Application of Nanomaterials for Thermal Dissipation

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Outline

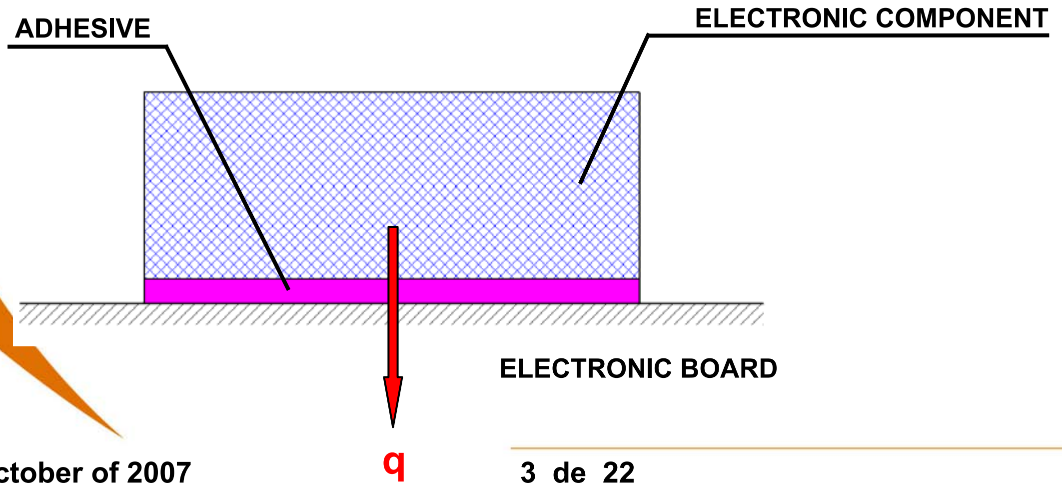
- Introduction
- Objective
- Modelling. FEM analysis
- Experimental
- Influence of manufacturing process on final properties
- Conclusions

Introduction

- High temperatures in electronic components
- Heat evacuated through conduction towards radiator(s)
- Good conductivity needed all the way. Adhesive's conductivity is critical

The aim of the THERDISS project (supported by ESA) is to conduct **research in nanocomposites** to be used **to dope adhesives for space conditions**. Thus, it is expected that the finally selected nanocomposite can **multiply at least by a factor of 3 the thermal conductivity of a standard epoxy solution**.

Objective



$$K_{adhesive} = 0{,}21 \frac{W}{mK}$$

NANOMATERIALS

$$K_{objective} = 6 \div 10 \frac{W}{mK}$$

Methodology

- MODELLING

  How much nanomaterial is needed to reach $K_{objective}$

- EXPERIMENTAL

  Real mix of nanomaterials and adhesive. Measurements.

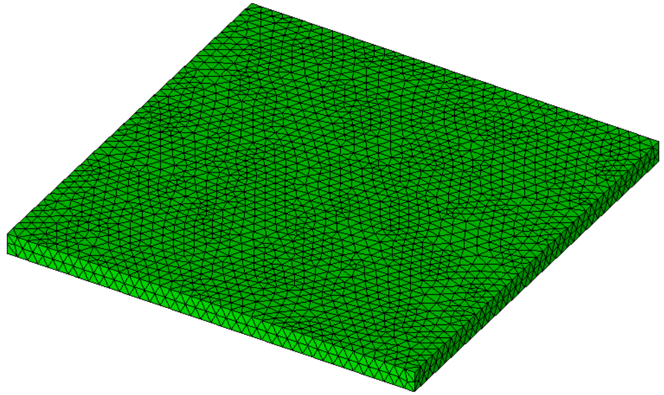
✓Commercial **non conductive** Hysol EA epoxy adhesive. K=0,2W/mk

