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TROY NY DEPT OF METALLURGICAL ENGINEERING
G S ANSELL ET AL. 01 OCT 85 N00014-85-K-0058

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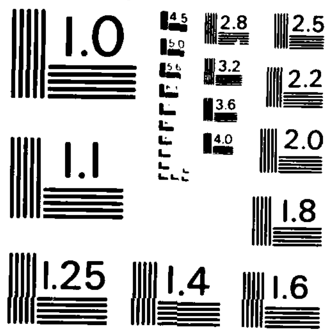

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October 9, 1985

Mr. R. C. Pohanka
Head, Materials Division (Acting)
Office of Naval Research
Arlington, Virginia 22217-5000

Dear Mr. Pohanka:

Enclosed please find the annual report for the ONR Contract No. N00014-85-K-0058, entitled DISPERSION STRENGTHENING.

The support received by the Office of Naval Research is greatly appreciated. I look forward to continued progress with the research on this contract during the coming year.

Sincerely,

Gary Judd
Acting Provost

GJ/pau

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End-of-the-Year Letter

DISPERSION STRENGTHENING

Contract No. N00014-85-K-0058
Task No. 031-689

Principal Investigators:

George S. Ansell
Adjunct Professor of Metallurgical Engineering
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Troy, New York 12181

and

President
Colorado School of Mines
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and

Gary Judd
Acting Provost
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Troy, New York 12181

ONR Scientific Officer: Bruce A. MacDonald

October 1, 1985

A. Description of Research

The purpose of this program is to develop a fundamental understanding of the role of finely dispersed second phase particles upon the properties of crystalline solids. The scope of this work has been directed towards studying the strengthening behavior of nickel-base superalloys, the strength of ferrous martensite, and the kinetics of the austenite to martensite transformation. The studies have focussed on the fundamental aspects of these two-phase systems that appear to control the structural characteristics and mechanical response of these important classes of engineering materials.

1. **Nickel-base Superalloys**: Nickel-base superalloys exhibit high strength at elevated temperatures due to the precipitation of a coherent, ordered phase, gamma prime. High strength in precipitation hardened materials is attributed to the lattice mismatch between the precipitate and the matrix, the stacking fault energy of the precipitate and the volume fraction of the precipitate. In this investigation, the gamma-gamma prime mismatch was measured over the temperature range 25 to 800°C. Alloys with different combinations of coherency strain, antiphase boundary energy, and volume fraction of gamma prime were compared. The flow stress of each alloy in the peak aged condition was determined, and the contribution due to gamma prime precipitation was evaluated over the temperature range 25 to 800°C. Steady state creep tests were also performed on each alloy over the temperature range 600 to 800°C. The important conclusions developed from this work are:

a. The coherency strain decreased with increasing temperature.

b. An increment in the flow stress, when normalized by the weight fraction of gamma prime, is linearly correlated to thegamma-gamma prime mismatch existing at a temperature within the 25 to 800°C temperature range.

c. Variations in coherency strain were found to have minimal influence on the steady state creep rate. The steady state creep rate was found to depend on the weight fraction of gamma prime. Increasing the weight fraction gamma prime decreases the steady state creep rate.

d. Dislocation-precipitation interactions during tensile deformation were studied for high and low coherency alloys. In high coherency alloys, the gamma prime particles were bypassed by dislocations, whereas in low coherency alloys, the gamma particles were sheared during tensile tests. It is also interesting that the macroscopic yield behavior did not show any variation from the particle bypass to the particle shear failure modes.

e. In contrast with previous literature on nickel base superalloys with low gamma prime volume fractions, coherency strain does not contribute to the strengthening mechanism. Order strengthening appears to be the strongest contributor to the strengthening associated with gamma prime precipitation in these nickel base superalloys.

f. A multiple regression equation was developed to correlate the lattice parameters of gamma and gamma prime to the alloy chemistry on Ni-15Cr-Ti-Al-Mo alloys. The equations can be stated as follows:

$$a_o^{\gamma} = 3.5238 + 0.00165\ \mathrm{Cr} + 0.00509\ \mathrm{Mo} + 0.00184\ \mathrm{Ti}$$

$$a_o^{\gamma'} = 3.5610 + 0.00030\ \mathrm{Cr} + 0.00093\ \mathrm{Mo} + 0.00731\ \mathrm{Ti}$$

where the unit of the lattice parameter is angstroms and the chemical concentrations are in atomic percent. Good correlation between experimental and empirical results has been observed.

g. A similar linear regression equation was developed to relate the thermal expansion coefficient of gamma and gamma prime to the alloy chemistry. This equation can be stated as:

$$\alpha_o^{\gamma} = (14.6456 - 0.389256\ \mathrm{Mo} + 0.269907\ \mathrm{Al} + 0.338253\ \mathrm{Ti}) \times 10^{-6}$$

$$\alpha_o^{\gamma'} = (14.2606 - 0.182603\ \mathrm{Mo} - 0.043648\ \mathrm{Al} - 0.278344\ \mathrm{Ti}) \times 10^{-6}$$

where the unit of the thermal expansion coefficient is in./°C and the chemical concentrations are in atomic percent. These equations are useful in predicting the gamma-gamma prime mismatch at high temperatures.

