GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. E-19-615 (CS: E-19-321) DATE 3/11/82

Project Director: Dr. E. A. Starke School/Lab Chemical Engr.

Sponsor: AFOSR; Bolling AFB, D.C. 20332

Type Agreement: Grant No. AFOSR-78-3471; Amend. E

Award Period: From 1/1/82 To 12/31/82 (Performance) 2/28/83 (Reports)

Sponsor Amount: $140,399 Contracted through:

Cost Sharing: $40,599 ~~GTRI~~/GIT

Title: The Effect of Microstructure on the Properties of High Strength Aluminum Alloys

ADMINISTRATIVE DATA

OCA Contact Linda H. Bowman

1) Sponsor Technical Contact:

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Defense Priority Rating: none

Security Classification: none

RESTRICTIONS

See Attached AFOSR Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT if under $1,000. $1,000 or more should be in approved budget or receive prior approval -- title will then vest with GIT.

COMMENTS:

Follow-on to E-19-636 due to change in OH rates. Amendment E extends project eight (8) months and increases funding by above amounts for the fifth (05) year.

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GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date September 13, 1983

Project Title: "The Effect of Microstructure on the Properties of High Strength Aluminum Alloys"

Project No: E-19-615

Project Director: Dr. E. A. Starke, Jr.

Sponsor: AFOSR

Effective Termination Date: 12/31/82

Clearance of Accounting Charges: 2/28/83

Grant/Contract Closeout Actions Remaining:

- [ ] Final Invoice and Closing Documents
- [x] Final Fiscal Report SF269
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Assigned to: Chemical Engineering (School/~~Laboratory~~)

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THE EFFECT OF MICROSTRUCTURE ON THE PROPERTIES OF HIGH STRENGTH ALUMINUM ALLOYS

AFOSR Six Month Progress Report
June 1, 1982

by
Edgar A. Starke. Jr.
Fracture and Fatigue Research Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332

Grant No. AFOSR-78-3471
Air Force Office of Scientific Research
Air Force Systems Command
Bolling AFB

This research was sponsored by the Air Force Office of Scientific Research Directorate of Electronics and Solid State Sciences under Research Grant Number AFOSR-78-3471.

THE EFFECT OF MICROSTRUCTURE ON THE PROPERTIES
OF HIGH STRENGTH ALUMINUM ALLOYS

This program was initiated in January, 1978, and is concerned with the effect of microstructure on the properties of two different classes of aluminum alloys of current interest to the Air Force: (1) high strength Al-Zn-Mg-X alloys and (2) low density, high modulus Al-Li-X alloys. During the first six months of 1982 the research was focused on Al-Li-X, and may be summarized as follows:

The effect of various grain structures, produced by thermomechanical treatments, on the monotonic tensile properties of the Al-Cu-Li-Mn-Cd alloy 2020 was investigated. Materials having a completely or partially recrystallized structure exhibit elongations between 4 and 8% when aged to peak strength. For both cases the low ductility is associated with (a) planar deformation, (b) random texture, (c) the presence of large intermetallic compounds along the recrystallized grain boundaries, and (d) precipitate free zones. The first three enhance crack nucleation at high angle grain boundaries, and subsequent crack propagation occurs along the precipitate free zones. The completely unrecrystallized materials have elongations between 10 and 13% in both longitudinal and transverse directions. The high ductility is associated with a sharp texture and a transgranular fracture mode. The maximum ductility is obtained by reducing the unrecrystallized grain size. The results of this study suggest that improved properties of a 2020-type alloy may be obtained by lowering the Fe and Si contents to remove coarse constituent phases, eliminating Cd, and replacing Mn with Zr in order to obtain a highly textured, unrecyrstallized structure.

Two modifications of the 2020 alloy were produced at LMSC for this program. Both had low Si and Fe contents and Mn was replaced by Zr in order to obtain the unrecrystallized structure. One variation was Cd-free and one had 0.2% Cd. Preliminary results indicate that a yield strength of 600 MPa with an elongation of 10% may be obtained with these materials. These studies will be completed during the next six months.

It has been previously recognized that underaging high strength aluminum alloys provides greater toughness than overaging to the same yield strength. It has also been established, for Al-Cu alloys, that maximum susceptibility to stress corrosion cracking (SCC) occurs in underaged tempers. In this study, it was found that an underaged temper of the Al-Cu-Li alloy 2020, with a yield strength 12% lower than the peak aged condition, had 80% higher plane strain fracture toughness (K_Q, SL orientation) and 300% higher crack propagation resistance (UPE, TL orientation). The SCC resistance was also very good; plateau velocities for short transverse, double cantilever beam samples exposed to an aqueous 3.5% NaCl solution were on the order of 10^{-10} meter/second. The maximum in SCC susceptibility was found to occur at a very early stage in the precipitation hardening process.

