Radiant Heating Tests of Several Liquid-Metal Heat-Pipe Sandwich Panels

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Abstract

INTEGRAL heat-pipe sandwich panels, which synergistically combined the thermal efficiency of heat pipes and the structural efficiency of honeycomb sandwich construction, were conceived as a means of alleviating thermal stress problems in a scramjet engine. Two different design configurations were fabricated and tested. The heat-pipe sandwich panels reduced maximum temperature differences, hence, thermal stresses, sufficiently to constitute a simple and efficient solution to the engine thermal stress problem. Other potential applications of the concept have been identified and are being investigated.

Contents

A research program to develop hydrogen-fueled airframe-integrated scramjet engines has been underway for sometime.[1] The present engine design uses full-depth (1.8 in.) honeycomb sandwich walls whose heated surfaces are cooled regeneratively by the circulation of hydrogen fuel through a cooling jacket. During transient engine operation (e.g., startup or shutdown) large temperature differences across the sandwich walls (1200°F) cause excessive thermal stresses in the facesheets (over 200 ksi) and greatly reduce engine life.

The heat-pipe sandwich panel was conceived as a simple and efficient solution to the engine thermal stress problem. The heat-pipe concept can drastically reduce maximum temperature differences across the honeycomb walls, and, hence, reduce thermal stresses with only a modest increase in mass (less than 10%) over the original, unacceptable nonheat-pipe design. This exceptional performance is possible because the integral heat-pipe sandwich panels synergistically combine the thermal efficiency of heat pipes with the structural efficiency of honeycomb sandwich construction. Several panels were fabricated and tested to verify feasibility of the concept.[2-4]

This paper summarizes the fabrication and radiant heat test results of several machine-manufactured stainless-steel heat-pipe sandwich panels having different honeycomb-core/wick construction and different working fluids (cesium, potassium, and sodium) and also discusses other potential applications of the concept.

Concept Description and Fabrication

The goal was to develop a sandwich panel, similar in structural integrity to the original nonheat-pipe sandwich panel design, which could reduce maximum temperature differences, hence, stresses, by 50% and make the design feasible.

The heat-pipe sandwich panel, shown schematically in Fig. 1, consists of a wickable honeycomb core, internally wickable facesheets, and a suitable working fluid. The term "wickable" is defined as porous and capable of wicking a working fluid by capillary pumping. For application to the scramjet engine, the working fluids considered are cesium, potassium, and sodium. During operation heat is absorbed at the heated face by the evaporation of working fluid. The heated vapor flows (see inset, Fig. 1), due to a pressure differential, to the cooler face where it condenses and gives up its stored heat. The cycle is completed with the return flow of liquid condensate back to the heated face by the capillary pumping action of the wickable core. The core is perforated to allow intracellular vapor flow and is notched at both ends to allow intracellular liquid flow along the internally wicked faces.

The heat-pipe sandwich panel test specimens were $6 \times 6 \times 1$ in. and were manufactured from stainless steel to reduce costs. For actual engine application the panels would be fabricated from a high-temperature superalloy. The facesheets were made internally wickable by sintering one layer of 120×120 mesh screen to 0.024-in.-thick sheet material. Two different types of wickable core were considered: 165×1400 mesh woven wire screen (0.0055 in. thick) and screen/foil composite, 325×325 mesh screen (0.0025 in. thick) sintered to 0.003-in.-thick foil. The entire sandwich panel is fabricated by simultaneously spot welding the core ribbons to each other and to the facesheets, forming a 0.375 in. cell configuration. This all-welded manufacturing technique eliminates concern for materials compatibility problems of the working fluid with a bonding agent. Details of panel fabrication, including cleaning and processing are given in Ref. 3.

For the present application, the heat-pipe panels will operate at 1100°F; this results in an internal vapor pressure of 0.44 psi for sodium, 1.89 psi for potassium, and 6.5 psi for cesium working fluids. The good pressure containment capability of this flat-plate heat pipe makes this concept attractive for low-temperature space radiator applications.

A total of 12 ($6 \times 6 \times 1$ in.) heat-pipe sandwich panels were fabricated: eight had a screen/foil composite core; three were filled with sodium, three with potassium, one with cesium, and one was empty. Four of the panels had the 165×1400 mesh screen core; one of each was filled with cesium, potassium, and sodium, and one was empty. The empty panels were used as controls during the radiant heat tests.

