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METHOD FOR REINFORCING THREADS IN MULTILAYER COMPOSITE TUBES AND CYLINDRICAL STRUCTURES

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ABSTRACT

Multilayer techniques such as: tape wrapping, braiding, and filament winding represent versatile and economical routes for fabricating composite tubes and cylindrical structures. However, multilayer architectures lack the radial reinforcement required to retain threads when the desired means of connection or closure is a threaded joint. This issue was addressed in the development of a filament wound, carbon-carbon composite impact shell for the NASA radioisotope thermoelectric generator. The problem of poor thread shear strength was solved by incorporating a number of radial elements of triangular geometry around the circumference of the thread for the full length of thread engagement. The radial elements significantly increased the shear strength of the threaded joint by transmitting the applied force to the balance of composite structure. This approach is also applicable to ceramic composites.

INTRODUCTION

The Department of Energy provides radioisotope thermoelectric generators to the National Aeronautics and Space Administration for powering deep space missions to the outer planets. These generators convert the decay heat from encapsulated radioisotope fuel into usable electricity to power a host of scientific instruments. The heat source shown in Fig. 1 is modular in design. Each module consists of a carbon-carbon composite aeroshell and two carbon-carbon composite impact shells that encapsulate four iridium-alloy-clad fuel pellets. This assembly provides thermal isolation and impact protection in the unlikely event of reentry or launch incident.

The ability of the modules to withstand impact without significant fuel clad damage was demonstrated in a series of tests [1] which simulated reentry of the general

purpose heat source modules into earth atmosphere and impact at terminal velocity (55 m/s). Impact tests were conducted on single assemblies using a gas gun to accelerate modules into a hardened steel target. The impact orientation was either face-on or side-on with the longitudinal axis of the impact shell parallel to the impact target in all cases. Post-impact analysis showed that impact shells typically fractured parallel to their longitudinal axis at four locations where fiber bundles intersected at 45° to the circumferential direction. The fuel pellet and cladding deformed during impact. Although the current configuration and material has proven to be adequate, increased margins of impact performance are of interest. A program was undertaken to develop and characterize alternative carbon-carbon composite materials for the impact shell having greater circumferential strength and higher energy absorption [2].

CONFIGURATION AND MATERIALS

The current configuration of the impact shell shown in Fig. 2 is a right circular cylinder having one integral closure and one threaded closure. The impact shell is currently machined from a block of Textron Fine-Weave Pierced-Fabric (FWPF). This material is a high density (1950 kg/m^3), orthogonal carbon-carbon composite produced by piercing two-directional carbon-carbon fabric layers with rigidized carbon-fiber bundles. The FWPF architecture is shown in Fig. 3. The impact shell is machined with its longitudinal axis parallel to the z-direction of the composite. The wall thickness, and thus the distance available for deceleration of the isotopic fuel, is only 4.2 mm for the current configuration. This distance represents only 4 unit cells for FWPF.

The specification of alternative carbon-carbon composite materials for the impact shell was guided by the early experience with the spherical impact shell of the multihundred watt, radioisotope thermoelectric generator [3] where energy absorbed during deceleration of the fuel assembly was shown to be a function of the bulk density, bulk modulus, available crush volume and crush strength. An intermediate density around 400 kg/m^3 above the preform density gave the greatest impact protection. One objective in fabricating alternative materials was to make a crushable structure which would be compacted during impact. The impact shell would then protect the fuel pellet by extending the time and distance over which it came to rest, thus reducing deceleration loads. The only constraint on developing an improved impact shell was to maintain the current geometry.

Although a number of candidate architectures were considered, filament winding demonstrated the greatest flexibility in achieving all the design objectives. Filament wound preforms are shown in Fig. 4 after machining to the final impact shell configuration. Filament winding enabled a variation of architecture through the impact shell wall. The fiber lay-up was nearly circumferential near the inside cylindrical surface to provide required circumferential strength. Fiber lay-up in the outer elements of the impact shell was ±45° to generate a more open architecture capable of crush-up during impact. Filament winding also proved to be uniquely suited to fabricating the integral closure.

THE THREADED CLOSURE PROBLEM

Opposite the integral closure is a threaded closure (end cap) which restrains the impact shell contents. The end cap is fabricated from FWPF. This closure has proven to be adequate for the current configuration and material. The possible advantages of employing a filament wound impact shell would not be realized without addressing the problem of low thread shear strength attendant with this architecture. The impact shell/end cap threaded joint exhibited poor thread shear strength for the filament wound architecture due to the absence of radial reinforcement as illustrated in Fig. 5. Poor thread shear strength is problematic for any multilayer cylindrical architecture where the matrix is significantly weaker than the fibers and interlaminar shear strength is dependent on load transfer to the fibers. The currently specified FWPF material provided periodic reinforcement to the thread.