PUBLICATIONS DURING THIS SIX-MONTH PERIOD:

1. H. C. Heikkenen, E. A. Starke, Jr. and S. B. Chakrabortty, "Modification of the Chakrabortty Model for Calculating Fatigue Crack Growth Rates," Scripta Met. 16 (1982) pp. 571-574.

2. E. A. Starke, Jr. and F. S. Lin, "The Influence of Grain Structure on the Ductility of the Al-Cu-Li-Mn-Cd Alloy 2020," submitted to Metallurgical Transactions A.

THE EFFECT OF MICROSTRUCTURE ON THE PROPERTIES OF HIGH STRENGTH ALUMINUM ALLOYS

Final Report on

AFOSR-78-3471

January, 1983

by

Edgar A. Starke, Jr.
Fracture and Fatigue Research Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332

This research was sponsored by the Air Force Office of Scientific Research Directorate of Electronic and Solid State Sciences under Research Grant Number AFOSR-78-3471.

Abstract

This program was initiated in January, 1978, and was concerned with the effect of microstructure on the properties of two different classes of aluminum alloys of current interest to the Air Force: (1) high strength Aℓ-Zn-Mg-X alloys and (2) low density, high modulus Aℓ-Li-X alloys. The program terminated on December 31, 1982. Work prior to 1982 has been described in detail in our Annual Scientific Reports, the last of which was issued in February, 1982. This Final Report will list publications resulting from work on AFOSR Grant No. 78-3471 and summarize results obtained in 1982.

1. The Microstructure and Properties of An Extruded P/M X7091 Plate (Walker and Starke)

Rapid solidification and powder metallurgy (P/M) consolidation offers a means of producing finer dendrite cells, finer dispersions of intermetallic compounds, fewer undissolved constituents and fewer inhomogeneities when compared with I/M methods. Early feasibility studies on combining age and dispersion hardening alloy additions in 7XXX alloys led to the development of a P/M consolidation process for fabricating high quality, blister free products. Although high axial tensile strength and good stress corrosion cracking resistance were produced, the products were plagued by low fracture toughness, especially in the short transverse direction. Since then, modifications to early fabrication processes have greatly improved fracture toughness and have allowed the production of 7XXX alloys with equal or superior combinations of strength, toughness and SCC resistance when compared with equivalent I/M alloys. To date, the quantitative evaluation of P/M microstructures and the relationship of these microstructures to cyclic stress and strain has been limited.

The purpose of this study was to characterize the microstructure of an extruded PM X7091 plate and to evaluate the alloy's monotonic and cyclic properties. The results were compared with 7XXX I/M alloys. Better combinations of tensile properties were obtained by rapid solidification and P/M consolidation methods. However, anticipated improvement in fatigue crack initiation resistance was not realized due to the presence of oxides along grain boundaries. In order to obtain better fatigue properties, processing procedures that dissociate the boundaries from the oxides should be utilized. A manuscript resulting from this research has been submitted to Powder Metallurgy.

2. The Influence of Grain Structure on the Ductility of the Aℓ-Cu-Li-Mn-Cd Alloy 2020 (Starke and Lin)

The main purpose of adding lithium to aluminum alloys is to obtain a better combination of low density, high elastic modulus, and high strength; properties especially attractive for aerospace applications. The first commercial lithium-containing aluminum alloy was made available by Alcoa in 1958, and designated 2020 by the Aluminum Association. Although 2020 had a room temperature strength comparable to 7075-T6 and an elevated temperature stability higher than other age hardenable aluminum alloys, its low ductility and fracture toughness in the maximum strength temper led to the termination of production in 1969.

The purpose of this research was to study the influence of grain structures, as produced by various TMT's, on the ductility of 2020 plate. Materials having a completely or partially recrystallized structure exhibited elongation between 4 and 8% when aged to peak strength. For both cases the low ductility was associated with (a) planar deformation, (b) random texture, (c) the presence of large intermetallic compounds along the recrystallized grain boundaries, and (d) precipitate-free zones. The first three enhance crack nucleation at high angle grain boundaries, and subsequent crack propagation occurs along the precipitate-free zones. The completely unrecrystallized materials had elongation between 10 and 13% in both longitudinal and transverse directions. The high ductility was associated with a sharp texture and a transgranular fracture mode. The maximum ductility was obtained by reducing the unrecrystallized grain size. The results of this study suggest that improved properties of a 2020-type alloy may be obtained by lowering the Fe and Si contents to remove coarse constituent phases, eliminating Cd, and replacing Mn with Zr in order to obtain a highly texture, unrecrystallized structure. The results of this program were published in Metallurgical Transactions

Vol. 13A, December, 1982, pp. 2259-2269.

