

PROJECT ADMINISTRATION DATA SHEET



ORIGINAL



REVISION NO. _____

Project No. E-19-668DATE 5/20/82Project Director: Dr. Edgar StarkeSchool/Lab ChESponsor: Boeing Commercial Airplane Co.; Seattle, Wash.Type Agreement: P.O. # L-405214-OD35N under Contract #F33615-81-C-5053Award Period: From 1/4/82 To 9/30/82 (Performance) _____ (Reports) _____Sponsor Amount: \$151,516 (\$37,879 partially funded through 9/30/82) Contracted through: _____

Cost Sharing: _____ GTRI/GRK

Title: Low Density Aluminum Alloy Development Program

ADMINISTRATIVE DATA

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Defense Priority Rating: noneSecurity Classification: none

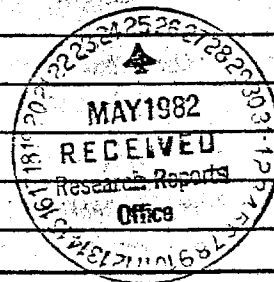
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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEETDate 11/1/83Project No. E-19-668School/ Ch EIncludes Subproject No.(s) N/AProject Director(s) Dr. Edgar StarkeGTRI ~~XXX~~Sponsor Boeing Commercial Airplane Co; Seattle, WATitle Low Density Aluminum Alloy Development Program.Effective Completion Date: 12/31/82 (Performance) 12/31/82 (Reports)

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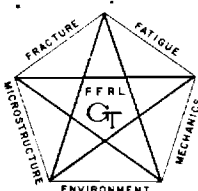
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FRACTURE AND FATIGUE RESEARCH LABORATORY
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404/8942880

June 17, 1982

LOW DENSITY ALUMINUM ALLOY DEVELOPMENT PROGRAM

MONTHLY REPORT
FOR THE PERIOD
May 1, 1982 - May 31, 1982

by

Keith M. Bresnahan and E. A. Starke, Jr.

Phase II, Task I - Quantitative Microstructural Analysis and Mechanical Property Correlations

The graduate student selected to participate in this research project is Keith M. Bresnahan. A literature review has been conducted over the past several months, and the results presented in a M.S. thesis research proposal. The scope of this proposal included the characterization of microstructures, deformation and fracture modes of new Al-Li alloys.

The alloys to be considered for initial investigation will be selected from the seven P/M alloys to be produced by Pratt & Whitney Aircraft from inert gas atomized powder, the three P/M alloys to be produced by INCO from mechanically alloyed powder, and the two I/M alloys to be produced by British Aluminium Company by standard DC ingot casting techniques. Although the chemical composition of these first iteration alloys has been determined, samples of the materials are not yet available. Quantitative microstructural analysis will begin upon receipt of sample materials, which is anticipated in June, 1982.

In an effort to become familiar with research techniques related to Al-Li-Cu-Mg, Mr. Bresnahan is performing microstructural quantitative characterization on the alloy Al-3Cu-2Li-1Mg-0.2Zr. The samples being examined are comprised

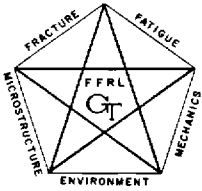
of consolidated splat-quenched powder particles, extruded to form rectangular bars. The solution treatment being used is 0.5 hours at 538°C, followed by quenching in water at ambient temperature. Artificial aging consists of 190°C for 6 hours and 24 hours. Samples are also being aged at 190°C for 6 hours after being stretched to 2% plastic elongation. The analytical methods being used are as follows:

Identification of the phases present in the alloy under study is established mainly through the use of transmission electron microscopy (TEM) and x-ray diffraction techniques. TEM is essential in the examination of the fine microstructural constituents. Bright-field and dark-field imaging is employed to observe shape, size and distributional characteristics of the precipitate particles. Due to the shape and preferred orientation of the T_1 phase (Al_2CuLi) it appears as a result of displacement fringe contrast. The θ' phase ($CuAl_2$ type) can also be distinguished by displacement fringe contrast. Other phases such as S' (Al_2CuMg), Al_3Zr , and Al_7Cu_2Fe are evident as a result of diffraction contrast. Selected area diffraction can be used to develop a correlation between the features observed through imaging techniques and the crystallography of the specimen. X-ray diffraction patterns from powder samples are recorded in a Guinier de Wolff camera, with the patterns from as many as four samples being determined simultaneously. Subsequent measurement of diffraction angles related to the diffraction lines on the film, and calculation of the planar spacing (d) generating the diffraction results in data which can be compared with d values from patterns of known materials. Internal standards are used to establish the camera constant for each exposure.

Optical microscopy is useful in determining the powder particle shape and size, oxide distribution and other microstructural features of sufficient size (i.e., large inclusions, precipitates, porosity, etc.). Good results have been

achieved through mechanical grinding and polishing of metallographic samples followed by an electropolish. This procedure results in a flat deformation-free surface with exposed oxide particles, and the distribution of these oxides can be easily characterized. Micrographs of the longitudinal and transverse planes can be combined to develop a three-dimensional image of the powder particle morphology. The powder production technique, consolidation and final sample processing will control this characteristic of the material which will significantly influence some of the sample properties.

Similar microstructural features are anticipated in the alloys to be studied in this research project. The quantitative characterization of the microstructures will be developed through optical and electron microscopy, and x-ray diffraction techniques. Completion of the microstructural analysis is anticipated by September, 1982, with mechanical property determinations to begin as soon as sufficient microstructural data is established.



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404/894-2880

October 14, 1982

LOW DENSITY ALUMINUM ALLOY DEVELOPMENT PROGRAM

Monthly Report for the Period
 September 1 - 30, 1982

Alloy samples of three different nominal compositions produced by INCO's proprietary mechanical alloying process were received August 23, 1982, and seven powder metallurgy alloys comprised of inert gas atomized powder from Pratt & Whitney Aircraft arrived September 14. The research objectives previously stated in the May 1982 Boeing monthly report were postponed, pending arrival of sample materials. Two of the rapidly solidified powder metallurgy alloys have been selected and approved as the subject of the initial investigation in this research project.

These alloys have the following nominal compositions: Al-4.0Li-3.0Cu-1.5Mg-0.20Zr (Alloy No. 1) and Al-4.0Li-3.0Cu-1.5Mg-0.18Cr-0.20Zr (Alloy No. 2). The rapidly solidified alloy samples are rectangular extrusions, measuring approximately 18 mm x 65 mm x 610 mm including a 1-3 mm thick periphery of casting aluminum (6061). In the as-received condition, these samples were not solution heat treated or stretched. Quantitative characterization of the microstructures through optical microscopy has begun. The primary objectives of this metallography are to determine the size and morphology of prior powder particles, and the size and distribution of constituent particles and oxides. A bromine etching technique will be used to expose constituent particles for examination. An extraction technique may be employed to isolate these particles. Oxides can be observed after electropolishing mechanically ground and polished surfaces. Although an anodizing treatment will be performed to produce grain contrast, the extent of grain refinement resulting from rapid solidification is unknown. Grain size may preclude observation through optical microscopy.

