AD-A186 101 FATIGUE FRACTURE AND STRAIN HARDENING OF HIGH CARBON 1/1
HARDENED ALLOY STEEL(U) COLORADO SCHOOL OF MINES GOLDEN
G KRAUSS 04 JUN 87 ARO-21316.4-MS DAAG29-84-K-0127

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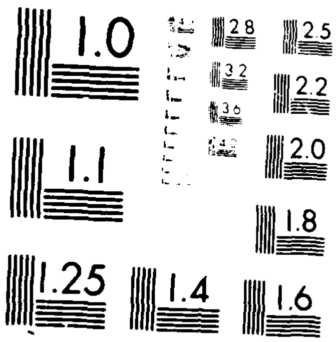
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ARO 21316.4-MS

FATIGUE, FRACTURE AND STRAIN HARDENING OF HIGH CARBON HARDENED ALLOY STEEL

FINAL REPORT

GEORGE KRAUSS

JUNE 4, 1987

U.S. ARMY RESEARCH OFFICE

CONTRACT/GRANT NUMBER

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GOLDEN, COLORADO 80401

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ABSTRACT

Medium and high carbon alloy steels have been heat treated to microstructures of low-temperature tempered martensite and retained austenite. Four point bending fatigue testing of 0.8 pct C steels showed that low cycle fatigue resistance was directly related to retained austenite content. The strain-induced transformation of retained austenite substantially increased strain hardening rates of the composite tempered martensite-austenite microstructures at high strains and increased the number of cycles required to initiate fatigue cracks at prior austenite grain boundaries in specimens with the highest retained austenite content. Transmission electron microscopy identified the transition carbides formed on tempering as the orthorhombic eta carbide, and the increasing density of the transition carbides with increases in carbon content was the major carbon-dependent structural parameter which correlated with flow stresses and strain hardening rates in medium carbon tempered martensite. Elastic limits, as measured with strain gages mounted in compression specimens, decreased with increasing retained austenite content. In medium carbon steels with lath martensite morphologies the retained austenite transformed to martensite by stress induced mechanisms, and in high carbon steels with plate martensite morphologies, the retained austenite transformed by strain-induced mechanisms.

STEAM CONDENSERS

CONDIMENTS
UF PEPPER
SEASONINGS
SPICES
BT FOOD

CONDITIONED RESPONSE
BT *RESPONSE(BIOLOGY)

CONDITIONING(LEARNING)
BT *LEARNING

CONDUCTION BANDS
BT ENERGY BANDS

CONDUCTION(HEAT TRANSFER)
BT HEAT TRANSFER

CONDUCTIVE LIQUIDS
BT *LIQUIDS

CONDUCTIVITY
BT PHYSICAL PROPERTIES
NT *ELECTRICAL CONDUCTIVITY
THERMAL CONDUCTIVITY

CONDUIT PLIERS
BT *PLIERS

CONDUITS

CONFERENCING(COMMUNICATIONS)
BT COMMUNICATION AND RADIO SYSTEMS

CONFIDENCE LEVEL

CONFIDENCE LIMITS
BT *STATISTICAL ANALYSIS

CONFIGURATION MANAGEMENT
BT MANAGEMENT

CONFIGURATIONS
NT *AERODYNAMIC CONFIGURATIONS
ANTENNA CONFIGURATIONS
COAXIAL CONFIGURATIONS
CRUCIFORM CONFIGURATIONS
*SHAPE
STUE CONFIGURATION

CONFINED ENVIRONMENTS
Restricted or isolated environments involving any number of people, such as in spacecraft, submarines, or bomb shelters.
BT ENVIRONMENTS

CONFINEMENT(GENERAL)
NT CONFINEMENT(NUCLEAR REACTORS)

CONFINEMENT(NUCLEAR REACTORS)
Systems or equipment that provide total isolation of hazardous materials in case of reactor accidents.
BT CONFINEMENT(GENERAL)
NUCLEAR REACTORS

CONFINEMENT(PSYCHOLOGY)
BT *STRESS(PSYCHOLOGY)

