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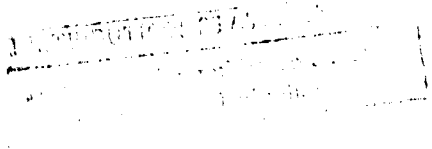
TECHNICAL REPORT NO. 11169

INVESTIGATION OF A LASER ILLUMINATOR -
THERMAL IMAGING SYSTEM FOR THE DETECTION
OF VOIDS AND DISBONDS

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by OTTO RENIUS

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INVESTIGATION OF A LASER ILLUMINATOR -

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TABLE OF CONTENTS

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ABSTRACT

An infrared nondestructive testing technique employing
laser heating of the specimen was developed and evaluated
on several bonded materials. Thermal images were obtained
using a two-dimensional reflective scanner coupled to a
30-watt CO_2 laser to irradiate the specimen and a thermal
imaging camera to view the specimens irradiated surface.
The technique is capable of providing a versatile, high-
resolution, real-time nondestructive test for subsurface
defects in large specimens.

i

INTRODUCTION

The use of infrared imaging devices for nondestructive
testing has expanded rapidly due in part to the advances
in military infrared technology. Highly sensitive detectors
and complex scanners were developed for military use. As
security restrictions were lifted, high resolution thermal
cameras were built for commercial applications. Today both
the industrial and medical fields, as well as the military,
make wide use of infrared in a variety of tests.

As contrasted with radiometry which presents a graphical
or digital output of the detector response, a thermal
imaging camera allows the construction of a picture of
an object which gives a visual presentation of variations
in heat emitted by the area under scrutiny. Thus, any
malfunction or defect which causes a sufficiently large
variation in the surface temperature of an object can be
detected by infrared imagery.

Thermal imaging techniques of nondestructive testing rely
on the contrast in radiation between components or sections
of a component to indicate the presence of defects and
malfunctions. To achieve this contrast, various methods
have been devised for heating the specimen in order to
obtain sufficient infrared emission for thermal imagery.
Most of these techniques result in excessive heating
times or require close proximity between the specimen and
heat source.

Infrared nondestructive testing techniques can be divided
into two broad categories, active and passive, as in
military infrared applications. In the passive mode, the
entire specimen itself is the source of radiation. It
may be in a transition between two temperature levels,
either heating up or cooling down to the background equili-
brium. In the active method, heat is selectively injected
into a specimen at or near ambient temperatures. Detectable
differences in heat transfer through the specimen are then
used to indicate the presence of voids of defects.

1

Preliminary calculations were performed to determine
the feasibility of employing active infrared methods
to make the examination of large specimens more prac-
tical. This approach had been taken by several inves-
tigators to study small specimens with radiometric
instrumentation, and had achieved limited success using
resistance heaters as the active source. [1,2] This task
investigated the use of a two-dimensional reflective
scanner coupled to a 30-watt CO_2 laser to irradiate the
specimen and a modified AGA three-channel infrared
camera to view the specimen's irradiated surface. The
system is capable of providing a high resolution real-
time nondestructive test for subsurface defects.

RECOMMENDATIONS

It is recommended that the laser illumination - thermal imaging technique for nondestructive testing be applied to materials testing problems involving the detection of near-surface voids and disbonds. To increase the versatility of the technique, further work should be devoted to the refinement of the two-dimensional scanner equipment to more readily alter the size of the area scanned, scanning speed, and distance between scanning lines.

3

SUMMARY

The development of a two-dimensional long wave-length
laser scanner for use in conjunction with thermal imagery
expands the application of infrared nondestructive testing
techniques. This is especially evident in the potential
application to relatively large specimens since the low
atmospheric absorption of the 10.6 micron laser beam [3]
allows a long scanning path to be used without serious
degradation of the beam intensity.