Electron microscopy and x-ray diffraction techniques will be used to examine finer microstructural features such as dispersoid particles, hardening precipitates and possibly grains.

The age hardening response to various solution heat treatment (SHT) temperatures will be examined for a SHT time of 30 minutes. A range of artificial aging temperatures are to be considered; and the combination of SHT temperature, artificial aging temperature and time which optimizes strength and ductility will be determined. Some deformation is to be induced in these materials prior to artificial aging by rolling or stretching, to introduce a homogeneous dislocation structure and provide nucleation sites for precipitate phases. Characterization of the solution heat treated and age-hardened microstructure will follow the development of this condition. This microstructural analysis should be complete by December, 1982, and mechanical property determination will begin as soon as sufficient microstructural data is established.

LOW DENSITY ALUMINUM ALLOY DEVELOPMENT PROGRAM
Monthly Report for the Period
October 1-31, 1982

Bromine etching and electropolishing techniques have been used to reveal microstructural features in the two alloys presently under study (Numbers 1 and 2). The bromine etching procedure involved submersing samples in a boiling solution of 10% bromine in methanol for 60 seconds. This solution selectively attacks the aluminum matrix exposing intermetallic particles in relief, while grain and subgrain boundaries are also revealed due to extreme susceptibility to the etchant. The bromine-etched surfaces were examined in a Cambridge scanning electron microscope (SEM). Electropolishing was performed in a 1:2 solution of nitric acid in methanol at 253K (-20°C). An electric potential of 12 volts was applied for 15 to 30 seconds, during the polishing procedure.

Alloy number 1 (RSN 773) was examined in the following conditions: as-received, solution heat treated (SHT) at 763K (490°C) for 30 minutes, SHT at 811K (538°C) for 30 minutes, and SHT at 811K (538°C) for 4 hours. In the as-received condition, a high volume fraction of particles was evident. Based on morphology, the particle distribution was at least trimodal; consisting of roughly spherical, plate, and irregular shapes. The largest particles apparent by this analytical technique were approximately 12 microns long, and the smallest was on the order of 0.2 microns. Some of the larger particles had fractured with the fragments separating in the extrusion direction, indicating that this deformation occurred during the extrusion process and that these particles existed prior to extrusion. Although a significant decrease in apparent particle volume fraction was evident after the 30 minute solution heat treatments, a relatively high volume fraction remained in the microstructure. No perceivable particle coarsening occurred during these shorter heat treatments. During the 4 hour SHT at 811K, a considerable reduction in particle volume fraction was

observed relative to the shorter heat treatments, however, the plate-shaped particles coarsened up to approximately 20 microns in size. Blistering due to incipient melting and out gassing was also evident after this heat treatment.

Alloy number 2 (RSN 775) exhibited particle distributions and SHT responses similar to alloy number 1. Since the only difference in these alloys is the 0.18 wt. pct. chromium added as a dispersoid forming element, these similarities were anticipated. Although both alloys had uniform particle distributions in general, streaked regions oriented parallel to the extrusion direction were evident in the as-received condition where larger particles were found but very few smaller particles existed. Also, many particles were located on grain and subgrain boundaries.

Diffraction scans were performed on the as-received and the 30 minute SHT conditions of these two alloys, to begin the precipitate phase identification process. The diffractometer was a Norelco unit equipped with a Philips copper K_{α} x-ray source. Most of the diffraction peaks resulting from the precipitation phase particles in the as-received condition were greatly suppressed by the 811K SHT for 30 minutes. The powder diffraction data files were reviewed to determine which intermetallic compounds had d-spacings corresponding to those determined from the diffractometer measurements. The following compounds have d-spacings corresponding to the diffractometer data: AlLi (δ phase), Al_6CuLi_3 (T_2 phase), Al_5CuLi_3 (R phase), and Al_2Cu . Some of the diffraction peaks evident in the diffractometer scans did not correspond to d-spacings in the available powder diffraction data files and other analytical means will be employed to identify the phases causing these diffraction peaks. Debye-Scherrer diffraction measurements will be performed to develop more exact d-spacings. Iron-rich particles were discovered with a Kevex energy dispersive fluorescence spectrometer which

may be $\text{Al}_7\text{Cu}_2\text{Fe}$. Quantitative analysis of Kevex data developed from extracted precipitate phase particles may be performed to aid in the phase identification. Transmission electron diffraction will also be used to characterize these phases.

Tensile tests were performed on alloy number 1 in the SHT at 811K for 30 minutes condition. A serrated load vs. elongation curve was observed in the plastic region. An ultimate tensile strength of about 350,000 MPa was measured with 7.5% elongation. No necking was apparent in the fractured tensile samples. Examination of the fracture surfaces in SEM revealed a large number of particles on these surfaces.

A determination of the stage of processing in which the intermetallic particles developed is planned. Strain localization resulting from the presence of these particles is contributing to poor mechanical properties, and a significant reduction in the as-received particle volume fraction is desirable. Samples of the rapidly solidified powder will be examined when received.

LOW DENSITY ALUMINUM ALLOY DEVELOPMENT PROGRAM

Annual Report
January 1 - December 31, 1982

PHASE II, Task I - Quantitative Microstructural Analysis and Mechanical Property Correlations

INTRODUCTION

The primary objective of this research program is to develop new aluminum-lithium (Al-Li) alloys with significantly lower density and greater specific modulus and strength relative to existing alloys. This effort is being performed in accordance with United States Air Force Contract F33615-81-12-5053 presented in Technical Proposals D6-49955-1 and D6-49955-2 by the Boeing Military Airplane Company. Literature reviews and the preparation of a formal research proposal were completed prior to receiving the first alloy samples in August. The work has been centered on alloys produced by powder metallurgy (P/M) techniques, involving mechanical alloying (MA) and inert gas atomization (rapid solidification, RS) processes. The ultimate goal of this program is to develop high performance aluminum alloys with optimized density, strength, and stiffness for application as airframe components.

The extremely high cooling rates (10^4 to 10^6 K/sec) achieved during RS processing generally result in a refinement of microstructural features, which can lead to improved mechanical properties when compared to ingot cast alloys. In the Al-Li system, the benefits of lower density and higher elastic modulus have been offset by reduced ductility, fracture toughness and stress corrosion cracking resistance. Improvement of these properties has been hindered by basic physical and mechanical metallurgical constraints. Segregation of lithium in slowly solidified cast ingots ultimately contributes to

low fracture toughness, and one of the most significant effects of rapid solidification processing is a reduction or elimination of segregation effects during solidification.

In a typical mechanical alloying process, constituent powder particles are repeatedly fractured and cold welded by the continuous impacting action of a milling medium. Composite powder particles are formed, with a composition corresponding to the percentages of the elements in the initial charge. The composite powders produced in this manner are characteristically dense, cohesive and homogeneous. Increased strength in MA alloys is attributed to the uniform distribution of fine dispersoids such as oxides and carbides achieved in the consolidated condition.

