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Final Report
on
FATIGUE AND FRACTURE LABORATORY IMPROVEMENT

By:

P. K. Mazumdar
General Engineering Department
University of Puerto Rico, Mayagüez Campus
Mayagüez, PR. 00680

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Submitted to:

Air Force Office of Scientific Research
F49620-93-1-0607
Dr. Walter Jones (Program Manager)

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June 1995

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1. INTRODUCTION

A proposal was sumitted to the DOD in early 1993 against a program that allows acquisition of research equipment in support of basic research underlying the technology goals of DOD. The Air Force Office of Scientific Research funded this project (Grant No. F49620-93-1-0607 with Dr. Walter F. Jones as Program Manager) in September 1993 to the University of Puerto Rico at Mayaguez. An opportunity such as this allowed us to upgrade our existing fatigue and fracture laboratory facility in the General Engineering Department. Most importanly, our works, as described below, over the last year and half benifited from this improvement significantly.

As the original proposal mentioned, this laboratory was equipped with some advanced instrumentations, yet it lacked basic facilities needed to do work on fatigue and fracture. So the objective with this grant was to add followings:

- surface preparation facility (for CT, fatigue, and other specimens) for metallugical examinations.
- micrometer slide with mounting kit for in situ monitoring fatigue crack growth with a traveling microscope.
- an extensometer (multiple gage) for tension/compression and low cycle fatigue tests.
- calibrator for extensometer and COD gages.
- Grips for CT, fatigue and tension test specimens.
- range cartridges (load, strain and displacement) for MTS-810 model.
- metallograph with quantitative microstructural characterization capability. After the proposal was approved, the AFOSR permitted us instead to get electron microscopes.

Most of the items allowed by the AFOSR fund were obtained in time. With the microscope system, we encounterd some problems that we did not anticipate at the time of our request to the AFOSR to allow us to get electron microscopes instead of the originally proposed quantitative metallograph. The problem areas were as follows:

- Unavailability of suitable room in the General Engineering Facility: Our plan was to convert a class room for the Electron Microscope Facility. So an engineer from JEOL visited the campus in March 1994 for environmental evaluation of the room. The AC fields they measured were higher than preferred. Though the microscopes can function normally under the existing condition, the site will certainly become unacceptable if there is any future increase in the field level within the area, a situation that can arise from installation of new electrical lines in the vicinity of this proposed room (Appendix -1). The Physical plant of the University could not assure the continuation of the present condition over even next five years.

- Lack of fund for room preparation: A proposal was writtren and submitted in 1994 to the NSF against their ARI prgram (No. NSF-93-166) for renovation of research facilities at the College of Engineering, University of Puerto Rico, Mayaguez. This proposal also requested $29,150.00 to prepare the room for the Electron Microscope Facility besides funds for renovating other existing facilities. It appears that they may fund this proposal; however, we have been instructed to revise the budget by eliminating the cost for the Electron Microscope Facility because it is currently a classroom and therefore is ineligible for ARI program funding (see Appendix -2).

- Lack of commintment for maintanance: Proper maintanance can only assure uninterrupted operation of such microscopes. For this we needed to convince the University Administration to hire a Technician and grant $16K/ yearly for the service contract of the microscopes. Despite the need of such a facility in the campus by numerou faculties, it was impossible for the University to make any future commitment due to budget contraint (Appendix-3).

These left us with no choice but to go for a microscope that could be used as a metallograph and for biological purposes (to facilitate our Biology and Agricultural Science faculties) as well. This prompted us to go for a Hi-Scope system with a bright and a dark field set up. This system can be used in situ for monitoring crack growth and slips as they develop and grow during fatigue, the events that can also recorded in real time in a VHS video recorder. The system in question also allows one to increase the depth of field, more than the one offered usually by a conventional metallograpgh, by attaching a 45^0 rotary device to this system. A couple of researhers from Physics, Biology and Mechanical Engineering Departments have already started using the system. This system did cost us little more than the one we proposed for microscope system in our proposal. So that we could have the system within the allocated AFOSR Grant, the University of Puerto Rico granted us some funds, though limited, for the purchase of some of the other componets.

2. EQUIPMENT ACQUIRED

Table- 1 lists the items acquired with the AFOSR's fund including their source, and acquired (with University PO/Company Invoice No.) and the amount involved.