From the results obtained under laboratory conditions,
it can be concluded that laser illumination – thermal
imagery can be used as a nondestructive testing technique
for a variety of bonded specimens. The technique is
particularly useful for the examination of specimens that
have a thin cross section or where the distance from the
outer surface to the bond area does not exceed 1/4 inch.
The potential usefulness of laser heating of thick spe-
cimens is limited to the evaluation of flat specimens
having shallow sub-surface voids. The technique, therefore,
should not be considered as a method for the evaluation of
track pad or road wheel metal-rubber bonds.

4

TECHNICAL CONSIDERATIONS

All matter continuously absorbs and emits electromagnetic
radiation. The continual motion of the charged particles
within a material result in this emission. Since the
thermal motion increases with temperature, the continuous
radiation from the material also increases with temperature.
The theory of this radiation is given by Planck's equation
which expresses the relationship between E_λ and λ

$$E_\lambda = \frac{2\pi c^2 h}{\lambda^5 (e^{hc/\lambda kT} - 1)}$$

When the limits $\lambda = 0$ to $\lambda = \infty$ are considered Planck's
equation yields the Stephan-Boltzmann Law $e_B = \sigma T^4$ where
σ is the Stephan-Boltzmann constant $= 5.735 \times 10^{-8}$ watts/
$M^2 - \deg^4$. This law states that the total energy radiated
by a perfect black body is proportional to the fourth
power of the absolute temperature. The ratio of the total
emissive power of any body to that of a perfect black body
at the same temperature is called the emissivity (e) and
is numerically equal to the absorptivity of the body.

When radiant energy from the CO_2 laser falls upon the
specimen, part is absorbed and part is reflected. Assuming
a uniform specimen surface, the amount of total incident
radiation absorbed by the specimen due to the continuously
scanning laser beam is equal for the entire surface. The
result is an increase in surface temperature and a flow of
heat through the specimen. For a homogeneous sample, the
quantity of heat that will flow by conduction per unit of
time is proportional to the thermal conductivity of the
material, and the irradiated surface temperature will de-
crease uniformly after the laser beam has passed.

If, however, voids exist in the specimen, the thermal con-
ductivity is altered, with a resulting alteration in sur-
face temperature in the area of non-homogeneity. This
non-homogeneity can then be detected by a radiometer or
thermal imaging device if it causes surface temperature
variations sufficiently large to fall within the sensi-
tivity range of the instrument.

APPROACH

Since a laser is capable of imparting a large amount of
thermal energy to a small surface area, it becomes a
convenient method of quickly raising the specimen's surface
temperature. A continuous wave CO_2 laser was tentatively
selected as the source because it is readily obtainable
with sufficiently high output to be useful. In addition,
the output (10.6 Microns) cannot be detected by the thermal
imaging camera which has a long wavelength cutoff of 5.4
microns. The infrared camera then sees only the energy
re-radiated by the specimen and is "blind" to any portion
of the laser beam scattered by the specimen or other
reflecting surfaces. The disadvantage of using the CO_2
laser as the energy source is the difficulty in locating
and aligning the invisible beam.

Two approaches were considered for expanding the 1/4
inch diameter laser beam to cover the total specimen area.
The first, use of a wobbling, cassegrain reflective op-
tical system to expand the beam, was discarded in favor
of a reflective two-dimensional scanning system which would
provide a rectangular scanning pattern.

EQUIPMENT DESCRIPTION

Reflective mirrors were prepared for positioning in
front of the laser to provide the two-dimensional scan.
Mirrors were fabricated from aluminum on pyrex, gold
on pyrex, and stannous chloride on pyrex. Freshly
deposited aluminum on pyrex proved to be the best re-
flector for the laser beam.