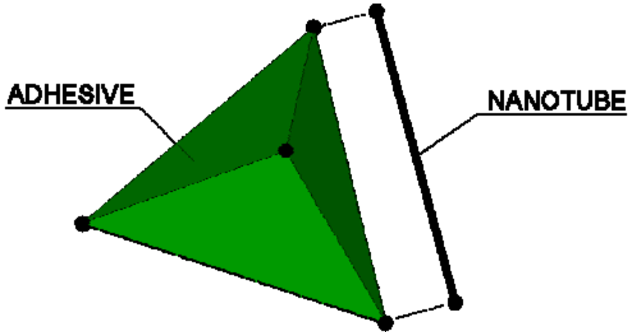
•Commercial **conductive** epoxy adhesive. K=2W/mk

Modelling. Finite Element Methods

1. Mesh the model with commercial software
   - Take into account the nano-material length
2. Export the mesh topology to an ASCII file
3. Add randomly the nanoparticles to the original mesh trough THERDISS in house developed software
   - According to the weight percentage
   - According to the properties of the nanomaterials
4. Establish the boundary conditions trough THERDISS
   - Surface temperatures
5. Solve the case with commercial software
   - The program calculates the heat flow q
6. Calculate the equivalent thermal conductivity by,

$$q = K_{eq} \cdot \frac{A}{d} \cdot \Delta T \rightarrow K_{eq} = \frac{q}{\Delta T} \cdot \frac{d}{A}$$

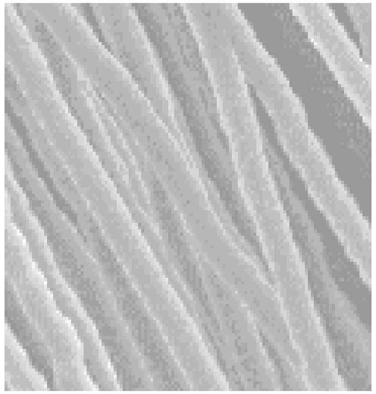
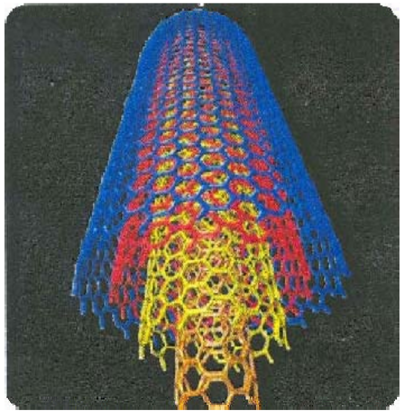
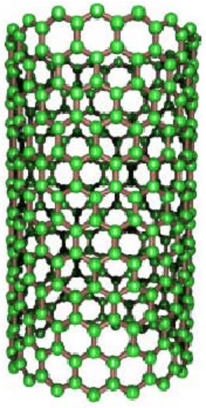
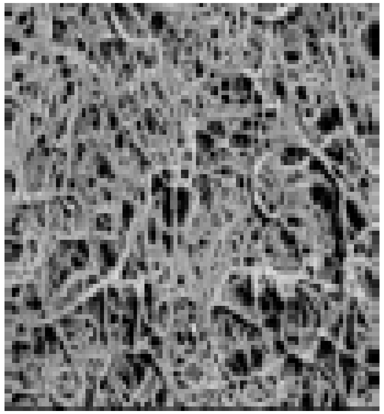




Materials

NANOMATERIALS

CNF	MWNT	SWNT	BUCKYPAPER

TYPE	Ø (m)	L (m)	K (W/mK)	ρ (kg/m^3)	Th. (m)
CNF	1.00E-07	1.00E-04 5.00E-05	1200	2100	-
MWNT	2.00E-08	4.00E-05 5.00E-07	3000	1350	-
SWNT	1.20E-09	4.00E-05 5.00E-07	1750 – 5800 3775 (mean)	1350	-
BUCKYPAPER	1.50E-08	2.00E-05 5.00E-06	1200	500	1.00E-4 5.00E-5