TABLE - 1: List of Components

	Source	Components	PO/ Invoice No.	Amount
Microscope System	Win systems of america Haworth, N.J. 07641 (201) 768-2810 Haworth, NJ 07641 (201)768-2810	*HI-Scope System (KH-2200) *Main Control Unit *Camera Holder *1000 & 2000x Coaxial Lens *XY Stage *Measurement Tool *Ultra-Zoom Lens (100-600X) -Lighting Adapter -Co-Axial Adapter -Rotary Head	1950918 4/6/95	$34,732.84
	Ind-Pack, Co. P.O. Box 1462 Caguas, PR 00725 (809)- 383-7793	*13 Color Monitor (Sony) *Color Video Printer (Sony) *Films for Printer	1950919 4/7/95	$4173.86

Extensometry and others	MTS Direct P.O.Box 46210 Eden Prairie, MN 55344	*Extensometer (632.31) *Extensometer Calibrator Frame -Fixtures Set for 632.02) -Micrometer Head (SI)	I940428 12/22/93	$9,306.56
		*458 DC Range Cartridge, *458 AC Range Cartridge	9100546 12/30/94	$639.46
		*7011 Magnetic Stand *513- 2 4 2 Dial Indicator	169025 2/3/94	$439.75
		*CT Test Clevis (3/4",17-4PH)	9100546 12/9/94	$919.62
		*Couplings (Female to Male)	910546 11/17/94	$692.90
		*Pu11 Rod (10 - 3/4) *0.5"CT Test Clevis (Reducing) *Round Spec Wedges (647.10) *Stud (1 in. - 14, 3 in. long) *Stud (1 in. - 14 4 in. long)	I940809 5/31/94	$3480.44
Polishing System	Buehler Ltd., 41 Waukegan Rd. PO BOX: One Lake Bluff, IL 60044 (708)295-6500	*Ecomet-3 Grinder/Poisher (8") *Automet-2 Power Head *Loading Plate (for Automet 2) *Blank Holder *Carbinet Discs (8") Grit 240 1 Bx of 100 *Carbinet Disc (8") Grit 320 1 Bx of 100 *Carbinet Discs (8") Grit 400 1 Bx of 100 *Carbinet Discs (8") Grit 600 1 Bx of 100 *Metadi II Diamond Polishing Compound (6 micron, 20 gms) *Nylon Polishi ng Cloth (8" dia) 1 pkg. of 10 *Automet Lapping Oi1 6oz. *Gamma Micropolish, 0.05m 60z Appli.cator Bottle *Polishing suspension 1m. 60z Appli.cator Bottle *Polishi ng Cloth (8") 1 pkg. of 10.	I940428 12/22/93	$9,031.92
Tool Box	Damark International 7101 Winnetka Ave. PO Box 29990 Minneapolish, MN55429 (800)729-9000	99 pc Tool Kit	I950089 8/15/94	$139.10
	Local Supplier	CD ROM	R402474 2/23/94	$360.88

	Local Supplier	Comuter Chips	P238-613	$588.00
				$64,505.33

As mentioned above the University of Puerto Rico also contributed to this project by allowing us to purchase some of the components with the fund from the School. These included

Micrometer Slide	$2521.00
Mounting Kit	$1,350.00
Travelling Microscope Objective Lens (2.3x)	$180.00
Range Cartidges(additional)	$400.00

3. ADDITIONAL EQUIPMENT

These additions have improved our capabilities to a great degree, yet problems are still being encountered with our MTS system. Evident is the rotation of the actuator during fatigue experiments, causing test interruptions and damage of the test specimens. As MTS suggested, only way to prevent this is to install an anti-rotation device. Another area that needs immediate attention is a VHS recorder for the Hi-Scope microscope system for recording the events as they occur during fatigue or crack growth in real time. The cost for An anti-rotation device and a compatible VHS recorder will cost about $1895 and $2000 respectively, totalling about $3900.00. We hope to purchase the with the fund left over from this project which amounts to about $4185.67.

4. IMPACT ON OUR RESEARCH

As indicated before, this grant is having great impact on our following works. over the last year and half.

1. Quantitative measurement of surface roughness and its significance in fatigue of aluminum-lithium and traditional aluminum alloys (sponsored by the FAA).
2. Fatigue crack propagation and local deformation of C-188 aluminum alloy (ALCOA).
3. Effect of magnetism on the fatigue crack propagation behavior of an AerMet 100 steel.