SOLUTION TO THE THREADED CLOSURE PROBLEM

A unique approach was developed to provide reinforcement to the threads of the filament wound impact shell. Triangular-shaped radial elements were placed at eight equally spaced positions and trapped there during fabrication of the filament wound preform. An illustration of a radially reinforced, impact shell thread is shown in Fig. 6. The radial elements were fabricated from an 86% unidirectional carbon-carbon composite. The novelty of this approach lies in the triangular geometry of the radial keys as shown in Fig. 7. When an outward axial force, F_{AX}, is applied to the thread by the endcap, the axial force is transmitted to the radial element without thread failure due to the high shear strength of the radial fibers. The applied axial force is resolved into axial and circumferential components in the impact shell wall. The axial force is balanced by axial components adjacent to the radial elements. The circumferential force is balanced by a tensile circumferential force component in the composite layers above the radial element and a compressive circumferential force component in the composite layers adjacent to the radial element. Consequently, the radial elements prevent interlaminar failure of the threaded joint by transmitting the applied force to the composite structure in a manner in which the forces can be carried without failure.

THREAD SHEAR TEST RESULTS

A simple mechanical test was devised to test the shear strength of the impact shell thread. A steel endcap engaged in a threaded section of the impact shell body was pushed out until failure was complete. Peak failure loads are shown in Fig. 8. The shear strength of a FWPF thread shear specimen, 3.3 kN, served as a reference value of adequate strength. A conventional cylindrical architecture having fibers oriented in the axial, radial and circumferential directions exhibited only about half the reference strength. Although this architecture provides 10% of total fiber volume in the radial orientation, this relative sparsity of radial reinforcement and the periodic nature of engagement with the thread resulted in an inadequate level of strength.

The filament wound impact shell material was tested with and without radial reinforcement. Since these composites had a phenolic resin matrix, a fraction of the thread shear strength could be attributed to the strength of the matrix. If these preforms had been carbonized, the shear strength contribution of the matrix would have been significantly reduced. The thread shear strength which may be attributed to reinforcement by the triangular radial elements is the difference in strength between the two, 4.2 kN. This value of shear strength is more than adequate for the impact shell.

CONCLUSIONS

- The unique solution described here for reinforcing threads enabled the utilization of a filament wound architecture for the impact shell.
- The thread reinforcement method described here could enable broader application of multilayer architecture, carbon-carbon and ceramic composites for tubes and cylindrical structures where the desired means of connection or closure is a threaded joint.

ACKNOWLEDGEMENT

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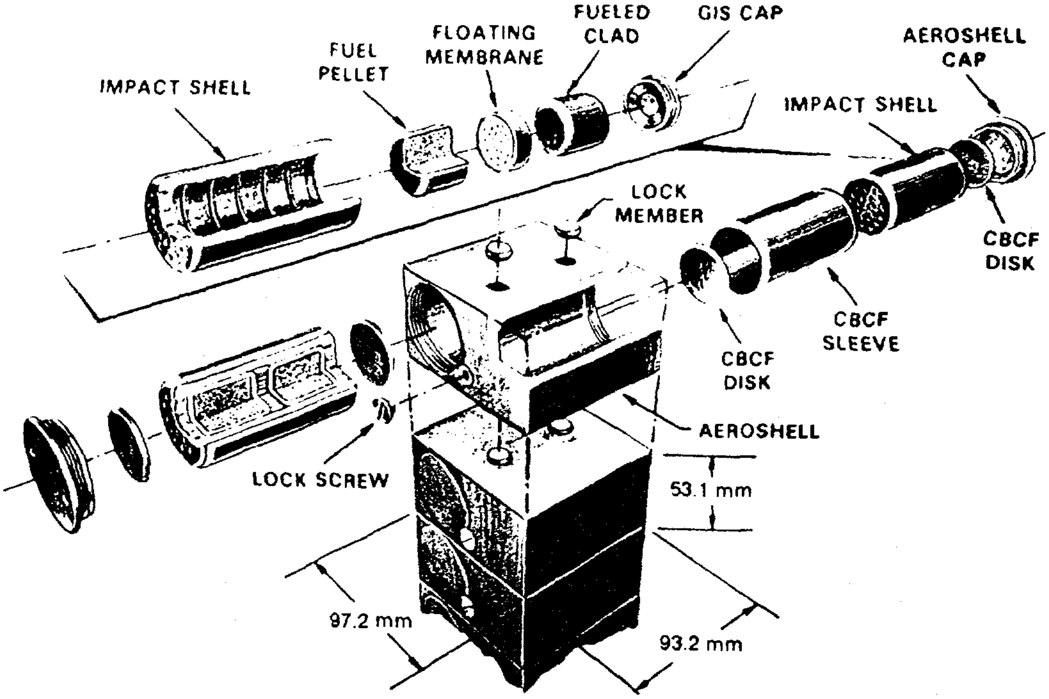