The graduate student selected to participate in this research project is Keith M. Bresnahan. A literature review has been conducted, and the results presented in a M.S. thesis reserach proposal. The scope of this proposal included the characterization of microstructures, deformation and fracture modes of new Al-Li alloys.

Alloy samples of three different nominal compositions produced by INCO's proprietary mechanical alloying process were received August 23, 1982, and seven powder metallurgy alloys comprised of inert gas atomized powder from Pratt & Whitney Aircraft arrived September 14. The compositions of these alloys are given in Table 1. Two of the rapidly solidified powder metallurgy alloys and one of the MA alloys have been selected and approved as the subject of the initial investigation in this research project. The rapidly solidified alloy samples are rectangular extrusions, measuring approximately 18 mm x 65 mm x 610 mm including a 1-3 mm thick periphery of canning aluminum

(6061). The MA Alloy samples are rectangular extrusions, measuring 13 mm x 51 mm x 305 mm (including the can). In the as-received condition, these samples were not solution heat treated or stretched. Samples of unconsolidated RS powder were received for alloys No. 1 and 2 in December.

EXPERIMENTAL PROCEDURES

Rapidly Solidified Alloys

Identification of the phases present in the alloys under study is being established mainly through the use of transmission electron microscopy (TEM) and x-ray diffraction techniques. TEM is essential in the examination of the fine microstructural constituents. Bright-field and dark-field imaging is employed to observe shape, size and distributional characteristics of the precipitate particles. Selected area diffraction can be used to develop a correlation between the features observed through imaging techniques and the crystallography of the specimen. X-ray diffraction patterns from powder samples are being recorded in a DeBye Scherrer camera, and diffractometer scans were recorded on the extruded material in the as-received and SHT conditions. Subsequent measurement of diffraction angles related to the diffraction lines on the film or scan chart, and calculation of the planar spacing (d) generating the diffraction results in data which can be compared with d values from patterns of known materials. Internal standards are used to establish the camera constant for each exposure. The diffractometer was a Norelco unit equipped with a Phillips copper K_{α} x-ray source.

Optical microscopy is useful in determining the precipitate particle shape, size, and distribution, and other microstructural features of sufficient

size (i.e., large inclusions, porosity, etc.) Bromine etching and electropolishing techniques have been used to reveal microstructural features in two alloys presently under study (Numbers 1 and 2). The bromine etching procedure involved submersing samples in a boiling solution of 10% bromine in methanol for 60 seconds. This solution selectively attacks the aluminum matrix exposing intermetallic particles in relief, while grain and subgrain boundaries are also revealed due to extreme susceptibility to the etchant. The bromine-etched surfaces were examined in a Cambridge scanning electron microscopy (SEM). Electropolishing was performed in a 1:2 solution of nitric acid in methanol at 253K (-20°C). An electric potential of 12 volts was applied for 15 to 30 seconds, during the polishing procedure.

A small amount of unconsolidated RS powder was cast in epoxy, ground and polished, and examined optically. The metallic powder sample was etched in a solution of 10 grams sodium hydroxide in 90 milliliters of water at 343K for 1 minute. The sample was then desmuted in a 50% nitric acid solution in water. A small section of the epoxy mount containing several etched powder particles was removed and fixed to an aluminum pedestal with copper print. The powder sample and pedestal were then covered with a very thin, conductive layer of gold palladium by sputter coating, and the powder particles were examined with a scanning electron microscope.

Cylindrical tensile samples were prepared for alloys No. 3 through 7 in the solution heat treated (SHT) condition at 773K for 30 minutes. Tensile samples were also prepared for alloys No. 1 and 2 in the SHT condition at 811K for 30 minutes. The yield stress, fracture stress and total elongation were determined, and the results are shown in Table 2. The tests were performed on

a hydraulic Material Testing System (MTS) machine at a strain rate of 5×10^{-3} cm/sec .

In order to optimize the size and distribution of the precipitate phase particles, heat treatments at various temperatures for different lengths of time have been applied to loose powder samples. Subsequent microstructural analysis should establish the precipitate phase particle size and distribution. To reduce oxide formation on the powder particle surfaces during heat treatment, the powder was wrapped in tantalum foil and vacuum encapsulated. Some powder samples were heat treated in a tantalum boat in an argon atmosphere.

Mechanically Alloyed Alloy

Solutionizing heat treatment was performed in a salt bath followed by artificial aging in an oil bath. The heat treatment schedule is given in Table 3. Cylindrical tensile samples were prepared and pulled on an MTS machine at a strain rate of 2×10^{-3} cm/sec. Low cycle fatigue specimens with 4 mm diameter and 10 mm gage length were polished to 1 micron finish before fatigue testing. Strain controlled fatigue tests were performed on the MTS machine with a strain rate of 2.5×10^{-3} cm/sec. To characterize the particle and grain sizes thin foils were prepared and examined with a TEM at 100 kv. Fracture surfaces were examined using a SEM.

EXPERIMENTAL RESULTS

Rapidly Solidified Alloys

Alloy No. 1 was examined in the following conditions: as-received, SHT at 763K (490°C) for 30 minutes, SHT at 811K (538°C) for 30 minutes, and SHT at 811K for 240 minutes. In the as-received condition, a high volume fraction

of particles was evident, Figure 1. Based on morphology, the particle distribution was at least trimodal; consisting of roughly spherical, plate, and irregular shapes. The largest particles apparent by this analytical technique were approximately 12 microns in longest dimension, and the smallest was on the order of .2 microns. Some of the larger particles had fractured with the fragments separating in the extrusion direction, Figure 2, indicating that this deformation occurred during the extrusion process and that these particles existed prior to extrusion. Although a significant decrease in apparent particle volume fraction was evident after the 30 minute solution heat treatments, a relatively high volume fraction remained in the microstructure, Figure 3. No significant particle coarsening occurred during these shorter heat treatments. During the 240 minute SHT at 811K, a considerable reduction in particle volume fraction was observed relative to the shorter heat treatments, however, the plate-shaped particles coarsened up to approximately 20 microns in size, Figure 4. Blistering due to incipient melting and out gassing was also evident after this heat treatment.

Alloy No. 2 exhibited particle distributions and SHT responses similar to alloy No. 1. Since the only difference in these alloys is the .18 weight percent chromium added as a dispersoid forming element, these similarities were anticipated. Although both alloys had uniform particle distributions in general, streaked regions oriented parallel to the extrusion direction were evident in the as-received condition where larger particles were found but very few smaller particles existed, Figure 5. Also, many particles were located on grain and subgrain boundaries.

Diffraction scans were performed on the as-received and the 30-minute SHT conditions of these two alloys, to begin the precipitate phase identifi-

cation process. Most of the diffraction peaks resulting from the precipitate phase particles in the as-received condition were greatly suppressed by the 811K SHT for 30 minutes. The powder diffraction data files were reviewed to determine which intermetallic compounds had d-spacings corresponding to those determined from the diffractometer measurements. The following compounds have d-spacings corresponding to the diffractometer data: AlLi (δ phase), Al_6CuLi_3 (T_2 phase), Al_5CuLi_3 (R phase), and Al_2Cu . Some of the diffraction peaks evident in the diffractometer scans did not correspond to d-spacings in the available powder diffraction data files and other analytical means will be employed to identify the phases causing these diffraction peaks. Iron-rich particles were discovered with a Kevex energy dispersive fluorescence spectrometer which may be $\text{Al}_7\text{Cu}_2\text{Fe}$. Quantitative analysis of Kevex data developed from extracted precipitate phase particles may be performed to aid in the phase identification. Transmission electron diffraction will also be used to characterize these phases.

