Thermal Effects of an Advanced Wire Mesh Packaging Material*

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INTRODUCTION

In order to be certified for transportation of radioactive materials, a container must be able to withstand a series of rigorous structural and thermal tests. Typical materials used in the construction of radioactive material transportation containers include stainless steel, mild steel, Cellotex and organic foams. This paper presents the thermal characteristics of an advanced composite material for use in radioactive material transportation containers. Experimental and analytical methods were used to characterize the advanced packaging material.

The composite material is made up of layers of aluminum wire mesh and insulating material. Laboratory results indicate that the wire mesh thermal conductivity is highly anisotropic. In- and out-of-plane wire mesh thermal conductivity differ by an order of magnitude, with the in-plane thermal conductivity higher than the out-of-plane thermal conductivity.

A test package was built consisting of a stainless steel outer shell, an overpack made of the advanced composite packaging material and a stainless steel containment vessel. The package was 99 cm (39 inches) long and had a diameter of 46 cm (18 inches). A steady state experiment and a transient experiment performed at the Sandia National Laboratories Radiant Heat Test Facility were conducted to characterize the packaging material. A heat source of 20 watts was included in the package to simulate the payload. The package was instrumented with type K thermocouples, and temperatures were recorded during the test.

The transient test results also show that the packaging material is a viable alternative to materials typically used in construction of radioactive material transportation containers. The seal temperatures did not exceed the maximum operating temperature of elastomeric materials. There was some localized melting of the overpack with an average depth of 6 mm (0.25 in) from the inside surface of the outer shell. The melting may help the fire resistance of the package in that the melt zone provided a constant temperature boundary condition. In addition, oxidation on the outer layers of wire mesh contributed to the fire resistance of the package.

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A thermal model was developed for a specific package incorporating the composite packaging material as an overpack. The model was used in analyses of normal transport and accident condition. The model results correlated well with the experimental data.

The experimental and analytical results show that the wire mesh composite material is a viable packaging material for use in construction of radioactive material transportation containers. A significant advantage of the wire mesh package technology is that even with tears in the outer skin, no additional heat load is presented to the containment vessel as would be experienced if combustible materials were used.

THERMAL TESTING

A steady state and a transient thermal test were performed in order to characterize the wire mesh material in a package configuration. A prototype design for a lightweight radioactive material transportation container was used for the thermal evaluation of the composite material. The design consisted of three concentric cylinders. The innermost cylinder is the inner containment vessel, the middle cylinder is the outer containment vessel, and the outer cylinder is the overpack. The containment vessel was made of stainless steel. Elastomeric O-rings were used for the seal.

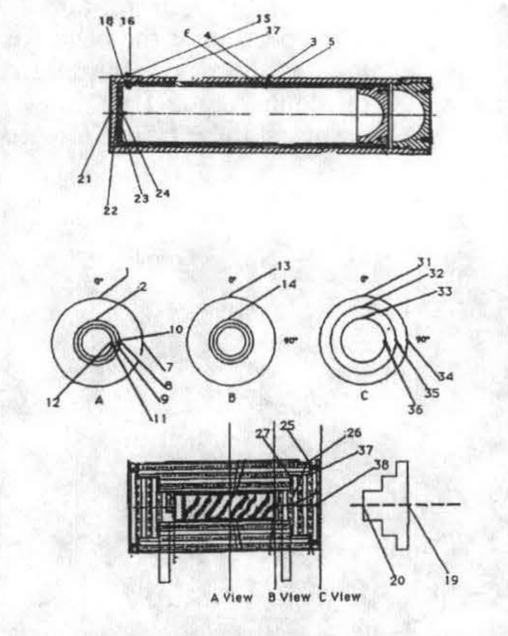

Figure 1. Package and thermocouple locations

The package was tested with a 20 watt heat source in the horizontal orientation for the steady state test. The horizontal orientation is the worst orientation for natural convection heat transfer from a cylinder. Therefore, the horizontal orientation should produce the highest internal temperatures.

The instrumentation used in the normal transport thermal test consisted of type K thermocouples, a data logger, and a computer. Figure 1 presents the locations of the thermocouples in the composite material transportation package. The heat source was monitored with a voltage and a current meter. Temperatures were recorded for 73 hours.

