In-situ ultrasonic imaging of CF/PEEK during delamination closure at elevated temperature

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SUMMARY: In this article, we present a technique for in-situ imaging of the delamination as it is being "healed" at elevated temperatures. This report presents results on the modification of the Scanning Acoustic Microscope (SAM) for in-situ observations of material changes at intermediate temperatures (up to 500°C). Described are the key problems and their solutions (*i.e.*, the thermal protection of the transducer and the peripheral equipment, the acoustic lens design for elevated temperature, the scanning mechanism, and the coupling medium). The intermediate temperature SAM was used to image the healing process of internal defects of a CF/PEEK composite caused by soft body impact. The results clearly demonstrate the usefulness of the SAM imaging with temperature control to high enough temperatures to monitor in-situ materials undergoing changes in the internal structure. The technique is completely non-destructive and lends itself for field development.

KEYWORDS: Scanning acoustic microscope, Intermediate temperature, In-situ observation, Delamination

INTRODUCTION

Nowadays composite materials (*e.g.*, a fiber reinforced plastic or the like) are applied to many different fields, ranging from sports equipment (*e.g.*, tennis rackets) to aircraft components. An interdisciplinary international effort is underway for developing Carbon fiber/PEEK matrix laminated composites for turbine blades, in the first stage of aircraft turbine engines. The objective of CF/PEEK turbine blades is to decrease the weight while maintaining strength and durability of the aircraft. Recent failures under soft body impact represented by the "bird strike" have shown that maintaining the integrity of the blades is critical [1-3]. Experience has shown that even though no damage is visible on the surface, the interior may be heavily damaged in terms of delaminations located at interfaces between the laminates making up the composite.

For this study, the Scanning Acoustic Microscope (hereinafter called simply "SAM") [4, 5] was modified for in-situ internal imaging of material changes at intermediate temperatures (up to 500°C). The key problems and their solutions during the modification such as the thermal protection of the transducer and the peripheral equipment, the acoustic lens design for elevated temperature, the scanning mechanism, and the coupling medium, are described. In this study, we provide acoustic images showing the "healing" (or "closing") process of the delamination of the CF/PEEK composite at elevated temperatures, wherein the acoustic images were obtained by the SAM modified for elevated temperature (hereinafter called the intermediate temperature SAM). The results clearly demonstrate the usefulness of the SAM imaging with temperature control to high enough temperatures to monitor in-situ materials undergoing changes in the internal structure. This technique is completely non-destructive and lends itself for field development.

EXPERIMENTAL SETUP

Fig. 1 shows the schematic diagram of the intermediate temperature SAM. The acoustic lens comprises a PZT transducer, a long ceramic buffer rod including a lens focussing the acoustic beam onto the specimen. The center frequency of the transducer is 10 MHz, and its diameter is substantially one inch. The length and the diameter of the buffer rod are 2 and 1 inch respectively. The lens is located within the chamber filled with automobile engine oil as a coupling medium for elevated temperature. A double wall cover for the chamber is adopted for heat protection, wherein air within the wall is used as a heat isolation material. The specimen is set within the chamber arranged on the heating plate mounted on the X-Y scanning stage. A specimen holder is used to stabilize the specimen. Temperature within the chamber can be controlled by the temperature controller, measured by a thermocouple, and increased up to 500°C by the heating plate. Because of the double wall cover and the low heat conductivity of the buffer rod, the temperature at the transducer is substantially below 100°C when the temperature of the coupling medium is increased up to 500°C.