DeBye-Scherrer diffraction measurements performed on samples of unconsolidated RS powder in various heat treated conditions revealed the presence of δ , T_2 and R phases. Diffraction lines corresponding to the d-spacings associated with these phases were also generated by as-received RS powder, indicating that these phases are forming during solidification. After heat treatment at 473K for 90 minutes, δ' (Al_3Li) diffraction lines appeared in the film exposures. This phase was not evident after heat treatment at higher temperatures and longer times. The appearances of the microstructure of the unconsolidated powder after heat treatment at 473K for 90 minutes and at 655K for 300 minutes are shown in Figure 6 compared to the as-received condition. The fine dendritic structure coarsens and begins to break down with increasing

The fine dendritic structure coarsens and begins to break down with increasing heat treatment temperature and time, and the interdendritic precipitate phase particles also coarsen.

Mechanically Alloyed Alloy

The MA Alloy studied had the following nominal composition, Al-2.5Li-1.5Cu-1.0Mg. A fine grained microstructure was exhibited with finely distributed equiaxed particles as shown in Figure 7. SHT resulted in a reduction of precipitate phase particle volume fraction. Grain size in this alloy ranged from 0.5 micron to 1.0 micron.

The hardness peaked rapidly during artificial aging, making it difficult to control the structure in an underaged condition. Table 3 lists the tensile properties of samples with different aging schedules. Although the yield strength was improved by artificial aging, the ductility was severely reduced. The extent to which the fracture occurs in an intergranular or transgranular mode remains undetermined at this time. It is likely that the particle interfaces are the crack path of least resistance, and this could be a contributing factor in the low ductility of this MA alloy.

The presence of Al_4C_3 has been confirmed by x-ray diffraction analysis, but Al_2O_3 peaks were not obtained in the x-ray analysis. The Al_2O_3 may be present in an amorphous form. Further particle characterization will require electron diffraction and energy dispersive x-ray analysis (Kevex).

To address the problem of low ductility, naturally aged specimens were selected for low cycle fatigue (LCF) testing. Figure 8 shows the LCF cyclic response. For a total strain amplitude below 1%, softening was observed in the first cycle, and cyclic hardening followed until saturation was reached. The

cyclic and monotonic stress-strain curves are shown in Figure 9. The cyclic hardening exponent, n' , can be expressed as:

$$\sigma_a = \sigma_f' \left(\frac{\Delta \epsilon_p}{2} \right)^{n'}$$

where σ_a is the stress amplitude and σ_f' is the fatigue strength coefficient. It was found that the cyclic hardening exponent was very close to the monotonic strain hardening exponent for this alloy. Fractographs of the fatigue fractured samples are shown in Figure 10, and the features exhibited here are similar to that of the tensile fracture surfaces.

A Coffin-Manson (C-M) plot of the LCF test is given in Figure 11. The results follow the C-M relationship which can be expressed as:

$$\frac{\Delta \epsilon_p}{2} = \epsilon_f' (2N_f)^{-c}$$

where $\Delta \epsilon_p$ is the plastic strain range, ϵ_f' is the fatigue ductility coefficient, $2N_f$ is the number of reversals to failure and c is the fatigue ductility exponent. The exponent c can be estimated from the C-M plot, and a value of $c = 0.5$ was obtained. No break point was observed in the C-M plot, and this indicates that the deformation and fracture modes are similar at high and low strain amplitudes.

CONCLUSIONS

Rapidly Solidified Alloys No. 1 and 2

A relatively high volume fraction of precipitate phase intermetallic particles are evident in the as-received extruded material. Although solution heat treatment at 811K for 0.5 hr reduces the amount of precipitate phase particles, a significant amount remains in the microstructure. SHT for periods longer than 0.5 hr results in significant particle coarsening.

Preliminary x-ray diffraction data indicates the presence of several precipitate phases common in Al-Li-Cu-Mg alloys, however, some of the diffraction data does not correspond to any alloy listed in the powder diffraction data files.

Failure in tensile tests most probably results from crack initiation at the interface between the precipitate phase particles and the aluminum matrix. Low ductility in the SHT condition may be the result of strain localization at the precipitate phase particles.

The precipitate phase particles are present in the RS powder, although they are very small and finely dispersed. Development of the large precipitate phase particles evident in the extruded powder is occurring during the extrusion preheat treatment.

Mechanically Alloyed Alloy

High strength and low ductility are demonstrated by this alloy. The high strength and low ductility is associated with a high volume fraction of particles and dense substructure. Low cycle fatigue properties of this alloy in the naturally aged condition show initial softening at the first cycle, followed by cyclic hardening. The initial softening is due to residual stress relief. Cyclic hardening is associated with dislocation-particle interaction.

TABLE 1. Nominal Chemical Composition for First Iteration Alloys

ALLOY TYPE	ALLOY NO.	ALLOYING ELEMENT (WT.%)									
		Al	Li	Cu	Mg	Zn	Zr	Ca	Cr	O	C
CLASS I ALLOYS PRODUCED BY PRATT & WHITNEY FROM INERT GAS ATOMIZED POWDER											
I	1	Bal.	4.0	3.0	1.5	---	0.2	---	---	---	---
	2	Bal.	4.0	3.0	1.5	---	0.2	---	0.18	---	---
II	3	Bal.	3.0	---	5.5	---	0.2	---	---	---	---
	4	Bal.	3.5	---	10.0	---	0.2	---	---	---	---
III	5	Bal.	1.5	2.0	2.0	7.0	0.2	---	---	---	---
	6	Bal.	3.0	2.0	2.0	7.0	0.2	---	---	---	---
IV	7	Bal.	3.0	2.0	1.0	---	0.2	---	---	---	---
CLASS II ALLOYS PRODUCED BY INCO FROM MECHANICALLY ALLOYED POWDER											
	1	Bal.	2.5	---	2.5	---	---	---	---	0.6	1.1
	2	Bal.	1.5	---	4.0	---	---	---	---	0.6	1.1
	3	Bal.	2.5	1.5	1.0	---	---	---	---	0.6	1.1

TABLE 2. Tensile Properties in the SHT Condition

ALLOY NO.	YIELD STRESS MPa	FRACTURE STRESS MPa	ELONGATION %
1	195	350	7.5
2	222	333	5.3
3	351	462	7.5
4	328	372	2.6
5	290	468	10.0
6	222	300	3.8
7	156	309	5.9

