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Nanoparticles Adding Influence on Fatigue Behavior of AA5052 and Aluminum Composite Materials

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for the Degree of Master of Science in Mechanical Engineering

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيم

”وَقُلْ رَبِّ زِدْنِي عِلْمًا“

صَدَقَ اللَّهُ العَظْيم

طه ﴿١١٤﴾

Supervisor Certificate

I certify that this thesis entitled **(Nanoparticles Adding Influence on Fatigue Behavior of AA5052 and Aluminum Composite Materials)** had been carried out under my supervision at the University of Diyala / College of Engineering - Mechanical Engineering Department in partial fulfilment of the requirements for the degree of Master of Science in Mechanical Engineering.

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Date: / / 2022

In view of the available recommendation, I forward this thesis for debate by the examination committee.

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Examination Committee Certificate

We certify that we have read this dissertation entitled **(Nanoparticles Adding Influence on Fatigue Behavior of AA5052 and Aluminum Composite Materials)** and as an examining committee examined the student (**Baqir Abed Ibrahim)** in its contents and that in our opinion it meets the standard of a thesis and is adequate for the award of the degree of Master of Science in Mechanical Engineering.

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Date: / / 2022
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DEDICATION

I dedicate this work to ....

My parents and my wife

My brothers and my sons.

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The Researcher

Abstract

In the present thesis, the influence of nanoparticles zirconia ZrO_2, titanium dioxide TiO_2 and alumina Al_2O_3 of the average size (25-35nm) adding with same weight percent 7% to Aluminum metal matrix AA5052 on tensile strength, Vickers hardness and fatigue properties was studied. Stir casting teqnique was used to fabricate the composite materials.

The analysis of SEM examination reveals that there is a uniform and good homogeneous dispersion of ZrO_2, TiO_2 and Al_2O_3 nanoparticles into the molten AA5052 alloy row matrix.

The results of this study showed that the mechanical properties, ultimate tensile stress, yield stress and Vickers hardness of the composites was improved compared to the row matrix AA5052. The composite with 7wt% ZrO_2 exhibited higher ultimate tensile stress, yield stress and hardness compared with the other two composites with TiO_2 and Al_2O_3 nanoparticles, the improvement was 54%, 33.8% and 25% percentage for ultimate tensile stress, yield stress and hardness respectively.

The study showed that the fatigue strength at 10^7 cycles under constant loading of the composite with 7wt% ZrO_2 exhibited higher than that of row matrix AA5052 as 31%, also the results showed improvement in fatigue life factor FLIF at different stress level 60, 50 and 45MPa as (40.6, 76.7 and 53%) respectively.

The improvement in fatigue life (FLIF%) under variable amplitude loading for high-low and low-high sequence loading of AA5052 with 7wt% ZrO_2 composite were enhanced by 44% and 37.7% respectively compared with the fatigue life of AA5052 at same amplitude stresses.

According to Miner rule the total damage for low-high sequence loading was (1.0101) for the matrix and (0.8825) for composite with ZrO_2, but for High-low sequence loading the total damage was 0.808 for matrix and 0.785 for composite with ZrO_2 .

A numerical solution by FEM was done using ANSYS.16.1 workbench to predict fatigue life of the composites. A good agreement in behavior was founded between the experimental work and numerical data. The maximum percentage error of fatigue strength between the experimental and numerical values doesn’t exceed 4.14% for the matrix and less than for composites.

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List of Symbols*

Symbols	Description	Units
wt.%	Weight percentage.	…..
A	Area	mm^2
d	Diameter	Mm
L_o	Gage length of the specimen.	Mm
a & b	Fitting constant depend on material or curve fitting parameters	……
I	Area moment of inertia	mm^4
σ	Normal stress	MPa
P	Load	N
σ_u	Ultimate tensile strength	MPa
σ_y	Yield stress	MPa
R	Stress Ratio	…..
N_f	number of cycles to failure	Cycles
σ_f	Fatigue strength.	MPa
σ_a	Applied stress (bending stress).	MPa
IP	Improvement percentage.	…..
FLIF	Fatigue Life Improvement Factor.	……
D	Total damage according to miner rule.	……

*The symbols not mentioned there were defined during the text.

