COMPOSITES 2006 Convention and Trade Show
American Composites Manufacturers Association
October 18-20, 2006
St. Louis, MO USA

Thermal Conductivity of FyreRoc Systems

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ABSTRACT:

FyreRoc Material Systems are used in many applications utilizing the material's high temperature properties. In most of these applications metal and/or a high temperature insulation is being displaced by the FyreRoc system for a variety of reasons ranging from weight to thermal behavior. The insulating properties of FyreRoc and the capability of building insulating constructions is one of the important characteristics allowing FyreRoc to compete against the presently available high temperature systems. To demonstrate the advantage of the FyreRoc's as an insulation system, requires being able to measure the thermal conductivity at elevated temperatures for various laminates and sandwich constructions. These thermal conductivity values for FyreRoc systems will then allow for the engineering of the cold side temperatures and thus optimization of thickness and weight for applications such as bulkheads, engine compartments and firewalls. This paper will report thermal conductivity data on the various constructions and laminates along with retention of strength for these systems after high temperature exposures. Discussion of these results and how they compare with present systems will also be included.

INTRODUCTION:

Thermal Conductivity is considered an important property for most thermal barriers, especially when the exposure is to high temperatures (excess of 500 C). Inorganic composite material systems represent a new material capable of withstanding high temperatures and thus opening opportunities that were not possible with organic composite systems. High temperature components such as exhaust washed parts, ablative liners and high temperature processing equipment are a few examples of applications where the component is exposed to temperatures too high for organics but not for the new inorganic composite systems. Fire barriers, an off shoot of thermal barriers, which are exposed to high temperature only during a fire also need to be good thermal barriers to meet fire requirement specified in many of the E-119 and UL-1709 fire curve test protocols. Thermal barriers design for repeated high temperature exposures and thermal barriers design for fire barriers differ in some aspects but in both cases need to withstand high temperatures in the excess of what organic composite can withstand.

Thermal barriers designed for repeated thermal exposures, such as exhaust washed parts, often need to have low thermal conductivity to prevent the cold side temperature from getting to high. A common method used for decreasing thermal conductivity is the use of an insulative core that can withstand the temperature of the repeated exposures. Organic material systems are limited in most thermal barriers applications to relatively low temperatures, less than 500 F. Inorganic material systems (e.g. ceramic matrix composites – CMCs) can withstand substantially high temperatures but in most cases are expensive and not easy to manufacture. Thus, opportunities exist for a low cost, high temperature barrier system capable of operating above the normal organic resin temperature range. Thermal barriers for high temperature exposure applications require good initial properties and retention of properties during and after thermal exposures. Depending on the temperature this retention of properties can be very difficult to achieve with cost effective material systems.

Barriers designed for FST applications where the part sees no high temperature exposures during its normal use are engineered differently. These parts are exposed to high temperatures for one time and in most applications do not need to retain properties. However, the cores used in FST applications do overlap the cores used for thermal barriers exposed to repeated heating based on the need in both cases for high temperature properties. The FST applications normally require more insulation due to the higher exposure temperatures.

EXPERIMENTAL:

The purpose of determining the thermal conductivity of various configurations of Inorganic resin and cores were to identify the best systems for long duration 630 C exposures and high temperature fire exposure. The requirements for these two types of exposures, the long/multiple exposures to 630 C scenarios and the single high temperature exposure fire scenario are different enough to require different material solutions. Thermal applications with relatively high temperatures and multiple exposures require materials capable of maintaining properties without degrading during the repeated cycles. Inorganic resin composite reinforced with silicon carbide fiber (SiC) was selected for the long duration, multiple 630 C exposures due to high temperature capability of the reinforcement, which would degrade most common fiber reinforcements.

Carbon fiber, glass fiber, or an organic fiber can not withstand this temperature leaving SiC and other ceramic fibers as the materials of choice. However, glass reinforced Inorganic resin can be used in non-structural FST applications due to relatively short duration of exposure and the one time use.

Thermal Application:

The thermal application investigated in this paper consisted of a hot side of ~ 630 C and an ambient cold side. Maintaining the cold side temperature below 250 F was considered important for this application. Thus, the Inorganic resin/SiC needs to have an insulative core to meet this 250 F requirement. Metal face sheets over an insulative core was also considered a potential candidate to meet the requirements but at the expensive of weight, corrosion and poor thermal shock performance.

