EXO-ELECTRON EMISSION FROM PLASTICALLY STRAINED AND FATIGUE DAMAGED METALS

by

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STATEMENT BY AUTHOR

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ABSTRACT

An experimental system and procedures are developed to determine the effect of plastic deformation and fatigue on exo-electron emission. A theoretical model is presented and compared with the experimental results. The experimental results are qualitatively similar to the theoretical predictions.

The thermally induced emission of exo-electrons from previously fatigued metals can be used as a means of predicting the remaining useful life of a metal.
CHAPTER 1

INTRODUCTION

When an alternating stress is applied to a metal structure, changes may occur in the metal on a microscopic scale. Sufficiently large stresses may induce localized plastic deformation which results in the generation of excess vacancies, dislocations, and eventually cracks. These cracks can produce a sudden and catastrophic failure of the structure. This phenomenon, called fatigue, is an important consideration in the application of materials, and knowledge of the accumulation and extent of fatigue damage can permit improved material utilization and greater structure reliability.

The purpose of nondestructive testing (abbreviated NDT) is to evaluate the strength or remaining useful life of a component without causing any physical damage or change in the material properties which might contribute to an early component failure. A large number of techniques for NDT have been developed; however most of these techniques are related to the detection of actual cracks which generally appear late in the fatigue process when failure is imminent.

In view of the preceding discussion, it is clear that a need exists for a new NDT device which can detect fatigue damage in its early stages.
It is known that the fatigue damaged region is close (12 microns) to the surface and that the damaged region itself is a complex mass of vacancies, dislocation loops, and slip lines which may be lumped under the generic term, defects. The defects pile up at a particular point in the metal until a crack is nucleated on or near the surface. It is this surface or near-surface pileup of defects, in the early stages of fatigue, that suggests that certain surface characteristics might be used to measure the fatigue damage that has been accumulated in the metal.

A surface phenomenon which shows promise as a method for detecting and measuring fatigue damage is exo-electron emission. It has been repeatedly demonstrated that when a metal is damaged or disarrayed by abrasion, strain, melting, radiation, or oxidation, a spontaneous emission of negative charge carriers results. It is the relation of this anomalous emission phenomenon, called exo-electron emission, to plastically deformed and fatigue damaged metals that this thesis is devoted.
CHAPTER II

BRIEF REVIEW OF EXO-ELECTRON STUDIES

Historical Introduction

For many years it has been known that freshly manufactured Geiger counters have a temporarily increased background count, which decreases with time. It has also been observed that metals subjected to ultraviolet, x-rays, and various mechanical treatments (scratching, polishing, grinding) cause a similar anomalous counting rate when introduced into a Geiger tube.

This irregular behavior of mechanically treated metals has been explained as an ionization phenomenon accompanying re-oxidation of those areas of the surface which have had their oxide layer removed by the preceding mechanical treatment (Lewis and Burcham, 1936; Grunberg, 1958).

In 1958, Kramer published a comprehensive account of his investigations into these anomalous emissions. Kramer's original explanation of this seemingly spontaneous negative charge carrier emission has for the most part been rejected; however, it will be briefly summarized here to explain the origin of the term "exo-electron."

Kramer postulated the existence of a nonmetallic (amorphous) phase of metals which was only thermodynamically stable below a characteristic transition temperature which varied from metal to metal. This nonmetallic phase was assumed to be produced by mechanical
treatments (scratching, polishing, grinding) of the surface while in the metallic phase. At temperatures above the transition temperature of a given metal the nonmetallic phase was thought to gradually transform into the stable metallic phase. The release of exothermal energy during this phase transition was considered to manifest itself in the emission of electrons from the surface of the metal. Since an exothermal process was considered responsible for the emission of electrons after mechanical treatment, the phenomenon was named exo-electron emission.

This concept of an exothermal process being responsible for the emission of electrons was used to explain a number of experiments; i.e., emission of electrons during the solidification of metals, emission maximums from alloys at the temperatures of their phase transitions.

Exo-Electron Emission from Metals

Although Kramer's original hypothesis of an exothermal process being responsible for the emission of electrons could explain some emission phenomena, other experimental results indicate that this model is not applicable to most exo-electron emission phenomena.

