STUDIES ON THE KINETICS OF FATIGUE CRACK GROWTH IN AL-BASE ALLOYS

by

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Submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the

Indian Institute of Technology, Delhi

Hauz Khas, New Delhi 110 016, India

January, 2006

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In the name of Allah the Beneficent the Merciful

"All praise and thanks be to Allah the creator of all that exists, matter and energy, life and death, the light and darkness, the knowledge and ignorance. Who taught man what he knew not and gave him the ability to express. To Him alone is the accountability and to Him is our return.
To Him alone I submit"

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To my late *ABBA* and *BHAIYYA* who have been the inspiration

all along

&

my beloved

***AMMA* who suffered infinite neglect during this work**

CERTIFICATE

This is to certify that the thesis titled "**STUDIES ON THE KINETICS OF FATIGUE CRACK GROWTH IN AL-BASE ALLOYS**" being submitted by **MOHAMMED NOOR DESMUKH** to the Indian Institute of Technology, Delhi, India for the award of the degree of '**Doctor of Philosophy**' in Applied Mechanics Department is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the standard fulfilling the requirements for the degree of 'Doctor of Philosophy'. The research report and results presented in this thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

January, 2006

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ACKNOWLEDGEMENTS

The initial problem formulation, progress of experimental work, analyses and successful completion of this research work would never have been possible without the constant guidance and encouragement provided all along by Professor R.K. Pandey. It is just unthinkable that I could have achieved anything without him. Those patient hearings, confidence boosting discussions, expert opinions on the minutest of observations and a very prompt evaluation of the work at every stage have lent an unparalleled support all along.

I am thankful to Professor Pandey from the depth of my heart and will be ever indebted to him for not only guiding me in this work but imparting to me a huge part of whatever knowledge in engineering I have gained till now. There were difficult times during my research work which could have easily become a mire of frustration but for his expert guidance and encouragement it looked all too easy. Besides the unforgettable lectures which built my foundation in the subjects of materials science, fatigue, fracture mechanics and failure analysis I could not have learnt better from anyone the patient approach to tackling problems.

My sincere thanks are also due to Dr. A.K. Mukhopadhyay for his help in the alloy development, TEM studies and numerous other inputs which have been very valuable and of great assistance in the completion of this work.

I also can not forget the support given by the staff; Prem Singh, Rana ji, Jagat Ram, Rishi and Madan and would like to thank them all for their co-operation.

I wish to sincerely thank Dr. Asif Hussain and Dr. Mohd. Ahmed for the constant moral support and encouragement they had given during the completion of this work.

I also don't find words to thank my mother who endured the neglect by me and prayed for my success, all through. I will be ever indebted to her.

My sincere thanks are also due to my sister, Tanweer and other family members who kept on motivating, to keep me going all along this stay at IIT.

Lastly, I thank all those who have directly or indirectly helpful in this task.

MOHAMMED NOOR DESMUKH

ABSTRACT

Fatigue is a phenomenon of progressive damage caused by repeated fluctuating loads, which are normally well within the elastic limit. It leads to crack initiation and propagation and ultimate catastrophic failure. High factors of safety may not be the necessary and sufficient solution for design against fatigue. Damage tolerance becomes the primary basis for fatigue design specially when dealing with high strength materials for aerospace structures, where optimization for weight saving becomes a necessity. Thus minute investigation of kinetics of fatigue crack growth becomes very important.

Amongst the various available materials for aerospace applications, the 7010 Aluminum alloys have shown a great promise. In the present work, studies have been carried out concerning the composition and microstructural parameters which lead to an improvement in the damage tolerant properties in this alloy. The alloying modifications studied were those consisting of Silver and Scandium additions. The studies also covered the effect of different types of aging treatment effects on the microstructure as well as the fatigue crack growth kinetics in the alloy. The studies were also conducted on differently heat treated 7010 alloys resulting in significant difference in their microstructures. The heat treatment of the alloys was done by initially solutionizing at 465°C, then water quenching and subsequently artificially aging in three different ways, two step near peak aging, single step peak aging and the over aging.

The experimental program included tensile testing, microstructural characterization, conventional fatigue strength determination and fatigue crack propagation studies in both the threshold as well as in the Paris region.

The base material used for all the alloying as well as various aging treatments was the 7010 aluminum alloy with the chemical composition in wt% as 6.3% Zn, 2.3% Mg, 1.55%Cu, 0.14% Zr, and the rest Al. The alloy was solution treated at 465°C for one hour, followed by water quenching and then artificial aging at a temperature of 120°C for 24 hours.