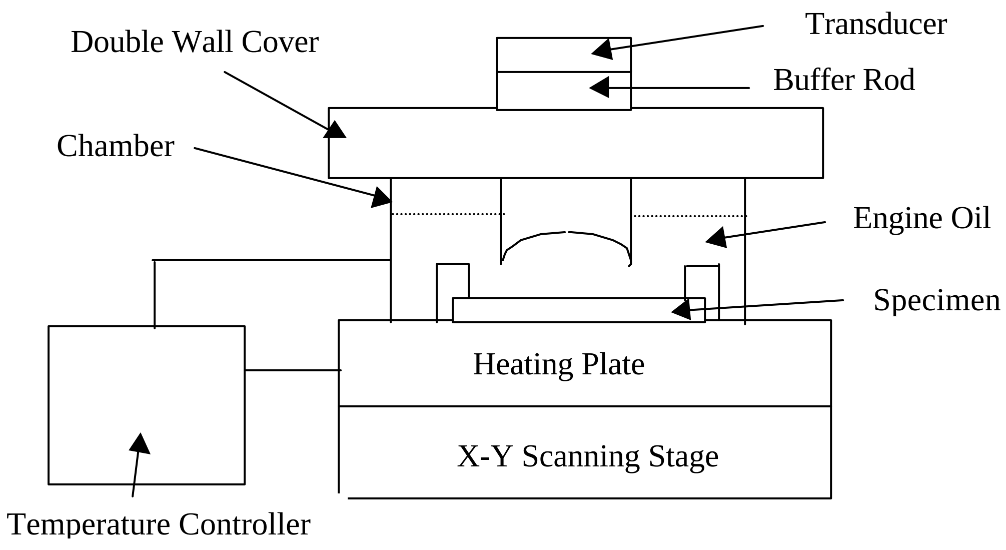


Fig. 1: Schematic diagram of key portions of the intermediate temperature SAM

SPECIMEN

A CF/PEEK composite $(0_3/30_3/-30_3)_s$ was selected for this experiment. The flat specimen was cut to 100×100 mm and its thickness was substantially 3 mm. A gas gun system (See Fig. 2) with a gelatin bullet was used for providing impact to the specimen. The specimen was aligned so as to be impacted at the center of the plate. The total mass of projectile was substantially 3 g. The impact velocity was 146.1 m/s, and corresponding impact energy was 32.1 J. As shown in Fig. 3, the delamination was introduced to the first interface of the specimen.

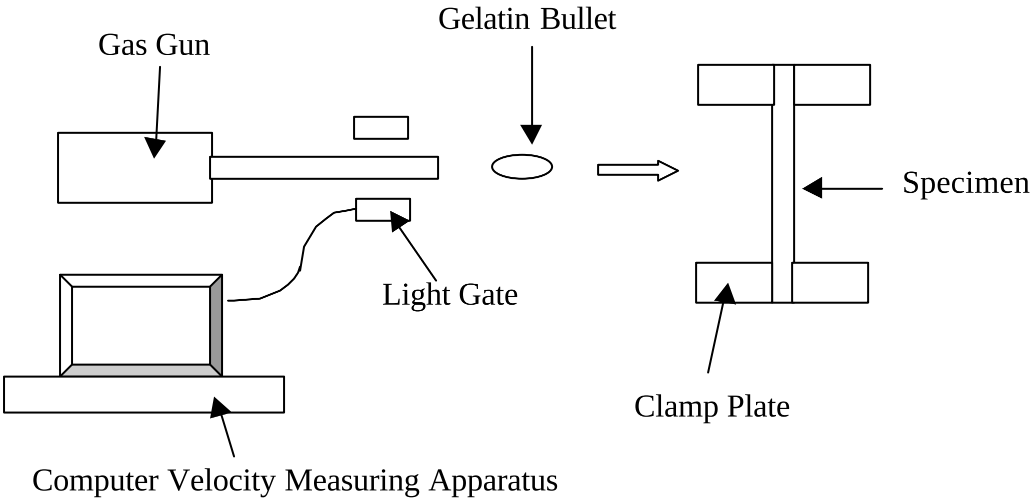
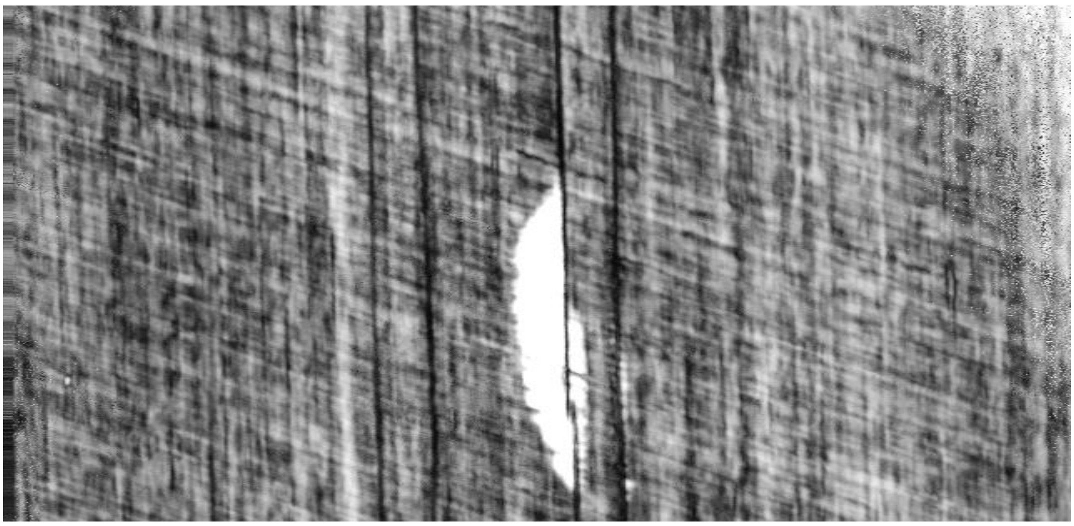