CONFLICT

CONFLUENCE

CONFORMAL MAPPING
BT *COMPLEX VARIABLES
MAPPING

CONFORMAL STRUCTURES
BT STRUCTURES

CONFORMITY

CONFRONTATION

CONGENITAL ABNORMALITIES
BT ABNORMALITIES

CONGESTION

CONGO RIVER
BT *RIVERS

CONGRESS
(81/09) - Legislature of the United States consisting of the Senate and the House of Representatives
BT *UNITED STATES GOVERNMENT
NT HOUSE OF REPRESENTATIVES
SENATE

CONICAL ANTENNAS
BT *BROADBAND ANTENNAS
NT BICONICAL ANTENNAS
DISCONE ANTENNAS

CONICAL BODIES
BT BODIES
GEOMETRIC FORMS
NT FRUSTUMS

CONICAL NOZZLES
BT NOZZLES

CONICAL SCANNING
BT SCANNING

CONICAL WINGS
BT *DELTA WINGS

CONJUGATED PROTEINS
use PROTEINS(CONJUGATED)

CONJUNCTIVITIS
BT *EYE DISEASES

CONNECTICUT
BT *NEW ENGLAND

CONNECTICUT RIVER
BT *RIVERS

CONNECTING RODS

CONNECTIVE TISSUE
BT TISSUES(BIOLOGY)
NT ADIPOSE TISSUE
*BONES
CARTILAGE
FASCIA
MAST CELLS

CONNECTORS
NT *ELECTRIC CONNECTORS

CONSCIOUSNESS

CONSERVATION
NT SOIL CONSERVATION
WATER CONSERVATION
WATER RECLAMATION

CONSERVATION LAWS(MATHEMATICS)
use DIFFERENTIAL GEOMETRY

CONSISTENCY

CONSISTENCY PROOF
use CALCULUS OF VARIATIONS
and MATHEMATICAL LOGIC

CONSOLES
BT *CONTROL PANELS
NT KEYBOARDS

CONSORTIUMS

CONSTANT SPEED DRIVES
use DRIVES
and SPEED REGULATORS

CONSTANTS
NT GRUNEISEN CONSTANT

CONSTELLATIONS

CONSTRICTIONS
NT VASOCONSTRICTING

CONSTRUCTION
NT *CONSTRUCTION MATERIALS
FILAMENT WOUND CONSTRUCTION
*MODULAR CONSTRUCTION
TAPE WOUND CONSTRUCTION
UNDERWATER CONSTRUCTION

CONSTRUCTION EQUIPMENT
NT ROAD BUILDING EQUIPMENT

CONSTRUCTION MATERIALS
BT CONSTRUCTION
MATERIALS
NT *CONCRETE
MORTARS(MATERIAL)

CONSUMABLE ELECTRODE PROCESS
BT *ARC MELTING

CONSUMER PROBLEMS
BT CONSUMERS

CONSUMERS
NT CONSUMER PROBLEMS

CONSUMPTION
NT ALCOHOL CONSUMPTION
ENERGY CONSUMPTION
FOOD CONSUMPTION
*FUEL CONSUMPTION
OIL CONSUMPTION
OXYGEN CONSUMPTION

CONTACT FUZES
use IMPACT FUZES

CONTACT LENSES
(84/12) - A thin lens fitted over the cornea to correct defects of vision
BT *OPTICAL LENSES

SPEECH COMPRESSION
THERMOCOMPRESSION
TIME COMPRESSION

COMPRESSION IGNITION
BT *IGNITION

COMPRESSION IGNITION ENGINES
BT *INTERNAL COMBUSTION ENGINES
NT DIESEL ENGINES

COMPRESSION MOLDING
BT *MOLDING TECHNIQUES

COMPRESSION RATIO
BT RATIOS

COMPRESSION SHOCK
use SHOCK WAVES

COMPRESSIVE PROPERTIES
Response to compression loads.
UF COMPRESSIBILITY
COMPRESSIVE STRENGTH
BT *MECHANICAL PROPERTIES
NT BEARING STRENGTH

