Ministry of Higher Education

and Scientific Research

University of Diyala

College of Engineering

CUMULATIVE FATIGUE DAMAGE OF AA7075-T6 UNDER DIFFERENT SURFACE TREATMENTS

A Thesis Submitted to the Council of College of Engineering,

University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

by

Marwa Sajed Mohammed

Supervisor by

(Prof.D.) Saad Theeyab Faris

2021 A.D **IRAQ** **1442 A.H**

﴿أَمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِرَةَ وَيَرْجُو رَحْمَةَ رَبِّهِ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُولُو الْأَلْبَابِ ﴾

COMMITTEE DECISION

We certify that we have read the thesis/ dissertation titled (**Cumulative fatigue damage of AA7075-T6 under different surface treatments**) and we have examined the student (**Marwa sajed mohammed**) in its content and what is related with it, and in our opinion it is adequate as a thesis for the **Degree of Master of Science in Mechanical Engineering.**

Examination Committee	***Signature***
Prof Dr. Saad Theeyab Faris(Supervisor)	……
Assist. Prof Dr. Dhia Ahmed (Member)	……
Assist. Dr.Raad Mohammed Abed(Member)	……
Prof Dr. Hussien J. M. Al-alkawi(Chairman)	……

The thesis was ratified at the Council of College of Engineering/University of Diyala.

Signature…….

(Ph.D). Anees Abdullah

Dean of College of Engineering / University of Diyala

Date: / / 2021

DEDICATION

I dedicate this work to ….

To my parents, my brother and my sister, To the person who supported me, Dr. Hussain Faleh Mahdi ,To all who admired this piece of a work

Acknowledgement

I would like to thank **Prof. Dr. Saad Theeyab Faris**, as they both provided me with many great points to include and gave me advice whenever it was required. Finally, I would also like to thank everyone who helped me in any possible way.

ABSTRACT

SP Peening (SP) and Ultrasonic Peening (UP) treatments with fatigue interaction were studied for 7075A-T6 Aluminum alloy under room temperature (RT) and stress ratio R = -1.

Experimental mechanical properties and fatigue behavior of the above alloy were obtained for different conditions of SP & UP surface treatments. The fatigue endurance limit was increased by 3.46% for UIP and 8.57%for SP.The fatigue life were enhanced by 35% for UIT and 54% for SP.

Constants fatigue behavior for the mentioned treatments have been also determined. constant as-received metal. Cumulative fatigue damage testing were carried out for two steps loading and it is observed that the fatigue life for LP and UP treated specimens were improved compared to the unpeened results. Two proposed cumulative non-linear models were presented one for SP and other for UP. The proposed models give a good correlation with the experimental fatigue lifetime. The proposed models gave better and conservative prediction of lifetime.

TABLE OF CONTENTS

Acknowledgement ..... **IV**
ABSTRACT ..... **V**
TABLE OF CONTENTS ..... **VI**
LIST OF TABLES ..... **IX**
LIST OF FIGURES ..... **XI**
LIST OF SYMBOLS ..... **XIII**
Chapter One 1
1.1 Introduction 2
1.2 Research Problems 4
1.3 Research Significance 5
1.4 Research Objectives 5
1.5 Methodology 6
Chapter Two 7
2.1 Introduction 8
2.1.1 Aluminum alloys 9
2.1.1.1Aluminum Industry Today 11
2.1.2 Fatigue 12
2.1.2.1 Historical overview of fatigue 12
2.1.2.2 Fatigue Failure 13
2.1.2.3 Metal fatigue 14
2.1.2.4Crack Initiation 15
2.1.3 Mechanical surface Treatments 16
2.1.3.1Shot Peening 17
2.1.3.1.1Types and Sizes of Shot 19
2.1.3.1.2 Residual Stresses 19
2.1.3.2Ultrasonic impact peening 21
2.1.3.2.1 Residual Stress (RS) amendment by Ultrasonic Peening 22
2.2 Fatigue loading 24
2.3 Endurance limits 25

2.3.1Constant amplitude loading 26
2.3.2Variable – amplitude loading 27
2.4 The present proposed cumulative model 28
2.4.1 Corten- Dolan theory 30
2.4.2 Marco and Starkey 30
2.4.3 Alalkawi Model 31
2.4.4 Alalkawi , Shot peening model 32
2.5 Application of the proposed model to the experimental data: 34
2.6 Literature Survey 35
Chapter Three 42
3.1 Introduction 43
3.2 Material Selection 45
3.2.1. Industrial Applications 45
3.3 Specimens preparation 47
3.4 Ultrasonic peening (UP) 51
3.4.1 Ultrasonic device 51
3.4.2 Mechanical properties under ultrasonic peening: 52
3.4.3 Fatigue test (after ultrasonic peening) 52
3.5 shot peening 53
3.5 Cumulative fatigue loading program 55
Chapter Four 57
4.2 Constant Amplitude Fatigue Test Results 58
4.2.1 S-N curves experimental results 59
4.2.1.1 Dry fatigue condition 59
4.2.1.2 Ultrasonic peening (UP) 59
4.2.4 Endurance limits: 62
4.2.3 Improvement factor 63
4.2.4 Cumulative fatigue damage 64
Chapter Five 69
5.1 Conclusions 70