The inorganic polymer candidate material systems were selected based on the following parameters, of which low thermal conductivity was only one of the considerations:

- Low cost
- Capability of maintaining physical and mechanical properties at 630 C
- Good environmental exposure performance
- Capable of multiple high/low temperature cycles – thermal shock
- Capable of being fabricated into complex large shapes
- Low thermal conductivity
- Secondary benefits of corrosion resistance and light weight

Inorganic resin Laminate + Inorganic resin Foam Sandwich

Candidate systems consisted of Inorganic resin/SiC laminate, Inorganic resin/SiC laminate with a hollow core and Inorganic resin/SiC laminate with a ceramic fiber core. Organic foams which offer very good insulation properties could not withstand the high temperature. Inorganic foams also could not be used due to the very high cost for low densities foams and the high density of the low cost foams (Refer to Figure 1). The thermal conductivity of the Inorganic resin/SiC laminate without insulation was measured first to determine the thickness that would be required to meet the 250 F requirement. The use of a thick Inorganic resin/SiC laminate however is not a viable option considering the high cost of SiC reinforcement. The two potential options that meet most of the requirements is first, a hollow core Inorganic resin/SiC panel and second, a rigid ceramic fiber core. These options were all tested using the same in-house thermal conductivity test equipment on six inch by six inch panels.

The thermal conductivity was measured at various temperatures. Thermal conductivity values normally increase as the temperature increases. The conductivity of the laminate without insulation increased in value as the temperature increased. However, the empty core panel and the ceramic fiber core panel did not increase but instead decreased slightly (Refer to Figure 2)..

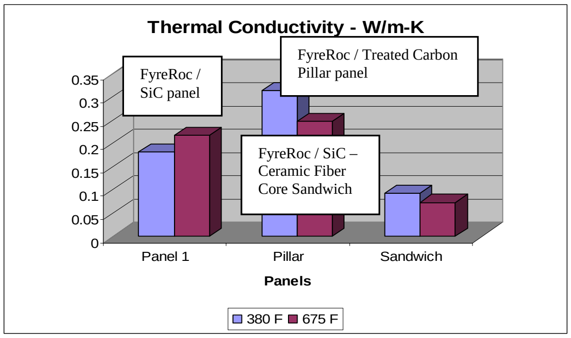

Figure 1 Thermal Conductivity Data

Fire Application:

Two different sandwich constructions were tested for fire performance both having a Inorganic resin/Glass on the hot side and vinyl ester/glass on the cold side with different cores.

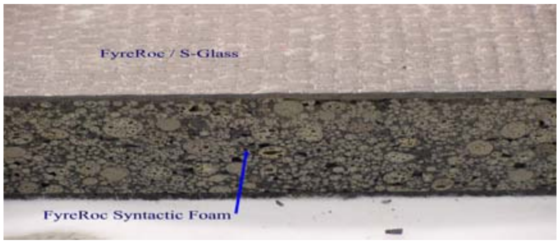

Figure 2: Inorganic Resin Laminate + Inorganic Resin Foam Sandwich

The two cores consisted of a Inorganic resin foam of 0.45 gm/cm3 and carbon foam with a density of 0.5 gms/cm3 (Figure 5: Inorganic resin/Glass/Carbon Foam/Vinyl Ester/Glass Sandwich Panel (1 ft. by 1 ft.). The Inorganic resin foam was formulated using syntactic beads of both large and small sizes resulting in a density of 0.45 gm / cm3 (Figure 2: Inorganic resin Laminate + Inorganic resin Foam Sandwich).. Sandwich constructions of Inorganic resin/glass and vinyl ester/glass with the two different cores were made using Inorganic resin as the adhesive for the Inorganic resin/glass and an epoxy adhesive for the vinyl ester/glass. The Inorganic resin/glass and vinyl ester/glass were both cured under vacuum pressure and 300 F. The hot side laminate and the foam core needed to insulate well enough to protect the vinyl ester laminate from decomposing, which was determined to be less than 250 F. Assuming that the cold side temperature can be maintained below the 250 F the panel will be able to maintain structural properties critical in many applications. A small scale fire test, 1 foot by 1 foot, using UL-1709 curve, was run as a screening test of the two cores and also various core thicknesses of 1 inch, 2 inch and 3 inches the Inorganic resin foam core (Figure 3: Small Scale Fire Test Furnace & Figure 6: Small Scale Fire Test Data on Sandwich).