3. Effects of Precipitation Heat Treatment on the Microstructure, Toughness, and Stress Corrosion Crack Propagation Resistance of Aluminum Alloy 2020 (Rinker and Sanders)

The objective of this research was to determine the effects of precipitation heat treatment on the strength, toughness, microstructure, and stress corrosion resistance of 2020. The peak strength temper and several underaged and overaged conditions were studied. Precipitation strengthening was found to be due to extensive co-precipitation of the $\theta'(A\ell_2Cu)$ and $T_1(A\ell_2CuLi)$ phases, confirming the results of previous studies. Although some evidence of δ' precipitation was also found, no significant contribution to strengthening was attributed to this phase.

Fracture toughness was found to decrease markedly with aging to peak strength due to an increasing tendency toward strain localization by the concentration of deformation into intense planar bands and the concomitant decrease in strain hardening capacity. The strength/toughness relationship for several high strength underaged tempers of 2020 was found to be superior to that for the peak strength temper and for standard tempers of other 2XXX alloys. One underaged temper with a yield strength 12% lower than the peak aged temper had 80% higher plane strain fracture toughness and 300% higher crack propagation resistance. The toughness of overaged tempers was found to be to be much lower than that of underaged tempers having the same yield strength.

The stress corrosion cracking resistance of 2020 in the peak strength temper and several high strength underaged tempers was found to be excellent. Poor SCC resistance was observed for a very underaged temper. A model was developed which associates SCC resistance with the electrochemical potential difference between grain boundary T_1 precipitates and the interior of grains.

A manuscript is being prepared for submission to Metallurgical Transactions.

PROFESSIONAL PERSONNEL

Dr. Edgar A. Starke, Jr.
Dr. Thomas H. Sanders, Jr.
Dr. Saghana B. Chakrabortty
Dr. Fu-Shiong Lin
Dr. M. Marek

GRADUATE STUDENTS

Charles Heikkenen
Paul Niskanen
John Rinker
John A. Walker
Tirumalai Srivatsan

DEGREES GRANTED UNDER AFOSR-78-3471

Fu-Shiong Lin, "Low Cycle Corrosion Fatigue and Crack Propagation of High Strength 7XXX-Type Aluminum Alloys," Doctor of Philosophy, April, 1978.

Bhaskar Sarkar, "Stress Corrosion Characteristics of Aℓ-Zn-Mg Alloys with Copper Additions," Doctor of Philosophy, August, 1979.

John Andrew Walker, "The Microstructure and Properties of Extruded P/M CT91-T7X151," Master of Science in Metallurgy, December, 1980.

Herman Charles Heikkenen, "A Study of the Fatigue Behavior of an Aℓ6Zn-2Mg-0.1Zr Alloy," Master of Science in Metallurgy, November 1981.

John George Rinker, "Effects of Precipitation Heat Treatment on the Microstructure, Toughness, and Stress Corrosion Crack Propagation Resistance of Aluminum Alloy 2020," Doctor of Philosophy, September, 1982.

PUBLICATIONS UNDER AFOSR-78-3471

Fu-Shiong Lin and E. A. Starke, Jr., "The Effect of Copper Content and Degree of Recrystallization on the Fatigue Resistance of 7XXX-Type Aluminum Alloys, I. Low Cycle Corrosion Fatigue," Mater. Sci. and Engr., 39, 27-41 (1979).

E. E. Underwood and E. A. Starke, Jr., "Quantitative Stereological Methods for Analyzing Important Microstructural Features in Fatigue of Metals and Alloys," in STP 675, ASTM, Philadelphia, PA, 633-682 (1979).

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Fu-Shiong Lin and E. A. Starke, Jr., "The Effect of Copper Content and Deformation Mode on the Corrosion Fatigue Crack Growth Behavior of Aℓ-6Zn-2Mg-XCu Alloys at Low Stress Intensities," Mater. Sci. and Engr., 45, 153-165 (1980).

E. A. Starke, Jr. and Fu-Shiong Lin, "Microstructure-Environment Influence on the Fatigue Behavior of Aerospace 7XXX Aluminum Alloys," Proceedings Institute of Environmental Sciences, 131-135, Philadelphia, PA (1980).