5.2 Recommendations.......... 72
References 73

LIST OF TABLES

Table No.	Titles	Page No.
Table 1	Proportion of the endurance limit to tensile strength for different materials	28
Table 2	Experimental and normal chemical composition; 7075A – T6 Al-alloy	46
Table 3	Mechanical properties of 7075-T6Al alloy	46
Table 4	The principal technical parameters of UP device	51
Table 5	S-N curve results of Al 7075-T6 alloy with Dry fatigue condition	59
Table 6	S-N curve results of Al 7075-T6 alloy with UIT	60
Table 7	S-N curve results of Al 7075-T6 alloy with UIT	60
Table 8	Basic S-N fatigue results at room temperature	61
Table 9	Fatigue endurance limit at 107	62
Table 10	Improvement of Endurance limit	63
Table 11	Cumulative fatigue results for dry condition	64
Table 12	Cumulative fatigue results of UIP	64
Table 13	Cumulative fatigue results of SP	64
Table 14	shows the improvement factor (IF) for cumulative fatigue life	66

Table 15	damage values obtained from the present model in comparison with Miner rule	67
Table 16	comparison of life predictions based on the experimental life	67

LIST OF FIGURES

Figure No.	Titles	Page No.
Figure 1	Wrought aluminium and aluminium alloys	10
Figure 2	Stress-number of cycles to failure (S-N) curve	15
Figure 3	Illustration of slip and monotonic loading during fatigue.[21]	16
Figure 4	Shot Peening specimen [25].	18
Figure 5	Shot Peening method (a) Elastic-plastic boundary (b) Indentations [26]	18
Figure 6	Shot peening that induces plastic deformation and activates a (CRS) region adjacent to the surface impact.[37]	20
Figure 7	Basic UP-600 system for fatigue life enhancement of parts elements	23
Figure 8	The perspective on the butt welds when use of UP	23
Figure 9	Under various stacking conditions, the commonplace fatigue stress cycle	25
Figure 10	endurance limit	26
Figure 11	S-N curves	27
Figure 12	Logarithm depiction of fatigue equation	32
Figure 13	The flow chart of the experimental plan	44
Figure 14	Boeing Aircraft: use of the AA7075 alloy in the structure of the skin and aircraft-wing	45

Figure 15	Tensile test machine WDW-200E with a stress specimen during the test	48
Figure 16	Tensile specimen during industry in CNC machine	48
Figure 17	Tensile test specimen, all dimension in mm.	49
Figure 18	Fatigue specimen configuration (mm)	50
Figure 19	Ultrasonic peening device type HC-S-1	52
Figure 20	Specimen under UP work	53
Figure 21	The shot peening device	54
Figure 22	Specimen before and after shot peening	55
Figure 23	Block diagram of cumulative fatigue testing	56
Figure 24	Experimental S-N curves of constant fatigue test for conditions	61
Figure 25	Effect UIT and SP on cumulative fatigue life	65

LIST OF SYMBOLS

Abbreviations	Meaning
A, α	Material constant
D	Damage
E	Young's elastic modulus
N	Number of applied cycles
N_f	Number of cycles to failure
R	Stress ratio
$\Delta\sigma$	Stress range
a	Curve fitting parameters
σ_{EL}	Endurance limit stress at 10^7 cycle
σ_H	High stress
σ_L	Low stress
σ_u	Ultimate tensile strength
YS	Yield strength
ASM	American society for Metals
ASTM	American society for Testing and Materials
HCF	High cycle fatigue
LCF	Low cycle fatigue
H-L	High- Low
L-H	low -High
LRD	Liner damage Rules
S-N	Stress-No. of cycles
SP	Shot Peening

UP	Ultrasonic peening

Chapter One

Introduction

CHAPTER ONE
INTRODUCTION

1.1 Introduction

In the world around us, engineered components have numerous and often exacting applications. It has been found experimentally that when a material is subjected to dynamic stresses, it fails at stress below the yield point stresses; such type of failure of a material is known as fatigue. The failure is caused by means of a progressive crack for motion which are usually fine and of microscope size. The failure may be occur even without any prior indication. If the stress is kept below a certain value, the material will not fail whatever may be the number of cycles; this stress is known as endurance limit. This study light on the effective modern means to prolong fatigue life, Such Shot peening and Ultrasonic techniques which will be selected to enhance the mechanical properties and fatigue resistance of 7075A-T6 aluminum alloy.[1]

