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MICROWAVE PROCESSING OF SILICON CARBIDE*

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ABSTRACT

Reaction-bonded silicon carbide (α-SiC) armor tiles were annealed at 2100°C using microwave radiation at 2.45 GHz. Ultrasonic velocity measurements showed that the longitudinal and shear velocities, acoustic impedances, and acoustic moduli of the post-annealed tiles were statistically higher than for the unannealed tiles. However, the exposed surfaces of the annealed tiles experienced slight degradation, which was attributed to the high annealing temperatures.

INTRODUCTION

Silicon carbide is currently being evaluated as a possible light-weight armor material. Previous investigations [1-4] have shown that armor composed of ceramic materials such as silicon carbide, alumina, titanium diboride, and boron carbide have better ballistic performances and are lighter in weight than traditional metallic armor. An earlier study involving several of the authors showed evidence that the ballistic performance of alumina could be significantly improved by an annealing operation using microwave radiation. This study also agreed with other research [1] which showed that a relationship existed between the ballistic efficiency and acoustic impedance.

This paper summarizes an investigation to improve the acoustic properties of SiC armor tiles by an anneal treatment using microwave radiation. Other researchers [5] have investigated microwave joining of SiC ceramics, but as of yet the use of microwaves to anneal large SiC bodies has been unreported. In this study, 28 reaction-bonded SiC tiles were heated to 2100°C in a microwave furnace operating at 2.45 GHz under a nitrogen atmosphere. Another four tiles from the same batch were not microwave processed in order to compare the microwave effects. Each tile was checked for hydroscopic density and acoustically scanned to reveal the uniformity of acoustic attenuation. After measuring the acoustic properties of the tiles, they were sent to the Army Research Laboratory in Aberdeen, Maryland for ballistic testing.

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EXPERIMENTAL PROCEDURE

A total of 32 armor tiles, which were supplied by Cercom, Inc., were used in this study. These tiles were composed of reaction-bonded α-SiC and measured 15.2 cm x 15.2 cm x 1 cm. Each tile had a mass of approximately 725 grams. Twenty eight of the tiles underwent a microwave annealing heat treatment, while the remaining four were used for a baseline comparison. Each of the 28 tiles was placed inside a 2.45 GHz microwave furnace and surrounded with alumina insulation. The furnace chamber was filled with nitrogen. The tiles were heated at a rate of 18°C/minute to 2100°C, held for one hour, and then cooled to room temperature at a rate of 20°C/minute. Hydroscopic density measurements were made on the baseline tiles as well as the post-annealed tiles. Density measurements were also made on five of the post-processed tiles prior to the annealing operation.

Acoustic material properties were determined for each tile using ultrasonic velocity measurements at 5 MHz. Through-transmission longitudinal and shear velocities were recorded at five locations on each tile. A total of three velocity measurements were taken at each location. A scan of the acoustic attenuation across each tile was made using through-transmission and pulse-echo inspections at 10 MHz.

RESULTS AND DISCUSSION

Hydroscopic Density Results

Among the tiles tested, there was no significant change in the density values associated with the microwave annealing process. However, the individual mass of the tiles was reduced an average of 1.26 grams during annealing. This weight reduction was likely caused by surface oxidation and subsequent vaporization.

Acoustic Inspection

Visual observations of the tile surfaces showed that they were discolored and roughened after the annealing operation. The through-transmission inspection indicated a uniform transmitted amplitude for the four untreated tiles, while the microwave-annealed tiles showed a wide range of variation in attenuation. A pulse-echo scan showed that attenuation seen from one surface was not seen on the other side. This indicates that the nonuniform attenuation observed in the annealed tiles is actually a surface effect and often corresponded to the visual appearance. The surface degradation was likely caused by the vaporization of a microscopic surface layer of silica, which is present on all SiC bodies. Because the dielectric properties of silica (SiO_4) and silicon carbide are different, the microwave energy would have been concentrated on the surface at the SiC/SiO_4 interface. In addition, the annealing temperature (2100°C) approaches the vaporizing temperature of silica. The exposed tile surface could then react with any residual oxygen present in the chamber atmosphere to recreate the surface layer of silica, which would then be subsequently vaporized. This process of oxidation and vaporization would remove material from the tile surface causing a significant reduction in the mass. The loss in weight plus the observed surface degradation following the annealing operation verify this assumption.