The transient test was performed at Sandia National Laboratories Radiant Heat Facility. The test was performed in order to determine package response in a high temperature environment. Figure 2 presents the package during the transient test. The package was exposed to a temperature of 1000°C for a period of 30 minutes. The test conditions exceeded the regulatory environment and were designed to show the durability of the packaging material.

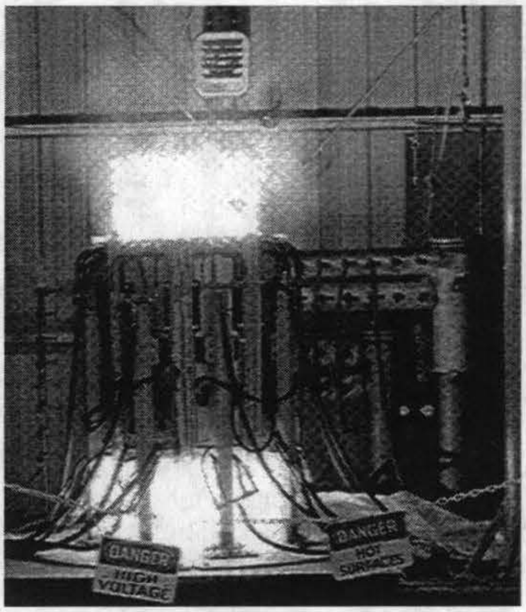

Figure 2. Accident Condition Thermal Test

The package was in a vertical orientation during the transient test. Prior to locating the package on the test pad, a pretest thermal soak was performed. The thermal soak consisted of heating the interior of the package with a 20 watt heat source and monitoring thermocouples until the package reached a quasi-steady state condition. After the package was located on the test pad, the 20 watt heat source was reapplied to maintain the quasi-steady state condition. The instrumentation used in the transient test was the same as used in the steady state test.

POSTTEST EVALUATION

A posttest visual inspection was performed on the composite material transportation package. A visual inspection of the package on the test pad revealed pieces of aluminum around the base of the package. The aluminum was presumed to be from the wire

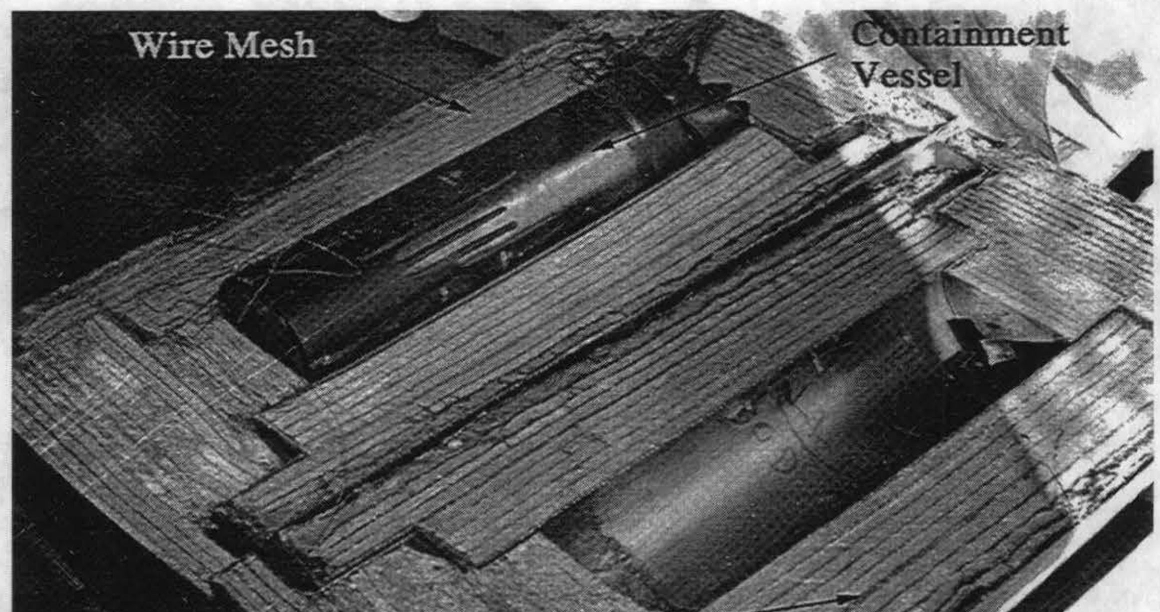

Figure 3. Posttest Package Evaluation

mesh in the package.

