LA-SUB--94-114

Enhancing through thickness thermal conductivity of ultra-thin composite laminates

Final report submitted to

Los Alamos National Laboratory
ATTN.: KEITH E. PALLESEN
REF.: 9-XZ2-7617E
P.O. BOX 990 MS P274
Los Alamos, New Mexico 87545

Submitted by
Professor Karthik Ramani
School of Mechanical Engineering
Purdue University
FAX: (317) 494-0539

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NOMENCLATURE

k_f	Axial thermal conductivity of the fibers
k_r	Resin thermal conductivity
k_a	Axial thermal conductivity
k_t	Transverse thermal conductivity
k_{eff}	Effective conductivity
v_r	Tow Resin volume fraction
v_f	Tow Fiber volume fraction
T_1	Temperature on the bottom surface
T_2	Temperature on the top surface
A	Area orthogonal to the heat flow
q	Heat flux
L	Thickness of composite panel

Enhancing through thickness thermal conductivity of ultra-thin composite laminates

**Professor Karthik Ramani
Aparna Vaidyanathan
School of Mechanical Engineering
Purdue University
West Lafayette, IN 47906-1288**

INTRODUCTION

The materials used in electronic applications have specific requirements for stiffness, thermal conductivity, and electromagnetic shielding making the choice of materials used very important. In products like computers, the size, appearance, cost and weight are important considerations. These considerations can utilize the properties of composite materials effectively. Electronic components are very sensitive to heat, hence the heat dissipation or cooling of the various components is necessary to prevent failure. Thus, any material used in the electronic industry must have a high thermal conductivity in addition to a specified thermal expansion, stiffness and strength properties.

One application of composite materials is the Super Conducting Super Collider [1]. The particle tracking device technology requires a high thermal conductivity of the cooling ring that provides structural support to the silicon wafers and other high density electronics. The cooling ring had to be made to a thickness of 400 μ and have a coefficient of thermal expansion close to that of silicon in order to minimize thermal stresses and subsequent failure.

The purpose of this project was to design and manufacture composite panels which would conduct heat from an electronic chip attached to the top surface to a cooling liquid flowing at its lower surface as shown in Figure 1. To maximize the heat conducted from the chip to the cooling liquid, the composite must have a high through thickness thermal conductivity. Further, design restrictions on the thickness of the composite panel had to be taken into account.

METHODOLOGY

The axial thermal conductivity of a high modulus carbon fiber is in general two orders of magnitude higher than that of the neat resin. Thus, to achieve a high through thickness thermal conductivity for the composite, the fiber volume fraction in the composite should be maximized. Failure of the interface between the chip and the composite can occur due to thermal stresses. The composite used for the application must be quasi-isotropic since it is bonded to a silicon wafers that are isotropic. In order to reduce the thermal stresses the composite and the chip should have the same order of in-plane coefficient of thermal expansion. Hence the fiber volume fraction and microstructure have to be tailored during the manufacturing process to control the coefficient of thermal expansion.

It is clear from the above considerations that the requirements of high through thickness thermal conductivity, specified range of stiffness for structural support and close control of the coefficient of thermal expansion to that of silicon make this project very challenging. It was recognized from prior work [1] that the through thickness thermal conductivity requirement and manufacturability were the limiting factors in using composite materials for this application. Hence this project focuses on intelligently investigating the through thickness thermal conductivity taking into consideration the manufacturability of the cooling ring with the aim of increasing the through thickness conductivity. Although the stiffness and coefficient of thermal expansion were not investigated in detail, they were factored into the design cycle.

In the preliminary concept the cooling ring was circular and has a channel like geometry with saw tooth's that support the silicon wafers. Using short fibers is a molding operation is one of the possible approaches to manufacture such a cooling ring. Further, short graphite fibers can provide a high stiffness and possibly high thermal conductivity when they are well packed. Graphite fibers, and in particular high modulus graphite fibers, have a very high longitudinal thermal conductivity and a low transverse thermal conductivity. However the molding operation induces a fiber orientation that is predominantly in-plane and hence does not utilize the high longitudinal thermal conductivity of the fibers.

One approach that was conceptualized at Purdue was to utilize the woven fabric structure to provide continuous heat conduction paths. The presence of continuous heat conduction paths, formed by the fibers along the thickness direction of the panel, by structures that

resemble the woven fabric structure, has the potential to increase the effective through thickness thermal conductivity significantly. The fibers in a composite made from woven fabric like structures can be made to traverse the thickness of the composite increasing the number of direct heat conduction paths.

