The Space Congress® Proceedings 2004 (41st) Space Congress Proceedings

Apr 30th, 8:00 AM

Paper Session II-A - Polyimide Foam Insulation Materials for Aerospace Vehicles and Spaceport Applications

Martha K. Williams
NASA- Kennedy Space Center

Erik S. Weiser
NASA-Langley Research Center, Hampton,

James E. Fesmire
NASA- Kennedy Space Center

Brian W. Grimsley
NASA- Langley Research Center, Hampton, VA

Trent M. Smith
NASA Kennedy Space Center

See next page for additional authors

Presenter Information
Martha K. Williams, Erik S. Weiser, James E. Fesmire, Brian W. Grimsley, Trent M. Smith, James R. Brenner, and Gordon L. Nelson

Polyimide Foam Insulation Materials for Aerospace Vehicles and Spaceport Applications

Martha K. Williams[1], Erik S. Weiser[2], James E. Fesmire[1], Brian W. Grimsley[2], Trent M. Smith[1,3], James R. Brenner[3] and Gordon L. Nelson[3]

[1]NASA, Spaceport Engineering and Technology, Testbed Technology Branch, YA-C2-T, Kennedy Space Center, FL 32899, U.S.A.
[2]NASA, Mail Stop 226, Langley Research Center, Hampton, VA 23681, U.S.A.
[3]Florida Institute of Technology, 150 W. University Blvd., Melbourne, FL 32901, U.S.A.

Advancements in high temperature materials by NASA have led to the development of polyimide foam systems with very attractive properties. The properties generated demonstrate the suitability of these materials for use as insulation for cryogenic fuel tanks on next generation vehicles, commercial and military ships, and potentially commercial aircraft. The significance of structural polyimide foams can be realized with a reduction in the overall weight of a launch vehicle. Due to a polyimide's high operating temperature (~260°C) structural polyimide foams can potentially reduce the amount of Thermal Protection System (TPS) and TPS integration structure that is required on launch vehicles. The low-temperature elasticity of other polyimide foams is an enabling feature for many new cryogenic applications. These high performance materials also have properties that fulfill the demanding upcoming needs in ground support equipment for a Spaceport Technology Center.

In a research study performed by Kennedy Space Center (KSC) and Langley Research Center (LaRC), polyimide foams were investigated for their physical, mechanical, thermal, and flammability properties. Variations in chemical structure, cell surface area, cell content and density on the resultant physical properties of the foams were studied. Data generated from this research revealed vital information involving foam technology and the interplay of factors such as foam density, open-closed cell content, surface area, and cell structure on the overall performance of the material. By controlling these parameters, new thermal insulation systems based on polyimide foam materials can be designed to meet demanding applications for spaceports and space vehicles.

Polyimide Foam Insulation Materials for Aerospace Vehicles and Spaceport Applications

Martha K. Williams[1], Erik S. Weiser[2], James E. Fesmire[1], Brian W. Grimsley[2], Trent M. Smith[1,3], James R. Brenner[3] and Gordon L. Nelson[3]

[1]NASA, Spaceport Engineering and Technology, Testbed Technology Branch, YA-C2-T, Kennedy Space Center, FL 32899, U.S.A.
[2]NASA, Mail Stop 226, Langley Research Center, Hampton, VA 23681, U.S.A.
[3]Florida Institute of Technology, 150 W. University Blvd., Melbourne, FL 32901, U.S.A.

Advancements in high temperature materials by NASA Langley Research Center have led to the development of polyimide foam systems with very attractive properties. The properties generated demonstrate the suitability of these materials for use as insulation for cryogenic fuel tanks on next generation vehicles, commercial and military ships, and potentially commercial aircraft. The significance of structural polyimide foams can be realized with a reduction in the overall weight of a launch vehicle. Due to a polyimide's high operating temperature (~260°C) and also good cryogenic insulation properties, these structural polyimide foams can potentially reduce the amount of Thermal Protection System (TPS) and TPS integration structure that is required on launch vehicles. See Figure 1 for a conceptual representation of a TPS system, where an insulation system would have to be reusable and exposed to both low and high temperatures upon launch and re-entry [1,2,3,4]. The low-temperature elasticity of other polyimide foams is an enabling feature for many new cryogenic applications. These high performance materials also have properties that fulfill the demanding upcoming needs in ground support equipment for a Spaceport Technology Center.

