AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
DEPT. OF AUTOMOTIVE ENGINEERING

STUDY OF MECHANICAL BEHAVIOUR OF ADHESIVE JOINTS FOR STRUCTURAL APPLICATIONS

A thesis submitted in fulfillment of the requirements
for the degree of Doctor of Philosophy
in Mechanical Engineering
to Ain Shams University, Faculty of Engineering
Department of Automotive Engineering

BY

Eng. Mossad Kandil Mohamed Kandil

Supervised by

Dr. M. S. EL-SHEIKH	Lecturer
Prof. Dr. T. A. NOSSEIR	Prof. of Automotive Engineering
Prof. Dr. G. VERCHERY	Prof. of Mechanical and Materials Engineering

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بسم الله الرحمن الرحيم

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STATEMENT

This dissertation is submitted to Ain-Shams University for the Degree of Doctor of Philosophy in Mechanical Engineering.

The work included in this thesis was carried out by the author at the Mechanical and Materials Department, Ecole des Mines de Saint-Etienne, France and the Department of Automotive Engineering, Ain-Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

Date: 3 - 4 - 1997
Signature :
Name: Mossad Kandil Mohamed

To my parents in gratitude

To my wife Hoda and my children
Sarah, Mohamed and Hesham in love

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CONTENT

SUMMARY

The present work is concerned with the mechanical behaviour of the adhesively bonded joints subjected to a uniform temperature rise in two-dimensional plane stress linear thermoelastic analysis.

The work contains two main parts. The first part, which is a theoretical aspect, contains survey of the previous work in this domain, and summary of the variational principles in solid mechanics. Also, it contains a presentation of the different methods of calculation by finite elements and the formulation of the displacement, mixed and mixed interface finite elements taking into consideration the thermal effect. The end of the first part is concerned with the development of the computer program " CASMIC " which exists in the Mechanical and Materials Engineering Department at the Ecole de Mines de Saint-Etienne in France, to introduce the thermal effect in the analysis of the structures. The tests of the program validity are given. It was observed that the thermal effect should be incorporated using fictitious equivalent forces acting on the element at the nodes. Also, it was observed that the mixed interface finite elements are the most effective elements for the heterogeneous structures analysis, specially with the interface problems.

The second part of this work presents the analysis of some application examples subjected to a uniform temperature rise only. The first three examples were three different types of adhesively bonded joints, namely : a double-lap joint, a double-bevel joint, and a butt joint. The fourth application example was, in the automotive field, a shoe assembly of a drum brake. The analyses of these examples included the change of several properties and dimensions parameters, in order to study the influence of their change on the resulting thermal stresses. These analyses showed that the change of some parameters highly affects the resulting thermal stresses, such as the ratio of the thermal expansion coefficients of the adherends, and the adhesive thickness. The analyses, also, showed that the change of some other parameters has no influence on the resulting thermal stresses, such as the coefficients of thermal expansion ratio between the shoe and lining materials and the adhesive type change in the drum brake. All the details of the application examples analyses are presented in this part.

In order to extend the capabilities of the program for the analysis of the mechanical behaviour of adhesive joints under thermal effects, variable temperature should be taken into account in future work, following the same concept developed in the present research.

LIST OF SYMBOLS

Below a list of principal english and greek symbols (upper case and lower case symbols) used in this work, although all are defined in the text as they occur. The symbols are listed roughly in the order of occurence in the sequence of the chapters. Other symbols are defined in context.

PRINCIPAL SYMBOLS

Π : total potential energy

U : strain energy

W_p : potential energy of the applied loads

W : variations of the work done by the loads

$\{\varepsilon\}$: strain vector

$\{\sigma\}$: stress vector

[D] : material elasticity matrix

$\{U\}$: displacements field vector

s_σ : surface of the prescribed tractions

$\{\overline{U}\}$: prescribed displacements vector

$\{\overline{f}\}$: body forces intensity vector or distributed body force vector