ADHESIVE

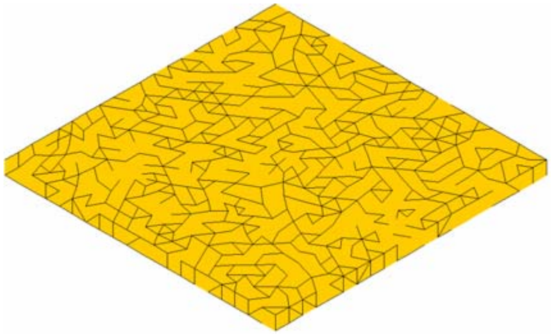
MATERIAL	K (W/mK)	ρ (kg/m^3)
HYSOL EA 9396	0.21	1150

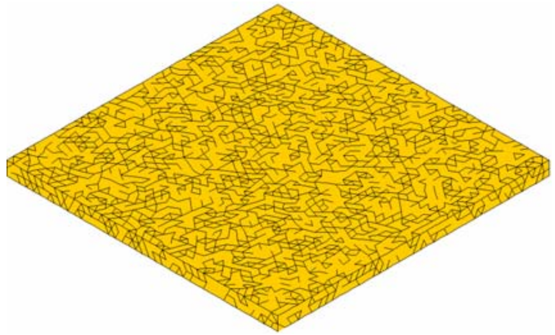
Finite Element Models

FEM 01 and FEM 02

	FEM 01	FEM 02
NANOMATERIAL	CNF	
DIAMETER (m)	100.E-9	
LENGTH (m)	100.E-6	50.E-6
W. PERCENTAGE (%)	0.1 ÷ 50	

SCALED MODEL	NO	
SCALE	-	
FEM DIMENSIONS (mm)	2 x 2 x 0.1	

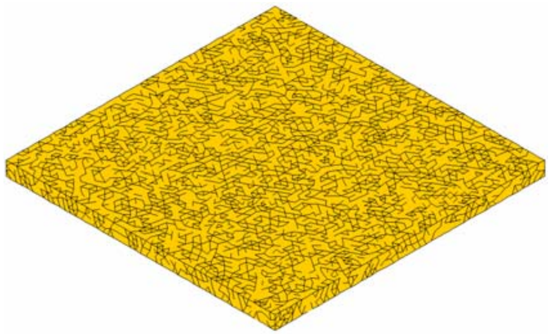




FEM 03 and FEM 04

	FEM 03	FEM 04
NANOMATERIAL	MWNT	
DIAMETER (m)	20.E-9	
LENGTH (m)	40.E-6	500.E-9
W. PERCENTAGE (%)	0.1 ÷ 50	

SCALED MODEL	NO	YES
SCALE	-	1000 / 1
FEM DIMENSIONS (mm)	2 x 2 x 0.1	20 x 20 x 100

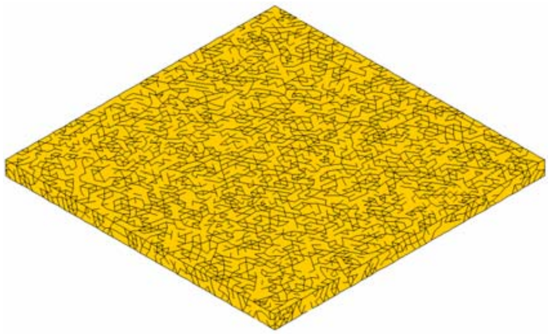


Finite Element Models

FEM 05 and FEM 06

	FEM 05	FEM 06
NANOMATERIAL	SWNT	
DIAMETER (m)	1.2.E-9	
LENGTH (m)	40.E-6	500.E-9
W. PERCENTAGE (%)	0.1 ÷ 50	

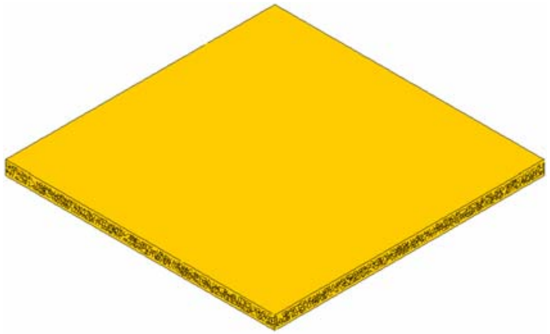
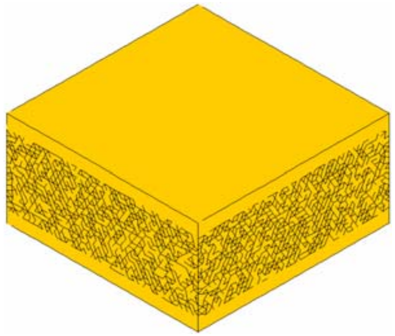
SCALED MODEL	NO	YES
SCALE	-	1000 / 1
FEM DIMENSIONS (mm)	2 x 2 x 0.1	20 x 20 x 100