The package was cut in half to inspect the interior. Figure 3 is a view of the package after the cut. Figure 4 shows a detail of the lid/side region of the package. The inspection revealed that the aluminum mesh had melted along the outer edge of the package. The average depth of the melt was approximately 6 mm (0.25 in). Some of the damage seen in Figure 4 is from the cutting process. In the lid/side region, melting occurred along the stairstep edge. The melting is probably due to heat conduction via the stainless steel outer skin. In addition, the darkened areas indicate there was oxidation of the wire. The oxide is more durable in high temperature environments than aluminum, so the oxidation actually increases the durability of the wire mesh in high temperature environments.

THERMAL MODEL

A thermal model of the package was also developed for evaluating wire mesh thermal response with various thermal boundary conditions. The model was developed using PATRAN and P/THERMAL. PATRAN was used for the pre- and postprocessing and P/THERMAL was the thermal equation solver. The model consisted of 31091 nodes and 30753 elements. Figure 5 is a schematic of the thermal model.

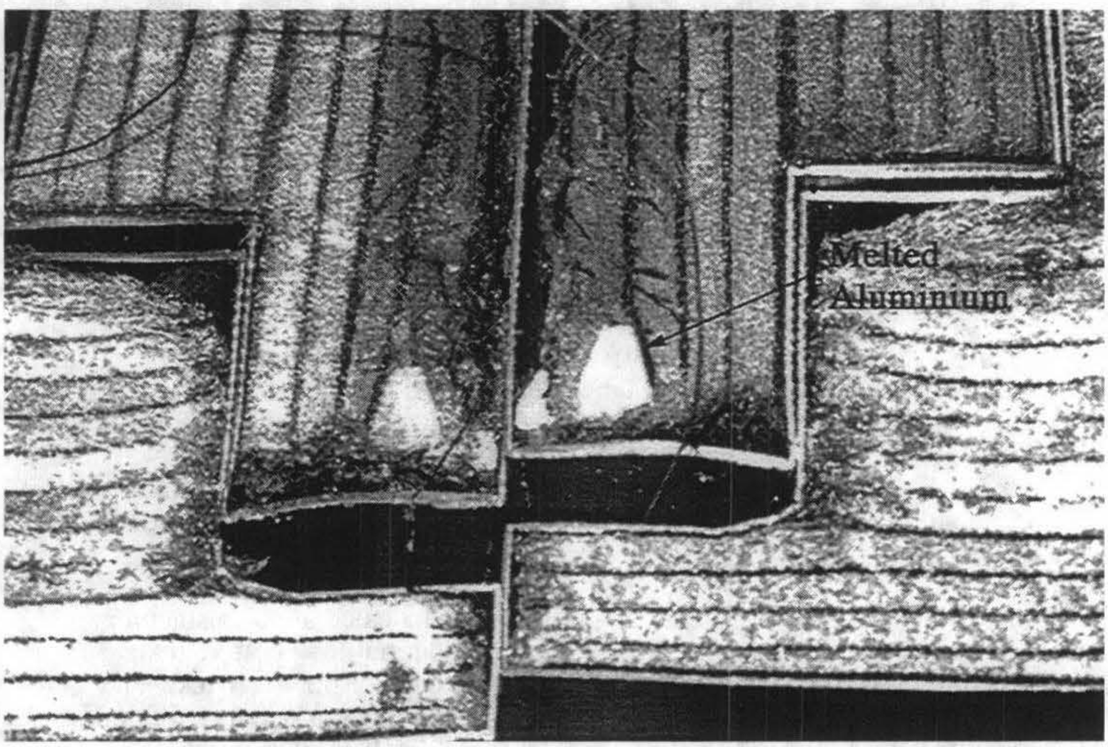

Figure 4. Posttest Package Evaluation Detail

The thermal conductivity of the composite material is highly anisotropic due to the aluminum wire mesh. The in-plane thermal conductivity of the composite material is an order of magnitude greater than the out-of-plane thermal conductivity. The wire mesh anisotropic material properties were included in the thermal model. Melting of the aluminum mesh was also included.

The thermal model was used to calculate thermal response of the package during regulatory normal transport and accident conditions. The thermal model was also benchmarked against both the steady state and transient thermal tests.