Acoustic Properties

The tiles which were microwave-annealed were found to have statistically higher acoustic velocities, impedances, and moduli than the four unannealed tiles. The ultrasonic velocity measurements for each tile are plotted in Figure 1, which shows substantially higher velocities for the annealed tiles in both longitudinal and shear directions. Similiarly, the corresponding impedances (Figure 2) and moduli (Figure 3) were also higher for the annealed condition than for the unannealed state. Although Figures 1, 2, and 3 show a wider distribution of properties for the annealed tiles, the standard deviations (as depicted by the error bars) show that the increased values are statistically valid.

Investigations to determine the cause for the enhanced property values have not yet begun. However, recent unpublished research [6] involving alumina and silicon nitride bodies points to microstructural changes and impurity reductions associated with microwave treatments.

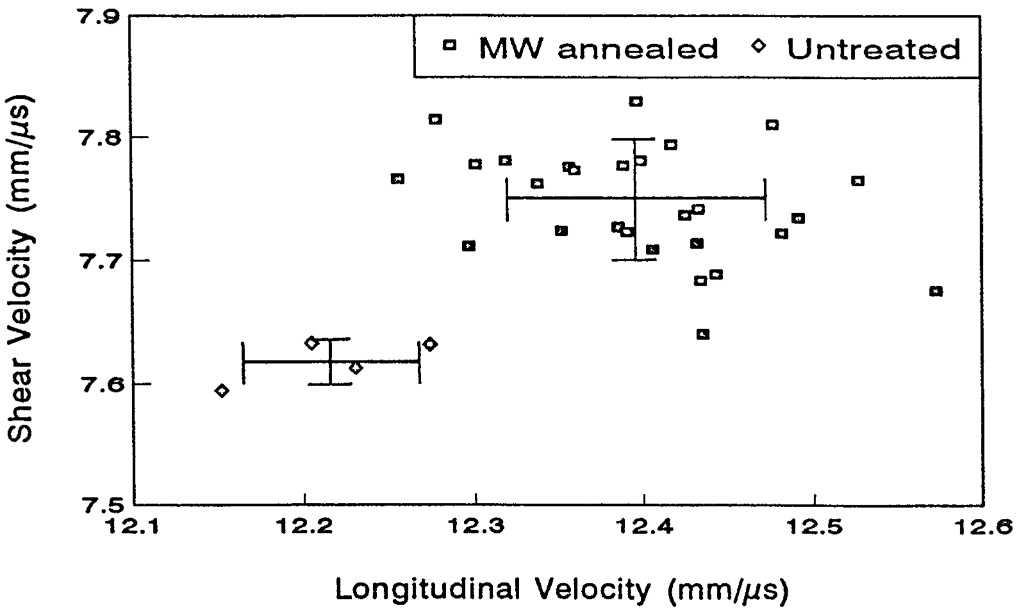

Figure 1. Longitudinal and shear velocities for the SiC tiles.