Fig. 1. The General Purpose Heat Source

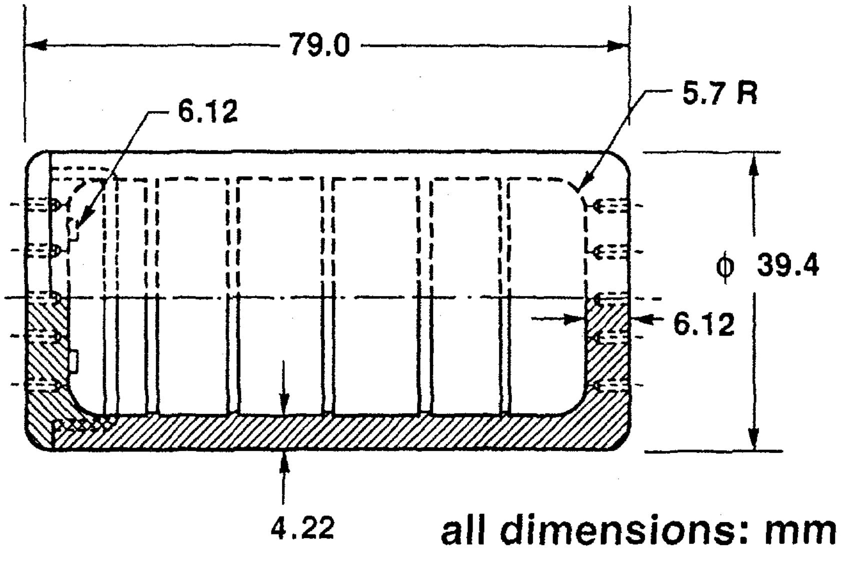


Fig. 2. Current Configuration of the Impact Shell.

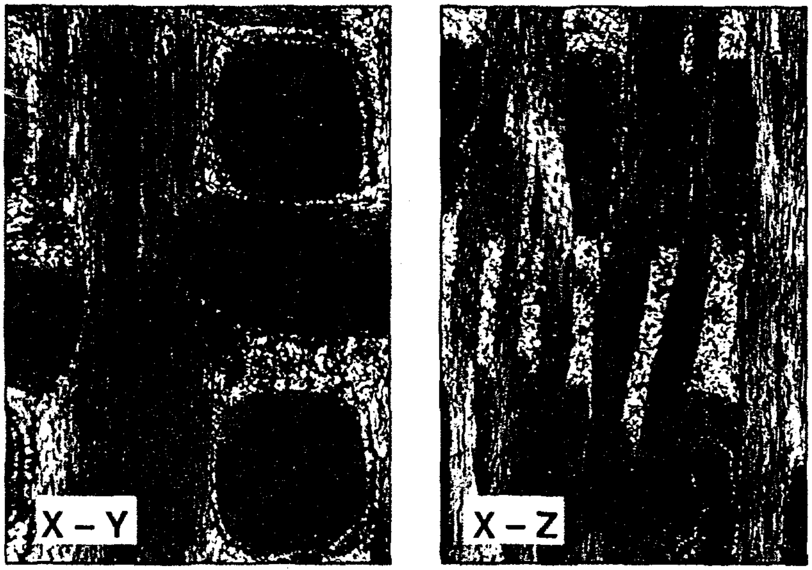


Fig. 3. Fine-Weave Pierced-Fabric Carbon-Carbon Composite.