It has been found that if sufficient care is taken to remove all surface films from alloys and they are kept under high vacuum (< 10^{-6} Torr), electron emission during phase transition is undetectable (Bathow and Gobrecht, 1956; Grunberg, 1958). If the vacuum is above 10^{-5} Torr, emission during phase transition is observed. Another set of experiments which display the effects of oxygen on exo-electron
emission were performed by Lohff (1956; see also Grunberg, 1958). Metal specimens were scratched in vacuum ($< 7 \times 10^{-5}$ Torr) with a steel brush, and the emission current was measured after oxygen was admitted to a specific pressure. The emission current at an oxygen pressure of $10^{-6}$ Torr was found to be very much greater than at an oxygen pressure of $7 \times 10^{-5}$ Torr. There is some question as to whether the emission was from the specimen or the steel brush, but the effect of oxygen pressure is significant. These results and others have led some investigators (Haxel, Houtermans, and Seeger, 1951; see also Grunberg, 1958; Ustinova and Krykova, 1968) to conclude that chemisorption of oxygen provides the energy of electron emission, and the name "chemo-emission" is sometimes applied to abnormal emissions of this type.

Studies by Conrad and Levy (1961) of the photoelectric emission from abraded aluminum and zinc in the near ultraviolet spectrum, as a function of the wavelength, indicates that the photoelectric threshold first shifts to longer wavelengths and then recedes with time. Further studies on a much broader variety of metals indicated that the emission is apparently independent of the type of metal or oxide involved. Investigations of electron emission from freshly abraded metals at a sequence of increasing temperatures yielded apparent emission peaks at specific temperatures. These emission peaks from freshly abraded metal surfaces at specific wavelengths or temperatures can be explained in terms of definite electronic energy levels in the forbidden band of the oxide and are not attributed to the substrate metal itself. Some investigators (Von Voss and Brotzen, 1959; Evdokimov, 1968) have
proposed point defects, such as vacancies, in the surface oxide layer as the source of energy levels in the forbidden band of the oxide.

Von Voss and Brotzen (1959) have conducted studies of electron emission from plastically strained aluminum and observed electron emission which increased with increasing strain in a complex manner. After straining stopped, the emission continued to increase for a while and then decayed away. This they explained by a vacancy diffusion model. This vacancy model is the one we have chosen to apply to our exo-electron experiments.

Vacancy Diffusion Models of Exo-Electron Emission

Vacancies are lattice sites at which one or more atoms are missing. Statistical thermodynamics predicts that a minimum number of vacancies will always be present. In thermal equilibrium the number $n_v$ of vacant sites, in a crystal containing $N$ atom sites, due to thermal vibrations of atoms is

$$n_v = N \exp \left(-\frac{E_v}{kT}\right)$$

where $E_v$ is the formation energy of a vacancy, $k$ is the Boltzmann constant, and $T$ is the temperature in degrees Kelvin.

In addition to vacancies produced by thermal vibrations of atoms, excess vacancies may exist at a given temperature for a number of reasons; i.e., quenching from a higher temperature, deformation of the crystal lattice, or bombardment by atoms or high-energy particles.
Vacancy diffusion can take place whenever an atom adjacent to a vacancy acquires the necessary energy to exchange lattice positions with the vacancy.

Von Voss and Brotzen (1959) proposed an exo-electron emission mechanism which was dependent on the production and diffusion of vacancies as follows:

1. Lattice vacancies are generated in the metal and in the oxide during plastic strain.
2. Vacancies, which are not captured by dislocations or other sinks, migrate toward the surface. The vacancies in the oxide surface layer may turn into singularities of the F-center type.
3. Emission takes place as these centers decay, possibly through interaction with shallow surface states.

Other investigators (Simoi, Hrianka, and Craciun, 1968) have proposed that defects in the metal lattice produce relatively high local energy levels, resulting in a reduced work function. The probability of the emission of electrons due to thermal excitation, and the photoelectric threshold, would, therefore, be dependent on the concentration and diffusion of vacancies.
CHAPTER III

DESIGN OF THE EXPERIMENTAL SYSTEMS

Vacuum System

The vacuum system consisted of a stainless steel vacuum chamber and a 6-in. i.d. Pyrex pipe, a Welch Duo-Seal rotary mechanical pump, a Varian 50-liter per sec Vac-Ion pump, and two pressure gauges. Figure 1 shows a diagram of the vacuum chamber and associated fittings.

Heater units were attached to the stainless steel body of the vacuum chamber to keep the system at 300°C. This permitted rapid pump down to ultrahigh vacuum.