Fig.2: The schematic diagram of the gas gun system



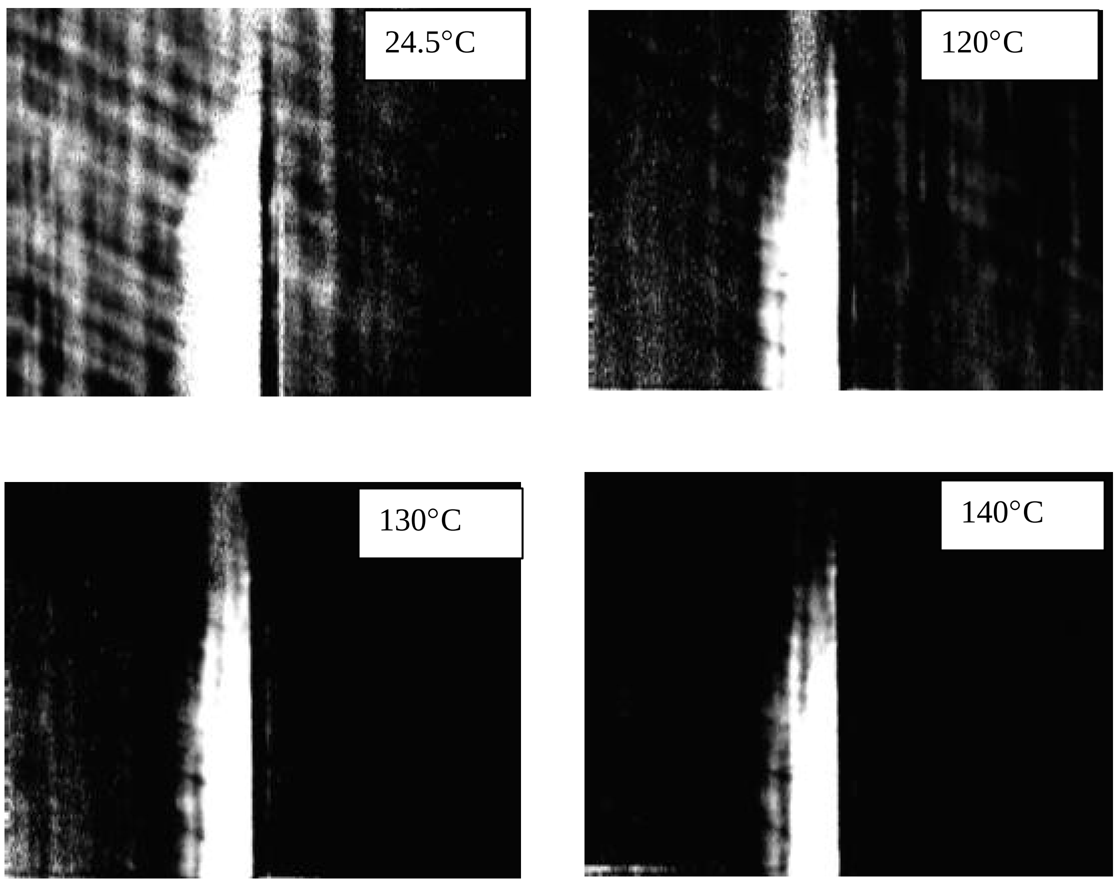
Fig, 3.: Whole acoustic image of delamination introduced by the gas gun system
Frequency: 30 MHz, Coupling medium: water

For obtaining the acoustic image shown in Fig. 3, the conventional C-scan system was used. Water (24.5°C) was used as the coupling medium as a scanning width of the acoustic image was 30 mm × 40 mm.

EXPERIMENTAL RESULTS

Fig. 4: shows the "healing" process of the CF/PEEK. As temperature was increased, first, the area of delamination was slightly increased by removal of residual stress and thermal expansion. Then, the area of delamination was gradually decreased. Finally, the delamination disappeared, and only a transverse crack remained.