Fu-Shiong Lin and E. A. Starke, Jr., "Mechanisms of Corrosion Fatigue Crack Propagation of 7XXX Aluminum Alloys in Aqueous Environments," in Hydrogen Effects in Metals, ed. I. M. Bernstein and Anthony W. Thompson, TMS-AIME, 485-492 (1980).

B. Sarkar, M. Marek, and E. A. Starke, Jr., "The Effect of Copper Content and Heat Treatment on the SCC Behavior of Aℓ-6Zn-2Mg-XCu Alloys," Met. Trans. A, 12A, 1939-1943 (1981).

P. Niskanen, T. H. Sanders, Jr., M. Marek, and J. G. Rinker, "The Influence of Microstructure on the Corrosion of Aℓ-Li, Aℓ-Li-Mn, Aℓ-Li-Cu Alloys in 3.5% NaCℓ Solution," in Aluminum-Lithium Alloys, ed. T. H. Sanders, Jr. and E. A. Starke, Jr., TMS-AIME, 347-376 (1981).

E. A. Starke, Jr., T. H. Sanders, Jr. and I. G. Palmer, "New Approaches to Alloy Development in the Aℓ-Li System," J. of Metals 33, 24-33 (1981).

H. C. Heikkenen, Fu-Shiong Lin and E. A. Starke, Jr., "The Low Cycle Fatigue Behavior of High Strength 7XXX-Type Aluminum Alloys in the T7351 Condition," Mater. Sci. and Engr. 51, 17-23 (1981).

F. S. Lin, S. B. Chakrabortty and E. A. Starke, Jr., "Microstructure-Property Relationships of Two Aℓ-3Li-2Cu-0.2Zr-XCd Alloys," Met. Trans. A, 13A, 401-410 (1982).

H. C. Heikkenen, F. S. Lin and E. A. Starke, Jr., "The Relationship Between Microstructure, Cyclic-Stress Strain Response and Fatigue Crack Propagation in Aℓ-Zn-Mg Alloys," Aluminium (in press).

T. H. Sanders, Jr. and P. W. Niskanen, "Microstructure, Mechanical Properties and Corrosion Resistance of Aℓ-Li-X Alloys - An Overview," Res Mechanica Letters 1, 363-370 (1981).

P. Niskanen, T. H. Sanders, Jr., J. G. Rinker and M. Marek, "Corrosion of Aluminum Alloys Containing Lithium", Corrosion Science (in press).

Edgar A. Starke, Jr., "Aluminum-Lithium Alloys," in 1981 Year Book of Science and Technology, McGraw-Hill Company, New York (in press).

H. C. Heikkenen, F. S. Lin, and E. A. Starke, Jr., "The Effect of Environment on the Low Cycle Fatigue Life and Fatigue Crack Propagation Behavior of an Aℓ-6Zn-2Mg-0.1Zr Alloy," in Environmental Degradation of Engineering Materials, ed. M. R. Louthan, Jr., R. P. McNitt and R. D. Sesson, Jr., VPI, Blacksburg, VA, 459-469 (1981).

T. H. Sanders, Jr., and E. A. Starke, Jr., "The Effect of Slip Distribution on the Monotonic and Cyclic Ductility of Aℓ-Li Binary Alloys," Acta Met. 30, 927-939 (1982).

H. C. Heikkenen, E. A. Starke, Jr. and S. B. Chakrabortty, "Modification of the Chakrabortty Model for Calculating Fatigue Crack Growth Rates," Scripta Met. 16, 571-574 (1982).

E. A. Starke, Jr. and F. S. Lin, "The Influence of Grain Structure on the Ductility of the Aℓ-Cu-Li-Mn-Cd Alloy 2020," Met. Trans. 13A, 2259-2269 (1982).

J. A. Walker and E. A. Starke, Jr., "The Microstructure and Properties of an Extended P/M X7091 Plate," submitted to Powder Metallurgy.

J. R. Pickens and E. A. Starke, Jr., "The Effect of Rapid Solidification on the Microstructures and Properties of Aluminum Powder Metallurgy Alloys," in Proceedings of the Third Conference on Rapid Solidification Processing: Principles and Technologies, NBS, Gaithersburg, MD (in press).

J. C. Williams and E. A. Starke, Jr., "The Use of Thermomechanical Processing in Tailoring and Microstructure and Properties of Titanium and Aluminum Alloys," in Deformation, Processing and Structure, ASM (in press).

C. J. Beevers, R. L. Carlson, K. Bell and E. A. Starke, Jr., "A Model for Fatigue Crack Closure," submitted to Engr. Fract. Mech.