Properties of a compliant ceramic layer

In structural high-temperature ceramics, such as silicon carbide, used in load bearing applications localized high stress and interface reactions at the contract points between hot metallic and ceramic parts of the strucutre must be avoided. Failure to do this can lead to premature material degradation either by chemical attack and/or mechanical effects. Compliant layers provide a means of avoiding these problems. The compliant material crushes at a threshold compressive stress determined by the microstructure and thus redistributes the load over a more extensive bearing surface. This increase in compliance and decrease of strength results in enhanced "machinability" relative to the base material. This allows contacting surfaces to be geometrically mated by lapping or grinding. The compliant layers also tend to provide some thermal insulation while local tailoring of these materials (base material and compliant layer) can be employed [1]. Although interfacial metal/ceramic reactions are not completely eliminated by the use of a compliant layer, they are reduced because the amount of free silicon is reduced [2].

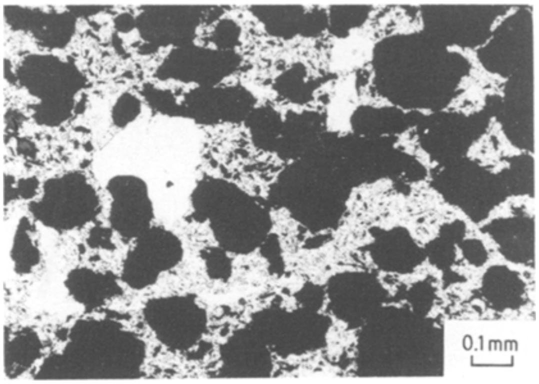


Figure 1 Photomicrograph of a 50 vol% BN compliant layer. Dark areas are BN, white areas Si and grey areas SiC.

Following a brief description of a compliant material,* the properties of the material will be discussed. These properties include density, elastic modulus, strength, impact resistance and erosion resistance. Also, the deformation characteristics of the material under monotonic, cyclic and constant loading at room temperature and 1200° C will be presented.

A photomicrograph of the compliant material is shown in Fig. 1. It consists of 40 mesh hexagonal boron nitride (BN) and 600 mesh SiC incorporated into a matrix of Si/SiC [3]. The BN content can be varied from zero to about 60 vol%, leading to a series of materials ranging from fairly strong but brittle Si/SiC to a soft compliant series of materials capable of preventing impact damage either by high velocity projectiles or vibration-induced

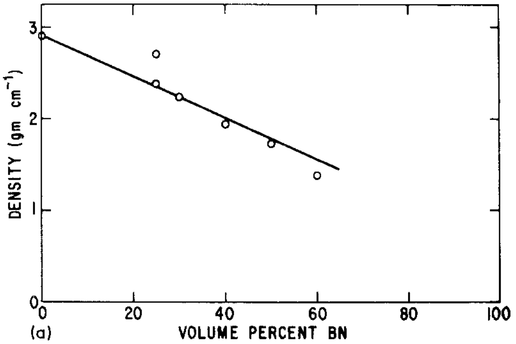
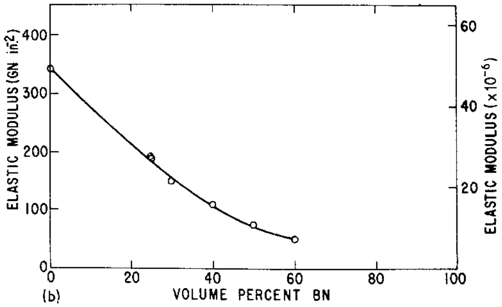
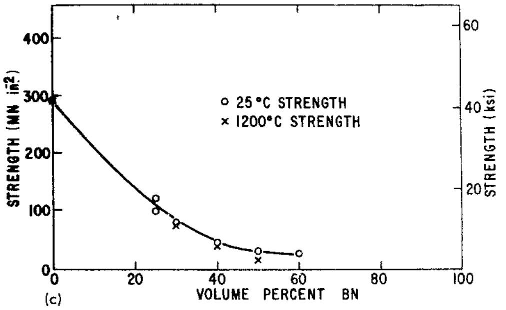


Figure 2 (a) Density of compliant material as a function of BN content, (b) elastic modulus of compliant material as a function of BN content and (c) strength of compliant material as a function of BN content.