There are two types of delaminations. One is completely healed with elevated temperature (See Fig. 5). The other is closed and its area is shrunk but not completely healed.



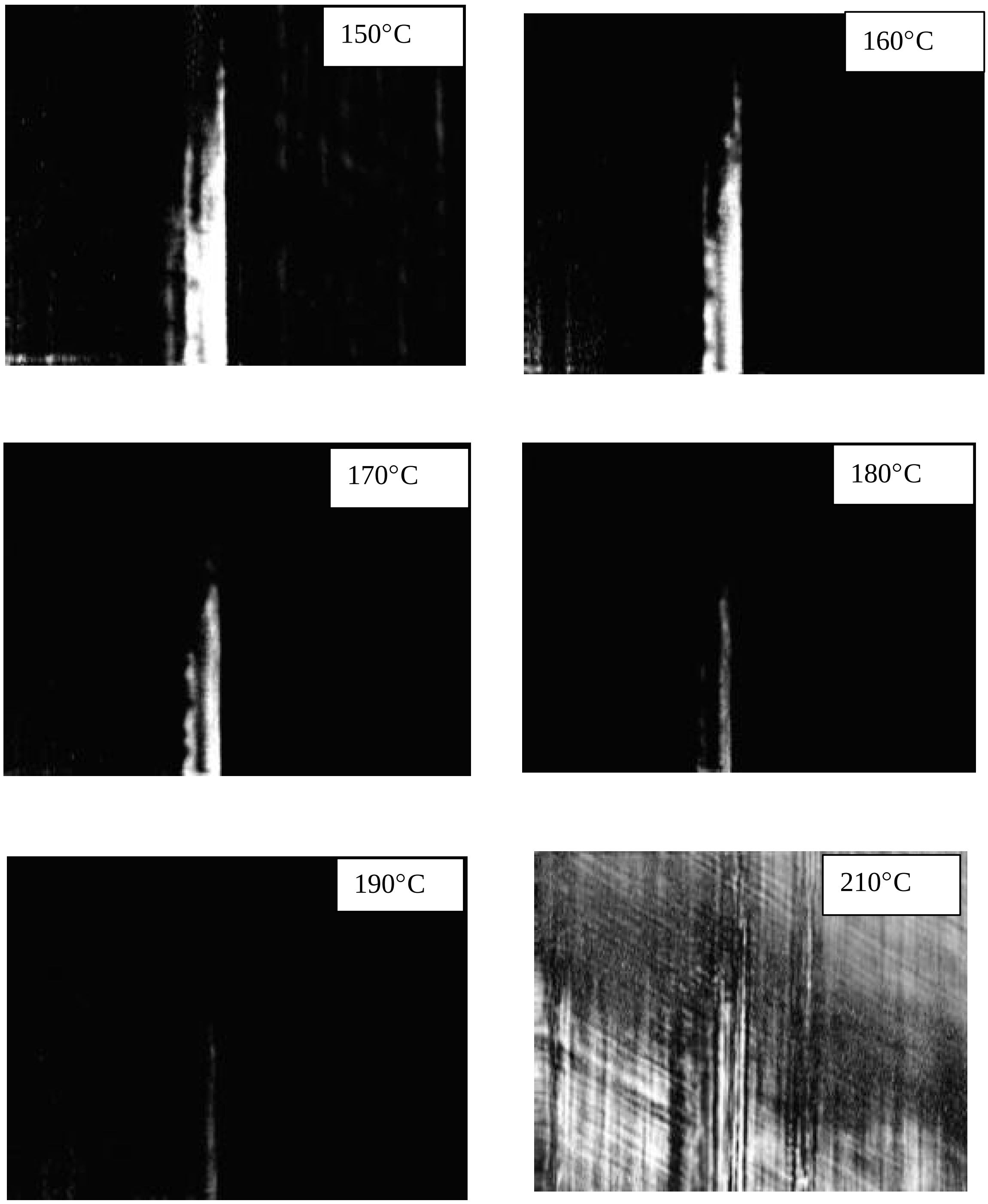


Fig 4 Acoustic images of delamination due to changes of temperatures
Frequency: 10 MHz, Scanning Width: 9mm×12mm, and
Coupling Medium: Engine Oil