A paper, as detailed below, has been prepared by the PI and students (both Graduate and Undergraduate) and has been sent to a Journal for publication consideration.

"FATIGUE CRACK GROWTH IN A MAGNETIZED AERMET-100 STEEL"

by

S. Benitez, E. Maldonado, M. Rosa and P. K. Mazumdar

A copy of this paper has been included in Appendix -4. We also hope to prepare a couple of additional papers for publications, the copies of which will be sent to the AFOSR in due time.

APPENDIX -1

A Letter from JEOL

JEOL

JEOL USA, INC. • 11 DEARBORN ROAD • P.O. BOX 6043 • PEABODY, MA 01961-6043
TELEPHONE (508) 535-5900 • FAX (508) 536-2205

April 15, 1994

Dr. P.K. Mazumdar
University of Puerto Rico
Dept. of General Engineering
Mayaguez, P.R. 00680

Dear Dr. Mazumdar;

Recently our engineer completed an environmental room evaluation on the laboratory site which is to be used for the installation of the JEM-100S and JSM-35 electron microscopes.

Our evaluation of this data resulted in the following comments regarding the site:

* The AC Fields measured throughout the laboratory are higher than we would have preferred but they are within the listed factory specifications. We expect the JSM-35 will exhibit the effects of this field when operating at magnifications greater then 50,000X. The JEM-100S should be able to functin normally under the existing conditions. Should there be any future increases in the field levels within the laboratory area, the site will certainly become unacceptable.

* The vibration levels measured throughout the area were all within the limits specified by our factory. They should not pose any problems with the operation of either microscope. We were very satisfied with the stability this third floor location exhibited.

* The laboratory space allotted for the instruments appears to be satisfactory.

It is our opinion that the site should be adequate for the installation of the two instruments. The only note of caution would be to assure that the existing AC fields do not increase any more prior to the delivery and installation of the instruments.

Our intentions are to bring both instruments into the Peabody Applications Laboratory for reconditioning prior to shipping the instruments to you. As this will involve time, any information that you may have on when your facilities will be completed and available would certainly be appreciated. When you have finalized your delivery requirements please notify me as soon as possible at (508) 535-5900.

I also understand that you are interrested in a reference source for scanning electron microsropy. The following is a good information source on the basic instrument and its operation as an electron microprobe:

Practical Scanning Electron Microscropy
Electron and Ion Microprobe Analysis
Goldstein & Yakowitz
Plenum Press; 227 West 11th St., New York, N.Y. 10011
Oct. 1977

Thanks you for allowing JEOL USA Inc. to be os service to you in this matter and I shall be awaiting furture correspondence with you.

Yours truly,

William C. Richards

William C. Richards
Installation Manager

APPENDIX -2

A Letter from the NSF

APR-10-95 14:57 FROM:NSF/OSTI ID:703 306 0129 PAGE 2/2

NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230

March 24, 1995

David Serrano, Ph.D.
College of Engineering
University of Puerto Rico
P.O. Box 5000, College Station
Mayaguez, PR
00681

Ref.: STI-9415119

Dear Dr. Serrano:

The Academic Research Infrastructure (ARI) program is in the process of making facilities award recommendations with 1995 program funds. I am pleased to inform you that your proposal, "Renovation of Research Facilities at the College of Engineering, University of Puerto Rico, Mayaguez," is recommended for an award.

Before I can proceed with an award recommendation, however, I need some additional information from you. Specifically I request a letter (and graphics as requested) addressing the following. Please do not submit a revised proposal.

1. A response to concerns raised in the panel summary and the individual reviews with particular attention to the construction costs and timeline for the project. The reviewers are concerned that the budget that is presented is inadequate to complete the project, and they are concerned that the 12 month timeline (as originally proposed) will not provide sufficient time to complete the project.

2. Additional information on the project space. Please submit a list of the number of square feet in each laboratory and indicate what percentage of each of the labs is utilized for research and research training. The ARI program funds *only* the renovation of space which is *currently* used for research and research training. It appears that the proposed Electron Microscope Facility is currently a classroom and therefore is ineligible for ARI program funding. XX

3. A floorplan for the Material Science Laboratory. (It was omitted from the original submission as was the floorplan for the Electron Microscope Lab.)

4. A description of the criteria to be used in the selection/appointment of the project manager who will be charged with oversight of the day-to-day renovation effort.

