# INVESTIGATION ON THERMAL MANAGEMENT FOR METALLIC FOAM SANDWICH MULTIFUNCTIONAL STRUCTURE TECHNOLOGY

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## *Abstract*

*This paper investigates the problem of a plate-like lamination that combines a thermal energy management capability with a structural capability. The lamination consists of high thermal conductivity filler fixed in porous metallic foam core encapsulated between two laminations carbon fiber/epoxy composite skins and two mental foam-cores. 3-D carbon-carbon is used as thermal doublers under the thermal simulator MCM controlled by flexible circuit patch which bonded onto the composite skin. Furthermore, the details of the thermal design method are presented, such as test of the mechanical properties of metallic foam sandwich panel; measuring of heater power density and temperature gradients by thermal vacuum tests. The result shows that this structure can be implemented realistically to reject moderate heat load generated by an MCM on MFS panel.*

## 1 Introduction

The micro-spacecraft must offer an order-of-magnitude reduction in flight system mass, volume and cost relative to current spacecraft designs which is one of the stratagem target for the 21st Century. Lockheed Martin (LM) Astronautics has developed the multifunctional structure concept that eliminates chassis, cables, connectors and folds the electronics into the wall of the spacecraft [1, 2]. Multifunctional structures (MFS) is an innovative concept that offers a new methodology for spacecraft design[3].The baseline MFS design consists of a structure composite panel that has multilayer copper/polyimide(Cu/PI) patches bonded to one side, heat-transferring devices embedded, and an outer surface acting as a radiator[2]. The advantage of MFS is integration electronic, thermal management into the structure function. Thus eliminate the parasitic mass used to package, connect and support. These parasitic components can contribute as much as 50 percent of the mass of space science spacecraft [4, 5].

Basically, there are two thermal management methods. The first is active thermal management, and another is passive thermal management. The latter is used in this research since is has advantages such as simple structure, high reliability, and long service lifespan. Metal foam used as the core is a type of relative new material which has big specific surface area, lightweight and excellent thermal performances, etc. Double-layer sandwich structure was chosen in this paper for its characters such as resisting the low velocity impact [6] and other excellent properties.

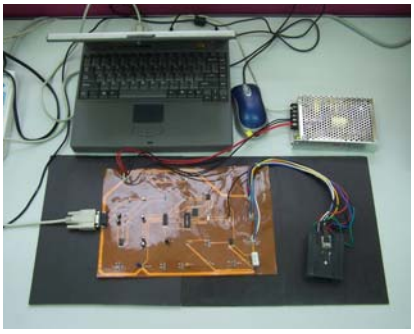

Fig. 1. MFS with Heat Simulator MCM on flexible circuit patch

The research aims at fabrication of a prototype of MFS which carry certain load as well as be used as radiator and part of avionics. Two kinds of experiments were carried out, the first is mainly the mechanical tests, and static-mechanical tests are preliminarily to obtain important parameter for the mechanical properties of the double-layer sandwich structure with core of metal foam. The tests carry out in this paper are mainly the compression test and three-point flexure test; the second is thermal vacuum tests, which aim to obtain the thermal properties characterized by temperature gradients and thermal power density. A sample was fabricated in this paper, as is shown in figure 1, consists of multifunction of electronic, thermal control and structure.

## 2 Experiment

### 2.1 Material

The face sheet material under research is T300/HD03 carbon fiber reinforced epoxy prepreg, which is widely used in high-performance composites employed in the aircraft, spacecraft and other industries. Open cell Cu-Ni metal foam (MF) is used as core which is 5.0mm thick, and has a relative density of $\rho$=0.342g/cm$^3$, 20 pores per inch (PPI), shown in Figure 1. The color of metal foam face was grayish-white and the face was handled by high-temperature alloy coursing process. The interior structure of this metal foam is three-dimension reticulate perforation metal cell, which increase the interior surface greatly.

