in several references [14–17]. Recently, the Edge Notched Disc Bend test (ENDB) test has been developed to characterize the mixed mode I/III cracking [17–19]. It allows simulating tearing of top-down crack propagation in the transverse direction of roads.

The general test configurations are remained in Fig. 1. In these entire test configurations, the specimens used can be made in laboratory or cored on site.

Among these test configurations, the standardized SCB [12,13] is the most popular in asphalt pavement community due to its

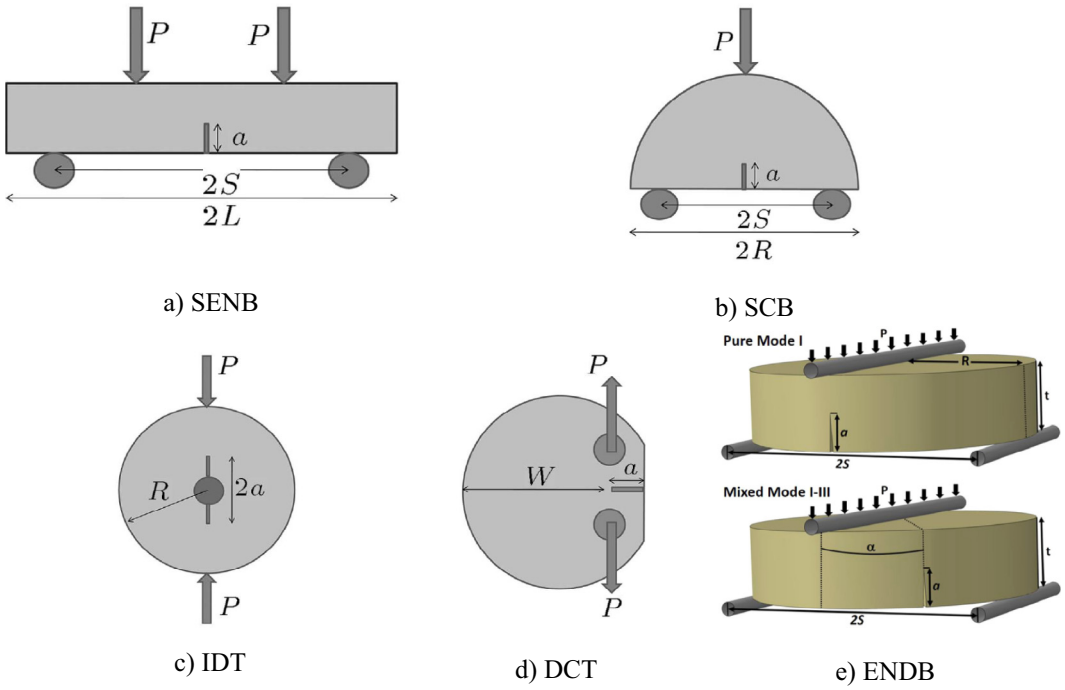

Fig. 1. Test configurations commonly used for testing asphalt fracture toughness.