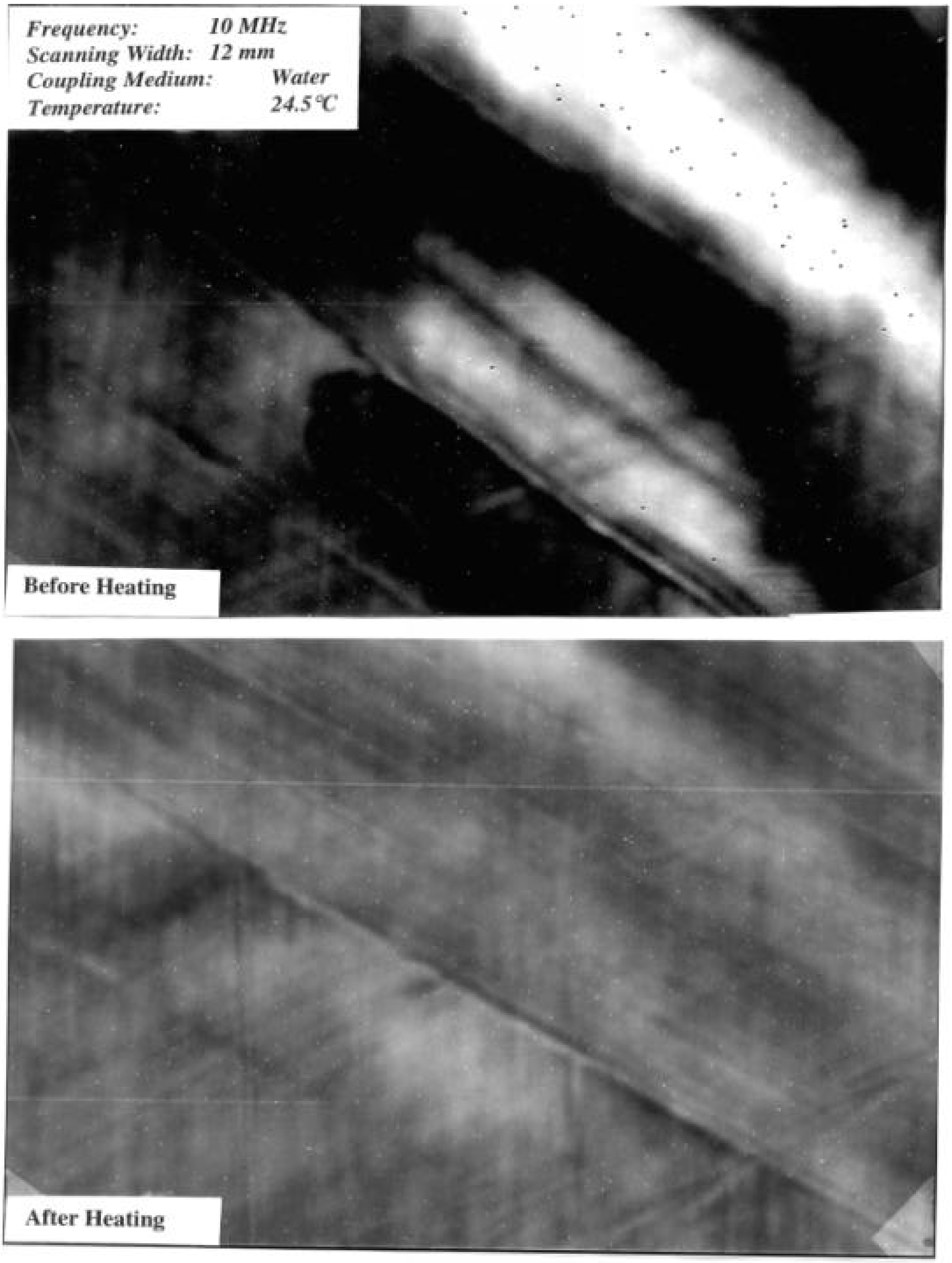


Fig.5: Healing process of delamination

CONCLUSIONS

1. The hardware, including the acoustic lens, of the scanning acoustic microscope was modified for intermediate temperature up to 500°C.
2. In-situ observation of the delamination healing process of CF/PEEK was carried out.

FUTURE WORK

The following tasks must be completed.

1. Increase the frequency to observe detailed structures of materials.
2. Carry out post mechanical testing to obtain changes of mechanical strength.
3. Establish the healing mechanism.

ACKNOWLEDGEMENTS

Authors are thankful to Dr. T. Adachi (Tokyo Institute of technology) and Dr. H. Kasano (Takushoku University) for helpful discussion, and Dr. H. Morita (Ishikawajima-Harima Heavy Industries Co., Ltd.) for contribution of specimens.

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