Motor driven cams were used to achieve a two-dimensional
scanning pattern. Figure 1 is the diagram of the scanner
which was fabricated.
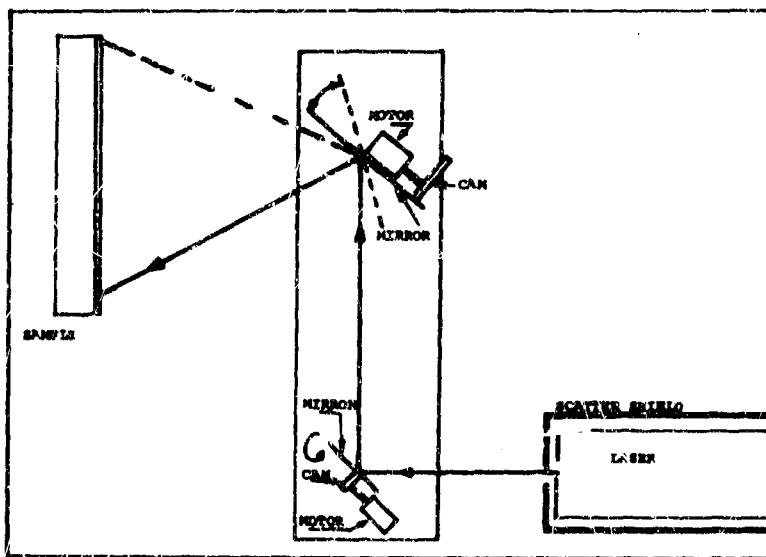
ARRANGEMENT OF TWO DIMENSIONAL SCANNER

FIGURE 1

After the beam emerges from the shielded laser source,
it strikes the first mirror and is reflected. This mirror
is pivoted so that it can be tilted in the vertical direction
when driven by a cam. The reflected beam strikes the second

7

mirror which rocks back and forth, reflecting the laser
beam in a horizontal line. At the end of each oscillation,
the mirror depresses a microswitch which activates the cam
driving the first mirror causing it to tilt slightly in
the vertical direction. A two-dimensional scanning pattern
is thus reflected onto the specimen's surface.

Figure 2 illustrates the scanner mounted in front of a
neon-helium laser to check the mirror alignment. It
was necessary to employ a relatively low power laser which
emitted visible light for this purpose. After acceptable
alignment was achieved, all mirrors were securely fastened
to the mounting frame.
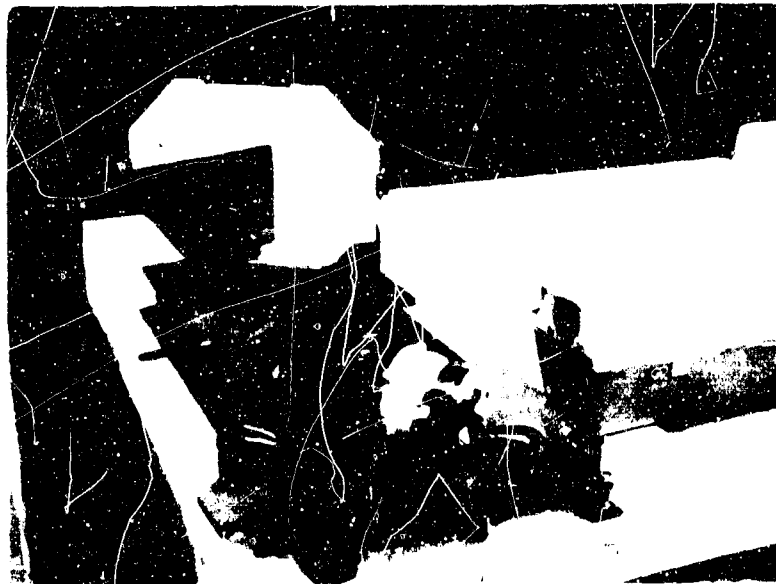
TWO DIMENSIONAL SCANNER WITH NEON-HELIUM LASER