$\{\overline{T}\}$: prescribed tractions vector

s_u : surface of the prescribed displacements

Π_c : total complementary potential energy

U_c : complementary strain energy

W_{pc} : complementary potential energy of the applied loads

W_c : variations of the complementary work done by the loads

[S] : material compliance matrix

L : Lagrangian functional

T : kinetic energy

ρ : mass density

Π_R or R : Reissner's functional

[N] : displacement shape functions

$\{q\}$: nodal displacements vector

$[L_2]$: linear operator

[B] : strain shape function

$\{\varepsilon_o\}$: initial strain vector

$\{\sigma_o\}$: initial (residual) stress vector

[K] : stiffness matrix or stiffness-compliance matrix

b : nodal balancing forces

r : external concentrated nodal force

$[M]$: stress shape functions

$\{\tau\}$: nodal stresses vector

$\{F_u\}$: displacement force vector

σ_{ij} : components of the stress tensor

$[L_1]$: linear operator

n_1, n_2 : normal unit components for the interface side of the reference element

L_u : length of the surface of the prescribed displacements

L_σ : length of the surface of the prescribed stresses

ΔT : uniform temperature rise

$\{\alpha\}$: coefficient of linear thermal expansion vactor

E : Young's modulus

ν : Poisson's ratio

G : shear modulus

N, T : normal and tangential stress components for the interface side (elem. TRL-1)

$\{\kappa_n\}$: vector of n generalized variables of the displacement field

$[\Phi]$: displacement field matrix of the approximation base function

$\{\beta_m\}$: vector of m generalized variables of the stress field

$[\Psi]$: stress field matrix of the approximation base function

$[X], [Y]$: nodal matrices relate the generalized variables to the nodal variables

h : thickness of element

$\{F_\sigma\}$: stress force vector due to initial strain

$[\Gamma], [\Omega]$: transformation matrices used for the condensation process

$[I], [0]$: identity and null matrices

$[K^*]$: condensed (reduced) stiffness-compliance matrix (case of element TRL-1)

$\{F^*\}$: condensed (reduced) force vector (case of element TRL-1)

$[J]$: Jacobian matrix

E_1, E_3 : Young's moduls for adherends M1 and M3

G_1, G_3 : shear moduls for adherends M1 and M3

E_2 : Young's moduls for adhesive M2

ν_1, ν_3 : Poisson's ratio for adherends M1 and M3

ν_2 : Poisson's ratio for adhesive M2

α_1, α_3 : coefficient of thermal expansion for adherends M1 and M3

α_2 : coefficient of thermal expansion for adhesive M2

L_1, L_3 : adherends length for M1 and M3 (double-lap joint)

t_1, t_3 : adherends thickness for M1 and M3 (double-lap joint)

L : over-lap length (adhesive length) (double-lap joint)

t_2 : adhesive thickness
L_2 : length of joint (double-bevel joint and butt joint)
2b : adherends thickness for M1 and M3 (double-bevel joint and butt joint)
2δ : adhesive angle (double-bevel joint)
E_{shoe} : Young's moduls for the shoe material (drum brake)
E_{lining} : Young's moduls for the lining material (drum brake)
ν_{shoe} : Poisson's ratio for the shoe material (drum brake)
ν_{lining} : Poisson's ratio for the lining material (drum brake)
α_{shoe} : coefficient of thermal expansion the shoe material (drum brake)
α_{lining} : coefficient of thermal expansion for the lining material (drum brake)
t_2 : shoe's flange thickness (drum brake)
t_3 : shoe's web thickness (drum brake)
t : lining thickness (drum brake)
H : shoe's web height (drum brake)
B : lining and shoe's flange width (drum brake)
θ : lining angle (arc length) (drum brake)
θ_1 : angular location of any point on the lining arc (drum brake)
θ_2 : shoe angle (drum brake)
θ_3 : angle for defining the position of any radial plane relative to the lining angle (drum brake)
x,y : coordinates of the real element
ξ,η : coordinates of the reference element

MAIN ABBREVIATIONS, SUBSCRIPTS AND SUPERSCRIPTS

V : body (element) volume
A : body (element) surface area
Q-4 : quadrilateral displacement finite element (4 nodes)
TR-3 : triangular displacement finite element (3 nodes)
RESS-3 : triangular mixed finite element
TRL-1 : triangular mixed interface finite element
d.o.f. : degrees of freedom
M1, M3 : adherends material
M2 : adhesive material
elem. : element
'th.' : subscript indicates 'thermal'
'mech.' : subscript indicates 'mechanical'
'e' : superscript indicates 'element'
'g' : superscript indicated 'global'