2. Martensite Strength and Transformation

We have continued the sequence of programs aimed at determining the relationship between process history, alloy effects and parent phase properties upon the strength and transformation kinetics of martensitic alloys.

a. Ferrous martensite: The mechanical properties of ferrous martensites have been shown to be sensitive to specific martensite morphologies. While the prevailing viewpoint in the literature states that martensite morphology is controlled by the carbon content and the Ms temperature, research carried out under this contract has shown that quench rate, chemical driving force, and austenite elastic properties can also alter the resulting martensite morphology. Morphology transitions without variations in the matrix chemistry suggest the existence of anisotropic modulus relaxation in the parent phase austenite just prior to the martensite transformation. Work completed under this contract has shown in ferrous polycrystalline samples the existence of an anisotropic decrease in the martensite shear modulus during cooling. This condition was observed in textured polycrystalline and not in untextured polycrystalline samples. This can be accounted for by grain boundary scattering and grain orientation effects. This result warranted additional research on single crystals.

Single crystals with lath, plate and mixed lath/plate morphologies have been prepared. Ingots of each alloy were directionally solidified to obtain large grains. Homogenization of the grains was performed by heat treating the samples at 1000°C for 1000 hours followed by a one half hour soak at 1200°C and a 100°C brine quench. Orientation of the single crystals has been performed using the back-reflection Laue technique. Carbon content verification has been obtained using a carbon determination apparatus. Differential scanning calorimetry has also been performed to accurately verify the Ms temperature.

A test apparatus incorporating resistivity, dilatometry, and ultrasonics has been developed to simultaneously measure the conditions present in the austenite parent phase just prior to the martensite phase transformation. A 50 MHz spherically focused transducer was designed to be submerged in a methanol cold bath for determining single crystal elastic properties. An acoustic measurement resolution within the sample of 2 microinches has been achieved. The acoustic transducer has been mounted to an optical microscope for accurate positioning and so that accurate optical position verification can be obtained. The ultrasonic electronics have been modified to obtain a ±0.2 nsec transit time accuracy. A Synertek microprocessor has been incorporated to monitor temperatures from room temperature to -130°C and automatically record measured dilation from four LVDTs and the resistivity of the sample. With the use of this testing system, an understanding of premartensitic effects and their interrelationship with the austenite-martensite nucleation kinetics will be achieved. This study is currently in progress and should be completed during the second year of this current contract.

B. Technological Significance

The observance of a variation in the dislocation-precipitation interaction during tensile deformation in nickel base superalloys was significant. Good correlation between experimentally obtained and empirically derived relationships between alloy chemistry, lattice parameter and thermal expansion coefficients in nickel base superalloys are important additions to the literature.

The design and fabrication of a test apparatus that can simultaneously monitor elastic properties, dilatometry and resistivity while accurately controlling temperature is an important technological contribution. This apparatus can also be used to study many other material systems.

C. Plan for Next Year's Research

The plan for next year's research is to complete experimental testing of the premartensitic effects on austenite-martensite nucleation kinetics of ferrous alloys. For the first time, simultaneous measurements of elastic properties, dilatometry, and resistivity in ferrous alloys with three known martensite morphologies will be observed as the temperature is controlled to within 5°C of the Ms temperature. A theoretical model will be generated to help understand how anisotropic modulus relaxation in large atomic displacement transformations, such as ferrous alloys, influence the nucleation of martensite.

D. Technical Reports

During this period, the following papers and talks have been presented at scientific meetings, submitted for publication, or have been published:

1. Papers

"A Model for the Growth of Thermoelastic Martensite in Cu-Zn-Al Alloys", H. Deng and G.S. Ansell, accepted for publication by Metallurgical Transactions.

2. Presentations

"An *Introduction of New Technology in Mining*", G.S. Ansell, invited speaker, American Mining Congress, San Francisco, September 23, 1985.

"The Strength and Transformation Behavior of Ferrous Martensites", G.S. Ansell, invited speaker, ASM Denver Section, October 1984.

E. Participants in Program

G.S. Ansell - Co-principal Investigator

G. Judd - Co-principal Investigator

C. Tomonto - Graduate Assistant - Ph.D. Candidate
(approximate date for completion of degree requirements - October 1986)

M. Naik - Graduate Assistant - M.D. Candidate
(completion of degree requirements - August 1985)

H. Giguere - Undergraduate Assistant

F. Other Sponsored Research

Dr. Ansell and Dr. Judd have no other sponsored research or applications pending at the present time.

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