Several other composite panels that included those made with fillers, short fibers, short fibers-fillers, continuous woven cloth, woven unit cells and short fibers-fillers-woven unit cells were made and tested for through thickness thermal conductivity. An automated finite element model for the thermal conductivity of filled composite with woven fabric unit cell and ceramic micro spheres were developed and compared with the through thickness thermal conductivity values obtained using the laser flash technique.

MATERIALS

Cyanate ester based composites are widely used in the electronics industry because of their low dielectric constant, high dimensional stability, and high temperature and moisture resistance [2]. In this project, cyanate ester resin system was used as the matrix in the composite panels. High modulus P-75 carbon fibers were used to maximize the conductivity. The properties of a composite material are dependent on the fiber form used. The fibers used in a composite material can be short fibers, continuous fibers or woven fibers. In addition to using fibers for increased stiffness and thermal conductivity, the stiffness and thermal conductivity can be altered by using fillers. In this project, silver coated ceramic micro spheres, with average diameters of 10 μm were used as fillers. The various composites investigated in this project are shown in Table 1.

Plain weave woven fabric was used in all the woven fabric composite panels in this project. A continuous plain weave fabric composite does not have the same coefficient of thermal expansion in all the in-plane directions. This makes a continuous woven fabric composite unsuitable for the desired application. A plain weave consists of a repeat pattern called the unit cell. The properties of the fabric are dependent on the properties of the unit cell. Thus, a composite made of randomly oriented chopped unit cells will have the same coefficient of thermal expansion in all in-plane directions.

PROCESSING

The processing steps for the manufacture of panels with woven cloth and woven unit cells was found to be the most challenging and is described in detail below. The various steps used in making a composite panel using randomly oriented unit cells is summarized in Figure 2 and described below.

The four stages outlined are:

- Selection and weaving of the carbon fiber tows,
- Initial consolidation of the woven cloth,
- Cutting into cells, and
- Final consolidation.

Weaving

Initial prototype panels were made using normal carbon fibers as P-75 woven cloth is expensive. P-75 woven fabric can be obtained in 1K, 2K, and 4K tow sizes. P-75 woven fabric, with a 2 K tow size, was ordered from weavers. A tightly woven plain weave with a thickness between 0.02 inches and 0.025 inches was ordered as it is best suited for the manufacturing a 400 μm thick composite panel. The weavers were able to weave P-75 fibers to a thickness of 0.0165 inches and a tow count of 12.5 x 12.5 per inch. A tighter weave was not possible since it was found to damage the fibers.

Initial Consolidation

In this stage a woven fabric composite panels were made. The quantity of resin required for a desired volume fraction was calculated and measured. Half of this resin quantity was spread on the mold. The woven fabric was then placed on the resin. Then the remaining resin was spread on top of the woven fabric. During the initial stages the bottom surface gets heated before the top surface leading to resin rich areas on the bottom surface. The resin rich areas do not allow the fibers to traverse the entire thickness of the panel. The uneven distribution of the resin also leads to warping and decreased flexural stiffness. To avoid this uneven distribution of the resin, more resin was spread on top of the woven cloth.

Cutting to unit cells

The consolidated woven fabric was cut into consolidated unit cells using a hand shear.

Final Consolidation

A predetermined quantity of resin was spread evenly on the mold surface. The resin was heated to 200° F for 5 to 10 minutes and then compressed in the die to get a 500 μm sheet. The resin was very tacky when hot, making it difficult to place the unit cells on it, without overlap of the unit cells. To avoid overlap of the unit cells, the resin sheet was allowed to cool. The unit cells were then placed on this sheet so as to achieve maximum packing and randomness without overlap. Overlap of the unit cells will not allow the mold to close properly and has to be avoided. When this resin sheet with the unit cells was heated, the resin flows causing the unit cells to shift their location, changing the packing and at times leading to resin rich areas. To avoid this shifting of unit cells, resin films were made and the unit cells were sandwiched between two resin layers as shown in Figure 3. The mold used to make the initial prototype panels had a 500 μm gap. The P-75 woven fabric used had a thickness of 400 μm . This led to a 100 μm excess resin layer in the samples. To avoid this excess resin layer, the mold was re-machined to reduce the gap to 400 μm .

The manufacture of the composite panels with fillers, short fibers and combinations of fillers and short fibers was not difficult and did not require an elaborate procedure similar to the woven fabric. The B-staged resin was melted to a thin layer in a mold and the fibers, fillers or combinations were added to the low viscosity resin and compression molded. The micrograph of the cross-section of a panel made with short fibers is shown in Figure 5 and that made with fillers is shown in Figure 6.