TABLE 3. Heat Treatments and Tensile Properties

SOLUTIONIZING SCHEDULE	AGING SCHEDULE	YIELD STRENGTH	ELONGATION
811K/0.5 hr	RT aging/48 hrs	460 MPa	4.4%
811K/0.5 hr	2% stretch + RT aging/48 hrs + 463K aging/0.5 hr	636 MPa	1 %
811K/0.5 hr	2% stretch + RT aging/48 hrs + 463K aging/4 hrs	535 MPa	1.8%

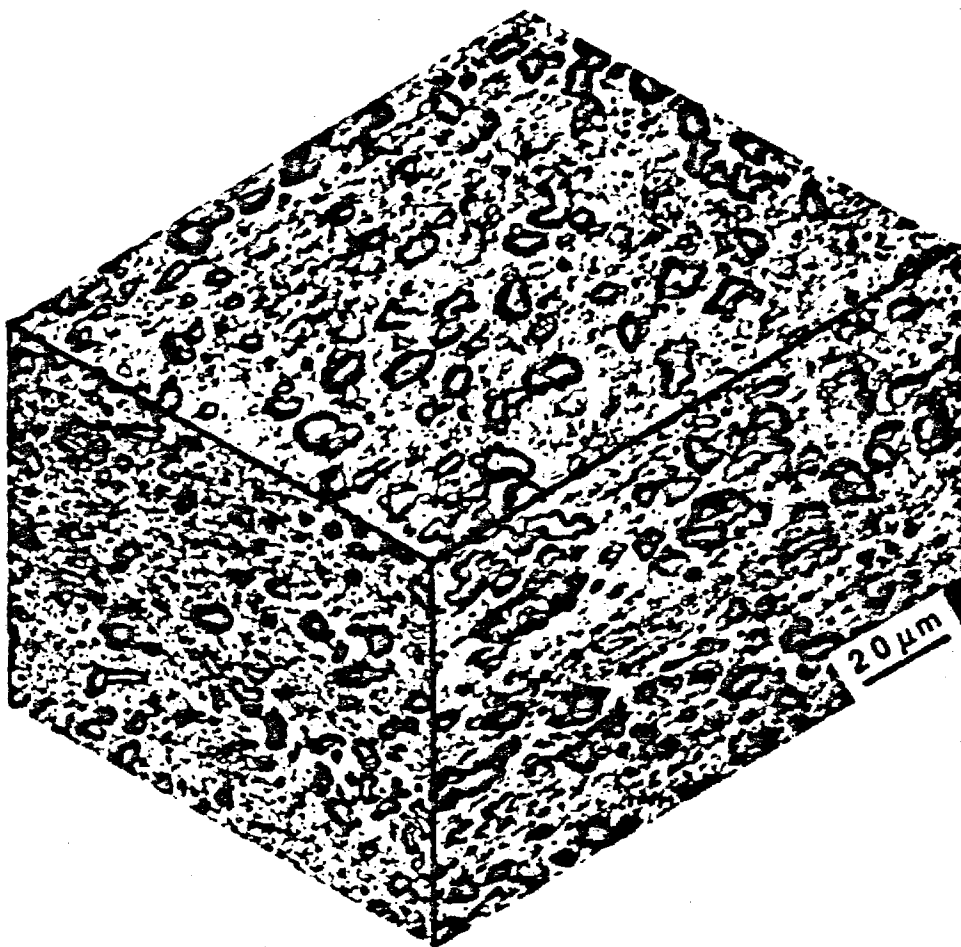


FIGURE 1. Optical micrographs of electropolished extruded alloy no. 1 in the as-received condition.

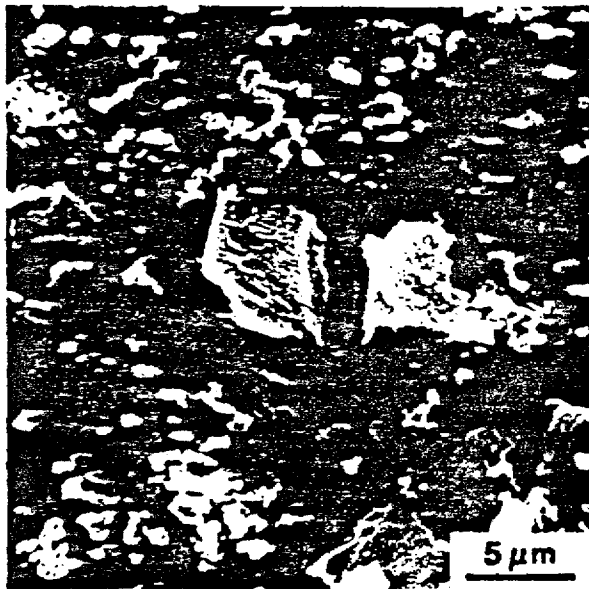


FIGURE 2. Scanning electron micrograph of bromine etched extruded alloy no. 2.

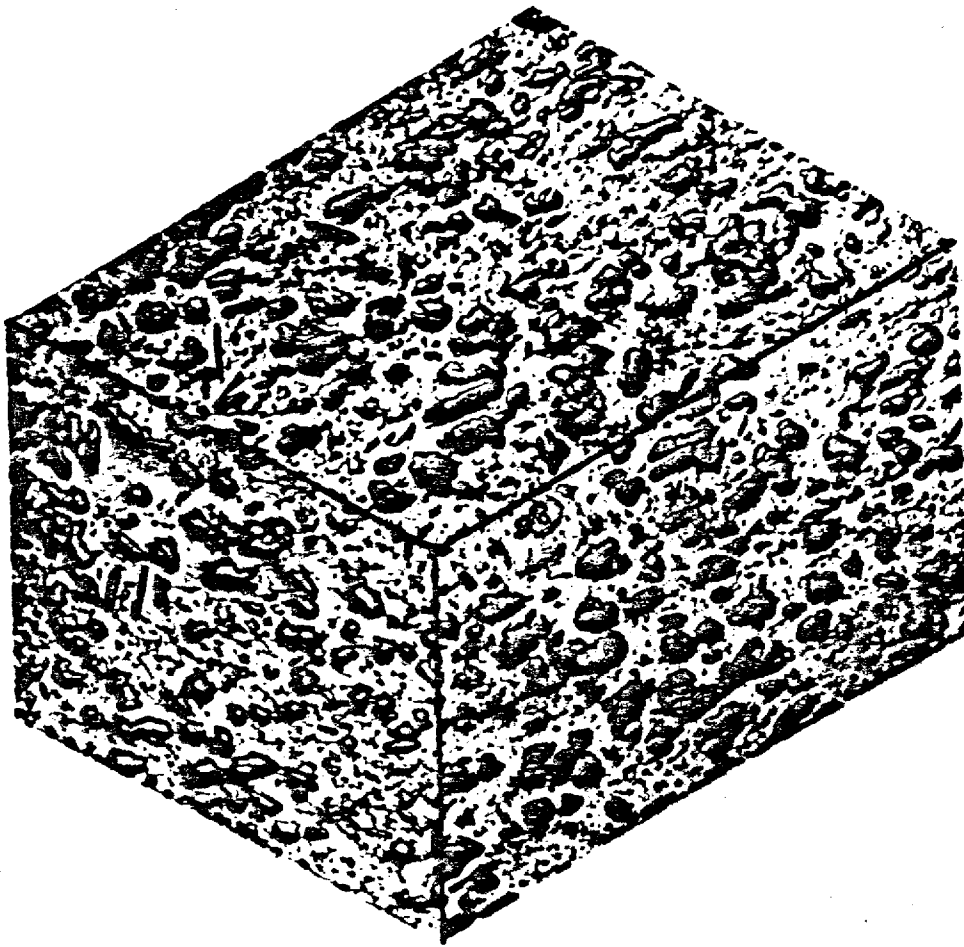


FIGURE 3. Optical micrographs of electropolished extruded alloy no. 1 SHT at 763K for 0.5 hr.