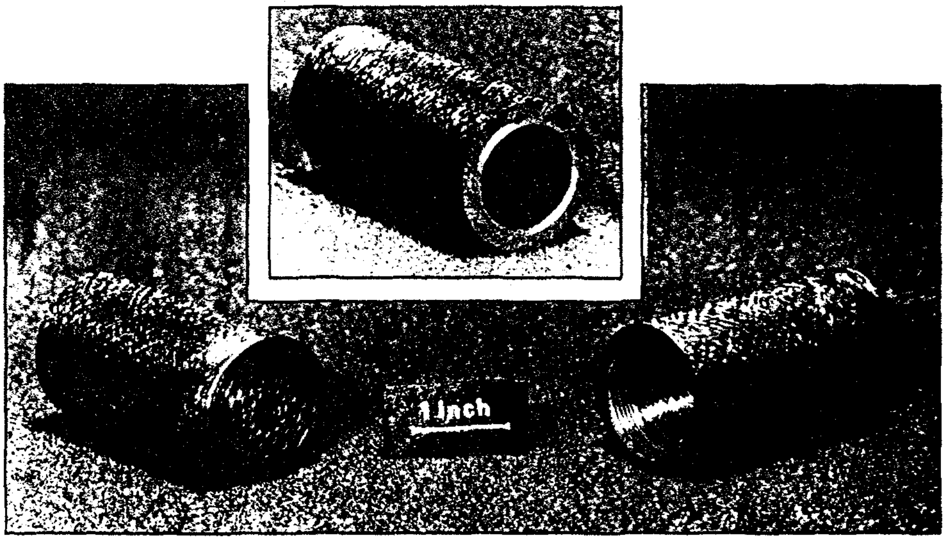


Fig. 4. Filament Wound Preforms After Machining to the Final Impact Shell Configuration.

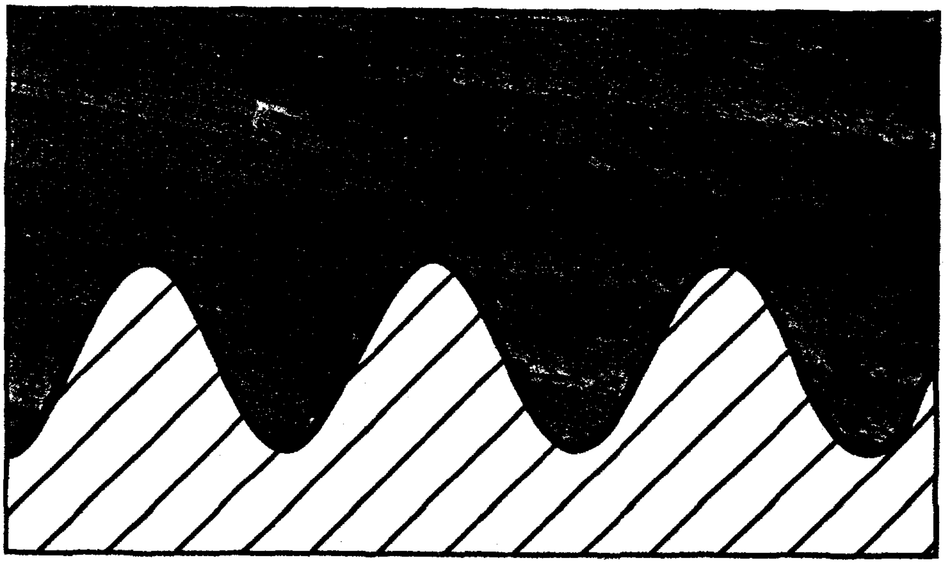


Fig. 5. Illustration of the Impact Shell/End Cap Threaded Joint for a Multilayer, Filament Wound Architecture. Absence of Radial Reinforcement Resulted in Poor Thread Strength.

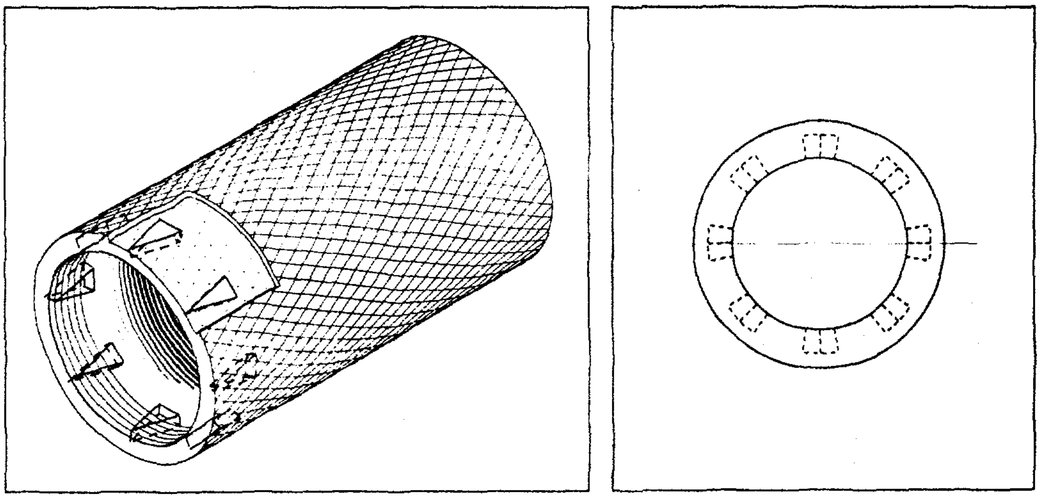


Fig. 6. Illustration of an Impact Shell Thread Reinforced by Eight Triangular Radial Elements.