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*Developed at the General Electric Research and Development Centre.

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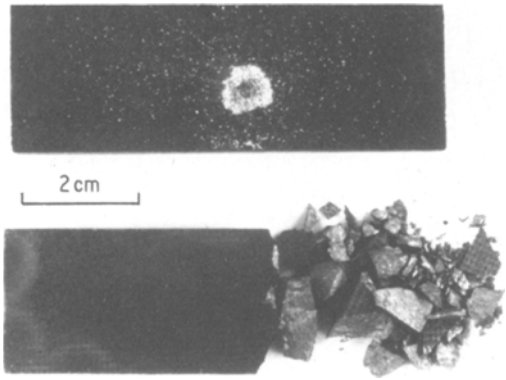

Figure 3 Si/SiC with and without a compliant layer after a projectile impact.

"chattering" at contact points. Some properties of this material are summarized in Fig. 2 as a function of the BN volume fraction. Fig. 2a shows the density decrease as a function of volume fraction BN, and Fig. 2b and c shows elastic modulus and strength, respectively, as a function of BN content. The elastic modulus was measured by a sonic technique* and the strength was measured in 3-point bending over a 25.4 mm span. The specimen size was 2.5 mm × 2.5 mm and the loading rate was 0.125 mm min^{-1}. The decrease in elastic modulus and strength is due to the addition of the low modulus, weaker second phase (BN).

The compliant material was initially developed as an impact absorbing layer on Si/SiC. The effectiveness of such a layer in preventing failure from projectile impact is illustrated in Fig. 3. The top bar was 7.6 mm thick with a 2.5 mm thick 50 vol % BN/Si/SiC layer; the bottom was not protected by a layer. Both specimens were subject to impact by a 4.52 mm diameter steel ball travelling at 162 m sec^{-1}. The protective layer prevented failure and any crack propagation, while the unprotected specimen failed in a catastrophic manner. With increasing BN content, the resistance to impact increases. This is shown in two photographs, Fig. 4a and b, which are sections through impact craters formed after the specimens were struck by a steel ball travelling at the same velocity. The tendency for cracking as the BN content is reduced may be noted. The BN/Si/SiC layer has also been used on experimental ceramic shrouds as a blade-tip seal and in a stacked ring combustor as a compliant layer at ceramic/ceramic and ceramic/metal interfaces [1].

With increasing BN content, the compliance and impact absorbing ability of the material increases. However, in certain applications such as turbine tip seals, erosion resistance from airborne particulates decreases with increasing BN content. Clearly, in these applications there must be a balance between compliance and erosion resistance. To evaluate the erosion resistance of this family of materials, a series of specimens were subjected to erosion by 50 μm Al_2O_3 from a sand blast gun