COMPRESSIVE STRENGTH
use COMPRESSIVE PROPERTIES

COMPRESSOR BLADES
BT *ROTOR BLADES(TURBOMACHINERY)
NT AXIAL FLOW COMPRESSOR BLADES

COMPRESSOR COMPONENTS
(84/12)
UF COMPRESSOR PARTS
BT COMPRESSORS

COMPRESSOR NOISE
BT *MACHINERY NOISE

COMPRESSOR PARTS
use COMPRESSOR COMPONENTS

COMPRESSOR ROTORS
BT ROTORS

COMPRESSOR STATORS
BT STATORS

COMPRESSORS
NT AIR COMPRESSORS
COMPRESSOR COMPONENTS
GAS COMPRESSORS
HIGH PRESSURE COMPRESSORS
MIXED FLOW COMPRESSORS
REFRIGERANT COMPRESSORS
*ROTARY COMPRESSORS
*SUPERCHARGERS

COMPTON SCATTERING
BT *GAMMA RAY SCATTERING

COMPTROLLERS
BT FINANCE

COMPUTATIONAL LINGUISTICS
BT LINGUISTICS
NT MACHINE TRANSLATION

COMPUTATIONS
BT *MATHEMATICAL ANALYSIS

COMPUTER AIDED DESIGN
BT COMPUTER APPLICATIONS

COMPUTER AIDED DIAGNOSIS
BT DIAGNOSIS(GENERAL)

COMPUTER AIDED INSTRUCTION
BT COMPUTER APPLICATIONS
*TEACHING METHODS

COMPUTER AIDED MANUFACTURING
(84/12) - The use of computers to communicate work instructions to automate machinery for the handling and processing needed to produce a workplace

COMPUTER APPLICATIONS
NT COMPUTER AIDED DESIGN
COMPUTER AIDED INSTRUCTION
*COMPUTERIZED SIMULATION
MEDICAL COMPUTER APPLICATIONS

COMPUTER ARCHITECTURE
BT *COMPUTERS

COMPUTER COMMUNICATIONS
BT COMMUNICATION AND RADIO SYSTEMS

COMPUTER FILES
BT *FILES(RECORDS)

COMPUTER GRAPHICS
BT DISPLAY SYSTEMS
GRAPHICS

COMPUTER LOGIC
BT LOGIC

COMPUTER OPERATORS
BT *OPERATORS(PERSONNEL)

COMPUTER PERSONNEL
BT PERSONNEL
NT PROGRAMMERS

COMPUTER PRINTOUTS

COMPUTER PROGRAM DOCUMENTATION
BT COMPUTER PROGRAMS
DOCUMENTS

COMPUTER PROGRAM RELIABILITY

COMPUTER PROGRAM VERIFICATION

COMPUTER PROGRAMMING
UF CODING(COMPUTERS)
PROGRAMMING(COMPUTERS)
BT COMPUTER PROGRAMS
NT AUTOMATIC PROGRAMMING
CONTROL SEQUENCES
DEBUGGING(COMPUTERS)
MACHINE CODING
MACROPROGRAMMING
MICROPROGRAMMING

COMPUTER PROGRAMS
NT COMPILERS
COMPUTER PROGRAM DOCUMENTATION
*COMPUTER PROGRAMMING
EXECUTIVE ROUTINES
FIELDS(COMPUTER PROGRAMS)
FIRMWARE
*PROGRAMMING LANGUAGES
SUBROUTINES

COMPUTERIZED SIMULATION
BT COMPUTER APPLICATIONS
*MATHEMATICAL MODELS
NT ANALOG SIMULATION
DIGITAL SIMULATION
HYBRID SIMULATION

COMPUTERIZED TOMOGRAPHY

COMPUTERS
BT *DATA PROCESSING EQUIPMENT
NT ANALOG COMPUTERS
ASYNCHRONOUS COMPUTERS
*CENTRAL PROCESSING UNITS
COMPUTER ARCHITECTURE
*DIGITAL COMPUTERS
*FIRE CONTROL COMPUTERS
GUIDANCE COMPUTERS
GUIDED MISSILE COMPUTERS
HYBRID COMPUTERS
*INPUT OUTPUT DEVICES
*MEMORY DEVICES
MICROCOMPUTERS
MINICOMPUTERS
NAVIGATION COMPUTERS
SUPERCOMPUTERS

CONCAVE BODIES
BT BODIES

CONCEALMENT

CONCENTRATED FOODS
BT FOOD

CONCENTRATION(CHEMISTRY)
BT CONCENTRATION(COMPOSITION)