Pulling Assembly and Associated Electronics

The pulling assembly and associated electronics are shown in Figure 2; a 6-in. i.d. Pyrex pipe was used to enclose the wire specimen and Instron* strain gauge load cell. A conducting phosphor screen was coated on the inside of the Pyrex pipe to serve as a collector and a screen for a field emission microscope. (The transparency of the Pyrex pipe was useful in that it aided proper coupling of the pulling and fatiguing assemblies to their respective drive member.) A fine mesh window screen was wrapped around the outside of the Pyrex pipe and grounded to serve as a Faraday shield.

*Gift of the Instron Corporation of Canton, Massachusetts, via Mr. A. Cozens.
Figure 1. Vacuum System.
Figure 2. Vacuum Pulling Assembly and Associated Electronics.
Rotary motion was converted to linear motion and transmitted into the vacuum system by a Varian Linear Motion Feedthrough. The Varian Feedthrough was driven by a reversible universal motor through a toothed belt and gear assembly.

The linear motion was coupled to the specimen via 1/4-in. stainless steel rods connected by a hook which allowed easy removal of the specimen (see Figure 2). The lower hook was covered with Teflon in order to electrically isolate the lower end of the pulling assembly from ground.

A 0 - 25 A ac-current source was furnished to heat the test specimen. A pico-ammeter was constructed with a Burr-Brown field effect transistor input operational amplifier. The strain gauge amplifier was constructed with a Burr-Brown instrumentation amplifier. Heath recorders were furnished to record the output of the pico-ammeter and strain gauge amplifier.

Fatiguing Assembly and Associated Electronics

The fatiguing assembly was designed to be compatible with the previously described pulling assembly. The fatiguing assembly and associated electronics are shown in Figure 3.

Unidirectional rotational motion was transmitted into the vacuum system by a Varian Rotary Motion Feedthrough. The rotary motion was coupled to the rotary-to-oscillatory motion converter by a slip joint (see Figure 4) to allow easy removal of the fatiguing system.
PORCELAIN INSULATORS

COLLECTOR

WIRE SPECIMEN

Rotary to oscillatory motion converter and coupling

TO PUMP AND GAUGES

TO VACUUM PUMP

MICRO-SWITCH

COUNTER

ROTARY MOTION FEED THROUGH

0-25 AMP A.C. SUPPLY

KEITHLEY PICO-AMMETER

HEATH RECORDER

HEATH MOTOR SPEED CONTROL

90 VDC

Figure 3. Vacuum Fatiguing Assembly and Associated Electronics.
Figure 4. Rotary to Oscillatory Motion Converter and Coupling.
A microswitch was fastened to the rotary motion feedthrough to provide a pulse for a counter which monitored the number of cycles. A normally open relay was held on by a small current through the test specimen which controlled the drive motor so that when the specimen failed, the motor stopped and the counter read the number of cycles to failure.

A 0 - 25 A ac-current source was furnished to heat the test specimen. A Keithley 417 pico-ammeter and a Heath recorder were furnished to measure the electron flow from the specimen to the collector.

**Preparation of Nickel Fatigue Test Wire Specimens**

International Nickel Company type 205 wire, 0.062-in. dia was cut into 10-in. lengths and straightened by tension. A gauge section was then etched in a 20% HCl solution as shown in Figure 5. The gauge sections were formed in about one hour with a current of 1 A ac. The specimens were then given a fine polish with emery paper, after which they were cut down to test length, 3.5 in.

In order to remove any internal residual stress induced by the straightening and to bring the specimens to a uniformly annealed state, they were heated to 900°C for 24 hours in a vacuum furnace. The resulting specimen finish was bright, indicating that the 10⁻⁵ Torr in which the specimens were annealed was sufficient to prevent excessive oxidation.
\[ V = 2.25 \text{ V-AC} \]
\[ I = 1.00 \text{ A-AC} \]
\[ T = 1.00 \text{ HR} \]

Figure 5. Etching Apparatus and Typical Specimen.
Low-Temperature, Ultraviolet-Stimulated Exo-Electron System

The low-temperature, ultraviolet-stimulated exo-electron system was designed to be operated in air and to serve as a "practical" test of exo-electron emission as a means of measuring the extent of fatigue damage. This practical test system is shown in Figure 6.

The specimen was held in place on brass brackets by clamps. The brass brackets were connected to a 0 - 100 A dc source which provided a heating current.