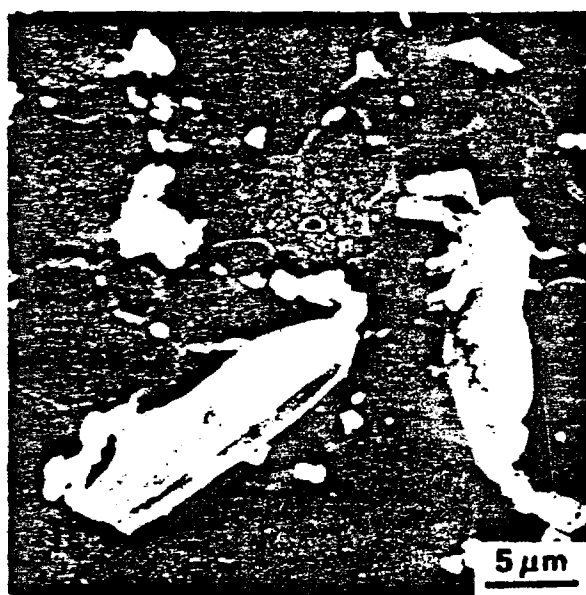


FIGURE 4. Scanning electron micrographs of bromine etched extruded alloy no. 1
SHT at 811K for 4.0 hrs.

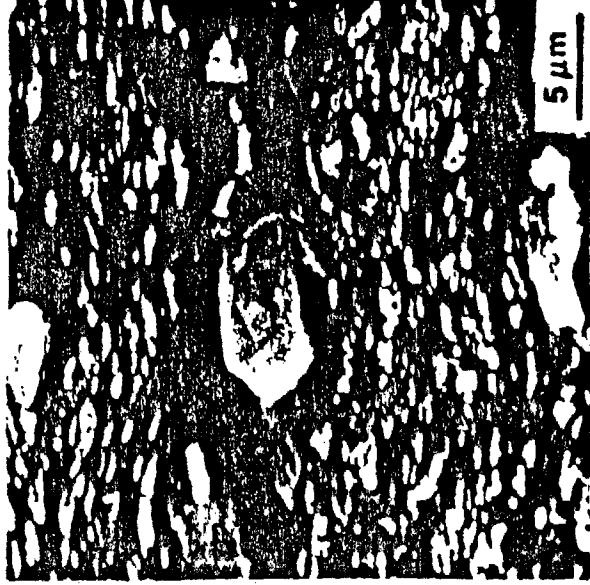
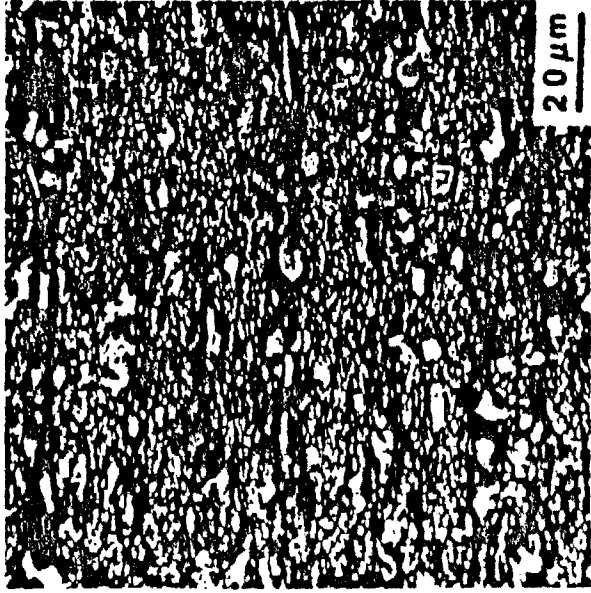


FIGURE 5. Scanning electron micrographs of bromine etched extruded alloy no. 2

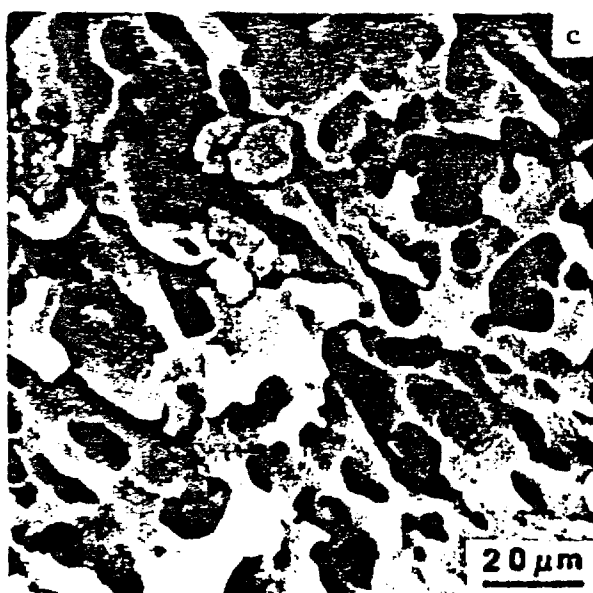
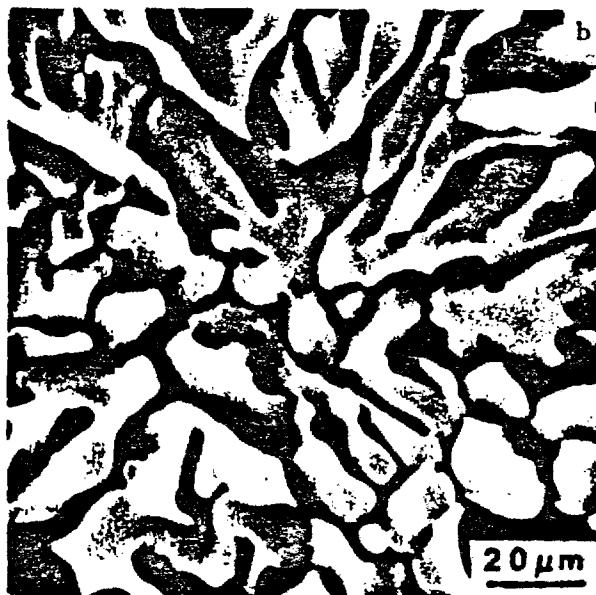
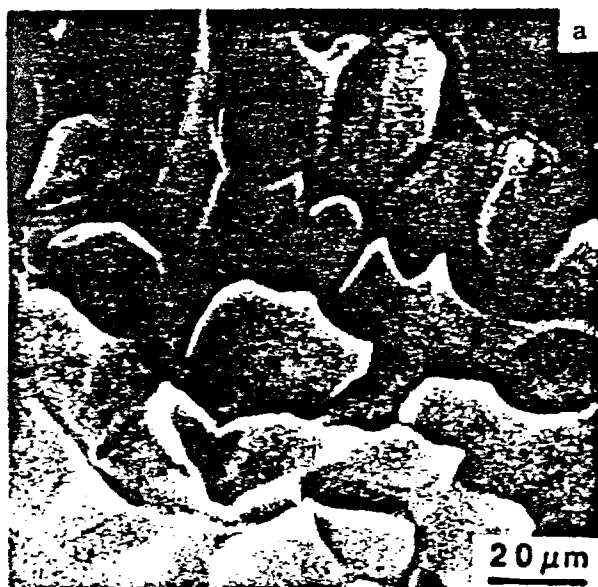