The results showed the Inorganic resin foam to be a much better insulator in spite of the Inorganic resin's higher density. The actual fire test was run at the Naval Research Laboratory (NRL) on a 3 ft. by 3 ft. panel for 30 minutes using the UL-1709 fire curve (Figure 7: Mid-scale Fire Test Data on Inorganic resin Foam Sandwich and Figure 4: Inorganic resin/Glass/Inorganic Resin Foam/ Vinyl Ester/Glass Sandwich Panel (3 ft. by 3 ft.). The test results show the cold side temperature reached only 180 F well below the required 300 F (250 F temperature rise). A secondary and equally as important characteristic as the temperature rise of the cold side is the very linear slope of the cold side temperature rise. This linear behavior allows for easy engineering of the panel thickness to meet specific fire test durations.

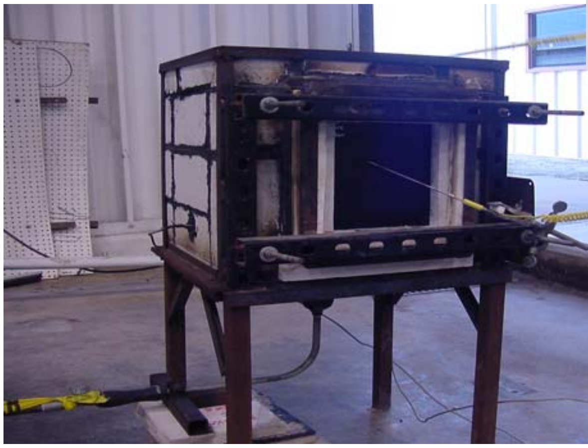

Figure 3: Small Scale Fire Test Furnace

Figure 4:Inorganic resin/Glass / Inorganic resin Foam / Vinyl Ester / Glass Sandwich Panel (3 ft. by 3 ft.)

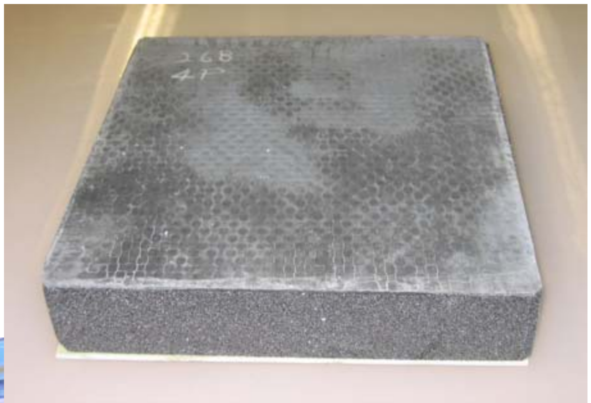

Figure 5:Inorganic resin/Glass / Carbon Foam / Vinyl Ester/ Glass Sandwich Panel (1 ft. by 1 ft.)

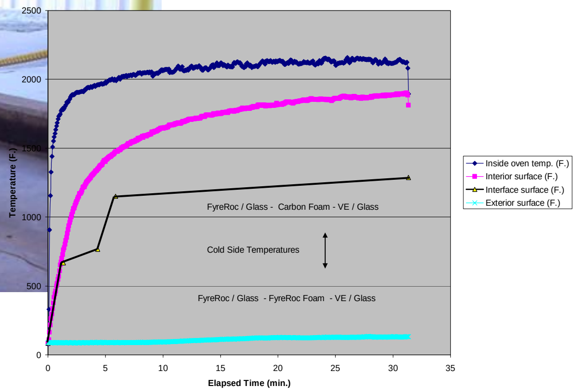

Figure 6: Small Scale Fire Test Data on Sandwich

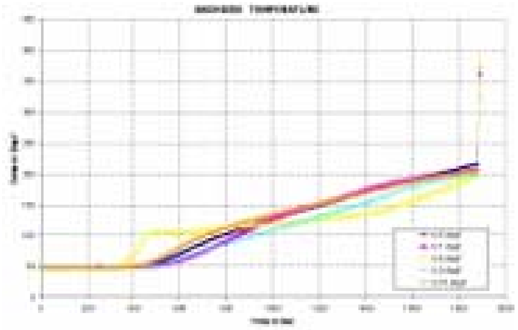

Figure 7: Mid-scale Fire Test Data on Inorganic resin Foam Sandwich

Discussion:

Thermal conductivity is a function of the material which can only be affected by altering the material itself. This is done by fillers, fiber reinforcements, void content, material morphology or chemistry modifiers. The Inorganic resin resin is an oxide based chemistry consisting largely of silicon oxide. The thermal conductivity of silicon oxide materials have been measured by many methods and sources. However, the Inorganic resin chemistry is modified with other oxides, and other chemicals resulting in a different network and morphology requiring the need to measure the materials thermal conductivity. Inorganic resin is not a resin used alone but as a matrix resin requiring a reinforcing fiber. Selecting Silicon Carbide fiber as the reinforcement for thermal application based on the temperature requirements and other requirements also turned out to be a effective selection for low thermal conductivity. High temperature transport is normally caused by the radioactive component of thermal conductivity. The use of SiC can absorb or scatter the radiation reducing the thermal conductivity this is normally important at use temperatures above 200 C. The two other modes of thermal conductivity, solid conductivity and gaseous conductivity are also important to a systems total thermal conductivity. The solid conductivity is an intrinsic property for a specific material, in this case the Inorganic resin/SiC laminate. The gaseous conductivity is a function of both the pore size and void content of the material. More air in the sample results in lower the thermal conductivity. In both of the foams tested the density was too high to offer optimum reduction in gaseous conductivity. Even in light of this high density, the inorganic foam provided an effective insulation solution. However, the optimization of void content and pore size also need to be evaluated versus other critical properties pertaining to strength and stiffness.

Composite panels fabricated to perform well in fire are normally made from fire resistant resins, such as a phenolic resin, with glass reinforcement or a laminate protected by an insulating passive fire protection. The two panel systems tested in this evaluation did not use a non-structural passive fire protection that performs a single function in protecting the panel from fire but instead a rigid core and solid laminate that can function as part of a structural panel. Panels of this type are not common due to the lack of structural cost effective foams capable of withstanding 2000 F. The foam core and Inorganic resin/Glass laminate in combination needs to insulate the cold side laminate as well as the non-structural passive insulation, which is primarily an insulation material. Thus, the thermal conductivity of the foam and laminate combination needs to be low to keep the panel thickness to a minimum. The fire test results for the two different inorganic cores showed the importance of having a low thermal conductivity core. The advantages of sandwich panel as a fire panel construction over a laminate protected by passive fire protection are the following:

- Rigid outer surface which can be painted
- No added cost for installing passive fire protection
- Better resistance to environmental exposure
- Stronger construction before and after fire

The disadvantage is that the sandwich construction is heavier then the passive fire protection which in many cases is the number one concern (Figure 8: Fire Protection Panel Systems).

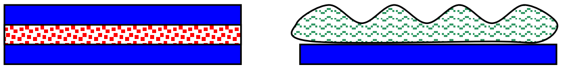

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Figure 8: Fire Protection Panel Systems

Conclusion:

Inorganic polymers represent a new material family that can perform at temperatures not possible with organic polymers but is possible with metals and ceramics. Thus, the use of these inorganic polymers will depend on secondary benefits in order to be selected over alternative materials. Low thermal conductivity is one good property for differentiating the inorganic polymer from metals. Thermal shock performance is another good behavior to show the advantages of inorganic polymers over metals. The inorganic polymer materials capability to be reinforced with continuous fiber, low temperature fabrication methods and low cost represents advantage over most high performance ceramic.

These Inorganic polymers are not intended to be a one-to-one substitution for any other material system but a unique materials system which offer pros and cons when compared with alternative systems. For the inorganic polymers to make a larger impact on the composite market the following improvements are needed;

- Enhanced mechanical properties
- Improved toughness
- Low density foam material.

Inorganic polymers in their present form can be used in many thermal and fire applications when engineered correctly.