A Pen Ray miniature quartz tube lamp was used as a source of ultraviolet light. The uv-light passed through a hole in the collector over the region of the specimen under test.

The specimen was held at -30 V dc with respect to ground while the collector was held at +45 V dc with respect to ground. This reduced the leakage current observed on the pico-ammeter and reduced the field intensity between the collector and the other parts of the system, while maintaining 75 V dc between the collector and the specimen.

The specimen shape used with this system is shown in Figure 7. The materials tested were aluminum 1100-0 and 7075-T6. The specimens were polished by a chemical etch (470 g per gal H₂O of NaOH, 756 g per gal H₂O of sodium sulfide, and 75.6 g per gal H₂O of sodium gluconate) to avoid extraneous non-fatigue related emission from scratches and yield a minimum scatter in fatigue life. The 1100-0 aluminum specimens were heated to 350ºC for 30 minutes in a vacuum to bring them to an
Figure 6. Low Temperature, Ultraviolet-Stimulated Exo-Electron System.
Figure 7. Test Specimen Shape for Use in the Low Temperature, Ultraviolet-Stimulated Exo-Electron System.
annealed state. The 7075-T6 aluminum specimens were not annealed since they had a specific heat treatment designated by the "T6."
CHAPTER IV

EXPERIMENTS

Objectives

There are many different and sometimes contradictory theories concerning the mechanism of exo-electron emission (see Chapter II). When the experimental studies were initiated, it was decided that determination of the mechanism would be the secondary rather than the primary objective of the experiments to be conducted. The primary objective was to establish whether or not a relationship between exo-electron emission and fatigue damage exists and if a relationship were found, to determine how it could best be utilized to detect the extent of fatigue damage in a structural member.

A sequence of three experiments was designed to accomplish the above objectives, as follows:

(1) Measurement of spontaneous emission during plastic deformation.

(2) Measurement of thermally induced emission from previously fatigued metals.

(3) Development of a practical system for fatigue evaluation by exo-electron emission.

Spontaneous Emission of Exo-Electrons During Plastic Deformation

Nickel wire, 0.032-in. dia, that had not been previously annealed was annealed at 1000°C for 24 hours, in a vacuum of $4 \times 10^{-6}$ Torr, by
passing a heating current of approximately 12 A ac through it while in the vacuum pulling assembly. This was done to stabilize the structure and remove some of the surface oxides and absorbed gases.

After annealing, the wire temperature was reduced to 950°C (as measured by an optical pyrometer) and allowed to stabilize. Then a tensile load was applied by pulling at an approximate rate of 0.4 in. per minute. During this loading period the exo-electron current was monitored and recorded. When the load reached approximately 1200 psi, pulling was stopped and the load was reduced in order to investigate the delayed peak and subsequent decay of exo-electron emission predicted by the vacancy diffusion theory (see Chapter II, page 6, "Vacancy Diffusion Models of Exo-Electron Emission"). After a duration of approximately 30 seconds at a reduced load, the pulling was resumed until failure occurred; the delayed peak and subsequent decay of the exo-electron current were observed again.

The exo-electron emission current and the load in pounds are shown in Figure 8. These results will be discussed in detail in the next chapter. Here we suggest that the plastic deformation generates vacancies which diffuse to the surface, resulting in exo-electron emission. The delay between stress and exo-electron emission is due to the rate of migration of vacancies through the nickel lattice.

**Thermally Induced Emission of Exo-Electrons From Previously Fatigued Metals**

The electro-formed nickel specimens described in Chapter III, page 10, were fatigued in the vacuum fatiguing assembly (see page 11).
Figure 8. Typical Results of Thermally Induced Exo-Electron Emission during Plastic Deformation. (32 mil nickel wire specimen, 4 x 10^-6 Torr pressure, 0.4 inches per minute pulling speed 950°C specimen temperature.)
The rotary-to-oscillatory motion converter shown in Figure 4 was set to twist the entire length of the 3/4-in. gauge section of the specimen through a total angle of 52° (±26° and -26°) at a rate of 8,930 cycles per hour.

In order to determine the average fatigue life of the specimens fatigued in this manner, 11 specimens were fatigued to failure at room temperature in a vacuum of 6 x 10^{-6} to 10^{-4} Torr. The number of cycles to failure was noted on the counter (see Figure 3) and recorded. The distribution of the specimen fatigue life is shown in Figure 9.