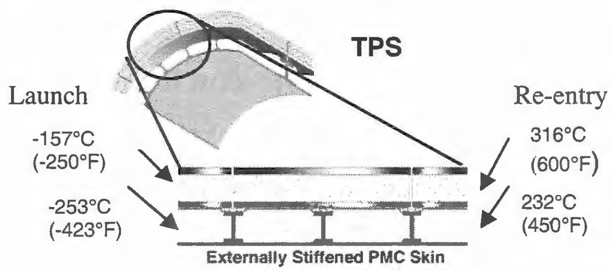

Figure 1. TPS conceptual representation using polyimide as insulating material

In research characterization studies performed by Kennedy Space Center (KSC) and Langley Research Center (LaRC), polyimide foams were investigated for their physical, mechanical, thermal, and flammability properties. Variations in chemical structure, cell surface area, cell content and density on the resultant physical properties and performance of the foams were investigated. TEEK-H series and TEEK-L series, (4,4′-oxydiphthalic anhydride /3,4′-oxydianiline and 3,3′,4,4′-benzophenone-tetracarboxylic acid dianhydride /4,4′-oxydianiline) were used for this comprehensive study. Open or closed cell content effects on thermal conductivity under a full range of vacuum pressures and also under ambient conditions were also studied [3]. This report is a review summarizing some of the data collected in these studies [5,6,7,8].

In Table 1, the characteristic properties and performance parameters of the foams are summarized and correlated with chemistry, density and surface effects. Data presented confirm that these newly developed polyimide foams are high performance polymers in their mechanical, physical and thermal properties. Radiant panel and cone calorimeter performance indicate that differences in the surface area or cell size of the foams appear to have a larger effect in fire performance than the densities or differences in chemical structure. Chemistry and density are the major contributing factors to mechanical and weathering performance [8, 9].

In studying thermal conductivity, it is expected that in closed cell foams the heat transfer coefficient in the cell will change as the blowing agent is replaced by air with time, and in open cell foams the overall thermal conductivity of the system will increase because of the open transfer of air into the cells through convection. The thermal performance of the material depends strongly on the vacuum pressure level of the material's environment. Optimum material properties for one vacuum level are different from those of another vacuum level, and so on, for all eight decades of vacuum pressure from no vacuum to soft vacuum to high vacuum [4]. The more closed-cell foam was found to be the better insulator (lower k-values) under high vacuum cryogenic conditions, with density also playing a role in thermal performance [10, 11]. See Figure 2 for comparative k-values under full range of vacuum pressures for polyimide foams.

Data generated from this research revealed vital information involving foam technology and the interplay of factors such as foam density, open-closed cell content, surface area, and cell structure on the overall performance of the material. By controlling these parameters, new thermal insulation systems based on polyimide foam materials can be designed to meet demanding applications for spaceports and space vehicles.

Table 1. Summary of foam properties or effects on performance parameters

Property or Performance	**Sample Series, Chemistry, Density, Cell Content or Surface Area Effects**
Mechanical tensile	H ~ L (density dependent)
Tensile at 177°C	H > L
Compressive Strength	L > H (chemistry>surface area>density dependent)
Compressive Strength 177°C	L > H (chemistry, surface area dependent)
Thermal Properties	L ~ H (chemistry dependent, diamine)
Isothermal TGA at 500°C	L ~ H (chemistry dependent)
Weathering Performance	H_{better} > L (chemistry dependent, dianhydride>density>surface area)
Radiant Panel Shrinkage	No precedence within series, surface area dependent
Peak Heat Release Rate same surface area	H_{higher} > L (surface area dependent)
Thermal Conductivity	Closed cell content major contributing factor>density effects