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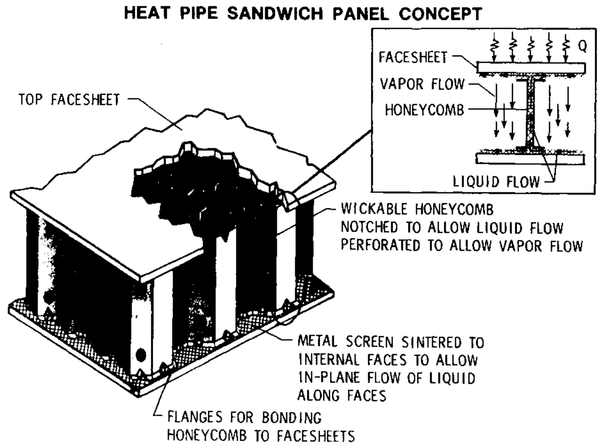

Fig. 1 Heat-pipe sandwich panel concept.

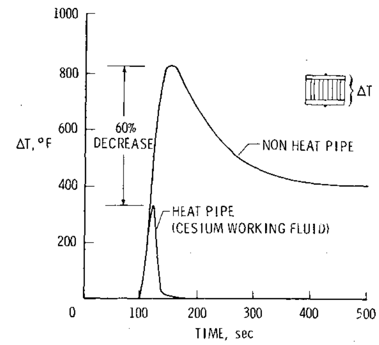

Fig. 2 Comparison of facesheet temperature difference histories of a cesium-filled heat-pipe panel and a nonheat-pipe panel.

Tests

Several preliminary tests were performed to obtain data to design and fabricate the test specimens. Wicking tests of the facesheets and core determined average pore sizes and permeabilities. Results of these tests were used in standard analytical expressions to calculate performance envelopes for each working fluid. These performance results indicated that any combination of wickable core and working fluid would be suitable for handling the design transverse heat load of 7 Btu/ft^2-s. Preliminary structural testing indicated the panel is capable of withstanding internal pressure up to 560 psi and that the screen/foil composite core actually increases the compressive strength of the foil core by 42%.

The sandwich panels were radiantly heated by quartz lamps to simulate the scramjet engine startup transient. Two panels, one empty and the other filled with working fluid, were tested simultaneously. The panels were subjected to the same heating environment; heat was applied over one surface of the panels (the top surface) while the other surface and sides of the panel were insulated to simulate adiabatic boundary conditions. Models were instrumented with thermocouples to monitor heat-pipe startup and performance and to determine maximum through-the-thickness (face-to-face) temperature differences.

Results of the tests indicate that four of the ten panels operated successfully. Of the four successful panels two were filled with sodium with the screen/foil core, one used potassium, and one used cesium; both with the 165×1400 mesh woven screen core. Failure of the six panels occurred because of small leaks in the 90 deg weld joints at the edge closures. These failures indicate that fabrication methods must be improved but do not indicate a basic problem with the concept. Better methods are available for closeout of the edges of honeycomb panels and these are being investigated. Results of the successful tests indicate that the heat-pipe sandwich panels with sodium working fluid were capable of reducing maximum temperature differences by 31% over a nonheat-pipe sandwich panel, by 46% using potassium as the working fluid, and by over 60% using cesium as the working fluid. Comparison of temperature difference histories of a cesium filled heat-pipe panel and a nonheat-pipe panel are shown in Fig. 2. As shown, the temperature differences of the front and back facesheets of both panels coincide up to about 300°F. At this point the heat-pipe panel begins to operate and reduces the temperature difference. The reduction in maximum temperature difference for this test is 60%. Hence, it appears that the heat-pipe sandwich panel concept can meet the goal of a 50% reduction in temperature differences and therefore is a promising solution for alleviating thermal stresses in a scramjet engine while resulting in only a 10% increase in mass over the original, unacceptable design. Details of radiant heat tests can be found in Ref. 4.

Another high-temperature application of the heat-pipe sandwich panel is to cool leading edges of hypersonic cruise or Earth entry vehicles.[5] Low-temperature applications (using different materials and working fluids) of the concept include: cooling electronic components or circuit cards, limiting thermal distortions in large space structures (e.g., antennas, laser mirrors, or other optical systems), and serving as radiators for space stations or space transportation systems. A radiator application which has the potential of reducing mass of other heat-pipe or fluid loop systems by over 50% and increasing efficiency from 0.8 to approximately 1 is currently being investigated.[6]

References

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