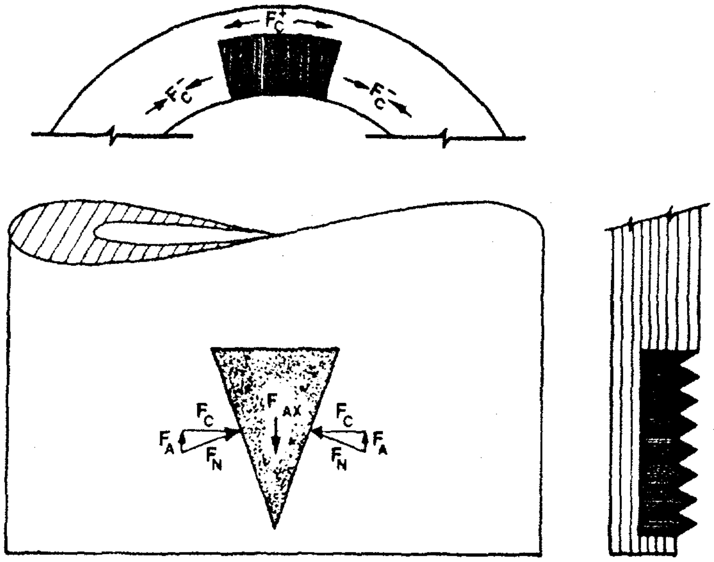


Fig. 7. Triangular Geometry of the Radial Elements Prevents Interlaminar Shear Failure of the Threaded Joint by Transmitting the Applied Force to the Composite Structure in a Manner in Which the Forces can be Carried Without Failure.

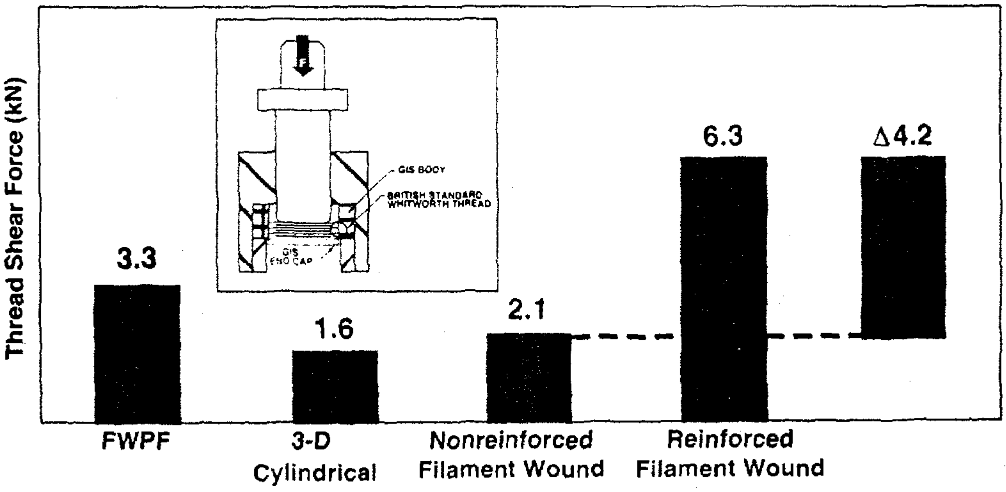
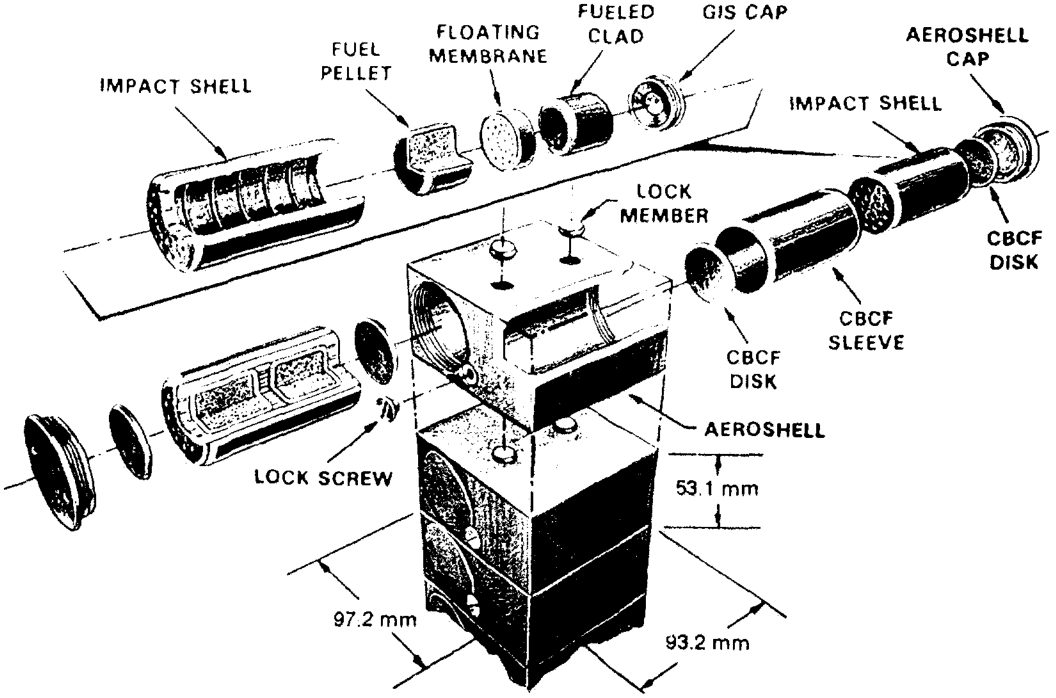


