Micromechanical analysis of fatigue crack initiation and growth behaviour of recycled cast aluminium silicon piston alloys

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A thesis submitted in partial fulfillment of the requirement for the Degree of
Master of Science in Mechanical Engineering in the Jomo Kenyatta
University of Agriculture and Technology

2015

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

To my loving wife, Gladys and our two sons, Ephantus and Fredrick; you are my driving force. Thank you.

ACKNOWLEDGEMENT

The research work presented in this thesis, while full of challenges, turned out to be an exciting, instructive and joyful experience that benefited from the appropriate direction of my supervisors; Dr. T.O. Mbuya and Dr. R. B. Mose. I am extremely grateful for their dedicated supervision, constant encouragement,academic guidance and constructive discussions during the course of this work.I also like to express my acknowledgement to the Chairman of the department of Mechanical and manufacturing Engineering of the University of Nairobi (UoN) for allowing me to use the laboratory facilities in UoN.

Last but not least, I am grateful to my wife forher constant support and encouragement. Her moral and spiritual support encouraged me to push on with the research even during desperate times. Thanks a lot.

NOTATION AND SYMBOLS

ABBREVIATION

$ACPD$	Alternating current potential difference
BMD	Bending moment diagram
$CTOD$	Crack tip opening displacement
DCPD	Direct Current Potential Difference
EDX	Energy Dispersive X-Ray
LEFM	Linear Elastic Fracture Mechanics
$OICC$	Oxide induced crack closure
OM	Optical Microscopy
PSBS	Persistent Slip Bands
R	Stress ratio
RICC	Roughness Induced Crack Closure
RT	Room Temperature
SDAS	Secondary Dendrite Arm Spacing
SEM	Scanning Electron Microscopy
SENB	Single Edge Notch Bend
SFCs	Short fatigue cracks
SFD	Shear force diagram
UTS	Ultimate tensile strength
ΔK	Stress Intensity Factor Range
da/dN	Crack growth rate
c	Paris constant parameter
m	Paris exponent
K	Cooling material constant
ΔK_{eff}	Effective stress intensity range
K_{max}	Maximum stress intensity factor

K_{op}	Crack opening stress intensity factor
U	Effective stress intensity factor range ratio
σ_{nom}	Nominal maximum stress
w	Specimen width
$M_{f(0)}$	Correction factor allowed for semi elliptical crack shape
$E_{(K)}$	Elliptical integral of the second kind
σ_b	Maximum bending stress
a	Half crack length
B_w	Finite area correction function due to tension
c	Bulk crack length
A_A	Area fraction
L_A	Lineal fraction
P_p	Point fraction
V_f	Volume fraction
K_c	Fracture toughness

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ABSTRACT

There are significant economic and ecological benefits of aluminum recycling. However, recycled aluminum alloys have not yet found widespread application in premium components. This is mainly due to difficulties in controlling the chemical composition of the recycled alloys attributed to the varied compositions of cast aluminum scrap. For this reason, existing secondary alloys (e.g. 319 type alloys) tend to have relatively more tolerant impurity element specifications and broader limits for major alloying elements. As useful as this may be, it does not alleviate the problems associated with recycling as regards to chemical composition control. This research is part of a wider investigation whose overall aim is to develop new high performance recycled alloys for selected automotive component applications. Previous work within the group has mainly concentrated on the development of recycle-friendly alloys for automotive piston applications. A preliminary evaluation of mechanical performance has been carried out on a suggested model secondary piston alloy that can be obtained via direct reuse of piston scrap. The current work involved a more detailed analysis of the microstructure-mechanical property characteristics of this alloy as affected by selected minor elements. The emphasis here was to assess the effect of microstructure on the fatigue performance of the base alloy as well as the effect of Sr, Mn, Cr and grain refinement.

Fatigue crack initiation was investigated at room temperature using S-N and short fatigue crack growth experiments. A 4-point bend test configuration was adopted for laboratory tests. Post failure analysis indicated that pores and intermetallic particles were detrimental in causing fatigue crack initiation. Porosity was observed to act as fatigue crack initiation sites in the base alloy, the alloy containing Cr, and in the alloy with a combined addition of Sr and Al-Ti-B grain refiner. In the alloy containing a combined addition of Mn and Cr, intermetallic particles were observed to cause fatigue crack initiation. Using EDX, the intermetallic particles were identified to be Al_9FeNi phases. Different fatigue crack growth behaviour was observed for all the alloys investigated. The highest crack growth rates were observed in the base alloy, and in the alloy with a combined addition of Sr and Al-Ti-B grain refiner as compared to the alloys containing Cr, or a combined addition of Mn and Cr.

From SEM images, all the alloys under investigation exhibited complex multiphase intermetallic phases. As result, the micromechanisms of fatigue are due to particle fracture and debonding for crack propagation continuity. The level of crack continuity depends largely on micro-damage behaviour experienced at the crack tip. It is the extent of this damage in the alloys that control the fatigue crack growth rates exhibited.

Chapter 1

INTRODUCTION

1.1 Background

The excellent properties of Al-Si alloys have led to the diversified range of application of these alloys [HYPERLINK \l "Placeholder2" **1**]. They have become the popular choice material for various applications in automotive, construction, aerospace and marine industries mainly due to their high strength to weight ratio, excellent castability, high corrosion resistance and good mechanical properties **2**]