FIGURE 6. Scanning electron micrographs of sodium hydroxide etched RS powder particles of alloy no. 1. a) as-received condition, b) heat treated at 473K for 1.5 hrs, and c) heat treated at 655K for 5.0 hrs.

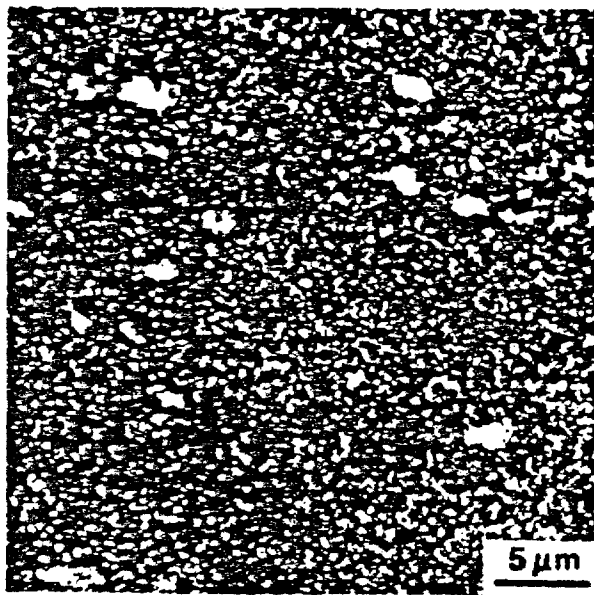


FIGURE 7. Scanning electron micrograph of bromine etched MA alloy Al-2.5Li-1.5Cu-1.0Mg.

Cyclic Hardening/Softening Curves

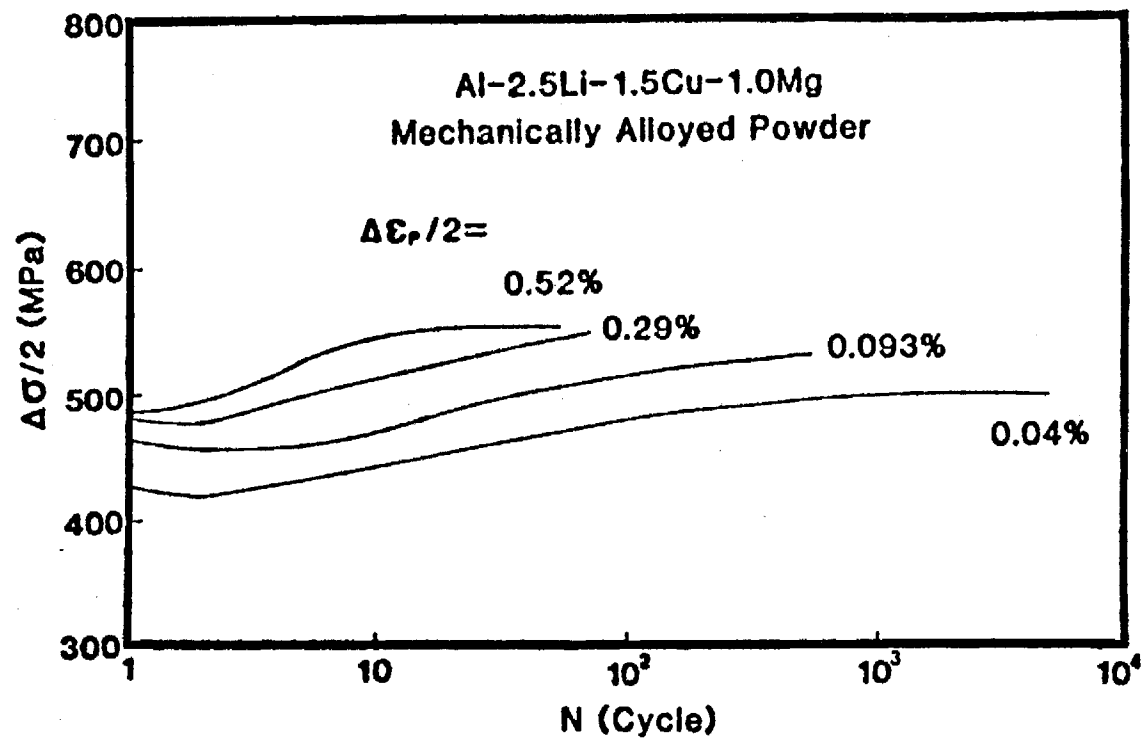
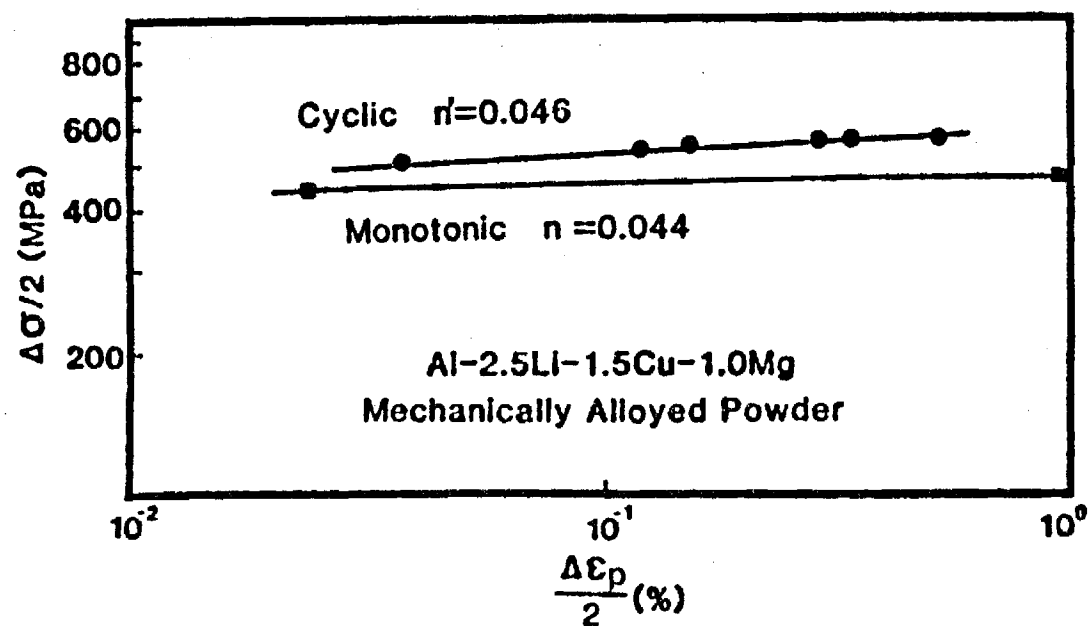


FIGURE 8.