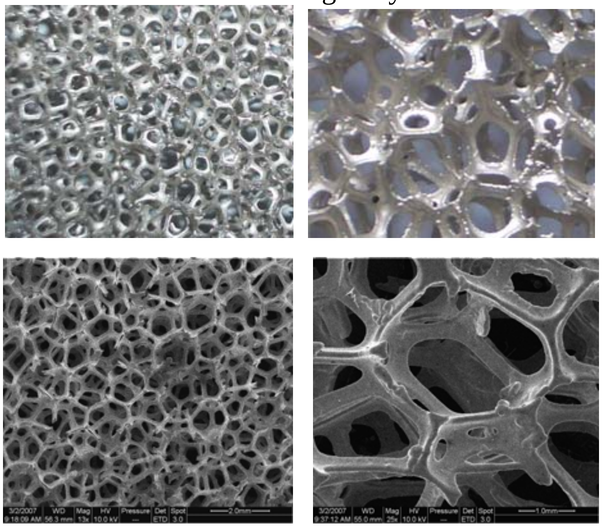

Fig. 2. Open cell metal Cu-Ni foam

### 2.2 Fabrication of Thermal Control Laminates

The rigidity face sheet plate was made of T300/HD03 carbon fiber reinforced epoxy prepreg, which are 270mm×170mm×2mm, and prepreg was stacked by means of rhombic symmetry[0/90]8s.The plate was fabricated by compression molding process. The cure process is as following. The temperature was increased to 90℃ from room temperature at a rate of 2℃/min and was held for 30 min. Then it was further increased to 130℃ at the same rate and held for the same time, the pressure was increased to 5MPa in this state. Then it increased to 175℃ at the same rate and held for 210 min. Finally it was cooled to room temperature. The double-layer sandwich panel consists of three layers face sheet plates and two layers cores, which stacked into a sandwich structure.

### 2.3 Fabrication of MFS Structure

In the design of MFS, flexible copper polyimide (Cu/PI) circuit patch was used instead of traditional printed wiring board (PWB). The advantage of Cu/PI circuitry is that Cu/PI circuitry offers significant mass and volume savings comparing with PWB and it has the property of flexible. Cu/PI circuit patch can be directly bonded onto the surface of the structure including flat plate and curved plate because of the property of flex. At the same time, temperature control, power and data distribution can be conducted by Cu/PI circuit patch by input/output (I/O) interface which connects with computer.

Four composite panels (270mm×170mm) were fabricated. The face sheets of them were all made of T300/HD03 and the core is Cu-Ni metal foam. But these four laminate have the different structures as shown in figure 3. Panel A is a single-core panel; panel B is a standard double-core panel with two Cu-Ni metal foam core and three same sheet laminations, each of which is 2mm thick. Panel C add heat filler under thermal simulation MCM, and the filler goes through the two cores and the middle T300/HD03 lamination; Panel D is the same with panel C except for an isotropic C-C doubler under MCM and the dimension of the C-C is 75mm×60mm×2mm. Adding C-C doubler aims at reducing the temperature gradients. At the same time, in order to compares the properties of tradition honeycomb core with metal foam core, panel A with single-core honeycomb core is also tested.

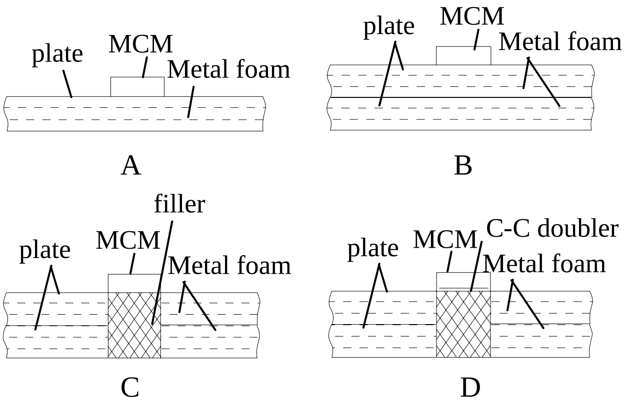

Fig. 3. Four MFS panel with thermal simulation MCM

## 2.4 Experimental Environment and apparatus

Experiments were performed in a vacuum environment in order to simulate the reality service environment of MFS and all of test data was measured in this state. Temperature was measured by k thermo couple and heat power density was measured by heat-flow meter. All measured data recorded by 4019 module. Cu/PI circuit control power and conductor temperature of MCM by computer through I/O interface.

## 2.5 Mechanical Testing

Static-mechanical test were conduced to acquire important parameter for the mechanical characterization and to verify the load-bearing capabilities of MFS.

## 3 Results and Discussion

## 3.1 Mechanical Results

### *3.1.1 Compression Test*

Figure 4 shows the compression force-displacement curve of double-core sandwich structure. The metal foam core bears all of compression load. The upper metal foam was destructed earlier and then was the downlayer metal foam, which characterized a distinctness time lag in phase. The compression properties of double-core sandwich are similar to that of single-core sandwich, but upper core took the roll of absorption of shock, so the structure has the properties of absorption power and increases resistance of compression. The lower curve in the figure presents the upper core destroyed point and the other two curve present the subjacent core began to destroyed and last for some time, until getting the crisis of the test apparatus.

