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Thermal Stress on Composite Materials

Process, Design, Experiments

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Dedication

To whole people who have encouraged me and granted me aids and supports over the years of study and search, especially my advisors. Also to my whole family, particularly, my late father, and my great mother. Included also are my husband, Emad, and my sons Kazem and Gawad.

Nagwa E. Elzayady

LIST OF SYMBOLES AND ABREVIATIONS

Symbol

Q (W/m^2)	Heat flux
ΔT (^oC)	Temperature difference
R	Thermal resistance of material
k ($W.m^{-1}\,^oC^{-1}$)	Thermal conductivity of solids
h ($W/(m^2.\,^oC)$)	Heat transfer coefficient of medium
g (W/m^3)	Energy generation rate per unit volume
CTE ($(^oC)^{-1}$)	Coefficient of thermal expansion
$\delta \ell$	Deformation through insulation layer
C_p (j/kg. ^oC)	Specific heat
ρ (g/cm^3)	Density
t (Sec)	Time
A	Surface area
V	Volume (cm^3)
$\alpha = k/\rho C_p$	Thermal diffusivity
Bi	Biot number
$L_s = V/A$	Characteristic length
Q	Rate of heat flow into the solid during heating process
dT (t)	Temperature changing of solid with time during heating or cooling process
d (t)	Change in time during the thermal cycle
T (t)	Solid temperature at certain time
T_∞ (^oC)	Fluid temperature during a thermal cycle.
$\dot{m}$ (kg/min)	Rate of water currency
$\dot{V}$ (cm^3/min)	Volume of water per time
ϑ (m/min)	Velocity of water
σ_c (MPa)	Thermal shock resistance of materials
E (GPa)	Young's Modulus
ν	Poisson's ratio
$G = \frac{E}{2(1+\nu)}$ (GPa)	Shear modulus
$K = E/3(1-2\nu)$ (MPa)	Bulk modulus

$\alpha_c = \dfrac{\alpha_m(1-\phi)K_m + \alpha_r \phi K_r}{(1-\phi)K_m + \phi K_r}$	Turner's model for estimation the metal matrix composite properties
ROM	Role of mixture for estimation the metal matrix composite properties
$¥_c = ¥_r\ \phi + ¥_m\ (1-\phi)$	Role of mixture equation
¥	Express a property of material
ϕ	Weight fraction (%) of the reinforcement in the composite
c	Subscript denotation for the composite material
r	Subscript denotation for the reinforcement
M	Subscript denotation for the matrix

CONTENTS

1. INTRODUCTION 1

1.1 Historical Background 1
1.2 Scope of work 6
1.2.1 Material processing 6
1.2.2 Material characterization 6
1.2.3 Thermal fatigue characterization 7
1.2.4 Design and construction required apparatus 7
1.2.5 Theoretical study of thermal properties of materials 7

2. LITERATURE REVIEW 8

2.1Material 8
2.1.1Al alloys 8
2.1.1.1 Al-Si alloys 9
2.1.1.1.1 Al-Si alloy system 9
2.1.1.1.1.1 A356 alloy 11
2.1.2 Metal Matrix Composites (MMCs) 11
2.1.2.1 Matrix Alloys 13
2.1.2.2 Ceramics 13
2.1.2.2.1 SiC ceramic 15
2.1.2.2.2 Albite ceramic 16
2.2 Material Characterizations 17
2.2.1 Microstructure 17
2.2.2 Mechanical properties 21
2.3 Processing of MMCs 25
2.3.1 Vortex 26

2.3.2 Infiltration 29
2.3.3 Rheocasting 30
2.3.4 Powder Metallurgy (P/M) 32
2.3.5 Spray Atomization/Codeposition 33
2.3.6 In-Situ production 33
2.4 Thermal Cycling Experimental Technique 35
2.5 Thermal Behavior of Material 41
2.5.1 General thermal properties 41
2.5.2. The influence of cyclic thermal test on the material behavior 42
2.5.3. The influence of cyclic thermal test on the microstructure 45
2.5.4. The influence of cyclic thermal test on mechanical properties 51
2.6 Theoretical Analysis of Thermal Stresses 53

3 EQUIPMENTS DESIGN AND CONSTRUCTION 55

3.1 Casting Equipments 55
3.1.1 Casting set-up description 55
3.1.2 Casting mould 56
3.2 Cyclic Thermal Tester Design and Construction 57
3.2.1 Design Procedures 57
3.2.1.1 Thermal system 58
3.2.1.2 Rotation mechanism 60
3.2.1.3 Control system 61
3.2.2 Analytical problems of thermal system 62
3.2.2.1 Heating process 62
3.2.2.1.1 Heat transfer modes 62
3.2.2.1.1.1 One-dimensional heat conduction equations 63
3.2.2.1.1.2 Three-dimensional heat conduction equations 63
3.2.2.1.1.3 Transient conduction 64
3.2.2.2 Cooling process 67