MODELING THE THROUGH-THICKNESS THERMAL CONDUCTIVITY

In order to gain further insight and understand the effects of the materials and manufacturing on the micro structure and therefore the thermal conductivity, finite element models were developed to determine the values of the through thickness thermal conductivity. The experimental and analytical values of the through thickness thermal conductivity were then compared. These finite element models that were experimentally

validated are extremely powerful, since they can save enormous prototyping efforts and in addition would allow a materials designer to experiment with different micro structures and their effects on the thermal conductivity.

A cross-section of the panel made with the woven fabric cells was observed under a microscope to determine the geometry of the woven fabric in the consolidated composite panel. The micro graph of the woven fabric composite showing the geometry is shown in Figure 4. Based on this geometry a finite element model was developed to predict the through thickness thermal conductivity of a woven cloth fabric composite and compared with experimentally determined values. The finite element model was implemented using the ANSYS finite element program [3].

A first-order two-dimensional finite element model for the thermal conductivity was developed where the effect of out-of-plane fiber bundles were neglected. Figure 4 shows the geometry of the unit cell used in the two-dimensional finite element model. Since the effective thermal conductivity is a material property and is independent of the boundary conditions, conduction or convection boundary conditions can be used in the model. Uniform temperatures T_1 and T_2 were prescribed to the top and bottom surfaces of the panel and the side surfaces were insulated.

The fiber weight fraction was determined by weighing the sample before and after burning off the resin. The conductivity's k_f and k_r were obtained from [4]. The axial conductivity of a uniaxial bundle of fibers impregnated with a resin was assumed to follow the rule of mixtures.

$$k_a = v_f k_f + v_r k_r \dots \dots \dots (1)$$

Hashin's [5] model was used to calculate the transverse thermal conductivity, k_t .

$$k_t = \frac{k_f(1 + v_f) + k_r v_r}{k_r(1 + v_f) + k_f v_r} k_f \dots \dots \dots (2)$$

The values for k_a and k_t obtained from equations 1 and 2 were used as the material properties for the tow region in the finite element model by appropriately changing the axes of definition of the material properties. Summation of the heat fluxes obtained from the ANSYS solution at the nodes on the top surface gives the effective heat flux through the panel " q ". Since the temperatures at the top (T_2) and bottom (T_1) surfaces were

prescribed as a boundary condition, the effective through thickness thermal conductivity k_{eff} of the composite can now be calculated using equation 3 below.

$$q = k_{eff} A \frac{(T_2 - T_1)}{L} \dots\dots\dots (3)$$

The results from the two dimensional model were then compared with the experimental results and it was found that the two dimensional model under predicted the effective through thickness thermal conductivity. The failure of the two dimensional model indicates that the heat taken in by the fiber tows at the top surface does not conduct effectively through the fibers and that a large percentage of this heat flux is lost to the resin. Further, the upper out-of-plane fiber tow in the cell carries out more heat than that comes into the plane from the lower out-of-plane fiber tow.

Since a two dimensional model was not able to capture the true heat transfer characteristics of the unit cell, a full three dimensional model was developed. The geometry used by the three dimensional model used is as shown in the Appendix A. The boundary conditions used in the model were uniform temperatures on the top and bottom surfaces and insulated side surfaces. A $80^\circ C$ temperature difference between the upper and lower surfaces was assumed. The heat flux profile shows that the heat entering the top surface is conducted mainly by the in-plane fiber and the out-of-plane fiber at top surface.

The sum of the heat fluxes at the nodes on the top surface, obtained from the solution of three dimensional model was found to be 2.54 W. The through thickness thermal conductivity of a 500 μm thick woven fabric composite panel using the three dimensional model obtained from this model was 0.516 W/mK. The experimental value of the through thickness thermal conductivity was found to be 0.565 W/mK. The model is seen to under predict the thermal conductivity by 8.7%. Further the solution of the effective thermal conductivity was found to be independent of the temperatures of the upper and lower surfaces. The value of the predicted thermal conductivity can be further improved by using a better geometrical model of the woven fabric unit cell, such as generating the node points through sweeping a circle along a curve to generate the sides of each cell.