In the Silver modified alloys 0.4% Ag was added which was found to have improved the crack propagation threshold by over 40% but the influence on the fatigue crack growth rate of the alloy does not appear to be significant. The microstructural observations and the investigated fatigue micro-mechanisms reveal that the rolled grains in this alloy have a larger width and result in a coarser fracture surface which could result in a higher crack closure and hence an improved fatigue threshold.

In the Sc containing alloy, 0.25% Sc is added which resulted in a higher strength properties but somewhat reduced fatigue strength, a decrease in ΔK_{th} value of about 40%, and a more than two fold increase in the fatigue crack propagation rate as compared to the base alloy. The higher strength in the alloy is considered to be due to the $Al_3Sc_xZr_{1-x}$ dispersoids, an unrecrystallized structure and a finer sub-grain size. The reduced fatigue strength as well as the fatigue crack propagation threshold was due to the finer grain structure whereas the inferior fatigue crack propagation resistance is believed to be due to the presence of additional coarse primary $Al_3Sc_xZr_{1-x}$ particles (2-5 μm) which showed a tendency to promote void formation on them. The fracture surface studies further provided an insight in to the causes of the above findings.

In the two-step near peak aged 7010 alloy the artificial aging was done in two steps, i.e. first at 100°C for 8hrs and then followed by aging at 120°C for 8hrs. The fatigue behavior shows the lowest fatigue strength (endurance strength) of 255 MPa. The crack propagation threshold value, ΔK_{th} was found to be 5.0 MPa$\sqrt{m}$ and the fatigue crack growth resistance was the highest amongst the other heat treated alloys. The alloy microstructure revealed a marked reduction in the width of precipitate free zones, PFZs adjacent to the grain boundary with small, closely placed η particles at the grain boundary besides the fine η' precipitate particles within the grain. The typical microstructural features of this alloy are considered to be the main cause of its observed fatigue behavior. The fractographic studies gave a further insight into the characteristic behavior of the alloy. The high resistance to fatigue crack growth could be due to the presence of shearable precipitates, less coarse grain boundary particles and a reduced width of PFZs.

In the case of 'Single step peak aging', the base alloy is subjected to an artificial aging at 120°C for 24hrs in a single step. The resultant alloy was in the peak aged condition as it possessed the highest strength properties. This alloy was found to possess an intermediate fatigue strength value of 260 MPa, whereas the ΔK_{th} was obtained as 5.2 MPa$\sqrt{m}$ which are higher than that in the near peak aged alloy. However the fatigue crack growth rate in this alloy is found to be about twice as compared to the near peak aged alloy. The alloy microstructure revealed a wide PFZ adjacent to the grain boundary and coarse grain boundary η particles, besides the coarse η' particles within the grains. These microstructural features have been instrumental in justifying the behavior of this alloy.

In the case of 'over aging' treatment, the base alloy was subjected to an artificial aging treatment in three steps i.e. at 100°C for 8hrs followed by aging at 120°C for

8hrs and subsequent aging at 172°C for 8hrs. The studies of the fatigue behavior of this alloy show a fatigue strength of 284 MPa, and a ΔK_{th} value of 6.2 MPa$\sqrt{m}$ which are the highest amongst all the aging treatments provided to the alloy. Interestingly, the fatigue crack propagation resistance in this alloy was found to be at the lowest level. The microstructural examinations showed the typical over aged features having coarser η particles at the grain boundaries, besides the coarse η' precipitates as well as η particles within the grain. These microstructural features explain the observed fatigue behavior. The overaged 7010 alloy deforms homogeneously due to the presence of non-shearable precipitates in the matrix and is characterized by the coarse grain boundary particles within the soft PFZ resulting in a poor fatigue crack growth resistance. The fatigue strength as well as the fatigue crack propagation thresholds are found to be the highest in the over aged alloy. The reduced matrix strength results in a reduced strength differential at the grain boundary which in turn leads to minimal strain localization which is possibly the reason for the improved fatigue properties in the over aged alloy. Further, the fractographic studies have been conducted on the fractured surfaces of these differently heat treated alloys revealing the micro-mechanism of the fracture and providing deeper insight into the features which have been instrumental in providing the observed results. Some limited closure studies have also been conducted which revealed the results supporting the earlier inferences.

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