CONCENTRATION(COMPOSITION)
NT CONCENTRATION(CHEMISTRY)
DEUTERIUM ION CONCENTRATION

CONCRETE
BT *CONSTRUCTION MATERIALS
NT *REINFORCED CONCRETE
SHOTCRETE

CONCUSSION
BT WOUNDS AND INJURIES

CONDENSATION
Change of state from gas or vapor to liquid or solid; also meteorological phenomenon. Excludes chemical reaction
NT *ATMOSPHERIC CONDENSATION
CONDENSATION NUCLEI

CONDENSATION NUCLEI
BT CONDENSATION

CONDENSATION REACTIONS
UF REFORMATSKY REACTIONS
BT CHEMICAL REACTIONS
NT GRIGNARD REACTIONS

CONDENSATION TRAILS
UF CONTRAILS
EXHAUST TRAILS
VAPOR TRAILS

CONDENSER TUBES
BT TUBES

CONDENSERS(LIQUEFIERS)
NT REFRIGERANT CONDENSERS

SUMMARY OF RESULTS

A major research effort previously supported by the Army Research Office at the Colorado School of Mines had led to the identification of the microstructural features associated with the fracture surface morphologies of hardened medium and high carbon steels. The findings were based on impact and fracture toughness testing with CVN and compact tension specimens. The work related carbide structures produced during the austenitizing, quenching and tempering stages of heat treatment to various fracture morphologies and levels of toughness.

The present contract was dedicated to extending the fracture studies to fatigue of hardened steels and to evaluating the effects of tempered martensite-austenite composite microstructures on the plastic flow and strain hardening of medium and carbon steels.

Table I lists the personnel associated with the present ARO contract and Table II lists the theses and papers which have been prepared as a result of the research efforts of the personnel involved in the ARO program. The following paragraphs summarize the results of the various component investigations of the program.

TABLE I

Personnel Associated with the Research of
ARO Contract DAAG29-84-K-0127

Name	Position
J. Bruce Kelley	M.S. Candidate
Kenneth P. Hayes	M.S. Candidate
Mark A. Zaccone	M.S. Candidate
Craig Van Thyne	M.S. Candidate
Gu Baozhu	Visiting Scientist Beijing Aeronotical Institute
J.M.B. Losz	Postdoctoral Associate
George Krauss	Principal Investigator

Kelley (2,6) performed four-point bending fatigue studies of a series of 0.8C steels with varying amounts of chromium. The various amounts of chromium in the alloys were designed to change austenite-carbide boundaries during austenitizing, but the major effect of increasing chromium content was to lower M_s and increase the amount of retained austenite in the tempered martensite-austenite microstructures of heat treated specimens. Reheating treatments produced dispersions of retained carbide particles, similar to those studied by Brown (10) and Hayes (1), and resulted in finer martensite-austenite structures. The fatigue tests showed that improved low cycle fatigue life directly correlated with increasing amounts of retained austenite and microstructural refinement.

Zaccone (3,13) examined the plastic deformation and strain hardening of the same steels tested by Kelley in an effort to understand the role retained austenite plays in the tempered martensite-austenite composite microstructures. He examined the plastic response in both the microstrain and macrostrain regimes by compression testing. Strain gages were used to follow the microstrain deformation behavior. Three stages of deformation behavior were found. The first stage was directly dependent on the amount and morphology of the retained austenite, with the specimens with the most retained austenite having the lowest elastic limits. The second stage was independent of the amount of retained austenite, while the third stage, marked by a decrease in the rate of decrease in strain hardening rates, was again dependent on austenite content. The specimens with the highest austenite content had the highest strain hardening rates, behavior which was shown to be a result of strain-induced transformation of austenite to martensite. It is high strain hardening rates associated with microstructures with high retained austenite contents which explain the results of Kelley's fatigue testing. Instability and crack initiation at embrittled austenite grain boundaries is delayed in specimens with high retained austenite content. Examination of plastic zones at points of fatigue crack initiation confirm that substantial strain induced transformation of retained austenite is associated with fatigue crack development.