5. A re-examination of federal funds that have been received for construction and renovation activities for the *entire* UPR-M campus. The list provided with the proposal, and subsequently updated, does not include an award to UPR-M for a $199.562 project led by Dr. Allen Lewis for renovation of research labs in Biology, Geology, and Chemistry. The list includes, perhaps inappropriately, instrumentation and some research funding. *Our interest is in the receipt of federal funds by the campus for construction/renovation only.*

6. A three year maintenance plan for the renovated space once it is completed. Please provide a brief list of building services and the annual amount budgeted for them.

7. A revised budget which eliminates costs for the Electron Microscope facility, any cabinets or worksurfaces which are not built into the facility, and any other costs for areas which are not currently utilized for research. Please carefully evaluate your project budget and be assured you have allowed sufficient funds for projection completion as specified.

8. A revised timeline with a May 1, 1995 start date and other adjustments as necessary. Please be certain to allow enough time to complete the project.

9. A letter from the appropriate institutional official which indicates the amount and source(s) of the project match and the date by which the match will be achieved.

Please coordinate the development and submission of the additional material with the campus architects/planners and the sponsored projects office before you forward it to me. The latter should sign off on the material to indicate they have been advised of the new information.

I am pleased to be in a position to negotiate this project for an award, but want to remind you this correspondence does not guarantee an award. I strongly encourage you to call me early next week at (703) 306-1040 to discuss my concerns and my request for additional information. I look forward to working with you on this worthwhile project.

Sincerely,

Martha E. Dennis

Martha E. Dennis
Program Manager, ARI
Office of Science and Technology Infrastructure

Enclosures: Panel Summary and Reviews

APPENDIX -3

A Letter from Dean, College of Engineering, UPR

Universidad de Puerto Rico
Recinto Universitario de Mayagüez
Colegio de Ingeniería - Oficina del Decano
Apartado 5000 - Estación Colegial
Mayagüez, Puerto Rico 00681-5000

University of Puerto Rico
Mayagüez Campus
College of Engineering - Office of the Dean
P.O. Box 5000 - College Station
Mayagüez, Puerto Rico 00681-5000

April 12, 1994

Dr. Pranab K. Mazumdar
Professor
General Engineering Department
Mayagüez Campus

Dear doctor Mazumdar:

The College of Engineering has been assigned the amount of \$50,980.89 from Research overhead fund. This is a non-recurrent assignment that will depend on the administrator at the time. We are aware that you have decided to buy two electron microscopes which require an annual maintenance cost of \$16,000.

Due to the non-recurrent basis of these moneys, we cannot make any long term compromise for these funds. In your letter, you mention potential users for the equipment from various departments. I recommend that you coordinate, with these professors, the inclusion of an amount in the budget of their proposals to cover these costs.

Cordially yours,

José F. Lluch
Dean of Engineering

JFLL:bhc

cc: Dr. Anand Sharma, Director
General Engineering Department

PATRONO CON IGUALDAD DE OPORTUNIDADES DE EMPLEO - M/F/V/I
AN EQUAL OPPORTUNITY EMPLOYER - M/F/V/H

APPENDIX -4

A Paper entitled
Fatigue Crack Growyh in a Magnetized AerMet-100 Steel
by
S. Benitez, E. Maldonado, M. Rosa and P. K. Mazumdar

FATIGUE CRACK GROWTH IN A MAGNETIZED AERMET 100 STEEL

S. Benitez*, E. Maldonado*, M. Rosa* and P. K. Mazumdar
*Department of Mechanical Engineering
Department of General Engineering
University of Puerto Rico
Mayaguez, PR 00680

INTRODUCTION

The presence of magnetic field can alter the mechanical response of ferromagnetic materials (1-4). The fatigue life ($\geq 5 \times 10^4$ cycles) of mild steel, for example, was shown to decrease gradually with increasing magnetizing current (i.e., applied magnetic field) and eventually to about three fold as applied field was raised further to bring material's magnetization to its saturation, λ_s (the maximum limiting value) (4). The life reduction so observed was conceived to result from decreased fatigue crack propagation (FCP) lifetime (5). Since the near threshold FCP behavior depending on the external and microscopic variables (e.g., environments, R- ratio, microstructures, grain size, etc.) (6,7) can affect such life period significantly, this work explores the effect of residual magnetism on the FCP behavior of such landing gear material as the Aermet 100 steel.