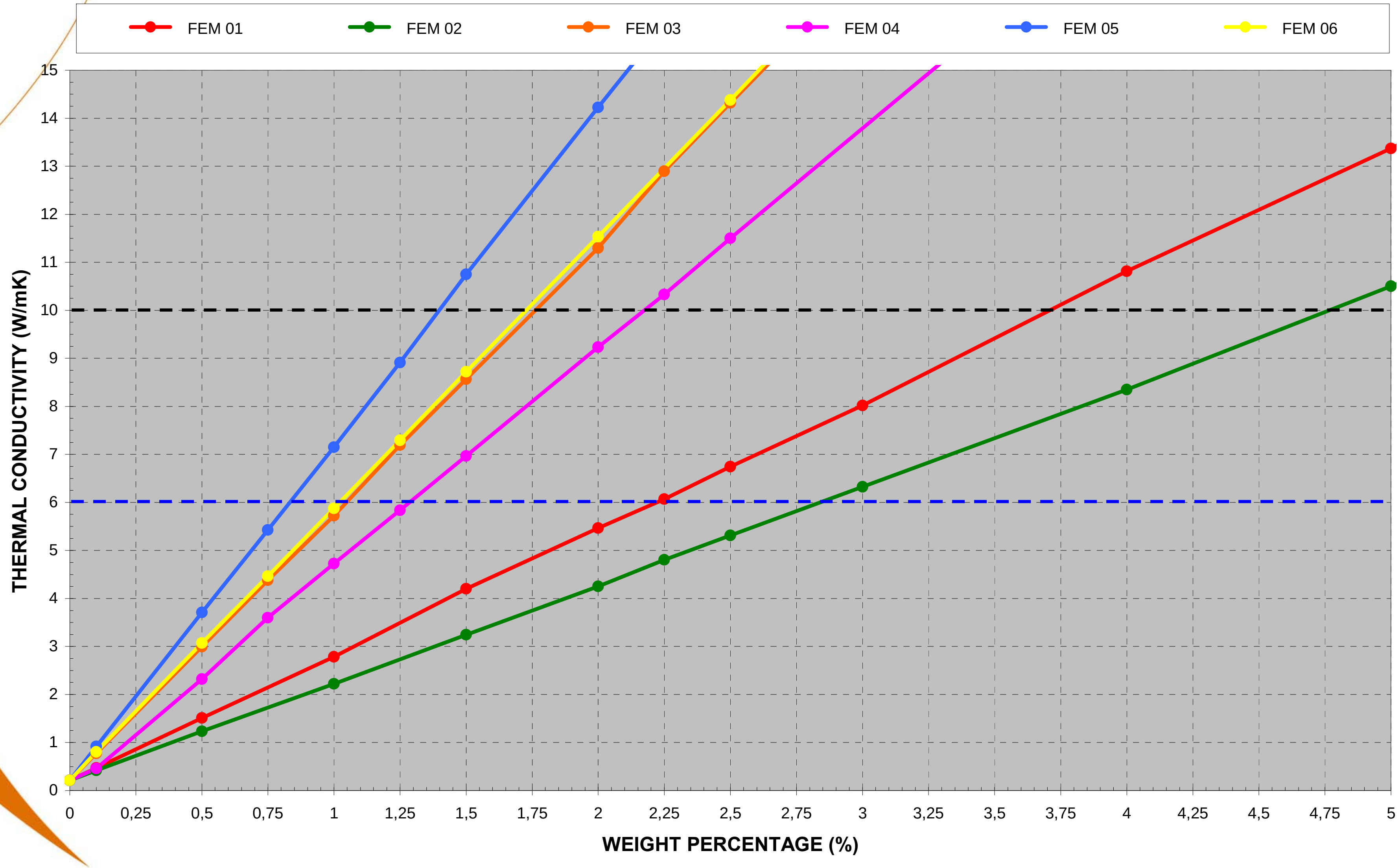

FEM 07 and FEM 08

	FEM 07	FEM 08
NANOMATERIAL	BP	
DIAMETER (m)	15.E-9	
LENGTH (m)	20.E-6	5.E-6
W. PERCENTAGE (%)	19.79 ÷ 36.33	

SCALED MODEL	NO	YES
SCALE	-	1000 / 1
FEM DIMENSIONS (mm)	2 x 2 x 0.1	200x200x100

Results for fibrous shaped nanomaterials



Experimental

Nanomaterials

CNF

Dispersion	SWNT <	MWNT <	CNF
Thermal properties	≈	≈	≈
Prize	SWNT>	MWNT>	CNF

Simulation: Ideal conditions

$$K_{adhesive} = 0{,}21 \frac{W}{mK} + \textbf{2.5 wt\% CNF} \longrightarrow K_{objective} = 6 \div 10 \frac{W}{mK}$$

Filler adition technology set up

Hardener ↓