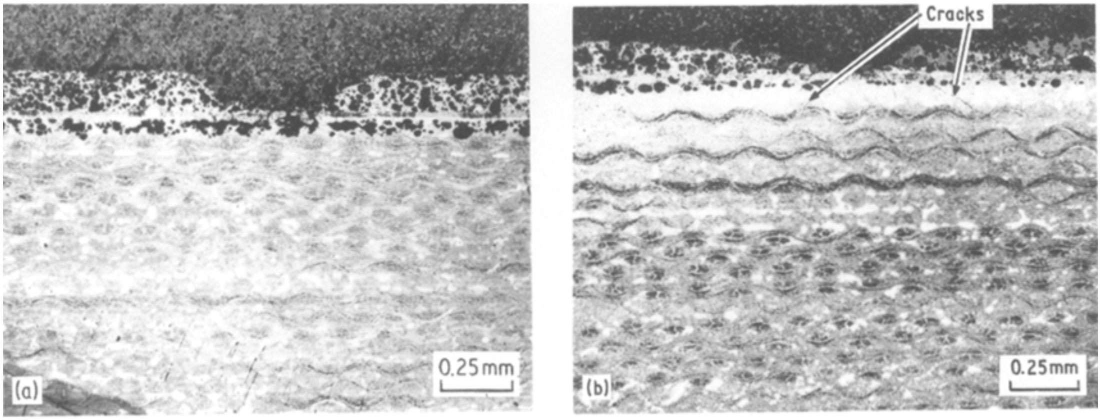

Figure 4 (a) Cross-section through impact crater of 30 vol % BN layer and (b) cross-section through impact crater of 25 vol % BN layer. Note small cracks emanating from crater.

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*Panametrics Intervalometer, Model 5054.

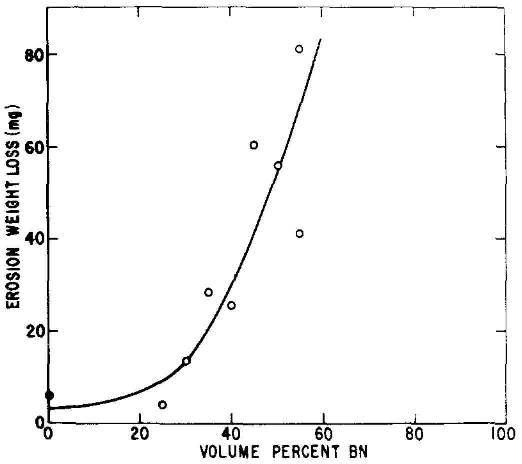

Figure 5 Erosion resistance of compliant material as a function of BN content.

operating at 207 kN m^{-2} for 45 sec through a distance of 12.7 mm. The erosion behaviour, expressed as a weight loss, is shown in Fig. 5. As expected, increasing the content of the softer BN material leads to increasing weight loss.

Deformation characteristics of a 50 vol % BN layer were also studied by applying a compressive load with a SiC rod with a hemispherical end (Fig. 6). Tests at both room temperature and 1200° C show a factor of 7 increase in compliance when compared to SiC. The smooth nature of the load–displacement behaviour at 1200° C is probably due to plastic flow of silicon in the compliant material [4]. Cyclic behaviour of the compliant layer was studied at 1200° C. In this test, the load was decreased to 0.222 kN at various load levels and reapplied for 25 cycles. The compliant nature is retained during the monotonic loading but the stiffness is about 5 times greater than the cyclic loading. For the cyclic loading at 1200° C the deformation behaviour can be described by a power law as shown in Fig. 7. At room temperature the cyclic deformation could also be described by a power law having the same exponent. Following the cyclic loading, the load was held constant at 2.22 kN. At this load at 1200° C the steady-state displacement rate seemed to be constant following a transient response (Fig. 8). At room temperature no additional displacement with time at constant load was detected. Thus, the cyclic behaviour seems to be progressive cyclic deformation at both

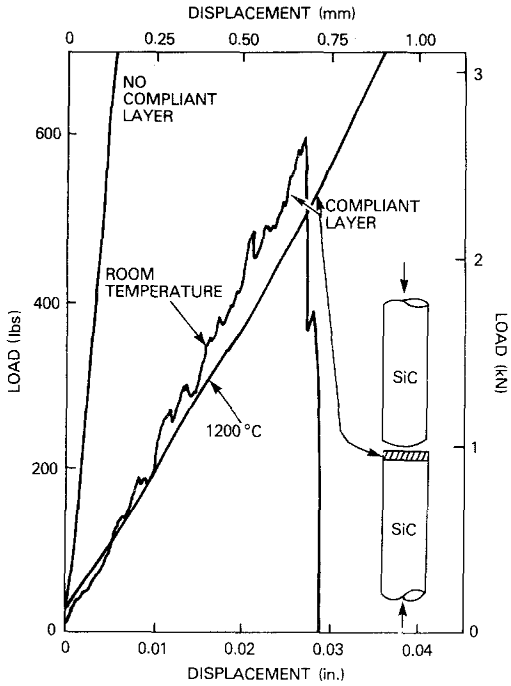

Figure 6 Stiffness of compliant material at room temperature and 1200° C.