Abbreviations**

Symbols	**Description**
AA	Aluminum Alloy.
MMC	Metal matrix composites.
MMNC	Metal matrix Nano composite.
AMNC	Aluminium matrix Nano composite.
ASTM	American Society for Testing and Materials.
SP.1	Specimens N° 1: Raw matrix (Pure AA5052 Aluminum Alloy).
SP.2	Specimens N° 2: Composite (AA5052 with 7wt. % of ZrO_2).
SP.3	Specimens N° 3: Composite (AA5052 with7wt.% of TiO_2).
SP.4	Specimens N° 4: Composite (AA5052 with7wt. % of Al_2O_3).
HCF	High cycle fatigue.
LCF	Low cycle fatigue.
SEM	Scanning Electron Microscopy.
S-N	Stress-No. of cycles
LDR	Linear damage accumulation rule, (Miner Rule).

**The abbreviations not mentioned her were defined during the text.

Chapter One

Introduction

1.1 Introduction:

The phenomenon of metal fatigue is very old and it is the major problem encountered by Designers, due to its abnormal nature and high unpredictability of fatigue failure; thus understanding the fatigue behaviour of materials and composites of all kinds is of vital importance. Fatigue is the degradation of mechanical properties of a material or a component under cyclic loading, many high volume applications of composite materials involve cyclic loading situations, e.g. components used in automobiles, trucks, and mass transit. Fatigue failure usually occurs at stress levels well below the material's static elastic strength (yield stress), by point defect, crack initiation, short crack growth, long crack growth and then sudden failure without the occurrence of phenomena that occur in the case of static loading in the material before its collapses, such as yield area and plastic deformation [1, 2].

Fatigue may occur under constant or variable loads, constant fatigue loading is defined as the fatigue under cyclic loading with a constant amplitude and constant mean stress or load; However, in service, structures or components are exposed to varied amplitude loads, which might result in a complex load-time history [3]. Although ships, offshore structures and a lot more engineering structures are subjected to variable loading, the majority of fatigue failure data are obtained from experiments with constant amplitude loading [4].

Many techniques were used to improve mechanical and fatigue properties for materials such as surface cold work, shot peening and laser process [5, 6].

1.2 The Fatigue Life:

The first attempts to analyze the fatigue behaviour of materials and structures were based on experience with constructions operating under real loading conditions. The fatigue life of any specimen or structure is the number of stress cycles required to cause failure, these numbers of cycles are influenced by many variables including stress level, stress state, cyclic wave form, fatigue environment, and the metallurgical condition of the material [7].

1.3 Composite material:

Composite materials are the combination of two or more distinct materials to form new materials that have quite different properties and do not dissolve or blend into each other. The different materials in the composite work together to give the composite unique properties [8].

The main component of the composite is the "matrix", which may be defined as the continuous phase, into which the reinforcements are inserted. The discontinuous phase is the "reinforcement", or reinforcing material. V The matrix function is to give the geometric shape and distribute the load on the reinforcement and kept them in their position, maintain them from chemical and mechanical damage, reduce crack propagation. Reinforcement achieve specific material properties and gives resistance and rigidity or it may be added to reduce costs such as adding glass beads to a thermoplastic matrix [9].

1.3.1 Metal Matrix Nanocomposite (MMNC):

Metal Matrix Nano-composite (MMNC) such as (Al/Al_2O_3, Al/CNT, Al/SiC, Ni/Al_2O_3, Fe/MgO) refers to materials consisting of a ductile metal or alloy matrix in which some Nano-Size, reinforcement materials are implanted. These materials combine metal and ceramic features such as ductility and toughness with high strength and modulus, for this reason, Metal Matrix Nano-Composites are suitable for the production of materials with high strength in shear/compression processes and high service temperature capabilities [11].

1.3.2 Particle-Reinforced Composite:

The reinforcement particles in the matrix can be metallic or non-metallic, the combination of particles and matrix can have high strength. The size of the dispersed particles and their volume concentration varies as per the strength requirements. These dispersions strengthen the material matrix by arresting the motion of dislocations and hence enhancing the forces required for fracture [12].

1.4 Nano Materials:

Nano-materials are a set of substances where at least one dimension of fewer than 100 nanometers, take advantage of their small size and novel properties such as the greater surface area to volume ratio than their conventional forms and become much more important in determining the properties of the material. In many cases, the particles from 1 to 100 nm are generally called nanoparticles, which have different shapes and structures; they can be spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc. In particle reinforced composites, particles can be ceramics, glasses, metal materials, while the modulus of a composite is higher than that of its matrix, the permeability and ductility are lower. Therefore, particle reinforced composites can sustain higher tensile, compressive and shear stresses, as well as bending, buckling and vibration [13].