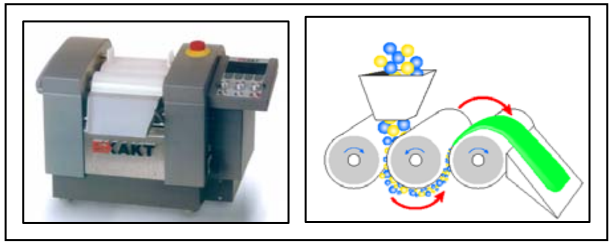
Epoxy resin → mixing → casting → defoaming → Curing ↓

Resin specimen

Nanoparticles ↓ Hardener ↓

Epoxy resin → DISPERSING → Mixing under vaccum → casting → defoaming → Curing ↓

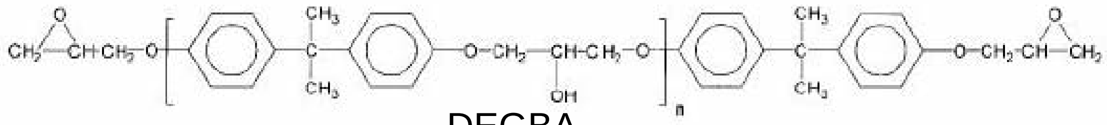
NANOADHESIVE



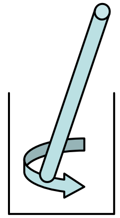
Three roll mill

Work Methodology

Manual Premix: CNF (2,5wt%) + Epoxy Part A

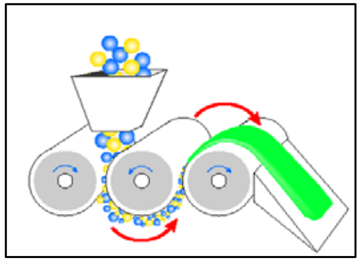


DEGBA



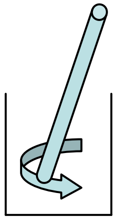
Dispersion device: Three roll mill

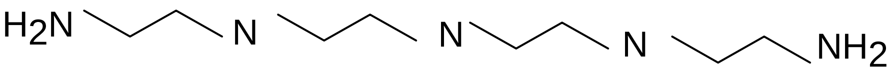
Control parameters: Gap and residence time