From the cycles-to-failure data, the percent of average total life vs. the number of fatigue cycles was determined; this curve is shown in Figure 10. Several specimens were then fatigued to each of five different percentages of the average total life at room temperature and in a vacuum of 10^{-5} Torr. After a specimen was fatigued to the appropriate percentage, a heating current of approximately 10 A ac was passed through the specimen and adjusted for a specimen temperature of 850°C (measured by an optical pyrometer with an accuracy of ±15°C).

The exo-electron current was measured during the 850°C heating with the pico-ammeter and recorded on a strip chart recorder. The results of this study will be discussed in the next chapter.

Low-Temperature, Ultraviolet-Stimulated Exo-Electron Emission

For this experiment the aluminum specimens shown in Figure 7 and heat treated as described in Chapter III, page 16, were fatigued
Figure 9. Distribution of Nickel Fatigue Test Specimen Fatigue Life. (Fatigued at room temperature in vacuum of $10^{-5}$ Torr, 3/4 inch gauge section twisted +26° and -26°.
Figure 10. Percent of Fatigue Life vs. Number of Cycles Fatigue for Nickel Fatigue Test Specimen. (Fatigued in vacuum of $10^{-5}$ Torr, 3/4 inch gauge section twisted $+26^\circ$ and $-26^\circ$.)
on a vibrating board.* One end of the test specimen was secured to a board which was supported on foam rubber feet; an unbalanced shaft was supported on the board by bearings and rotated by a flexible shaft connected to a motor. This caused the board to vibrate at the rate at which the unbalanced shaft turned, and the inertia of the free end of the specimen caused the specimen to be bent through a small angle at the rate of rotation of the unbalanced shaft. For the 1100-0 aluminum specimens the motor rpm, and therefore the fatigue cycles per minute, were 3550. The 7075-T6 aluminum specimens required an additional weight of 550 g attached to their free end, and the rate of fatigue was 340 cycles per minute.

In order to determine the average fatigue life of specimens fatigued in this manner, 10 specimens of 1100-0 aluminum and 7 specimens of 7075-T6 aluminum were fatigued to failure and the time to failure noted from a clock controlled by a relay photocell system which turned off when the specimen failed.

The average number of cycles to failure was determined to be 100,300 ± 800 for the 1100-0 aluminum specimens and 13,380 ± 2,600 for the 7075-T6 aluminum specimens. Percentages of these average fatigue lives were calculated, and four specimens were fatigued to each of these percentages of average fatigue life.

*Designed and built by Mr. Christian Savitz of the Department of Electrical Engineering, University of Arizona.
After the specimens were fatigued to the proper percentage of average fatigue life, they were irradiated with uv-light until a steady emission current was observed. An initial heating current of 280 A dc was then set and irradiation with ultraviolet continued in the system described in Chapter III, page 16, and shown in Figure 6. This heating current of 280 A dc produced the temperature vs. time curve shown in Figure 11.

The heating/irradiation cycle ran for eight minutes; during this period the exo-electron emission current was measured by a pico-ammeter and recorded on a strip chart recorder.

After a specimen test was completed, the brass brackets which supported the specimen were allowed to cool to room temperature before another specimen was tested to ensure that each specimen was exposed to the same heating cycle.

The results of these tests will be discussed in detail in the next chapter.
Figure 11. Temperature vs. Time Curve for 1100-0 Aluminum Specimens with an Initial Heating Current of 280 A dc.
CHAPTER V

RESULTS

Spontaneous Emission of Exo-Electrons During Plastic Deformation

In Figure 8 results of a typical run at a wire temperature of 950°C are shown. It is important to note in Figure 8 that the steady state emission level observed before pulling began has been subtracted from the total current. The net exo-electron component is plotted vs. time as a dashed line, and the applied stress vs. time is plotted as a solid line on the same graph.

From time zero to A in Figure 8 the exo-electron current decreases below zero; this may be due to the decrease in the thermal emission level as the wire straightened and necked down slightly causing a decrease in the temperature of the wire. At time A the stress began increasing in the elastic range, and the exo-electron emission also began to increase, but only slightly. The emission increased more rapidly after time B when the wire specimen was being plastically deformed. At time C when the stress level was rapidly reduced, the exo-electron emission continued to increase for approximately 5 seconds and then decayed more slowly than the applied stress. At time D the pulling was resumed, and the exo-electron emission increased slowly until plastic deformation of the wire specimen began
at time E, as before, after plastic deformation began, the exo-electron emission increased much more rapidly.

