

STIFFNESS AND VIBRATIONAL CHARACTERISTICS OF
SMA/DER331 COMPOSITES WITH SHAPE MEMORY
ALLOY LONG FIBERS

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COMPOSITES WITH SHAPE MEMORY ALLOY LONG FIBERS

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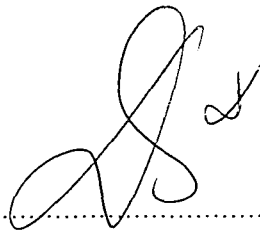
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COMPOSITES WITH SHAPE MEMORY ALLOY LONG FIBERS**


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A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Mechanical Engineering

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APRIL, 2008

“I declare that this project report entitled “Stiffness and Vibrational Characteristics of SMA/DER331 Composites with Shape Memory Alloy Long Fibers ” is the result of my own research except as cited in references.”

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*To my loving wife, Zulaika A. G. Khan, M. Naseem Khan and M. Zarif Khan (sons),
Ainaa Syahirah (daughter), my mother and my father, my family and my supporting
friends ...*

"THANK YOU for your support"

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ABSTRACT

SMA-composites are an adaptive composite in which SMA elements are incorporated into fiber reinforced epoxy composites. Many researches have been done on investigating the properties of shape memory effect and superelastic influence in SMA composites. However, little information available on the effect of different fiber volume fraction with continuous flexinol long wire to mechanical strength and vibrational characteristics. This study is mainly focused on the integration of shape memory alloy (SMA) elements with epoxy composites based on different fiber volume fraction. The aim is to analyze and investigate static and dynamic mechanical properties of SMA/DER331 by measuring the first vibration mode of clamped cantilever beams, elastic strength and hysteresis behavior of SMA-composites through monotonic tensile, cyclic and vibration analysis. This observation indicates that the Young's modulus increases (1667.083MPa) at 2.4% fiber volume fraction of flexinol wire of SMA/DER331 compared to matrix Young's modulus (904.495MPa). The increase of temperature up to 75°C and 90°C lead to the recovery of stress and strain and therefore closed hysteresis achieved. The temperature dependency of vibration property is affected largely due to the addition of SMA Flexinol long fibers. The vibrational characteristics of SMA composites can be improved by the addition of certain amount of flexinol wire. The addition of 2.4% fiber volume fraction of flexinol long fibers resulted in the highest natural frequency with the value of 171Hz at the temperature of 70° C.

ABSTRAK

Komposit aloi memori bentuk merupakan gabungan dimana elemen-elemen aloi memori bentuk disatukan ke dalam bahan komposit. Terdapat banyak kajian dijalankan berkenaan sifat dan kesan aloi memori bentuk dan sifat *superelasticity*. Bagaimanapun, terdapat sedikit maklumat berhubung kesan kekuatan mekanikal dan getaran. Kajian ini memberi tumpuan kepada pendekatan terhadap integrasi aloi memori bentuk dengan komposit *epoxy* berasaskan kepada perbezaan pecahan isipadu serat. Objektif kajian ini adalah untuk menganalisa dan menyiasat ciri-ciri mekanikal secara statik dan dinamik bagi integrasi (SMA/DER331) dengan mengukur mod getaran asas bagi rasuk, kekuatan elastik dan sifat histerisis bagi komposit aloi memori bentuk menerusi tegangan monotonik, kitaran dan analisis getaran. Hasil kajian menunjukkan bahawa *Young's modulus* meningkat sebanyak 1667.083MPa pada 2.4% isipadu serat komposisi dawai flexinol bagi integrasi (SMA/DER331) berbanding 904.495MPa bagi matrik. Peningkatan suhu sehingga 75°C dan 90°C pula menyebabkan kewujudan pengembalian terikan dan tegasan pada struktur dan histerisis lengkap juga dicapai. Sifat-sifat getaran dipengaruhi secara nyata oleh peningkatan serat panjang aloi memori bentuk dan suhu. Ciri-ciri getaran bagi komposit aloi memori bentuk boleh diperbaiki dengan penambahan jumlah dawai flexinol pada kadar yang tertentu. Penambahan sebanyak 2.4% pecahan isipadu serat bagi dawai flexinol menghasilkan frekuensi semulajadi yang tertinggi sebanyak 171Hz pada suhu 70° C.