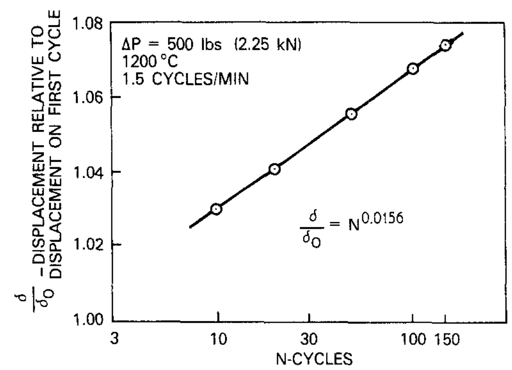

Figure 7 Cyclic deformation of compliant material.

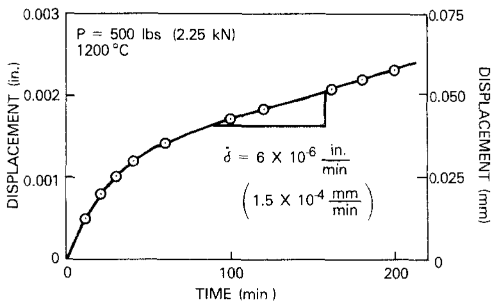

Figure 8 Deformation under constant load.

1200° C and room temperature, while the behaviour at constant load seems to be due to a creep deformation mechanism that exists only at high temperatures.

It may be seen from the experimental data that the BN/Si/SiC compliant material is effective in relieving localized high stresses and providing impact resistance. With these data on impact resistance and erosion resistance, a balance can be obtained between impact and erosion resistance for a particular application. The information on strength and deformation characteristics for monotonic, cyclic and constant loading is needed to design compliant attachments which are necessary in the structural application of silicon carbide ceramic materials.

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R. L. MEHAN
G. G. TRANTINA
C. R. MORELOCK
*General Electric Company,
Corporate Research and Development,
Schenectady, New York,
USA*

Shrinkage as a measure of the deformation efficiency of ultra-oriented high density polyethylene: Authors' addition

It is proposed, with this letter, to offer a set of short additions to an earlier paper, of the same title, [1] that may be of aid to the reader.

In [1], the headings for Table I were omitted. They should read, from left to right, "Sample", "Extrusion temperature (° C)", "Extrusion draw ratio", "Recovery (%)", "Molecular draw ratio", and "Tensile modulus (GPa)"; see also the Erratum, this issue.

The definition previously published for the molecular draw ratio (MDR) requires alteration, see also the Corrigenda, this issue. For perfect elastic recovery in the shrinkage test, the correct equation is

$$\text{MDR} = \frac{\Delta L}{L_0} + 1,$$

where $\Delta L = L_T - L_S$ and L_0 is the length prior to draw, L_T is the total length after draw and L_S is the shrunken length after draw.

There is a systematic set of draw ratios calculable from the die geometry for solid-state extrusion and consequent molecular response:

$$\text{DDR} \geqslant \text{EDR} \geqslant \text{MDR} \geqslant [\Delta L/L_0] + 1,$$

where DDR is the die cross-sectional area ratio, EDR is the extrusion displacement of lines on the sample, MDR is the molecular draw ratio calculated from shrinkage, and $[\Delta L/L_0] + 1$ is the measured elastic recovery on reheating. All calculations assume a constant density during draw with the inequalities above representing measures of the inefficiency for the draw and subsequent recovery processes on reheating, with the latter being the difference between values obtained using the two above methods for calculating the MDR.

Silicone oil is preferred as the heating liquid for shrinkage tests, rather than the glycerol originally

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