The delayed peak and the delayed decay of exo-electron emission after the stress has been relieved may be explained in terms of a vacancy diffusion model (see Chapter II, page 6). We suggest that the delay phenomenon represents the time for vacancies to diffuse to the surface, and the decay represents the rate at which the vacancy content is exhausted. The magnitude of the current is then a measure of the number of vacancies and the rate at which they diffuse to the surface.

**Thermally Induced Emission of Exo-Electrons**

**From Previously Fatigued Metals**

In this case metals were fatigued at room temperature and then heated to induce exo-electron emission. Two typical exo-electron current vs. time curves are shown in Figure 12. The exo-electron current for each run was integrated over time by a trapezoid approximation and multiplied by $6.24 \times 10^{-16}$ electrons per coulomb in order to obtain the total number of exo-electrons emitted from each specimen. The total number of exo-electrons emitted was plotted vs. the percentage of average fatigue life fatigued for all the runs made and is shown in Figure 13.

In Figure 13 it can be seen that the total number of exo-electrons emitted increased with fatigue level up to about 55% of average fatigue life. At a fatigue level of 56% the data are very erratic; and for a fatigue level of 68%, the total number of exo-electrons emitted has dropped below the number emitted from specimens that had not been fatigued.
Figure 12. Typical Exo-Electron Emission vs. Time for Nickel Fatigue Test Specimens Fatigued 4,000 and 12,000 Cycles. (Fatigued in vacuum of $10^{-5}$ Torr at room temperature, the specimen temperature was 850°C while the exo-electron current was measured.)
Figure 13. Total Number of Exo-Electrons Emitted vs. Percent of Fatigue Life, for Nickel Fatigue Test Specimens. (Fatigued in vacuum of $10^{-5}$ Torr at room temperature, the test specimen temperature was 850°C while the exo-electron current was measured.)
The erratic data obtained for specimens fatigued to the 56% level may be due to a high degree of nonlinearity in the number of exo-electrons emitted as a function of fatigue level at the 56% level and the large scatter in the number of cycles to failure (see Figure 9). (Note that for the dashed curve in Figure 13 a scatter of only $\pm 20\%$ in the percent of fatigue life could result in the range of measurements obtained at the 56% level.)

The correlation between exo-electron emission and structural fatigue shown in Figure 13 can be explained by a vacancy diffusion model where the number of exo-electrons emitted is related to the concentration of vacancies. A vacancy diffusion model would agree with the rise and then fall of exo-electron emission as the fatigue level increases to 56% because a high density of vacancies and dislocations is known to impede vacancy diffusion. We would expect that at a high fatigue level exo-electron emission would be small until the metal was heated enough to activate dislocation motion.

**Low-Temperature, Ultraviolet-Stimulated Exo-Electron Studies**

Tests with the low-temperature, uv-stimulated system described in Chapter III, page 16, and conducted in the manner discussed in Chapter IV, page 23, have indicated that a correlation does exist between the fatigue history of a specimen and its exo-electron emission when heated and exposed to ultraviolet in ambient air. However, sufficient tests have not been conducted to warrant presentation of data in this thesis.
The results discussed in Chapter V are consistent with a vacancy diffusion model of exo-electron emission. The correlation between the exo-electron emission and structure fatigue (Figures 12 and 13) is significant and indicates that exo-electron emission can be an effective tool for studies of the fatigue process.

The application of exo-electron emission from fatigued metals to practical nondestructive testing was described earlier. The ultimate objective of this research was to determine whether this test technique could serve as a measure of fatigue, be applicable to large or small structures in an air ambient, and provide an unambiguous readout suitable for use by military personnel.

To date we have demonstrated that for at least one material (aluminum), exo-electron emission at low temperatures (90°C) in air can be used to measure specimen fatigue.

Further studies with the vacuum pulling assembly and vacuum fatiguing assembly, discussed in Chapter III, will be conducted in ultrahigh vacuum in an attempt to further understand the exo-electron phenomenon. Extension of the low-temperature, air ambient tests to titanium, steel, and 7075-T6 aluminum will be part of the program.
We will begin development of a portable heating system and a photographic film electron detector so that this NDT technique can be used in the field.
LIST OF REFERENCES