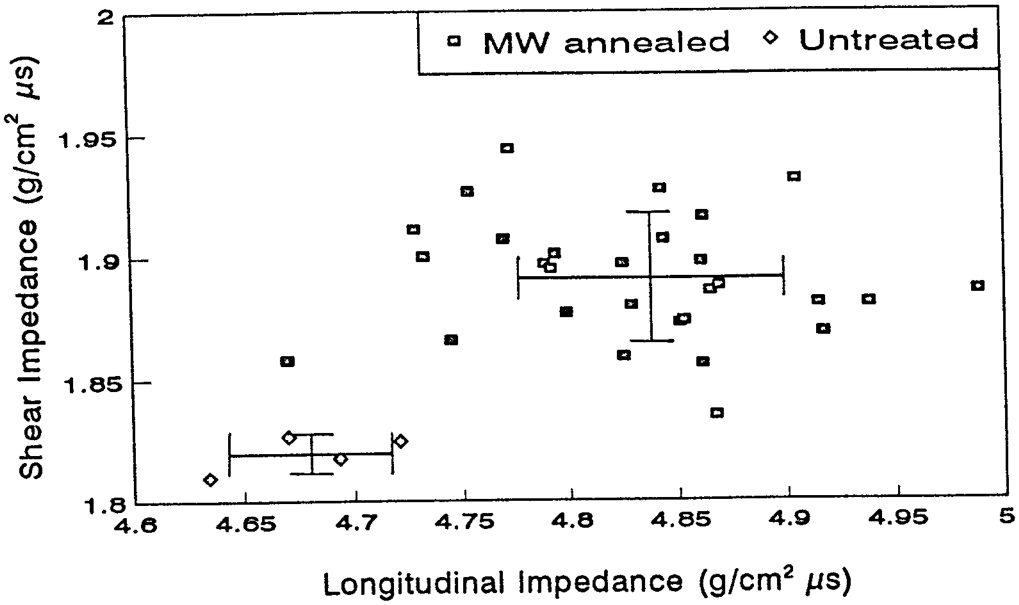

Figure 2. Longitudinal and shear impedances for the SiC tiles.

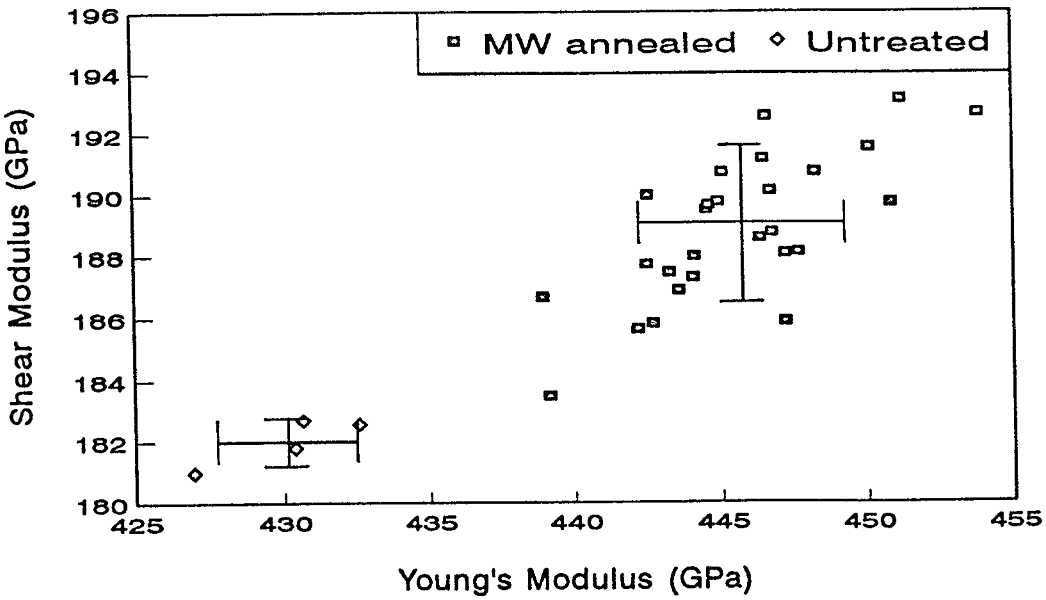

Figure 3. Young's and shear moduli for the SiC tiles.

CONCLUSIONS

1. The acoustic velocities, impedances, and moduli were statistically higher for silicon carbide tiles annealed at 2100°C using microwave radiation than for those which were unannealed.

2. The SiC tiles which were annealed at 2100°C experienced a significant weight loss and suffered surface degradation which could be seen using acoustic imaging techniques.

REFERENCES

[1] Viechnicki, D.J., et al, "Development and Current Status of Armor Ceramics," Bull. Am. Ceram. Soc., 6, 1035-1039 (1991).

[2] Rugger, G.R., "Materials for Armor," presented at the 12th National Symposium, (1992).

[3] Rupert, N.L., and Schoon, R.J., "Evaluation of High-density Ceramics for Ballistic Applications," Dynamic Loading in Manufacturing and Service, February (1993).

[4] Hauver, G.E., et al, "Variation of Target Resistance During Long-rod Penetration into Ceramics," presented at the 13th International Symposium on Ballistics, June (1992).

[5] Ahmad, I., et al, "Microwave Joining of Dissimiliar SiC Ceramics," Ceram. Trans., 36, 409-415 (1993).

[6] Tiegs, T.L., personal communication, February (1994).