Degassing

Hardener Part B





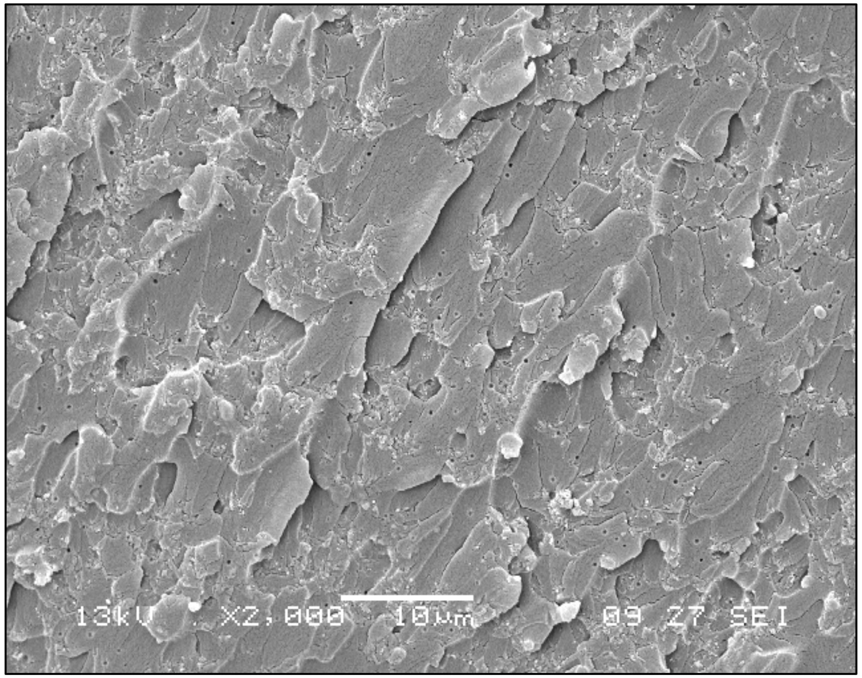
Aliphatic Amine

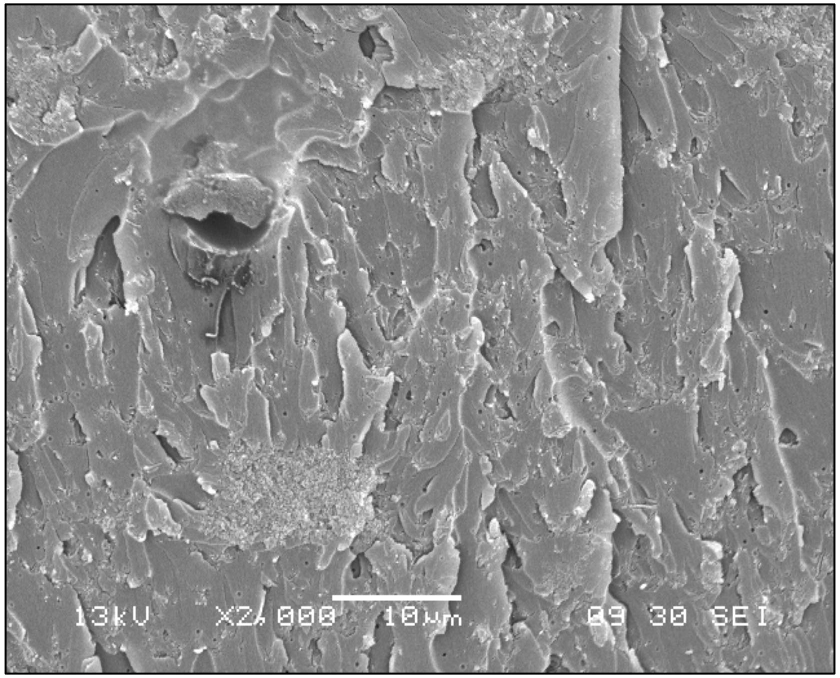
Curing

NANOADHESIVE

Nanoadhesive Morphology

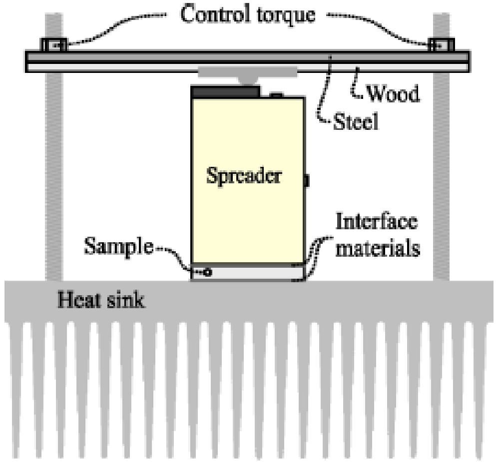
CNF distribution into the polymeric matrix