It has been found experimentally that a material fails at stresses below the yield point stresses, when it is subjected to repeated stresses. That type of failure of a material is known as fatigue. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. The failure may occur even without any prior indication. The fatigue of material is affected by the size of the component, relative magnitude of static and fluctuating loads and the number of load reversals. If the stress is kept below a certain value, the material will not fail whatever may be the number of cycles . This stress is known as endurance or

fatigue limit. It is defined as maximum value of the completely reversed bending stress which a polished standard specimen can withstand without failure, for infinite number of cycles (usually 10^7 cycles) [1]

By various ways, shot peening (SP) and ultrasonic effect penning can be introduced into the surfaces of engineered components with residual compressive pressures (UIT). Both treatment processes incorporate real residual stresses by introducing major residual stresses in both treatment processes by plastically deforming the surface layers, by means of hard round bead bombardment in the casing of shot peening . In the past, shot peening was the most effective and commonly used way of producing Compressive Residual stresses (CRS) in the surface layers of engineered components. In general, shot peening is relatively inexpensive, uses effective and thus reliable process equipment and, when necessary, can be useful in separate size areas. SP method, however, has its limitations. The shot peening method is semi quantitative in limiting the degree of production of compressive stresses. In versatile metals such as aluminium alloys, the residual stresses caused by the shot peening process are often constrained in depth and do not normally exceed 0.25 mm, The method for shot peening is to be done on rough surfaces during treatment, mostly in softer metals[2]. It is typically important to eliminate this caused roughness before these components can be placed into operation. In addition, the efficiency of the treatment to eliminate this roughness tends to remove much of the residual compressive stress layer caused in the part. Fatigue is described in this work as a crack or damage to a complex bad structure or part. Harm can be defined as localized deformation of plastic contributing to the creation of cracks. Approximately 90% of mechanical failures is practically fatigue failure. AA7075-T6 aluminum alloys are commonly used in the aerospace and AA7075-T6 has low material cost for the automotive industry,

high strength , good resistance to corrosion and general [3] Most machine parts are exposed to cyclic loads in functional sector. If the stress amplitude varies over time contributes to loss known as accumulated fatigue damage (CFD). In other words, this kind is named (CFD) when fatigue tests are conducted under variable amplitude loading [4]. Surface treatments such as shot penning (SP) or ultrasonic impact penning (UIP) have been performed to improve cumulative fatigue life. Several researchers have demonstrated that SP and UIP have increased the cumulative fatigue life for aluminum alloys [5].

1.2 Research Problems

Fatigue failure is one of the most common types of failure for engineering parts that are subjected to variable loads, and because aluminum alloys are used in aircraft structures, missiles, and other air equipment that is constantly subjected to variable amplitude loading , surface enhancement technologies, which are used to improve the properties of components including fatigue, are required. Among these advances in surface improvements, SP is a popular and commonly used method that has long been used in airplane segments to maximize fatigue efficiency of components. UP is a test developed late and is being studied in this report. Due to its precise position and reliable operation , In spite of the fact that it costs more than shot peening due to its low output volume, shot peening and ultrasonic peening can be applied to various airplane parts, such as fuselage, cutting edges and wing, with great repeatability and durability. Shot peening due to its low production rate. Ultrasonic peening induces deep compressive residual stress in the surface layer by plastic deformation occurs in the surface layer, this prevents cracks or stop their growth, then increases fatigue resistance and increase the life of the functioning

1.3 Research Significance

Technologies to strengthen the surface that essentially modifies the surface properties of components that use a wide variety to enhance the component's properties, including fatigue, between these technologies:

1. Ultrasonic peening on the metal surface used , it is a moderns techniques that apply of most often on a limited area and produces surfaces , and also can be used to surface treatment of engineering components in their original positions.
2. Shot peening, which is a traditional and popular process, can be used to harden metallic surfaces, such as aluminum, and creates residual stress layers to maximize the mechanical specifications that can be studied during this discovery.

1.4 Research Objectives

1. Study the effect of surface treatment for the Aluminum alloy 7075-T6 by shot and Ultrasonic peening after that comparison each other and with original metal.
2. To obtain the optimum case for improving the surface properties mechanical and fatigue behavior to help the designers and workers in this field.
3. Compare between the two surface treatments technique and to reach the best of enhancement.
4. To propose mathematical model describes the behavior of fatigue optimize at these two techniques.

1.5 Methodology

A- Theoretical part

1. Survey of modern research in shot peening and ultrasonic to improve fatigue life for metals and aluminum alloys.
2. Survey of mathematical models describes the behavior of fatigue for Al-alloy, and put propose mathematical model.

B. Practical part

1. Manufacturing of fatigue test specimens.
2. Conducting chemical tests to find out the chemical composition of AA7075-T6 Al-alloy.
3. Manufacturing required specimens for tensile tests.
4. Tensile tests.
5. Fatigue tests with constant and variable stress without any treatment (shot or Ultrasonic)
6. Fatigue test with constant and variable stress after treatment by shot peening and ultrasonic peening respectively.
7. Application of proposed model to shot and ultrasonic peening cumulative testing.
8. Comparison between mechanical properties and fatigue behavior AA7075-T6 under Shot & ultrasonic peening.