The morphology and fine structure of tempered martensites in medium and high carbon steel (5,7-0) were further characterized. In particular, the very fine transition carbide distributions, dislocation substructures, and retained austenite contents (11,12) of a series of medium carbon 41XX steels containing 0.3, 0.4, and 0.5 pct carbon were evaluated by transmission electron microscopy and related to deformation and fracture behavior. The flow stresses of tempered martensite in steels containing 10.3 to 0.5 pct carbon was linearly dependent on carbon content. Austenite grain size, martensite lath size and martensite packet size were constant. However, the density of transition carbides increased, and spacing of the carbides decreased, and retained austenite increased with increasing carbon content. Strain hardening and flow stresses in the microstrain regime were dependent on retained austenite and stress controlled transformation of the austenite to martensite. At higher strains, the substructure of the tempered martensite controlled deformation, with the higher carbon structures exhibiting higher strain hardening rates consistent with the finer spacings of the transition carbides in these structures.

The study (4) on the boron-containing carburizing steels is still in progress. The work is being done in cooperation with the ASME Gear Research Institute. Gears have been fabricated and heat treated and single teeth have been subjected to low cycle bending fatigue. The boron containing steels showed low cycle fatigue resistance intermediate to that of carburized 8627 and 4820 geer teeth. All steels failed by intergranular fatigue crack initiation, apparently in association with oxides produced during gas carburizing.

The details of the various investigations performed in the ARO program are or will be given in the theses and papers listed in Table II.

TABLE II

List of Publications Based on Research Supported by
ARO Contract DAAG29-84-K-0127
July 1984 through February 1987

THESES

1. Kenneth P. Hayes: "The Effect of Intercritical Heating and Phosphorus on Austenite Formation and Carbide Distribution of AISI 52100 Steel", M.S. Thesis No. T-2971, Colorado School of Mines, Golden, Colorado, October 1984.

2. J.B. Kelley: "The Effects of Chromium on the Microstructure and Bending Fatigue Behavior of 0.82 pct C, 1.75 pct Ni, and 0.75 pct Mo Steels", M.S. Thesis No. T-2942, Colorado School of Mines, Golden, Colorado, October 1984.

3. Mark A. Zaccone: "Flow Properties of High Carbon Tempered Martensite", M.S. Thesis No. T-3394, Colorado School of Mines, Golden, Colorado (to be defended in June 1987).

4. Craig Van Thyne: "Fracture of Carburized Boron-Containing Steel", M.S. Thesis (to be completed Fall 1987).

TECHNICAL PAPERS

5. George Krauss: Tempering and Structural Change in Ferrous Martensitic Structures", in Phase Transformations in Ferrous Alloys, edited by A.R. Marder and J.I. Goldstein, TMS-AIME, Warrendale, Pennsylvania, 1984, pp. 101-123.

6. J.B. Kelley and G. Krauss: "The Effect of Chromium on Microstructure and Bending Fatigue of 0.75Mo-1.8Ni C Steels", Proceedings of the 4th International Congress on Heat Treatment of Materials, June 1985, Berlin, vol. 1, pp. 147-163.

7. G. Krauss: "Martensite Morphology in Steels", Proceedings of the 4th International Congress on Heat Treatment of Materials, June 1985, Berlin, vol. 1, pp. 0.1-0.14.

8. G. Krauss: "Struktur von Martensit in Stählen", Härterei-Technische Mitteilungen, 41, 1986, pp. 56-60 (translation of paper #7 into German).

9. G. Krauss: "Morphologie de la Martensite dans les Aciers", Traitement Thermique, 201, 1986, pp. 15-19 (translation of paper #7 into French).

TABLE II (continued)

10. E.L. Brown and G. Krauss: "Retained Carbide Distribution in Intercritically Austenitized 52100 Steel", Metallurgical Transactions A, Vol. 17A, 1986, pp. 31-36.

11. G. Baozhu, J.M.B. Losz, and G. Krauss: "Substructure and Flow Strength of Low Temperature Tempered Medium Carbon Martensite", in Proceedings of the International Conference on Martensitic Transformations (1986), The Japan Institute of Metals, pp. 367-374.

12. G. Baozhu and G. Krauss: "The Effect of Low-Temperature Isothermal Heat Treatments on the Fracture of 4340 Steel", J. Heat Treating, 4, 1986, pp. 365-372.

13. M.A. Zaccone, J.B. Kelley, and G. Krauss: "Fatigue and Strain Hardening of High Carbon-Martensite-Austenite Composite Microstructures", to be published in Heat Treatment '87, The Institute of Metals, London.

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