The finite element model for the spherical fillers requires the generation of the micro structure of the filled composite using a vision system with image processing capability. This procedure is time consuming since it requires the manual picking of the filler regions

of each filler, since image processing procedure that can automatically recognize the centroid of each of the "blobs" (fillers) do not exist. Present state of the art vision systems can only recognize the properties of a blob after the region of interest has been narrowed down to a single feature (blob or filler). An alternative procedure that was developed in this project was found to be very successful. This procedure involves the generation of non-intersecting random circles generated in the required region until they met the criteria for the specified volume fraction. The thermal conductivity of filled composites (38% by weight of filler) was found from the finite element model to be 0.91 W/mK and 0.89 W/mK using filled regions of 1cm x 0.4 cm and 2 cm x 0.4 cm respectively. The experimentally predicted value for the through thickness thermal conductivity for a filled composite was 0.978 W/mK.

RESULTS

Table 2 lists the through thickness thermal conductivity's for the various samples obtained experimentally using the laser flash apparatus along with the weight fractions of the constituents used in the sample. Micro graphs of a composite panel made with short fibers and one with fillers are shown in Figures 7 and 8 respectively. The composite with silver coated ceramic micro spheres has the highest through thickness thermal conductivity but it is very brittle and cannot be used for this particular application. The composite with short fibers and fillers has a relatively high through thickness thermal conductivity and is tougher.

The presence of a resin rich layer reduces the through thickness thermal conductivity of the 500 μm thick woven fabric composite panel. Due to this there are no continuous heat conduction paths. Hence the 400 μm thick woven fabric composite panel has a higher through thickness thermal conductivity than the 500 μm thick woven fabric composite panel. The fibers are well dispersed in the short fiber composite panel. This leads to more conduction paths and a higher through thickness thermal conductivity than in the 400 μm thick woven fabric composite panel.

CONCLUSION

The presence of excess resin adversely affects the conductivity of a woven fabric composite due to which the through thickness conductivity of the 400 μm thick panel was

better than the 500 μm thick panel. The through thickness conductivity of the panel with short fibers alone was better than that of the woven cloth panel. This is because the short fibers are closely packed leading to a large number of conducting paths. The panel with the fillers has the highest thermal conductivity but is extremely brittle. Taking the stiffness and the through thickness thermal conductivity into consideration the composite with fillers and short fibers offers a better balance of properties.

The finite element model developed for *a priori* prediction of the through thickness thermal conductivity of the composite panels is a very powerful tool that can save enormous prototyping times and associated costs. The models for the thermal conductivity of woven fabric unit cell and a composite with ceramic micro-spheres were developed and compared with experimentally predicted values and agreed within errors the geometric model and an accurate representation of the actual micro structure. This approach could be further developed using automatic image processing algorithms to represent the true micro structure and would save tremendous efforts involved in typical prototyping required.

REFERENCES

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COMPOSITE	WOVEN CLOTH	SHORT FIBERS	FILLERS
Panel (1)	X	--	--
Panel (2)	--	X	--
Panel (3)	--	--	X
Panel (4)	--	X	X
Panel (5)	X	X	X

X : present

-- : absent

Table 1 : Composites considered in the design of the panel.

SAMPLE	THROUGH THICKNESS THERMAL CONDUCTIVITY (W/ cm K)	WEIGHT PERCENT OF THE CONSTITUENTS OF THE COMPOSITE
* Continuous Woven Cloth (500 μ m thick)	0.00565	39.8 %
Continuous Woven Cloth	0.00612	41 %
Short Fibers	0.00654	42.5 %
Woven unit cells	0.00528	40.5 %
Fillers	0.00978	38 %
Short fibers and fillers	0.00818	Fillers + short fibers: 41.5% Fillers ~ 20 % Short Fibers ~ 20 %

* All samples except * are 400 μ m thick.

Short fibers, fillers and woven unit cells	0.00437	Short fibers fillers and cells : 38 % Equal quantity of each constituent was initially used.
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Table 2 : Experimentally determined through thickness thermal conductivity's for the various samples.

Figure 1: Composite panel supporting and conducting heat from a silicon wafer

Figure 2: Stages in the fabrication of the panels with the fiber forms

Figure : Schematic of the fabrication of the composite panel with woven fiber cells

Figure 4: Micro graph showing the geometry of the woven fabric unit cell in the consolidated composite

Figure 7 : Micro graph of the composite panel made by consolidating short fibers in the resin

Figure 8: Micro graph of the composite panel made by consolidating fillers in the resin.

