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Review article

Concrete strains under transient thermal conditions: A state-of-the-art review

Giacomo Torelli [a], Parthasarathi Mandal [a,*], Martin Gillie [a], Van-Xuan Tran [b]

[a] School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Manchester M13 9PL, UK
[b] EDF Energy, R&D UK Centre, UK

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ABSTRACT

Extensive research has been carried out over the past four decades on the behaviour of mechanically loaded concrete under transient thermal conditions. The purpose of this paper is to provide a concise review of the existing experimental and analytical works with a strong focus on the load-induced thermal strain (LITS) component. In order to eliminate ambiguities in definitions, the existing terms used to describe the strain components that develop in concrete under a transient thermal regime are compared and a clear definition of LITS and its components is given. The analysis of the existing experimental work shows that LITS is: a strain occurring only during first heating of loaded concrete to a given temperature; significantly influenced by the moisture flux in the temperature range 100–250 °C; and independent of aggregate type for temperatures up to about 400 °C. Examination of the existing multiaxial test data demonstrates that LITS is the result of markedly confinement-dependent phenomenon and that experiments on concrete subjected to triaxial compression and transient temperatures above 250 °C are needed. In the light of the experimental evidence, for temperatures up to about 400 °C LITS seems to be mainly due to chemical reactions and microstructural changes taking place in the cement paste, such as dehydration, drying and rearrangement of the water molecules within the cement paste. By contrast, for higher temperatures, thermomechanical damage due to thermal incompatibility between cement paste and aggregates is believed to contribute significantly to the development of LITS. Moreover, the necessity for modelling explicitly the LITS component in the case of Heating-Cooling (HC) cycles is discussed. Finally, a review of the main existing uniaxial and multiaxial explicit LITS models is given, and the advantages and drawbacks of each model are outlined.

Contents

* Corresponding author.
E-mail address: P.Mandal@manchester.ac.uk (P. Mandal).

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Nomenclature

a, b, c	polynomial coefficients
E	Young's modulus of elasticity of material
k_{tr}	transient strain coefficient
T	temperature
$\bar{T}$	normalized temperature
V_a	volume fraction of aggregates
α	thermal expansion coefficient expressing the ratio between the increment in free thermal strain and the increment in temperature
α_T	thermal expansion coefficient expressing the slope of the free thermal strain curve
β	load-induced thermal strain function for multiaxial models
C_m	triaxiality coefficient for multiaxial models
$\Delta\varepsilon_{ela}$	increment in the elastic strain
δ_{ij}	Kronecker symbol
ε	strain
$\varepsilon_{0,3}$	load induced thermal strain for load $\sigma_i/\sigma_{u0} = 3$
ε_{cr}	creep strain
ε_{cra}	smeared crack strain
ε_{cr^*}	creep strain plus transient strain
ε_{dcr}	drying creep strain
ε_{ela}	elastic strain
$\varepsilon_{ela,0}$	elastic strain at ambient temperature
ε_{heat}	strain developed during the heating phase of a load-then-heat test
ε_{ij}	components of the total strain tensor
ε_{lits}	load-induced thermal strain
ε_{lits^*}	load-induced thermal strain without increment in the elastic strain
ε_m	mechanical strain
ε_{sh}	shrinkage strain
ε_{th}	thermal expansion strain
ε_{tot}	total strain
ε_u	ultimate strain
ε_{ts}	transient strain
ε_{ttc}	transient thermal creep strain
ε_σ	instantaneous stress-related strain
ν	Poisson's ratio
ν_{lits}	load-induced thermal strain Poisson's ratio
σ	stress
σ_i	initial compressive stress before heating
σ_{u0}	compressive strength

1. Introduction

Experimental evidence shows that mechanically loaded concrete specimens exhibit a significant quasi-instantaneous load-induced thermal strain, usually referred to as LITS, upon virgin heating. Accurate understanding and modelling of this phenomenon is crucial for a reliable assessment of the effects of thermal loads on concrete structures, particularly if a certain level of performance is required in the case of accidental loads such as fire. This is the case for nuclear structures, such as prestressed concrete pressure vessels (PCPVs). For example, the recent Fukushima accident, where reactors overheated due to a failure of the power station cooling system, clearly highlights the importance of considering a wide range of possible accidental conditions in designing and assessing nuclear structures. Moreover, other applications in civil engineering occur whenever concrete is loaded in compression under transient