3.2.3 Fitting of thermal analysis with the apparatus 68
3.3 Application of Thermal Cycling Using the Designed Apparatus 72
3.3.1 Evaluation of material properties degradation
due to thermal cycling 72
3.3.1.1 Thermal shock resistance (σ_c) 72
3.3.1.2 Mechanical properties affected by thermal cycling 73
3.3.1.3 Oxidation behavior of materials 74

4 EXPERIMENTAL WORK 75

4.1 Material Preparation 75
4.1.2 Processing 75
4.1.3 Sampling 76
4.2 Testing Before Thermal Cycling 77
4.2.1 Microstructure before thermal cycling 77
4.2.1.1 Optical microscopy 77
4.2.1.2 Scanning Electron Microscope 77
4.2.2 Mechanical testing 78
4.2.2.1. Tensile test 78
4.2.2.2 Compression 78
4.2.2.3 Hardness 79
4.2.2.4 Impact 79
4.3 Thermal Cycling Test 80
4.3.1 Temperature adjustment 81
4.3.2 Thermal Cycling procedures 81
4.3.2.1 Thermal cycling of impact samples 82
4.3.2.2 Thermal cycling of tensile samples 83
4.3.2.3 Thermal cycling of compression samples 84
4.4 Testing After Thermal Cycling 84

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5 RESULTS AND DISCUSSION 85

5.1. Material Characterization before Thermal Cycling 85
5.1.1 Microstructural characterization before thermal cycling 85
5.1.1.1 Optical microscopy 85
5.1.1.2 Scanning Electron Microscope SEM and EDAX Analysis 86
5.1.2. Mechanical characterization before thermal cycling 89
5.1.2.1 Tensile properties 89
5.1.2.2. Compression 92
5.1.2.2.1. Compression strength of materials at elastic stage 92
5.1.2.2.2 Compression strength of materials at plastic stages 92
5.1.2.3 Hardness 97
5.1.2.4. Impact 98
5.1.3 Fractography before thermal cycling 101
5.1.3.1Tensile fractograghs before thermal cycling 101
5.1.3.2 Impact fractograghs before thermal cycling 103
5.2 Material Characterizations after Thermal Cycling 107
5.2.1 The influence of cyclic thermal fatigue test
on the impact samples characterizations 107
5.2.1.1 The influence of cyclic thermal test
on the dimension stability of impact samples 107
5.2.1.2 The influence of cyclic thermal test on the microstructural
Characterization impact samples 109
5.2.1.3 The influence of cyclic thermal fatigue
test on the impact toughness 113
5.2.1.3.1 The influence of cyclic thermal fatigue on
the impact strength of A 356 and (A356-3% Albite) MMC 113
5.2.1.3.2 The influence of cyclic thermal fatigue on the impact
strength of (A356-3% SiC) MMC 115

5.2.1.4 Influence of cyclic thermal fatigue test on the
impact fractogragh 117
5.2.2 The influence of cyclic thermal fatigue test on the
tensile sample characterizations 120
5.2.2.1The influence of cyclic thermal test on the dimension
stability of tensile samples 120
5.2.2.2 The influence of cyclic thermal
test on the microstructure of tensile samples 121
5.2.2.3 The influence of cyclic thermal test on the ultimate
tensile strength 125
5.2.2.4 The influence of cyclic thermal
test on the elongation percent 126
5.2.2.5 General Discussion of tensile results
(strength and elongation %) during thermal cycling 127
5.2.3 The influence of cyclic thermal fatigue
test on the compression sample characterizations 130
5.2.3.1The influence of cyclic thermal test
on the dimension stability of compression samples 130
5.2.3.2 The influence of cyclic thermal fatigue on the
compressive stress 131
5.2.3.2.1 The influence of cyclic thermal fatigue
on the compressive stress in elastic stage 131
5.2.3.2.2 The influence of cyclic thermal fatigue
on the compressive strength at plastic stage 132
5.2.3.2.3 General discussion of compressive stress in both elastic
and plastic stage after thermal cycling stages 135
5.3 General Discussion of the Whole Materials Properties 135

6 THEORETICAL ANALYSES of THERMAL STRESS 139

6.1 Theoretical Estimation of Thermal Stresses 139
6.1.1 Estimation of MMCs' properties 139
6.1.2 Determination of heat transfer coefficients during thermal cycling 141
6.1.3 Thermal shock resistance of materials 143

CONCLUSION 147

REFERENCES 149

APPENDICES 159

Appendix (A) Thermal Cycling Apparatus Construction 159
Appendix (B) Description of Equipments of Experimental work 169
Appendix (C) Experimental Results of Impact Test 174
Appendix (D) Experimental Results of Tensile Test 184
Appendix (E) Experimental Results of Compression Test 189