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LIST OF SYMBOLS & ABBREVIATIONS

A	Cross-sectional area
A_s	Austenite start temperature
A_s^0	Austenite start temperature (stress –free value)
A_f	Austenite finish temperature
A_f^0	Austenite finish temperature (stress –free value)
A -phase	Austenite phase
Al	Aluminium
a_M, a_A, b_M, b_A	Material constant in terms of transition temperature
	A_s, A_f, M_s, M_f
Cu	Copper
C_A, C_M	SMA material constant related to stress-induced phase transformation
$D(\xi)$	Young's modulus
D_m	Young's modulus for the SMA 100% martensite
D_a	Young's modulus for the SMA 100% austenite
E	Modulus of elasticity/Young's modulus
E_l	Young's modulus in 1/or x direction
E_f	Young's modulus for an isotropic fiber.
E_m	Young's modulus for an isotropic matrix
E^Ω	Fourth order elastic tensor of SMA
E^M	Fourth order elastic tensor of matrix
G	Shear modulus of the material
I	Second order identity tensor

I	Area moment of inertia
J_2	Second invariant of the deviatoric tensor
J_3	Third invariant of the deviatoric tensor
M_s	Martensite start temperature
M_s^0	Martensite start temperature(stress –free value)
M_f	Martensite finish temperature
M_f^0	Martensite finish temperature(stress –free value)
M -phase	Martensite phase
$NiTi$	Nickel-Titanium
T	Temperature
T_0	Reference temperature
T_c	Temperature above which yield strength of A-phase lower than stress required to induce A –M transformation
V	Volume
V_f	Volume of fibers / Total volume of composite material
V_m	Volume of matrix / Total volume of composite material
X	Thermodynamic force
X	Inclusion volume
c	Damping
c_c	Critical damping
d	Deviatoric strain
d'	Transformation strain
f	Natural frequency
h	Material parameter indicate the slope of the linear stress transformation
k	Stiffness
k	Bulk modulus of the material
k^3	Versor in the direction of fiber
k^3	Versor in the direction of fiber
kl	Standard k_l/l value based on common beam boundary condition

	(fixed –free)
l	Length
p	Volumetric stress
s	Deviatoric stress
vs	Versus
wl	Weight
x	Displacement
σ	Stress
σ_{eq}	Equivalent stress
σ^M	Stress tensor of matrix
σ^Ω	Stress tensor of SMA
σ_t	Uniaxial critical stress in tension
σ_c	Uniaxial critical stress in compression
ε	Strain
ε_l	Recovery strain limit/Maximum recoverable strain
ε^M	Total strain of matrix
ε^Ω	Total strain of SMA
ξ	Martensite fraction
Θ	Thermoelastic tensor
$\Omega(\xi)$	Transformation tensor
η^M	Elastic strain of matrix
τ	Inelastic strain of matrix
α^M	Expansion coefficient
η^Ω	Elastic strain of SMA
π	Inelastic strain of SMA
x_1, x_2, x_3	Coordinate system
α^Ω	Expansion coefficient of SMA
δ	Possible pre-strain
ε_l	Material parameter of the maximum transformation strain
∂	Volumetric strain
(\bullet)	Scalar product

α	Back stress
β	Material parameter linked to the dependence of the critical stress on the temperature
$\dot{\zeta}$	Plastic multiplier
ω_n	Natural frequency for free oscillation
ζ	Damping ratio/ damping factor
ρ	Density
>	Greater than
<	Lower than
$^{\circ}C$	Degree Celsius
$^{\circ}C / \text{min}$	Degree Celsius per minute
<i>GPa</i>	Giga Pascal
<i>Hz</i>	Hertz
<i>K</i>	Kelvin
kg / m^3	Kilogram per cubic meter
<i>mg</i>	Milligram
<i>mm</i>	Millimeter
<i>MPa</i>	Mega Pascal
<i>mPa.s</i>	Milli pascal second
<i>N</i>	Newton
%	Percentage
ASTM	American Society for Testing and Materials
CNC	Computer numerical control
DER	Liquid epoxy resin by DOW
D-MX-90	Pseudoelasticity test for MX at temperature of 90°C
D-RC1-90	Pseudoelasticity test for RC1 at temperature of 90°C
D-RC2-90	Pseudoelasticity test for RC2 at temperature of 90°C
D-RC3-90	Pseudoelasticity test for RC3 at temperature of 90°C

DSC	Differential Scanning Calorimetry
M	Matrix material
MX	Matrix
RC1	Reinforced composites with fiber volume fraction of 0.8% (3 wires)
RC2	Reinforced composites with fiber volume fraction of 1.6% (6 wires)
RC3	Reinforced composites with fiber volume fraction of 2.4% (9 wires)
MX-30C,45C, 60C, etc	Matrix specimen tested at temperature of 30°C,45°C, 60°C, etc.
RC1-30C,45C, 60C, etc	RC1 specimen tested at temperature of 30°C,45°C, 60°C, etc.
RC2-30C,45C, 60C, etc	RC2 specimen tested at temperature of 30°C,45°C, 60°C, etc.
RC3-30C,45C, 60C, etc	RC3 specimen tested at temperature of 30°C,45°C, 60°C, etc.
ROM	Rules of mixtures
RVE	Representative volume element
SMA	Shape memory alloy
SME	Shape memory effect