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FRACTURE IN HIGH PERFORMANCE FIBRE REINFORCED CONCRETE PAVEMENT MATERIALS

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THESIS SUMMARY

FRACTURE IN HIGH PERFORMANCE FIBRE REINFORCED CONCRETE PAVEMENT MATERIALS

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An innovative pavement system known as Ultra Thin Continuously Reinforced Concrete Pavement (UTCRCP) was recently developed in South Africa. The technology is currently being implemented on some major routes in the country. The system consists of a high performance fibre reinforced concrete pavement slab with a nominal thickness of approximately 50 mm. The material has a significant post crack stress capacity compared to plain concrete. Current design methods for UTCRCP are based on conventional linear elastic concrete pavement design methodology, which does not take into account post crack behaviour. Questions can be raised with regards to the suitability of conventional approaches for the design of this high performance material.

The hypothesis of the study is that the accuracy of design models for UTCRCP can benefit from the adoption of fracture mechanics concepts.

The experimental framework for this study includes fracture experiments under both monotonic and cyclic loading, on specimens of different sizes and geometries and produced from several mix designs. The aim is to quantify size effect in the high performance fibre reinforced concrete material, to determine fracture mechanics material parameters from monotonic tests, and to investigate the fatigue behaviour of the material.

As part of the study a method is developed to obtain the full work of fracture from three point bending tests by means of extrapolation of the load-displacement tail. This allows the specific fracture energy (G_f) of the material to be determined. An adjusted tensile splitting test method is developed to determine the tensile strength (f_t) of the material.

The values of G_f and f_t are used in the definition of a fracture mechanics based cohesive softening function. The final shape of the softening function combines a crack tip singularity with an exponential tail. The cohesive crack model is implemented in finite element methods to numerically simulate the fracture behaviour observed in the experiments. The numerical simulation provides reliable results for the different mixes, specimen sizes and geometries and predicts the size effect to occur.

Fracture mechanics based models for the prediction of the fatigue performance of the material are proposed. The predictive performance of the models is compared against a model representing the conventional design approach.

It is concluded that the findings of the study support the thesis that design methods for UTCRCP can benefit from the adoption of fracture mechanics concepts. This conclusion is mainly based on the following findings from the study:

- The high performance fibre reinforced concrete material was found to be subject to significant size effect. As a consequence the MOR parameter will not yield reliable predictions of the flexural capacity of full size pavement structures,
- In contrast to the MOR parameter, the fracture mechanics damage models developed as part of this study do provide reliable predictions of the flexural behaviour of the material,
- The fatigue model developed based on fracture mechanics concepts, though not necessarily more precise, is more accurate.

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NOMENCLATURE

Abbreviations:

C&CI	South African Cement and Concrete Institute
CMOD	Crack Mouth Opening Displacement
CTOD	Crack Tip Opening Displacement
$CTOD_c$	Critical Crack Tip Opening Displacement
EDM	Embedded Discontinuity Method
FCM	Fictitious Crack Model
FEM	Finite Element Method
FPB	Four Point Bending
FPZ	Fracture Process zone
FRC	Fibre Reinforced Concrete
HVS	Heavy Vehicle Simulator
LE	Linear Elastic
LEFM	Linear Elastic Fracture Mechanics
LVDT	Linear Variable Displacement Transducer
MOR	Modulus of Rupture
SANRAL	South African National Road Agency Limited
SDA	Strong Discontinuity Approach
TPB	Three Point Bending
UTCRCP	Ultra Thin Continuously Reinforced Concrete Pavement
UC Davis	University of California at Davis
UP	University of Pretoria

Symbols:

γ	Specific surface energy	[N/mm]
δ	Deflection	[mm]
ε^f	Fracture strain	
ν	Poisson's ratio	
σ	Stress	[MPa]
σ_1	Major principal stress	[MPa]
σ_I	Stress at base of crack tip singularity	[MPa]
σ_f	Stress at fracture	[MPa]
σ_d	Design value of tensile stress	[MPa]
σ_N	Nominal stress	[MPa]
σ_{Nu}	Ultimate nominal stress	[MPa]
σ_{xx}	Horizontal normal stress	[MPa]
μ	Shear modulus	[MPa]
a	Notch depth or crack length	[mm]
a_1	Calibration constant	
a_2	Distance to corner of slab	[mm]
a_c	Critical crack length	[mm]
a_e	Equivalent effective elastic crack length	[mm]
b	Specimen width	[mm]
b_1	Calibration constant	
f_t	Tensile strength	[MPa]

h	Specimen height or slab thickness	[mm]
h_c	Width of fracture zone	[mm]
k	Subgrade stiffness	[N/mm]
l	Radius of relative stiffness	[mm]
m	Calibration constant	
l_c	Characteristic length	[mm]
n_i	Number of load cycles applied at stress level S_i	
s	Span	[mm]
w	Crack width	[mm]
w_1	Critical crack width	[mm]
w_I	Crack width at base crack tip singularity	[mm]
E	Young’s modulus	[MPa]
C	Paris’s constant	
$E’$	Effective Young’s modulus in plain strain condition	[MPa]
E_t	Tangent modulus	[MPa]
G_f	Specific fracture energy	[N/m]
I	Moment of inertia	[mm^4]
K	Bulk modulus	[MPa]
K_I	Crack tip stress intensity	[MPa mm$^{1/2}$]
K_{Ic}	Critical crack tip stress intensity	[MPa mm$^{1/2}$]
N	Number of load cycles	
N_i	Number of cycles at stress level S_i	
P	Total of external loads	[N]
P_u	Peak load	[N]
S	Stress level	[MPa]
S_1	Surface energy	[N m]
$U*$	Strain energy	[MPa]
W_f	Work of fracture	[N mm]