FIGURE 2

8

Figure 3 illustrates the pattern which was obtained when
the scanner was operated in front of a neon-helium laser.
The area covered by this scan was 9 inches X 18 inches.
For the remainder of the studies, the scanner was positioned
in front of the 30 watt CO_2 laser.
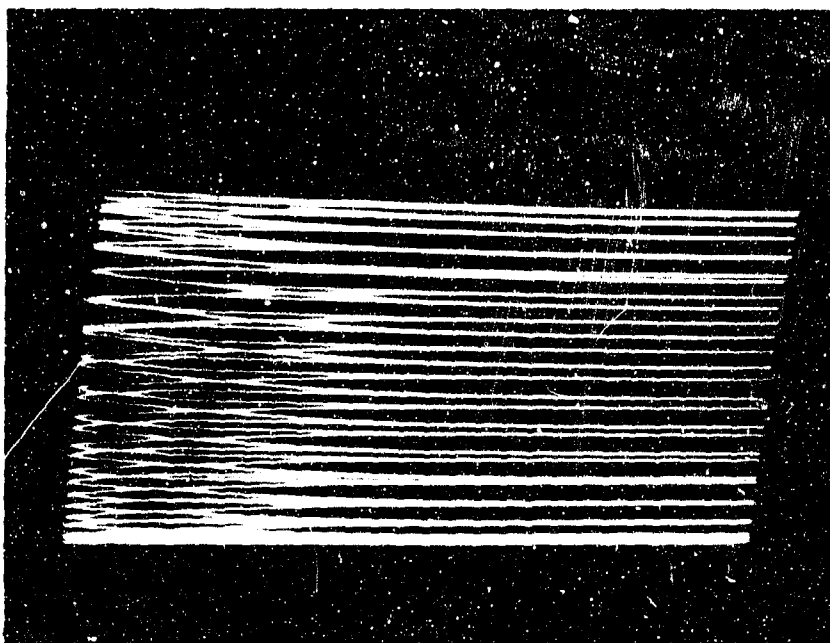
SCANNING PATTERN OF LASER BEAM

FIGURE 3

Thermal images of the specimens were obtained with a
three-channel infrared camera modified such that the energy
from the specimen is displayed in three different optical
regions. The three optical bandpasses are: 2.0 to 5.4
micron, 3.6 to 4.4 micron and 4.35 to 5.15 micron. A
description of the camera is given in the following summary
of data:

|	
Range of focus	Two meters to infinity
Field of view	$5^{\circ} \times 5^{\circ}$ (1 m X 1 m at 10 meters)
Number of lines per frame	100
Frame rate	16 per second
Optical resolution	About 100 elements per line
Thermal discrimination	Two black body areas at room temperature can be separated if their temperature difference is larger than $0.2^{\circ}C$.
Picture temperature range (black to white)	Maximum $200^{\circ}C$ Minimimum $1^{\circ}C$
Object temperature level	$-30^{\circ}C$ to $+200^{\circ}C$
Isotherm width	From 1% to 30% of the sele ted temperature range
Detector type	ndi m antimonide cooled by liqui nitrogen. Detector dewar holds 100 cc, sufficient for four hours.

SPECIMENS

A laminated plate with built-in defects was used as the
primary specimen for evaluating the laser-thermal imaging
system. This specimen consisted of a 1/8 inch rubber
sheet bonded to an one inch thick aluminum backing plate.
Two voids were machined into the aluminum plate prior
to cementing the rubber to the surface. Each void was
7/8 inch diameter. One void was machined 1/8 inch into
the plate and the other was machined 1/2 inch deep.

Other specimens were prepared from bonded sheet metal,
a section of foamed-in-place polyurethane between two
panels of 1/4 inch fiberglass, and from tank track pads.
A 3/8 inch diameter void was drilled in the fiberglass
specimen to provide the defect. The track pads had
known separations which were located by radiographic
examination prior to thermographic evaluations. The
bonded sheet metal specimen is described in the section
"Results".