Monotonic And Cyclic Stress-Strain Curves

FIGURE 9.

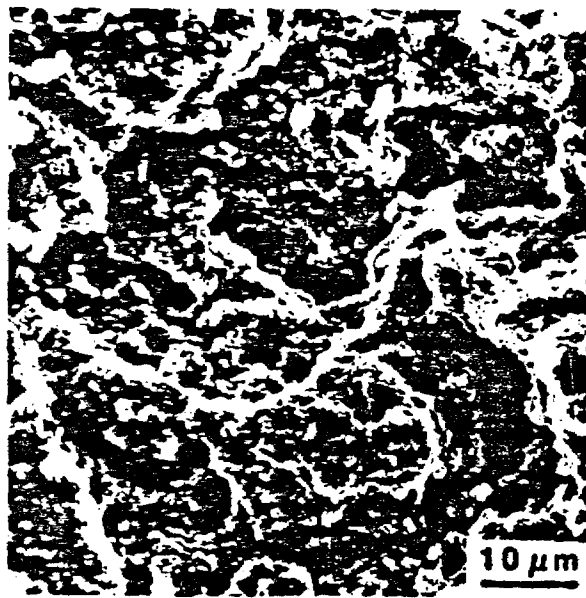
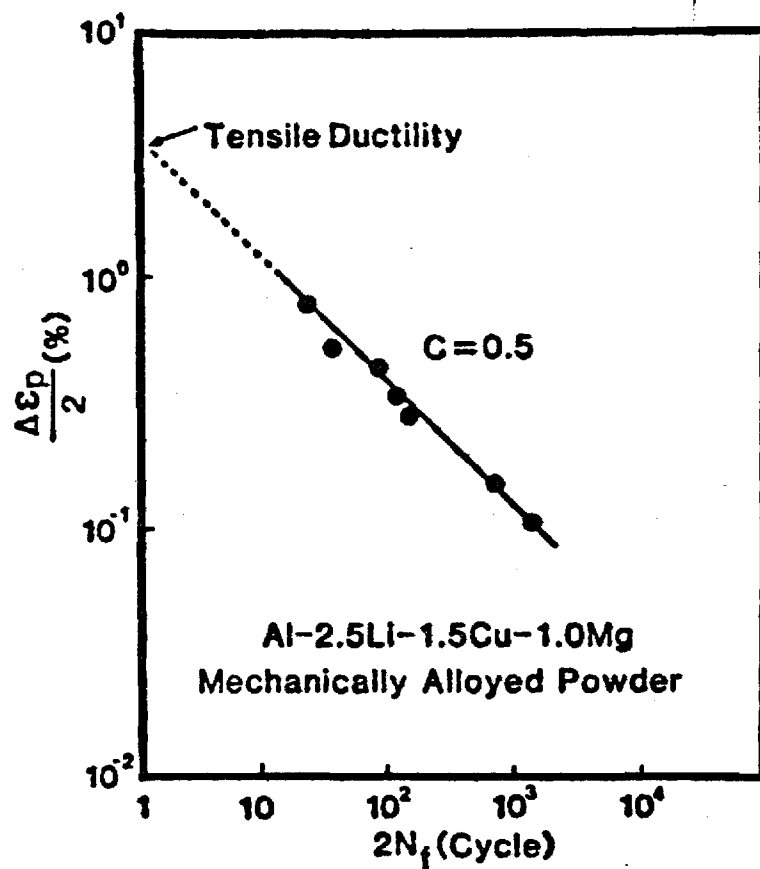


FIGURE 10. Scanning electron micrograph of LCF fracture surface.



LCF, Coffin-Manson Plot

FIGURE 11.

(E-19-604)

Final Report

LOW DENSITY ALUMINUM ALLOY DEVELOPMENT PROGRAM
Air Force Contract No. F33615-81-C-5053

To

Boeing Commercial Airplane Company
P.O. Box 3707
Seattle, Washington 98124

From

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Fracture and Fatigue Research Laboratory
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January 17, 1983

Georgia Tech E-19-668

ABSTRACT

Study of the RS alloys comprised of inert gas atomized powder from Pratt & Whitney Aircraft has been centered on Alloys No. 1 and 2. Samples of extruded bars were examined in the as-received and SHT conditions. Microstructural features were revealed by electropolish and bromine etching techniques. A relatively large volume fraction of precipitate phase intermetallic particles was evident in the as-received condition. Solution heat treatment at 811K for 0.5 hr. provided the best results; however, a significant amount of precipitate phase particles remained in the microstructures. Based on morphology and x-ray diffraction data, the precipitate phase particle distribution is at least trimodal.

Tensile tests performed on all seven RS alloys in the SHT condition demonstrated relatively low ductility. Examination of tensile fracture surfaces revealed a large number of precipitate phase particles on the surfaces, apparently intact. The precipitate phase-aluminum matrix interface seems to be involved in the crack initiation and propagation processes.

Microstructural features and x-ray data indicate that the precipitate phases are present in the RS powder prior to extrusion. A fine dendritic microstructure exists in the unprocessed RS powder, with no precipitate phase particles apparent at magnifications up to 6000 diameters after a sodium hydroxide etch. Diffraction lines resulting from precipitate phases do appear in Debye-Scherrer measurements on the unconsolidated RS powder. Heat treatment of unconsolidated powder results in a breakdown of the fine dendritic structures and apparent coarsening of precipitate phase particles. In the extruded material, fragmented precipitate phase particles are evident indicating

their formation prior to extrusion. Based on the information developed at this time, the formation of precipitate phase particles as they appear in the extruded samples is occurring during the extrusion preheat treatment. Optimization of this preheat treatment may significantly improve the mechanical properties of these alloys by changing the precipitate phase particle type, size and distribution.

The alloy with nominal composition Al-2.5Li-1.5Cu-1.0Mg, produced by INCO's mechanical alloying process, has been studied. A fine grained microstructure with finely distributed, equiaxed particles is apparent in this alloy. The monotonic and cyclic mechanical properties were investigated in an appropriate SHT and aged condition. This treatment involved SHT at 811K for 0.5 hr, stretching to 2% total strain, followed by natural aging for 48 hrs and artificial aging at 463K. High strength and low ductility are demonstrated by this alloy. The high strength and low ductility is associated with a high volume fraction of particles and dense substructure. Low cycle fatigue properties of this alloy in the naturally aged condition show initial softening at the first cycle, followed by cyclic hardening. The initial softening is due to residual stress relief. Cyclic hardening is associated with dislocation-particle interaction.