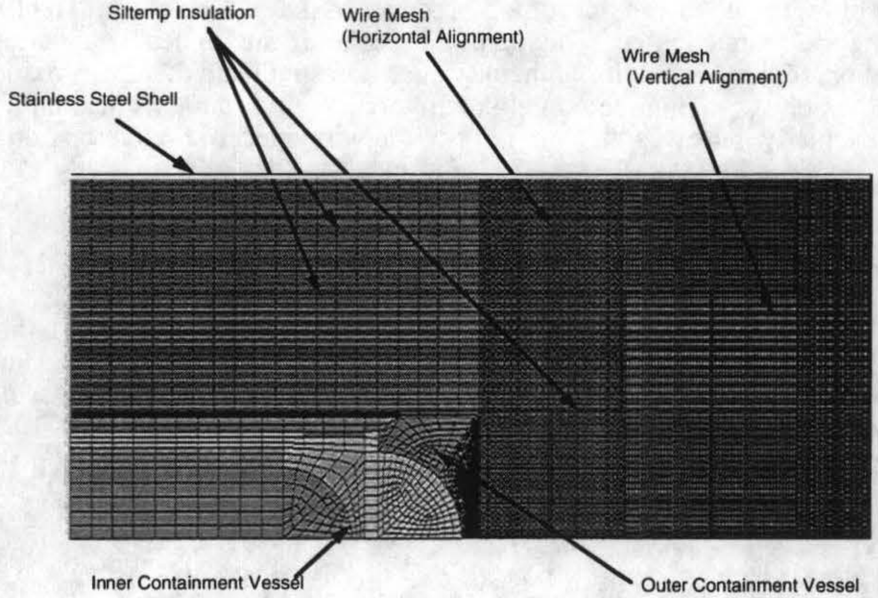

Figure 5. Thermal Model

RESULTS

Figures 6 and 7 present a comparison between the model calculations and the steady state and transient test data, respectively. Figure 6 shows that the model calculations for the steady state condition compare favorably to the steady state test data. The maximum temperature difference between the steady state test and the thermal model was 7°C. Differences in the temperatures can be attributed to the slightly different starting temperature and to variations in the convective coefficient and ambient temperature during the steady state test.

Figure 7 shows that for the transient condition the model calculations also compare favorably to the transient test data. Differences in the initial temperature increase are most likely due to the melting occurring on the outer edge of the overpack. The temperature difference between the transient test data and the model calculations at the peak temperature was only 10°C. The small temperature difference at the peak temperatures shows a good correlation between the transient test data and the model calculations.

Figure 7 also shows that the seal region did not attain a temperature which could cause a seal failure. Elastomeric seals can be made to withstand temperatures over 200 °C for short durations, while the seal area temperature during the test did not exceed 170° C.