EXPERIMENTAL PROCEDURE

A heat penetrameter was fabricated to insure that the
infrared camera focus was optimum under all experimental
conditions. This penetrameter consisted of a thin sheet
of molybdenum spaced 1 inch in front of an aluminum plate.
Three holes were spaced in the molybdenum. The holes
were 1/4 inch, 3/8 inch, and 1/2 inch diameter. The
molybdenum sheet was then resistance-heated to a temperature
slightly above ambient and viewed with the thermal imaging
camera. Focus was adjusted for a maximum resolution of
the three holes. The 1/4 inch hole was visible only when
the instrument was properly focused and adjusted. Figure
4 is a thermal image of the heat penetrameter with the
three holes visible.
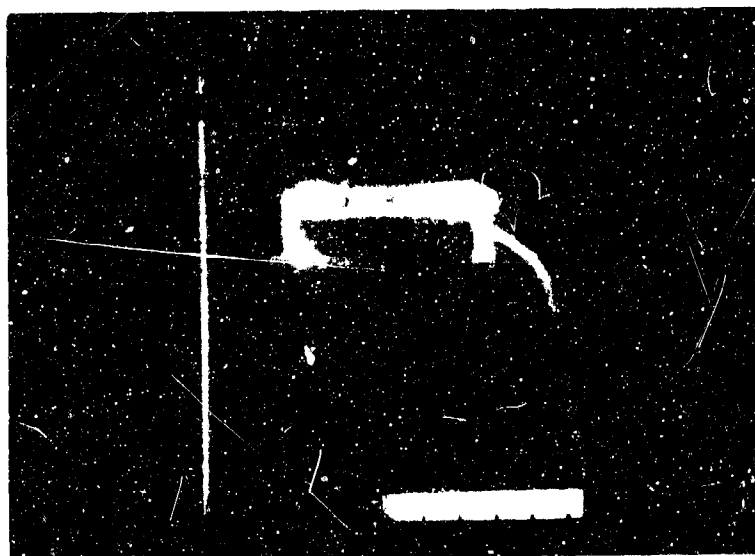
THERMAL IMAGE OF HEAT PENETRAMETER

FIGURE 4

After positioning the scanner in front of the CO_2 laser, beam alignment was achieved by viewing with the thermal imaging camera. This also served to determine the effects of the 30-watt laser beam on the specimen's surface. Figure 5 illustrates the laser beam striking a steel plate continuously for 30 seconds. The lateral dissipation of heat is seen as the steel is heated in the area of the beam.
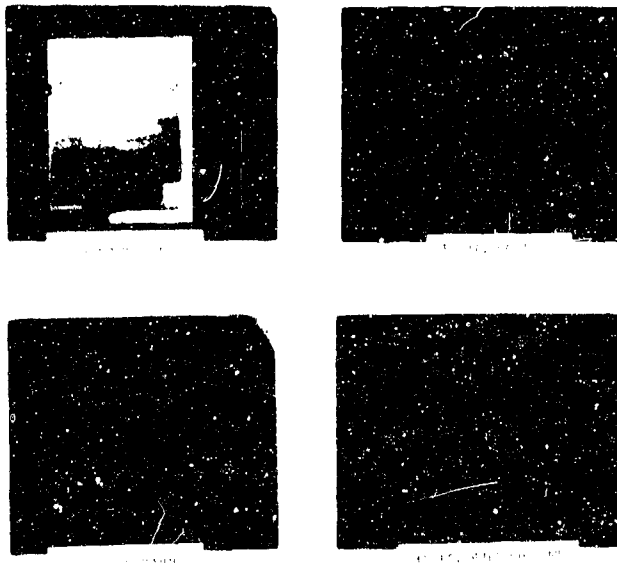

1/16 INCH STEEL PLATE
19MA-BEAM

EFFECTS OF CO_2 LASER BEAM STRIKING A STEEL PLATE

FIGURE 5

The difficulty in locating the moving laser beam with
respect to the specimen made it necessary to provide a
visual indicator of the beam position. Indicator lights
were placed on the scanner control assembly to show the
beginning of the scanning pattern in the upper left
corner of the area to be illuminated. This allowed the
initial position of the laser beam to be established
before the laser was turned on and the specimen surface
heated.

To provide some measure of the increase in surface tem-
perature due to the scanning laser beam, a chrom-alumal
thermocouple was fabricated and placed on the specimen's
surface. The laser beam was then scanned across the
junction and the temperature profile of the thermocouple
at the specimen's surface was recorded. Figure 6
illustrates the thermocouple at the specimen's surface.
Figure 7 is a recorder trace of the temperature increase
in the specimen at the thermocouple junction as the
laser beam crossed the specimen and returned to its
starting position, thus striking the junction twice.
The scanning beam at the laser-to-specimen distance
of 43 inches made a two-pass scan in 9.0 seconds and
traveled a total horizontal distance of 34 inches. By
retracing its path in completing a horizontal scan,
the laser beam imparted sufficient energy to raise the
specimen's surface temperature by 18°.