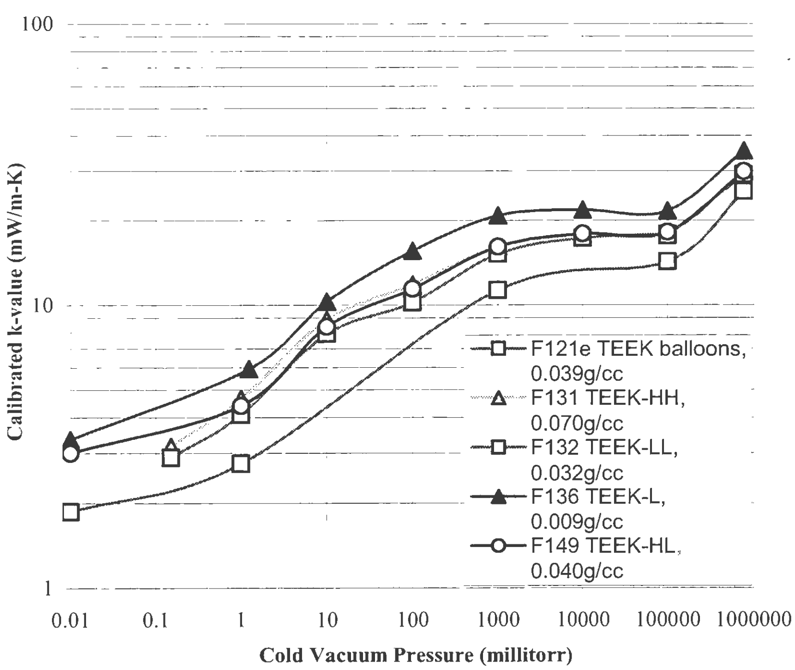

Figure 2. Thermal Conductivity of TEEK-H and TEEK-L series foams under full range of vacuum pressures.

References

1. Weiser, E.S., Johnson, T.F., St. Clair, T.L., Echigo, Y., Kaneshiro, H., Grimsley, B.W. Journal of High Performance Polymers 12 (2000), 1-12.
2. Weiser, E.S., Baillif, F.F., Grimsley, B.W., Marchello, J.M. High Temperature Structural Foam, Proceeding of the 43nd International SAMPE Symposium, May, (1998), 730-744.
3. Weiser E.S., Grimsley B.W., Pipes R.B., Williams M.K. Polyimide foams from friable balloons. 47th International SAMPE Symposium and Exhibition, Long Beach, CA, May (2002), 1151-1162.
4. Williams, M.K., Fesmire, J.E., Weiser, E.S, and Augustynowicz, S. Thermal Conductivity of High Performance Polyimide Foams. *Cold Facts*, Cryogenic Society of America, Spring 2002, Vol. 18, Number 2, pp. 10-11.
5. Williams M.K., Nelson G.L., Brenner J.R., Weiser E.S., St. Clair T.L. *Fire and Polymers: Materials and Solutions for Hazard Prevention, ACS Symposium Series 797*; Nelson GL, Wilkie CA, Eds.; 2001. American Chemical Society, Washington D.C.; 49-62.
6. Williams M.K., Weiser E.S, Grimsley B.W., Brenner J.R., Nelson G.L. Density Effects in High Performance Foam Materials. *ACS PMSE Preprints* 2003; **86**: 132.
7. Williams M.K., Nelson G.L., Holland D.B., Melendez O, Brenner J.R, Weiser E.S. Aromatic Polyimide Foams: Factors that Lead to High Performance. Proceedings of 9th European Meeting on Fire Retardancy and Protection of Materials, Lille, France, 2003; 23-24.
8. Williams, M.K., Nelson, G.L., Brenner, J.R., Weiser, E.S., St.Clair, T.L. Cell Surface Area and Foam Flammability, Proceedings of Recent Advances in Flame Retardancy of Polymeric Materials, (2001).
9. Williams M.K., Melendez O., Palou J., Holland D., Smith T.M., Weiser E.S., Nelson G.L. Characterization of Polyimide Foams after Exposure to Extreme Weathering Conditions. *J. Adhesion Sci. Technol.* 2004; in press.
10. Fesmire, J. and Doctor, M., Thermal conductivity testing of polyimide foams under ambient conditions, KSC Cryogenic Laboratory Technical Report, October 10, 2003.
11. Johnson, T.F., Weiser, E.S., Grimsley, B.W., Jensen, B.J., and Fesmire, J.E. Cryopumping in Cryogenic Insulations for Reusable Vehicle. Journal article in press.