1.4.1 Aluminum oxide (Al_2O_3)

Aluminum Oxide, also called "Alumina" is a ceramic material, used in some composite materials as a filler (Al_2O_3 particles) or matrix (for example, reinforced with SiC particles). Due to high mechanical characteristics, low density and availability, Al_2O_3 is the most common material used in ceramic armour. The importance of alumina nanoparticles is due to the high-pressure solidity, high strength, high resistance to erosion, high heat conduction, high electrical resistance, transparency in front of frequencies or microwave blaze [14].

1.4.2 Zirconium dioxide (ZrO_2):

Zirconium oxide is a white crystalline oxide of zirconium that is also known as zirconia. It is the most common form, which has a monoclinic crystalline structure. Cubic zirconia is a dopant stabilized cubic structured zirconia created in a variety of colours for use as a gemstone and a diamond stimulant. When compared to other advanced ceramic materials, zirconia has exceptional strength at room temperature. Other principal properties of this material include high fracture toughness, high density, high hardness and wear resistance, good frictional behavior [15].

1.4.3 Titanium dioxide (TiO_2):

Titanium dioxide is commonly known as Titania. TiO_2 nanoparticles have a white solid appearance and are extensively used in paints and varnishes. The major source of titanium dioxide is ilmenite ore, followed by rutile, which contains around 98 per cent crude titanium dioxide. TiO_2 is a compound of great importance due to its remarkable catalytic and distinctive semiconducting properties. Nano TiO_2 is strong oxidizing agent with a large surface area, low production cost and a high dielectric constant, it is an inexpensive material. [16].

The physical and chemical properties of the Al_2O_3, TiO_2 and ZrO_2 nanoparticles are summarized in Table (1.1).

Table: 1.1 Al_2O_3, TiO_2 and ZrO_2 nanoparticles properties. [14 , 16].

Properties	**Al_2O_3**	**TiO_2**	**ZrO_2**
Density g/cm3	3.6	4.23	5.89
Crystal Structure	FCC	Tetragonal	Monoclinic
Appearance	White solid	White solid	White solid
Ultimate strength, MPa.	2004 – 2096	………..	2550 – 2700
Young's modulus (GPa).	380	244	171
Melting point ċ	2054	1870	2715
Thermal conductivity W/m K	29	8	5.5

1.5. Fabrication of the metal matrix composite: [17]

Primary processes for manufacturing (MMNCs) can be classified into two main groups:

1. **Liquid state processes**: include (stir casting, spry casting, squeeze casting).

2. **Solid-state processes**: include (friction stir processes, diffusion bonding and vapour deposition.

1.5.1 Stir casting technique:

Stir Casting is a liquid state method for the fabrication of composite material, in which a dispersed phase is mixed with a molten matrix metal particularly. Creating good wetting between the particulate reinforcement and the liquid alloy such as (aluminium Alloy) and getting homogenous dispersion of the particulates are very important. This route is the simplest, less expensive, and flexible so it is the preferred method for mass production [18].

1.6 Advantages and applications of aluminium matrix composite:

Aluminium matrix composites have been used to substitute cast iron and bronze alloys, as well as steel and steel alloys, in a variety of applications, resulting in superior predetermined properties. Aluminium metal matrix composites are gaining widespread acceptance for automobile, aerospace, agriculture farm machinery and many other industrial applications because of their essential properties such as High strength/weight, low density, good wear resistance, tribological properties, hardness, temperature resistance, endurance fatigue limit, high damping capacity, high thermal conductivity, high specific modulus, and high abrasion and wear resistance compared to any other metal [19, 20].

1.7 The Aims of the present work:

The main aims of the present work are to study and investigate the influence of adding different ceramic nanoparticles on fatigue behavior and mechanical properties (tensile strength and hardness) to AA5052 alloy.

1.8 Thesis Outline:

The provided thesis consists of six chapters, which are as follows:

1. Chapter one: **The Introduction (theoritcal background).**

   The general concepts of the entire project and the study's aim are explained in this chapter.

2. Chapter Two: **Literature Review.**

   This chapter introduces the literature survey about the mechanical and fatigue properties of Aluminum Composite, as well as the summary of this literature and the current research's stance in comparison to prior research.

3. Chapter Three: **Theoretical Considerations.**

   Theoretical concepts of fatigue theories are presented in this chapter.

4. Chapter Four: **Experimental Work.**

   This chapter Includes Equipment descriptions, Specimen geometry, and experimental technique for manufacturing Nano Composite for mechanical and fatigue properties testing.

5. Chapter Five: **Results and Discussion.** The experimental analysis, results, and discussion are presented, in this chapter; the results of the experiments are given in the form of graphs and tables.

6. Chapter Six: **conclusion and Recommendations for future work.**