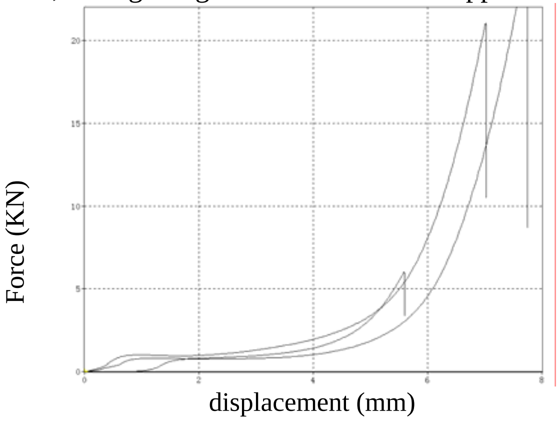

Fig. 4. Double-core metal foam sandwich compression force-deforming curve

### *3.1.2 Bending Test*

Figure 5 shows the force-displacement curve of double-core sandwich lamination. Metal foam destructs first as the increasing of the bending stress and the format is worst in the bending point and relieve as increasing the distance from the bending point. Double-core sandwich structures can absorb more shock power than single-core sandwich. The upper metal foam core of double-core structure deformed and subjacent metal foam core hardly deformed. Then the whole double-core sandwich structure bends as the increasing of stress, and upper structure present the same destruction format with the single-core sandwich with metal foam core. Yet subjacent structure only presented bending deform instead of visible destruction. As increasing of compression stress further, upper metal foam structure was destructed entirely, subjacent metal foam presented slightly homogeneously compressing destruction of the whole structure. At last, at the point of the maximum compression stress, the upper carbon/epoxy composite lamination showed extrusion breakdown, bending deform took place of the carbon/epoxy lamination of the middle and underlayer, yet no significant destroyed of the underlayer structure. The profiles of the destructions are influenced by the structure of double-core. Under bending stress, compression stress worked on the upper carbon/epoxy lamination, then transferred to the metal foam core, the biggest compression stress is on the compression point and gradually descending to the edges. The bending stress through upper sandwich structure showed homogeneity compression stress, thus middle carbon lamination and underlayer sandwich structure no significant destructed.

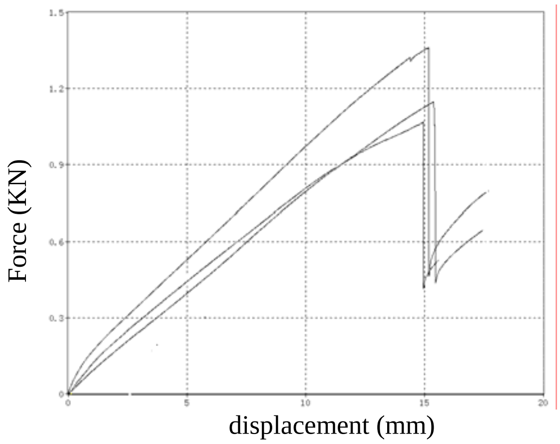

Fig. 5. Double-core metal foam sandwich bending force-deforming curve

## 3.2 Temperature Gradients Results

Temperature gradients through the panel of structure 'B', 'C' and 'D' were shown in figure 6. Figure 6 indicates that structure optimization conducted in this research obtained the expected results. The aim of reducing temperature gradients is to keep constant temperature of the radiator, and constant temperature radiator can obtain the biggest efficiency of rejection of heat. The test results proves that C-C doubler offers a good approach to reduce the temperature gradient and increases the efficiency of the structures to reject heat. At the same time, MFS with Hi-k filler also reduces temperature gradients of the structure. Each single curve indicates that little heat translated on orthogonal anisotropy composite plate, majority heat rejected through the panel, so increase the thermal conductivity is a practices way to reduce the temperature of heated face.