14

THERMOCOUPLE JUNCTION

PATH OF LASER BEAM
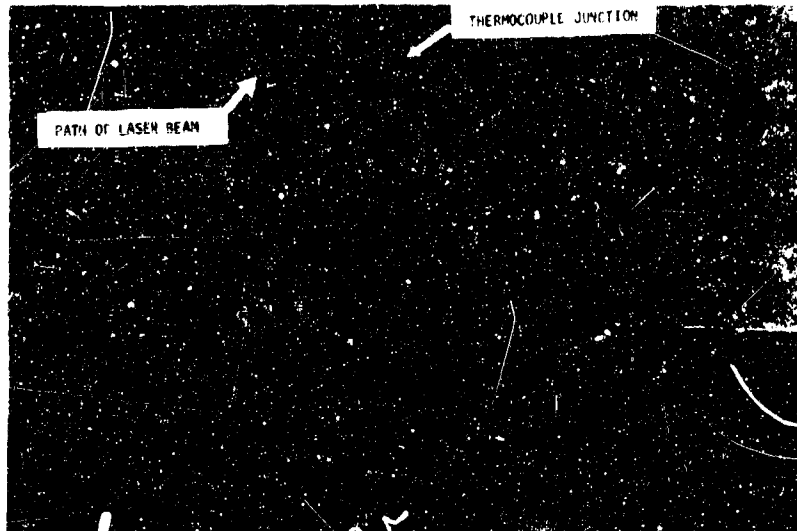
THERMOCOUPLE FOR SURFACE TEMPERATURE MEASUREMENT

FIGURE 6

COOLING CURVE OF THERMOCOUPLE AFTER TWO SWEEPS
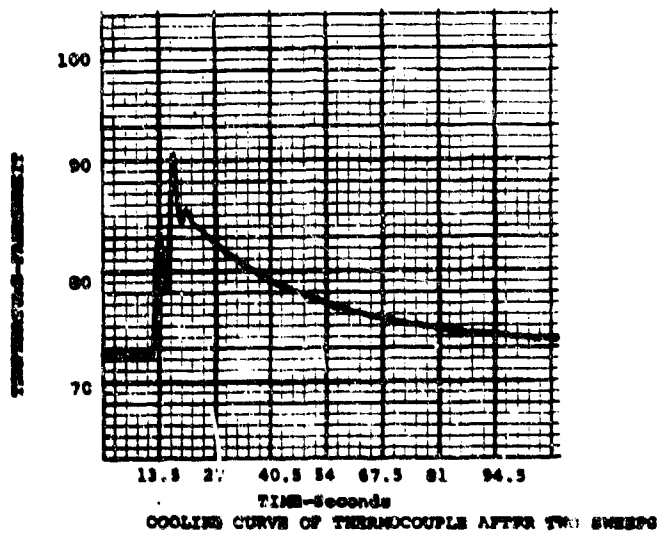
TIME-Seconds

FIGURE 7

15

RESULTS

A composite specimen was fabricated which consisted of:

Flat black enamel outer coating

1/32 inch stainless steel panel

Steel defcon adhesive

1/32 inch aluminum with one inch diameter hole

Steel defcon adhesive

1/32 inch stainless steel back panel

Figure 8 is a thermogram of the specimen in the passive mode of testing. The specimen had been heated with hot air and was cooling to room temperature. Figure 9 shows the same specimen as viewed in the active mode. The backing panel shows the effects of the scanning beam.