EXPERIMENTS

For this process improves toughness without sacrificing other properties, a block (50mm x 48mm x 38mm) of AerMet 100 steel was heat treated as follows (8). It consisted of solution treatment of the block at 1625°C for 1 hour followed by oil quench (1-2 hours) and then refrigiration in liquid nitrogen (1 hour) prior to air warming and aging for 5 hours at 482°C.

10 mm thick CT specimens (with a notch size of 8mm) were prepared by wire EDM from the heat treated block in T-L orientation. The specimens were polished with emery papers, diamond paste and 0.05 micron alumina powder prior to precracking of the specimens, at room temperature, by fatigue to yield a 4mm long crack from the notch tip. One of the specimen was then magnetized as described below before subjecting this and the virgin specimens to room temperature FCP rate (FCPR) tests in a computer-controlled MTS machine at a frequency and a load ratio (R) of 20 Hz and 0.1 respectively under decreasing-stress intensity (K, K-gradient = -0.0787/mm) and constant load conditions. The crack length was monitored with a front face COD gage continuously and, occassionally, by a 100x travelling optical microscope. The crack lengths observed by these two methods did not differ more than 1.8%. Also the crack size as measured optically on one side of the specimen was within 1.8% from the other. The crack lengths measured by the COD gage were considerd to determine the FCPRs and the crack tip stress intensity ranges (ΔKs).

The specimen was magnetized by placing it inside a solenoid (89mm long with 3400 turns) to direct the field in loading direction (Figure 1). The current (or field, H) was increased gradually to its maximum value (i = 0.42 amp at 28.14volt, H = 216 Orstead) to raise specimen's magnetization to its saturation (λ_s= 16250 Gauss) (9). The applied field was held at this level for thirty minutes before current was decreased to zero to remove the field and allow the specimen to retain residual magnetism equals to about 62% of its saturated value (9).

RESULTS & DISCUSSIONS

Figure 2 depicts the FCPR data of the virgin and the magnetized Aermet 100 steel. The presence of magnetism is seen to lower the threshold stress intensity range (ΔK_{th}) to 5.0 MPa; so its effect is pronounced in the near threshold level but not at higher ΔKs. Such FCP rate dependence on the ΔK level is not unique in light of the FCP rate data of this alloy in other environments (8,10). These environments were also noted to affect the FCPRs, as expected (6,7), in the near threshold level instead at higher ΔKs. This insensitivity, as ours, can be attributed to the FCPRs and their dependence on the continuum behavior rather than the variables at high ΔKs (11).

To see this effect of magnetism quantitatively, it should be recognized that the grains in a ferromagnetic material consist of magnetic domains, each with dipoles aligned in one direction (12,13). In a material that has never been exposed to a magnetic field, the domains are orientated at random, so its net magnetization is zero. As field is introduced, the domains rotate towards the direction of the applied field because they experience spontaneous magnetic strain (λ) along their magnetization direction. The mismatch between these two directions decreases with increasing field and vanishes to zero as field is increased further to allow the material to attain its saturation i.e., when domains align with the direction of the applied field (or $\lambda \approx \lambda_m \approx \lambda_s$) (Figure 3). However, if field is removed, many of the domains instead of going back to their original orientation remain close to the direction of the field, causing residual magnetism (the remanence, $\lambda < \lambda_s$) to retain in the material.

When domains are at random, the misorientation of their walls provides barrier to the flow of dislocations. Rotation of the domains as field is introduced, minimizes this misorientation or the interactions among their walls and, through this, the resistance to the flow of dislocations. The effect of increasing applied field is to minimize this resistance further (14,15). Since this motion governs dislocation mechanism (16) an exsisting idea can be modified to see its effect on the FCPR through such parameter as the activation volume (υ) (17)

$$\frac{da}{dN} \propto [\Delta K_{eff} / \upsilon]^2 \qquad 1$$

ΔK_{eff} (= K_{max} - K_{op}) is the actual driving force acting at the crack tip during loading part of the cycle. It may be smaller than the nominally applied value ($\Delta K = K_{max} - K_{min}$) if crack faces close prematurely which commonly occurs during unloading part of the cycle in the early stages of FCP (6,7). K_{op} (> K_{min}) is the stress intensity to open the crack faces. The near crack tip dislocation activity may then be considered to depend on the ΔK_{eff} as (18)

$$\upsilon \propto [\Delta K_{eff}]^{-q} \qquad 2$$

where q is a constant. If q is large the driving force is expected alter the dislocation activity rapidly and vice versa.