CHAPTER 1
INTRODUCTION

1.1 Historical Background

Metal-matrix composites (MMCs) have been attracting growing interest. MMCs' attributes include alterations in mechanical behavior; tensile, compressive, creep, notch resistance, and tribological properties by the filler phase. Also physical properties; intermediate density, thermal expansion, and thermal diffusivity can altered [1]. Engineering interests in aluminum-based metal matrix composites (MMCs) has increased [2]. Among Aluminum alloys, Aluminum-Silicon (Al-Si) alloys are most versatile materials, comprising 85% to 90% of the total aluminum cast parts produced for the automotive industry, depending on the Si concentration in weight percent (wt.%) in the Al-Si alloy systems [3]. Aluminum-silicon alloys supplies a good combination of mechanical properties and castability and for those reasons, they are widely used in the automotive and aerospace industry. [4] Silicon increases the fluidity in aluminum casting alloys and reduces the solidification interval and hot tears tendencies [4, 5].

Al-Si alloys such as A356 (Al-7Si- 0.3Mg) and A390 (Al-17.0Si-4.5Cu-0.6Mg) have been commercially used to produce an engine block due to their high strength over weight ratio [6].

Compared to conventional Al alloys, the Al alloy matrix based composites, reinforced with ceramic particles have the best density-properties-price combination. Therefore, it is legitimate to expect that these materials will substitute for part of conventional materials in mass production, for example in automotive, as well as in other industries of transport vehicles

[7]. Aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties [8].

Particulate reinforced MMC's have recently found special interest because of their high specific strength and specific stiffness at room or elevated temperatures. Interest in particulate reinforced aluminum MMCs is mainly due to easy availability of particles and economic processing technique adopted for producing them [9]. The particulate reinforcements have been classified as the by-products from other technologies (e.g., SiC, SiO_2, Al_2O_3, aluminosilicates, graphite, and fly-ash) and are readily available or are naturally renewable at affordable cost (e.g., coconut shell char, mica, palm-kernel shell char, and zircon). Further, the potential nature of these filler materials is attractive. For example, SiC has good thermal and chemical stability, both during synthesis and under severe service conditions, strength, cost (about $13/kg for the particulate), and availability [1]. Also, Albite is common feldspar ceramic, a mineral aluminosilicate ($NaAlSi_3O_8$) that occurs most widely in acid igneous rocks such as granites [9 &10]. It's basically consisting of silicates; it is abundantly available in the earth's crust. Albite ranges from white to dark grey in colour and is extremely wear resistant, having a Moh hardness of about 6.5, almost rivaling that of SiC but exceeding that of alumina. It has a low coefficient of thermal expansion of 2.3 x 10^{-6} C^{-1} [9, 11]. Also low thermal conductivity (2.8 $W.m^{-1}.C^{-1}$) of Albite and density (2.6 g/cm^3) which is much lower than those of SiC (3.1 g/cm^3) and alumina (4.0 g/cm^3) [9, 11, 12]. These properties make Albite a candidate reinforcement material in MMCs. Among metal-ceramic combinations, the Al-SiC couple has been one of the most widely studied systems over the last years [8].

Continuously and discontinuously reinforced Al/SiC metal matrix composites (MMCs) are promising modern, light weight materials with excellent properties, such as: high hardness and strength at ambient and elevated temperatures, good wear resistance, and high modulus of elasticity.

Currently, the use of MMCs is limited predominantly to the military and the aerospace industry. However, the penetration of these materials has already begun also in civilian applications [7]. With increased SiC addition, the module of elasticity increases linearly and thermal expansion decreases. Unfortunately, with increased content of reinforcement the ductility of the composite is drastically decreased. Tensile and compression ductility of Al/SiC MMCs are very different. These composites have high compression strength, but they are very sensitive to tensile load. Therefore, these materials are appropriate for hot forming in closed dies (die forging, hot pressing, extrusion etc.) [7]. (Al-SiC) MMC has been studied by large number of searchers whom save plenty of concerning data. While, there is a leakage of information about (Al-Albite) MMC.

A great portion of the research efforts is focused on producing the MMCs by solidification processing, which is likely to be more economical and relatively simple in comparison with the competing solid processing [2].
Vortex method and forming in semi-solid state (SSM) has been proved as an advantageous route for producing Al alloys as well as their composites. Several advantages of semi-solid forming process are proved, the most important of these, in the view of most technologists today, is the non-turbulent filling of the die, which results from the high and controllable viscosity of the semi-solid material. This smooth mold filling eliminates the air entrapment encountered in the conventional die-casting process and

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