Fig. 8. Peak Load Required to Cause Shear Failure of the Impact Shell Threaded Joint. Δ4.2 kN is the Value of Shear Strength Attributed to Reinforcement by Radial Elements.



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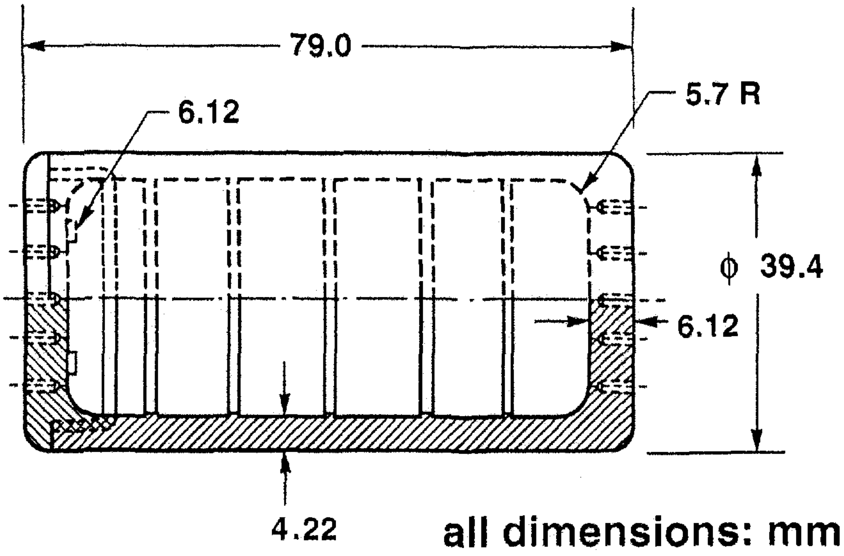