The normal strain ($\Delta\varepsilon$) acting at the crack tip facilitates FCP. If a part of $\Delta\varepsilon$ converts to shear strain ($\Delta\gamma$) it promotes strain hardening (plastic deformation) locally and, through this, lower the crack tip driving force and the FCPRs as well. As shown elsewhere (19), the ΔK_{eff} acting at the crack tip then is

$$\Delta K_{eff} = \Delta K \left[1 - \frac{2\Delta\gamma}{\Delta\varepsilon}\right]^p \qquad 3$$

It shows that $\Delta K_{eff} < \Delta K$ if $2\Delta\gamma < \Delta\varepsilon$, an effect that is expected to vanish rapidly with increasing ΔK because of its increasing effect on the near crack $\Delta\varepsilon$ (20). The exponent p is a constant. Furthermore, if the magnetic strain (λ) is tensile in nature and if its component in the direction of loading is λ_h, the following modification of Equation 3 can be made to include this effect

$$\Delta K_{eff} = \Delta K \left[1 - \frac{2\Delta\gamma}{\Delta\varepsilon + \lambda_h}\right]^p \qquad 4$$

which with Equations 1 and 2 gives

$$\frac{da}{dN} \propto \left[1-\frac{2\Delta\gamma}{\Delta\varepsilon+\lambda_h}\right]^p \Delta K^{2(1+q)} \quad 5$$

an expression that can be used to rationalize the present FCPR data as follows.

Because of its increasing effect on the near crack tip $\Delta\varepsilon$, the near crack tip $\Delta\varepsilon$ in compared to the $\Delta\gamma$ and λ_h may be significant at high ΔKs. If this is so, it could then control the dislocation motion and the FCPR Δas $\Delta K_{eff} \approx \Delta K$ (Equation 4) at high ΔKs and, as observed (Figure 2), not the magnetic field. On the other hand, the strains such as the $\Delta\gamma$ and the λ_h may become important for the magnetic specimen at low ΔKs due to the lowering of the near crack tip $\Delta\varepsilon$ with decreasing ΔK. The decreased ΔK_{th} of such specimen (Figure 2) can then be considered to result from higher driving force (i.e., ΔK_{eff} for a given $\Delta\gamma$ as $\lambda_h \neq 0$, Equation 4) acting at its crack tip as it is likely to open at a lower load level than the one in virgin specimen. For a credence to this, consider the load- compliance traces measured with a front-face COD gage during loading part of the cycle for the magnetic specimen at $\Delta K = 5.12$ MPa$\sqrt{m}$ and, in normalized form, for the virgin specimen at $\Delta K = 7.77$ MPa$\sqrt{m}$ (Figures 4a and b). If the deviation of the data point from the linearity measures opening, the magnetic specimen's crack tip, as just noted, is seen to open at a lower load fraction (18% of the maximum load) than its virgin counterpart.

Another way to rationalize the detrimental influence of magnetic field is to recall the importance of λ_h at low ΔKs. Obviously, its presence can cause strain intensification in the cyclic plastic zone, formed due to applied load in the near crack tip area allowing the crack tip in a magnetic specimen to grow at a lower ΔK than its virgin counterpart. The magnitude of λ_h should determine the extent of reduction of ΔK_{th}. This is expected to be maximum if $\lambda_h = \lambda_s$ and as such λ_h should depend on the direction of the applied field it will be interesting to examine the near threshold FCPRs in terms of the direction of the applied field.

ACKNOWLEDGEMENT

We thank Mr. G. Hartman (University of Dayton Research Institute) for experimental assistance and Dr. E. W. Lee (NWAC, Pa) for donating the AerMet 100 steel and the Air Force Office of Scientific Research for an instrumentation Grant (No. F 08671-9301658; Dr. Walter Jones, Program Manager) which greatly facilitated this work.

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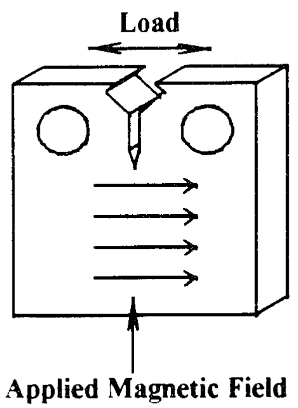

Figure 1: Direction of applied magnetic field in relation to specimen's loading direction.