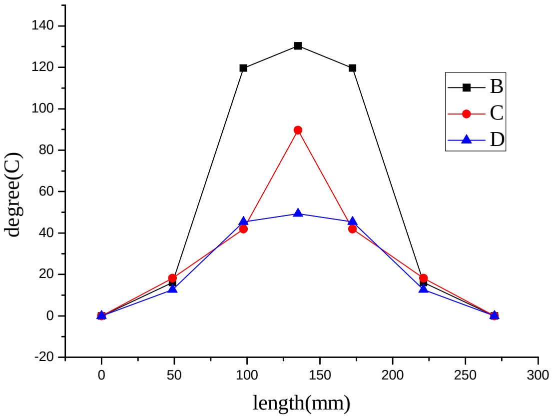

Fig. 6. Temperature gradients-position curve of MFS

## 3.3 Heater Power Density Results

The profiles of heater power density were obtained through thermal vacuum experiment. Figure 7 shows the results profiles of three different structures, in which the heater power density varies as time increasing, and the state changes from transient phase to steady phase, and we are interested in the data of the latter. Curve 'a' indicates the heat power density profile of the single-core sandwich structure in which Hexcel aluminum honeycomb type of CRⅢ-1/4-5052-0.0007N was used as the core. Curve 'b' represents the heat power density profile of single-core sandwich structure in which Cu-Ni metal foam was used as the core. The core is $0.342g/cm^3$ dense, 5mm thick, and 20 pores per inch, the structure is shown in figure 3, structure 'a'. Curve 'c' represents the heat power density profile of double-core sandwich structure with double layer Cu-Ni foam core, the same with curve 'b' and the structure was shown in figure 3, structure 'b'. These three profiles show the same changing tendency, but different values and the rough parts caused by unsteady degree of vacuum and environment compression. Figure7 shows that heat power density of the single-core sandwich is the largest of three structures, about $1700\times11.6W/m^2$, which indicates that the structure can reject more heat. Meanwhile, the double-core structure profile shows the worst capability of rejecting the heat because the structure increases the thermo resistance through panel and increases the length of the thermo access.

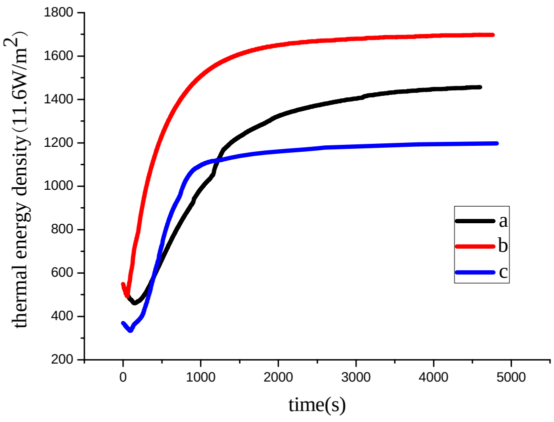

Fig. 7. Thermal power density-time curve of MFS panel

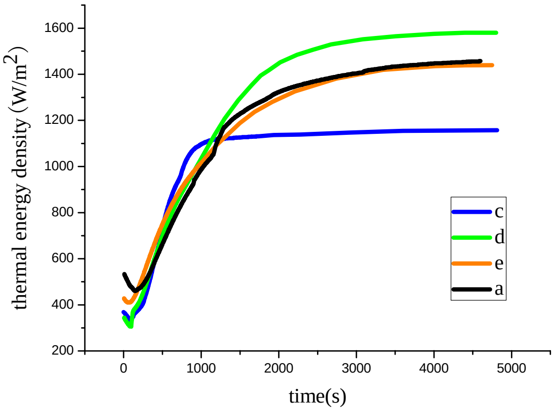

Fig. 8. Thermal power density-time curve of MFS panel

The profiles of heat power density of all four structures are shown in figure 8. The MFS with the thermal conductivity corefiller (curve 'd') shows the enhanced capability of rejecting the heat. The heat power density is about $1540\times11.6W/m^2$, and the value exceeds that of the other structures, but MFS with C-C heat doubler doesn't obtain the expected results (curve ‘e’), and the reason lies in the hard contact between the C-C and the surface of the sandwich MFS structure which reduced the power conductance.

## 4 Conclusions

This work proposed an approach to design a double-core MFS, and an experiment prototype is fabricated. Cu/PI flexible circuit patch which is lightweight and saving cost is used instead of the traditional PWB. Double-core sandwich laminate with metal foam core and Hi-K filler are used to be a radiator as well as the wall structure. Thus this experiment prototype integrates the function of electronic, thermal management, load-bearing and structure.

The load-bearing function has been evaluated by compression tests and three point bending test. The results of the test verified that this MFS composite laminate can be used as the structure which bears certain compression and flexural load.

The vacuum test evaluates the capability of the MFS to reject the heat by measuring the heat power density and comparing the temperature gradients. The results have shown that this MFS can reject moderate heat fluid generated by thermal simulation MCM and reduce the temperature gradients of the structure.

More attention should be paid to practical and commercial applications of MFS in order to save mass, volume and cost of composite structures.

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