APPENDIX A

THREE DIMENSIONAL MODEL GEOMETRY

The cross-section of the fibers are assumed to be square. Consider a fiber that is along the X-axis as shown in the Figure. The fiber cross-section has a height and width of d that is half the thickness of the panel. The angle q was measured off the micrograph to be 15° .

$$b = \left(\frac{d}{\tan(q)} \right)$$

Triangles ABC and BCD are right angled, hence $q=p$. Therefore

$$c = d * \tan(q)$$

Hence

$$a = \left(\frac{1 - c - b}{2} \right)$$

The parameters a, b, c, d, q and the thickness t of the woven cloth define the 3-D geometry completely.

APPENDIX B

THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF WOVEN UNIT CELL

3-D Finite element mesh for the fibers in a unit cell of woven cloth

3-D Finite element mesh for the resin in the unit cell of the woven cloth

APPENDIX C

AUTOMATED TWO-DIMENSIONAL FINITE ELEMENT ANALYSIS OF FILLED COMPOSITES

The two dimensional finite element analysis was automated by developing an algorithm which generated the position of fillers to a specified volume fraction in a region. The algorithm ensured that the fillers did not intersect. The corresponding finite element code was also generated automatically. The thermal conductivity determined by the finite element model was found to be independent of the size of the region and was also close to the experimentally determined values. The concept demonstrated is extremely valuable, since one does not have to manually generate the finite element code for each volume fraction and representative micro structure. The model however does rely on the accuracy of the thermal conductivity of the fillers, which was assumed constant for the present model.

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MP,kzz,2,.50096
MP,KXX,3,.467169
MP,kyy,3,.0368
MP,kzz,3,.0368
MP,KXX,4,.0368
MP,kyy,4,.0368
MP,kzz,4,.46717
MP,KXX,5,.002

SAVE

** Dividing lines into segments for meshing***

LDVS,ALL,,1				
LDVS,	87,	0.	,	3, 1.000000
LDVS,	70,	0.	,	3, 1.000000
LDVS,	68,	0.	,	3, 1.000000
LDVS,	103,	0.	,	3, 1.000000

K,,,.5

K,,1,.5

K,,1,.5,1

K,,,.5,1

L, 51, 6

L, 50, 7

KPLOT

L, 52, 49

L, 52, 5

L, 8, 49

LPLOT

L, 49, 50

L, 51, 50

L, 52, 51

AL,P44A, 6

	109	81	87	58	106	113
--	-----	----	----	----	-----	-----

AL,P44A, 6

	109	84	95	3	110	108
--	-----	----	----	---	-----	-----

AL,P44A, 6

	110	1	69	29	107	111
--	-----	---	----	----	-----	-----

AL,P44A, 6

106	54	103	35	107	112				
AL,P44A,	4								
113	108	111	112						
lplot									
VA,P44A,	10								
54	70	18	26	12	71	72	73	74	75

```

lplot
LDVS, 113, 0. , 3, 1.000000
LDVS, 112, 0. , 3, 1.000000
LDVS, 111, 0. , 3, 1.000000
LDVS, 108, 0. , 3, 1.000000
LDVS, 109, 0. , 1, 1.000000
LDVS, 106, 0. , 1, 1.000000
LDVS, 107, 0. , 1, 1.000000
LDVS, 110, 0. , 1, 1.000000
save
/eof