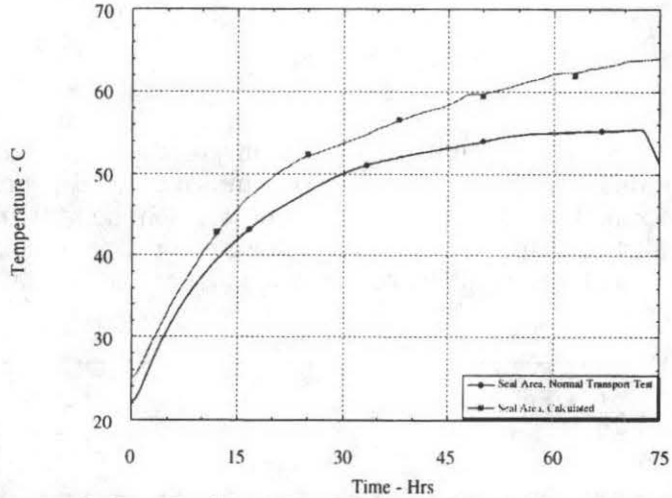

Figure 6. Steady State Package Temperature Comparison

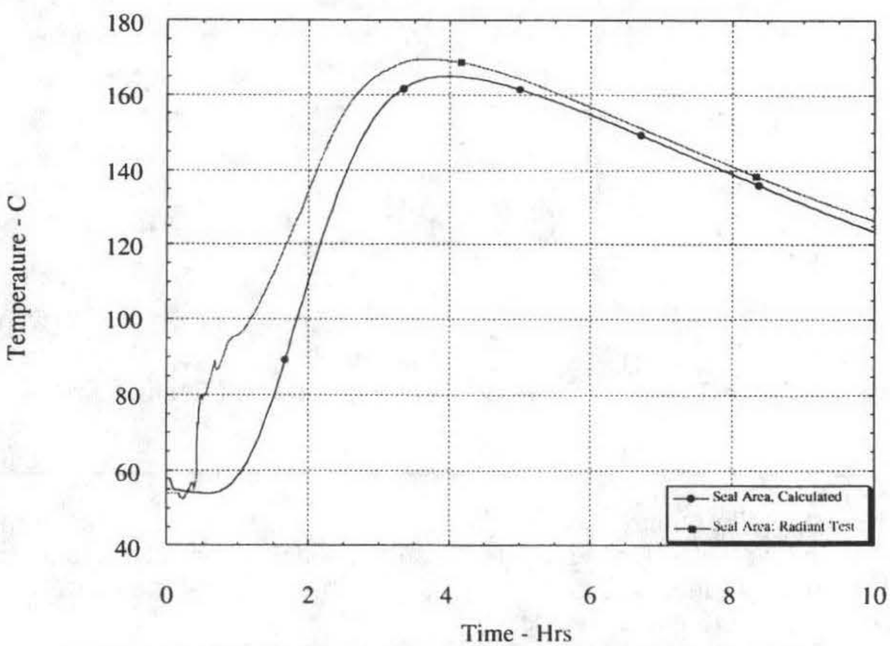

Figure 7. Accident Condition Temperature Comparison

Figure 8 presents the model thermal response for a regulatory accident thermal environment. The calculations show that the seal area does not exceed the maximum operating temperature for an elastomeric seal. Figure 8 also shows that the model includes material phase change, as evident by the temperature stepping occurring at the package surface.

CONCLUSIONS

The wire mesh material is an excellent radioactive transportation package material, with respect to the material thermal response. The tests demonstrate that the material thermal response is adequate for both the normal transport and accident conditions. Factors that make the material a robust transportation package material include the material anisotropic thermal conductivity and the phase change and oxidation that occurs in high temperature environments.

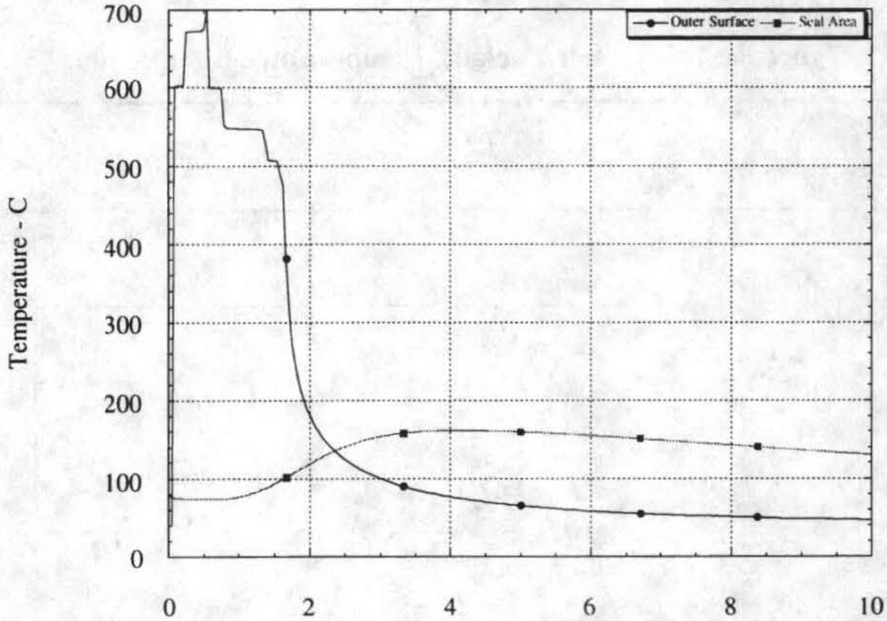

Figure 8. Package Thermal Response to a Regulatory Thermal Environment

A thermal model was built and benchmarked against test data. The results of the benchmark show that the material properties can be modeled correctly in a thermal analysis. The ability to model the material and determine the material thermal response is very important for future package design.

The package seal area did not exceed 200°C, which means that the package would probably survive the thermal test in the certification process.

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