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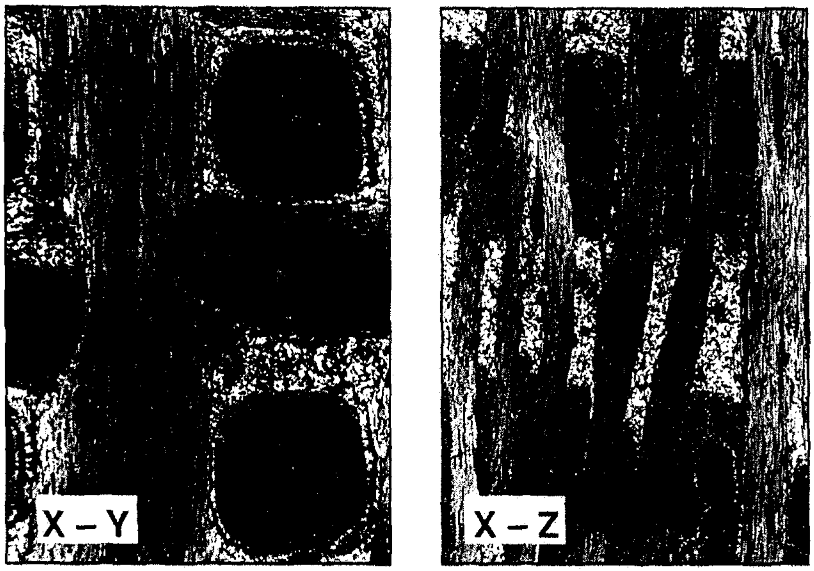
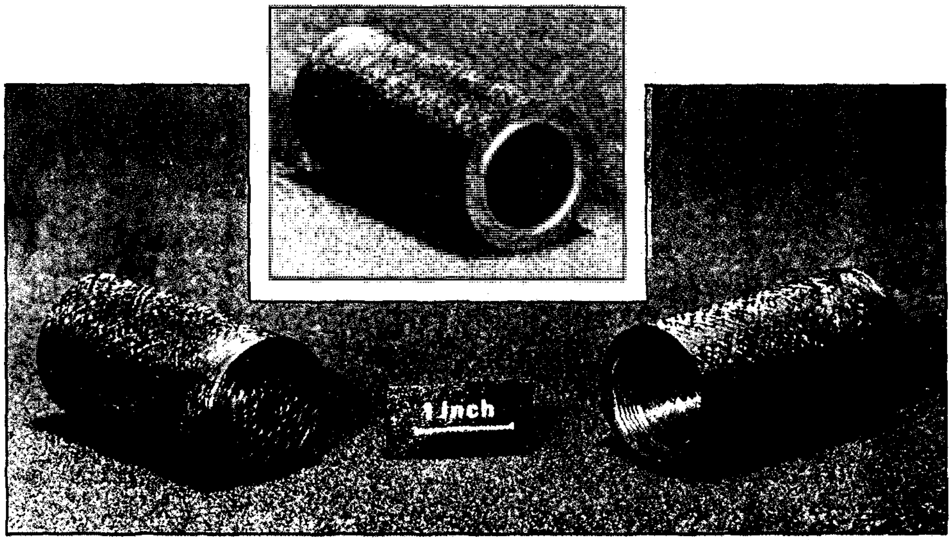


Fig. 3. Fine-Weave Pierced-Fabric Carbon-Carbon Composite.



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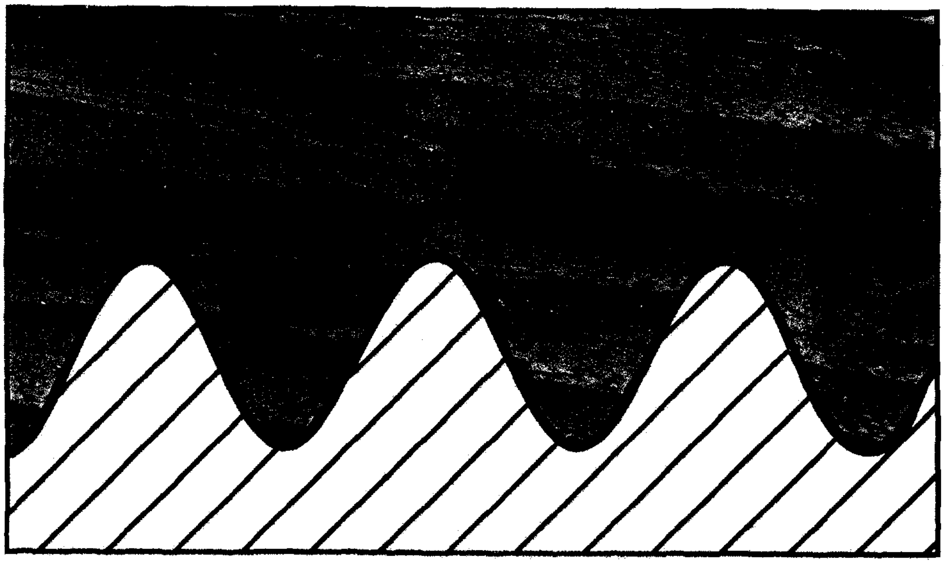