NOT REPRODUCIBLE
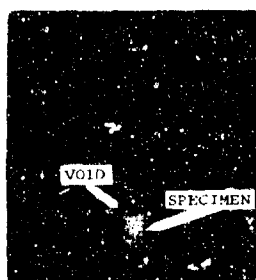
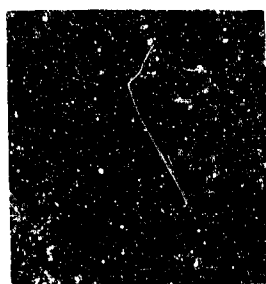PASSIVE THERMOGRAM

BONDED STEEL SPECIMEN

FIGURE 8
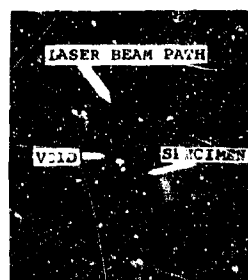
ACTIVE THERMOGRAM

BONDED STEEL SPECIMEN

FIGURE 9

It can be seen that under the passive testing technique
the void appears as a "cold" spot in the heated specimen.
Under active illumination, the void appears "hot" to the
thermal imaging camera while the remainder of the specimen
has cooled to near ambient conditions. The resolution
of the void under the active condition was superior. and
the general shape and size could be determined. Under
passive conditions, only the presence of a defect could
be stated with any degree of certainty.

Prior to the application of a flat black enamel front
surface to the composite specimen, the laser beam could
not be located while traversing the specimen. Consequently,
the defect could not be located. This was due to the
high reflectivity of the polished stainless steel surface
to the 10.6 micron laser radiation. Although a drawback
to the use of the laser illumination technique on a
routine basis, the problem is conveniently solved by the
application of a coating which will absorb the laser
radiation and hence emit efficiently.

Figures 10 and 11 illustrate a rubber bonded to aluminum
specimen as evaluated by the passive and active techniques,
respectively.

PASSIVE THERMOGRAM

RUBBER PONDED TO ALUMINUM

FIGURE 10
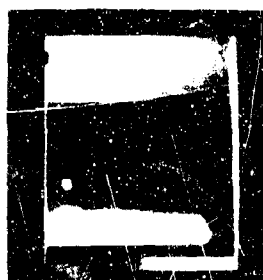
ACTIVE THERMOGRAM

RUBBER BONDED TO ALUMINUM

FIGURE 11

17

Again it is noted that two voids appear as "hot" spots under passive examination and as "cold" spots when scanned actively. In Figure 11, the scanning laser beam continues to irradiate the lower portion of the specimen. The defects in the central portion appear soon after the scanning beam has passed the area. Since the rubber front surface of the specimen has a high emissivity, it was not necessary to overcoat the specimen to absorb the laser beam efficiently. The defects in the specimen were detected under a wide range of laser scanning speeds and beam power.

A T136 Tank track shoe was selected as a typical bonded specimen having a relatively thick cross section. The track shoe consists of a formed steel plate approximately 3/16 inch thick to which a rubber pad is bonded. The rubber varies in thickness from approximately 1/2 inch on the edges to 1-11/16 inches in the central portion of the track shoe. When viewed in either the passive or active modes, results were inconclusive and non-reproducible. Although defects were known to exist in the specimens, it was not possible to accurately detect these areas. Figure 12 illustrates a passive thermogram of a heated track shoe. A portion of the difficulty in locating the disbond areas can be attributed to the irregular surface on the metal side of the track. On some specimen track shoes the metal surface was clear of any rubber. On other specimens, rubber had formed over a portion of the metal in an irregular pattern. Figure 13 illustrates the metal side of a track shoe with some build-up of rubber on the metal. The twin "hot" areas are due to metallic mounting bolts on the track shoe.
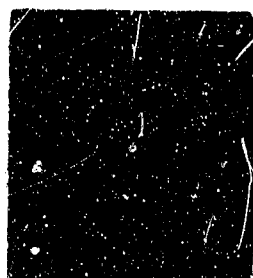
PASSIVE THERMOGRAM

TANK TRACK SHOE

PASSIVE THERMOGRAM

TANK TRACK SHOE

FIGURE 12   FIGURE 13

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70-159.

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20

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13. ABSTRACT

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NON DESTRUCTIVE TESTING						
LASERS						

31