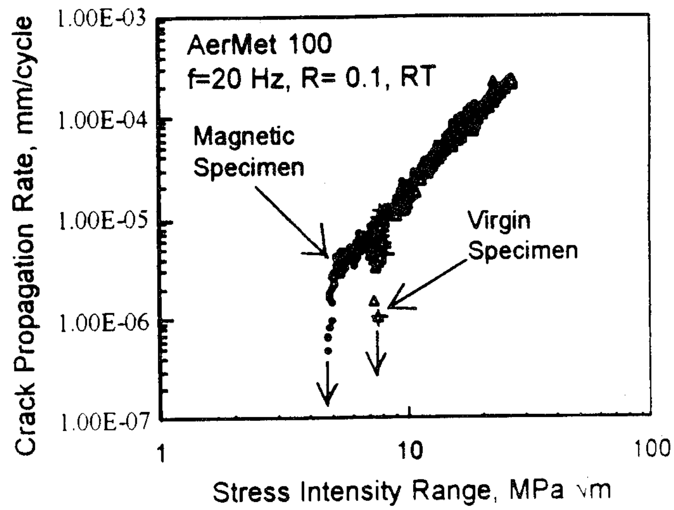

Figure 2: Effect of magnetism on the FCP rate of an AerMet 100 steel.

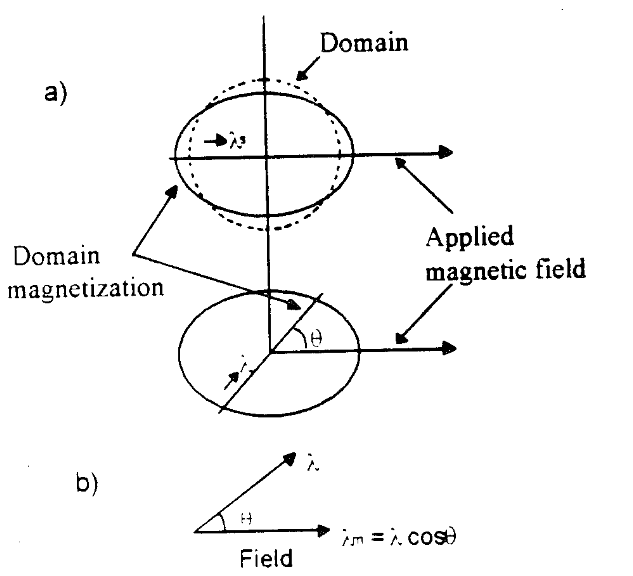

Figure 3: Effect of applied magnetic field on the (a) rotation of the domain and (b) the magnetic strain along the direction of the applied field.

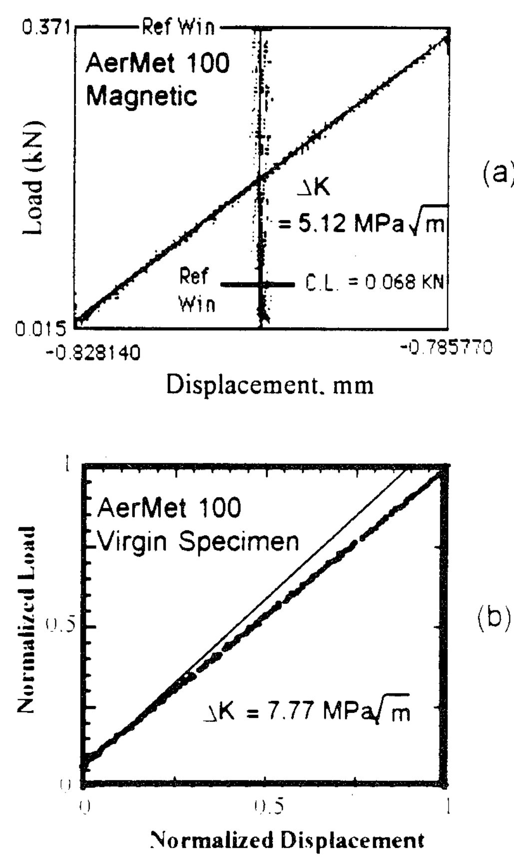

Figure 4: Load compliance traces for the (a) magnetic specimen and (b) virgin specimen around the threshold level