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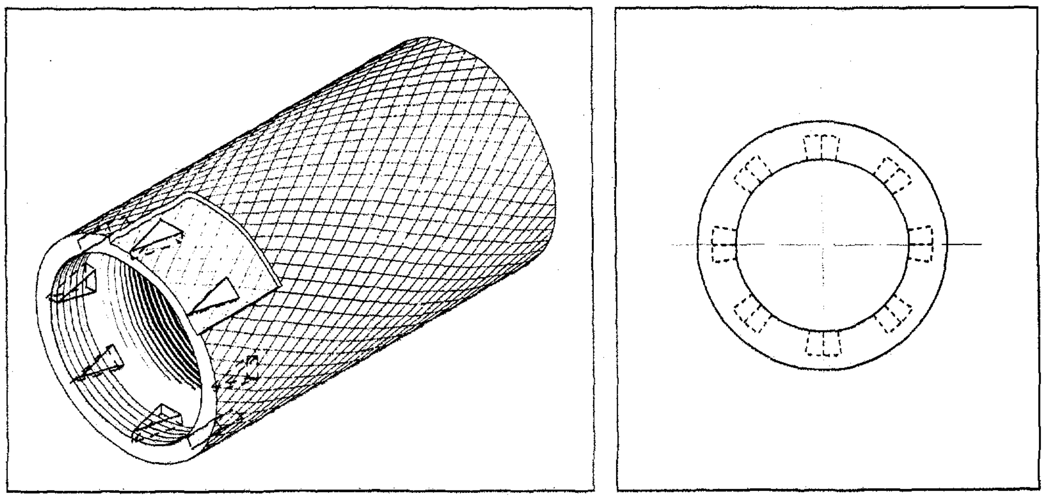

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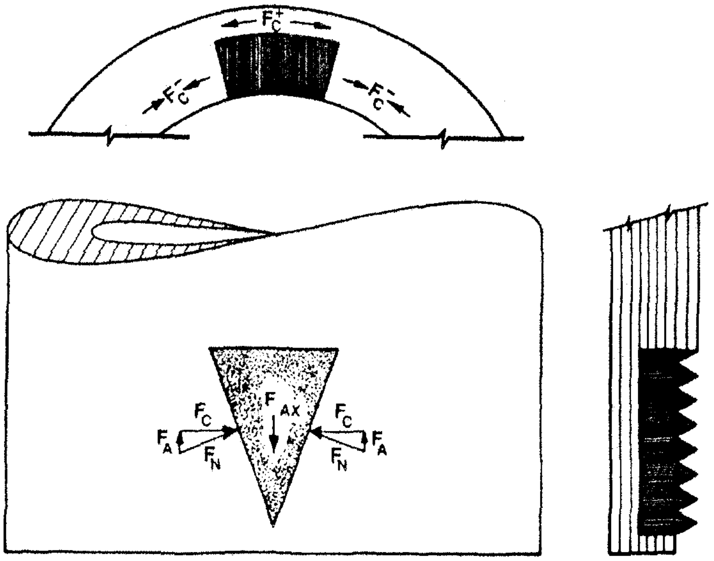

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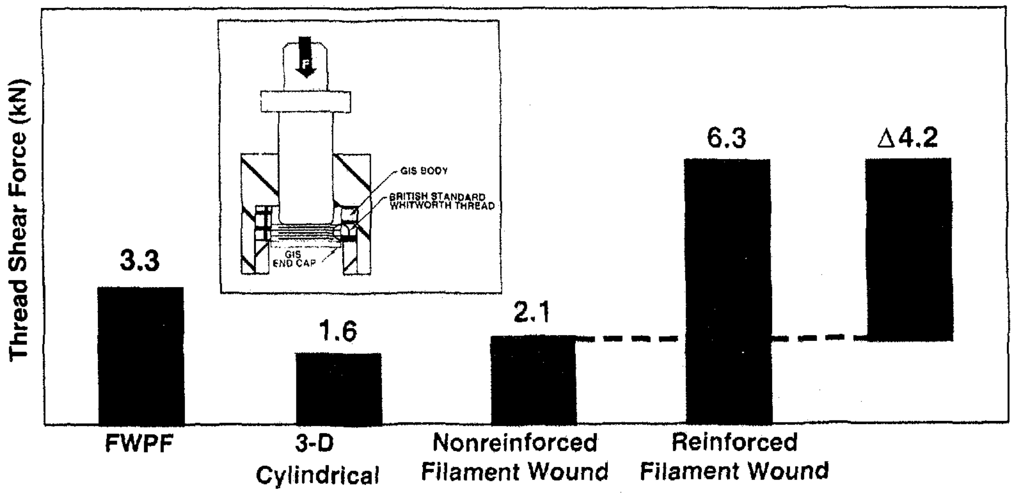

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