```

```

dimension u(100),v(100),cr(100,4),ct(4),r(100)
c    ** PROGRAM TO RANDOMLY GENERATE FILLERS AND WRITE AN ANSYS INPUT
C    FILE *****
C    **** SYMBOLS *****
C    ***** vf= VOLUME FRACTION OF FILLERS IN COMPOSITE *****
C    **** RA ana RB : DIMENSIONS of SAMPLE AREA *****
C    **** n: NUMBER OF RANDOM NUMBERS GENERATED BY MATLAB *****
read(*,*) vf,n,ra,rb
c    **** L: NUMBER OF FILLERS GENERATED *****
l=1
i=0
c    *reading the matlab generated nos. and converting to sample size*
do 45 k=1,n
read(*,*) u(k),v(k),r(k)
c    *u,v,r : X, Y COORDINATES AND RADIUS Of Kth FILLER *****
u(k)=ra*u(k)
v(k)=rb*v(k)
45  r(k)=0.4-0.1*(1-r(k))
c    **** CHECKING WHETHER FILLEER IS IN SAMPLE AREA *****
lm=0
1    i=i+1
if(i.gt.n) goto 100
c    **** WRITING COORDINATES AND RADIUS INTO SINGLE ARRAY ct *****
ct(3)=r(i)
ct(2)=v(i)
ct(1)=u(i)
if (ct(1).le.0) goto 1
if(ct(1).ge.ra) goto 1
if(ct(2).ge.rb) goto 1
if(ct(2).le.0) goto 1
if(ct(3).le.0) goto 1
aa=ct(3)+ct(1)
bb=ct(3)+ct(2)
cc=-ct(3)+ct(2)
dd=-ct(3)+ct(1)
if(aa.gt.ra) goto 1
if(bb.gt.rb) goto 1
if(cc.lt.0) goto 1
if(dd.lt.0) goto 1
lm=lm+1
if(lm.gt.1) goto 1111
c    *** IF FILLER IN SAMPLE THEN CHECKING WHETHER THIS FILLER OVERLAPS
C    WITH PREVIOUS FILLERS *****
cr(1,1)=u(i)
cr(1,2)=v(i)
cr(1,3)=r(i)
1111 do 10 k=1,l
c    ***** CHECKING WHETHER VOLUME FRACTION EXCEEDED *****
10  f=f+22*(cr(k,3)**2)/7
if(f.ge.vf) goto 100
do 30 k=1,l
a=(cr(k,1)-ct(1))**2
b=(cr(k,2)-ct(2))**2
d=sqrt(a+b)
rq=abs(cr(k,3)-ct(3))
if (d.le.rq) goto 1
rqq=cr(k,3)+ct(3)
if(d.le.rqq) goto 1
30  continue
l=l+1
cr(1,1)=u(i)
cr(1,2)=v(i)
cr(1,3)=r(i)
goto 1
c    **** ANSYS INPUT FILE *****
100 write(*,*)'/prep7/'

```

```

write(*,*)'kan,-1'
write(*,*)'et,1,35'
c ***** MATERIAL DATA INPUT *****
write(*,*)'mp,kxx,1,0.2'
write(*,*)'mp,kxx,2,0.000128'
do 120 k=1,1
write(*,*) 'K','k','','',cr(k,1),'','',cr(k,2)
120 continue
write(*,*)'mat,1'
do 121 k=1,1
write(*,*) 'circle','k','','',cr(k,3)
write(*,*) 'al','4*k-3','','',4*k-2,'','',4*k-1,'','',4*k
121 continue
c ***** DIVIDING LINES FOR MESHING *****
write(*,*) 'ldvs,all,,5'
ll=1*5
write(*,*)'K','',''
write(*,*)'K','','',ra','',''
write(*,*)'K','','',ra','','',rb
write(*,*)'K','','',rb
write(*,*)'l','','ll+1','','',ll+2
write(*,*)'l','','ll+2','','',ll+3
write(*,*)'l','','ll+3','','',ll+4
write(*,*)'l','','ll+4','','',ll+1
l2=4*1
c *Area commands*
write(*,*) 'al','','l2+1','','',l2+2,'','','l2+3,'','','l2+4
nsa=1+1
i=1
c ***** SUBTRACTING FILLER AREAS FROM RESIN AREA *****
write(*,*)'asba','','nsa','','',i
ns=nsa+1
if(i.eq.1) goto 1256
nsa=nsa+1
i=i+1
write(*,*)'asba','','nsa','','',i
ns=1
if(i.eq.1) goto 1256
nsa=1
do 131 i=3,1
write(*,*)'asba','','nsa','','',i
if (nsa.ge.2) goto 132
ns=2
nsa=nsa+1
goto 131
132 nsa=1
ns=1
131 continue
1256 write(*,*) 'save'
c ***** MESHING *****
write(*,*)'ldvs,all,5'
write(*,*) 'amesh,ns'
write(*,*) 'save'
do 133 i=1,1
write(*,*)'al','','i','','',i+1,'','','i+2,'','','i+3
133 continue
write(*,*)'ldvs,all,5'
write(*,*)'mat,1'
135 do 136 i=1,1+1
if (ns.eq.i) goto 136
write(*,*)'amesh','i
136 continue
write(*,*)'save'
c ***** BOUNDARY CONDITIONS *****
write(*,*) 'nsel,y,0.4'

```

```
write(*,*) 'nall'  
write(*,*) 'nse1,y,0'  
write(*,*) 'd,temp,0'  
write(*,*) 'nall'  
write(*,*) 'finish'  
*Solution*  
  write(*,*) '/solul'  
  write(*,*) 'solve'  
write(*,*) 'finish'  
write(*,*) 'save'  
write(*,*) '/eof'  
end
```

c