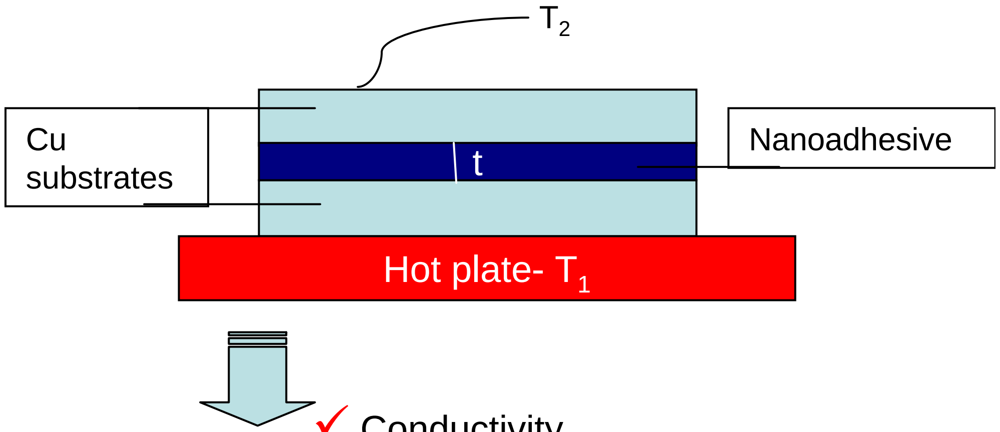


Thermal Conductivity Results

Guarded hot plate method	Termocouple method



Mechanical assembly



- ✓ Conductivity
- ✓ Mechanical test

Results. Guarded Hot plate

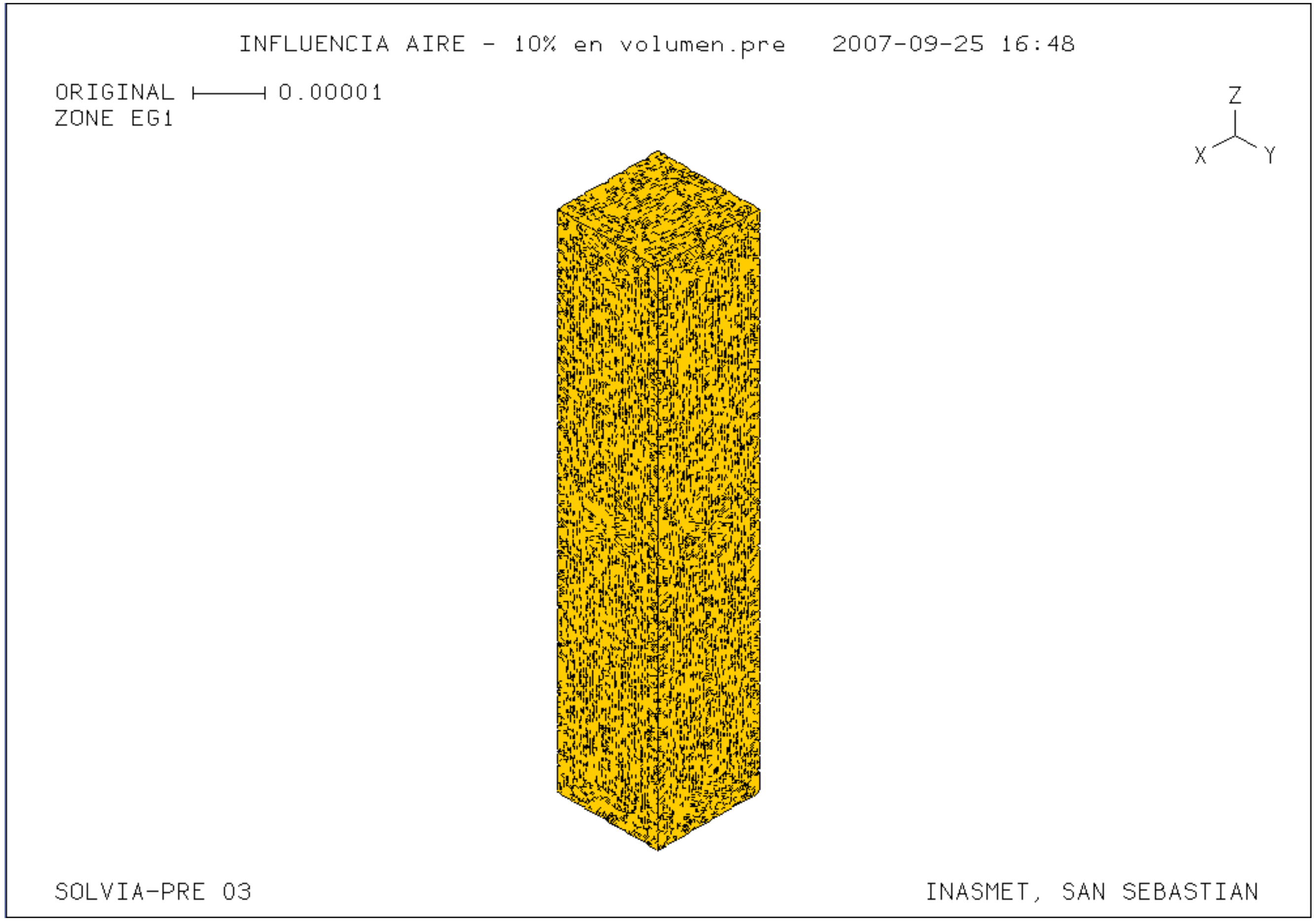
$$K_{adhesive} = 0{,}21 \frac{W}{mK}$$

$$K_{nanoadhesive} = 0{,}5 \frac{W}{mK} \neq K_{objective} = 6 \div 10 \frac{W}{mK}$$

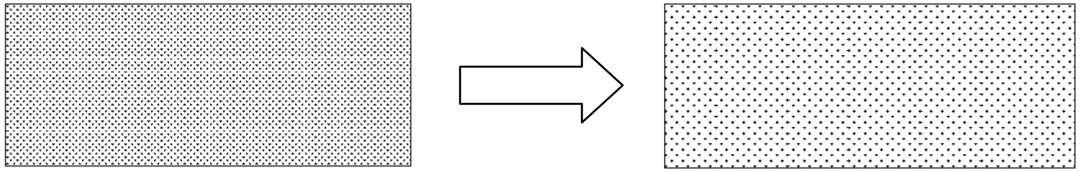
INFLUENCE OF LACK OF DISPERSION, AIR PRESENCE AND NO CONTACT

Influence of air presence on the thermal conductivity

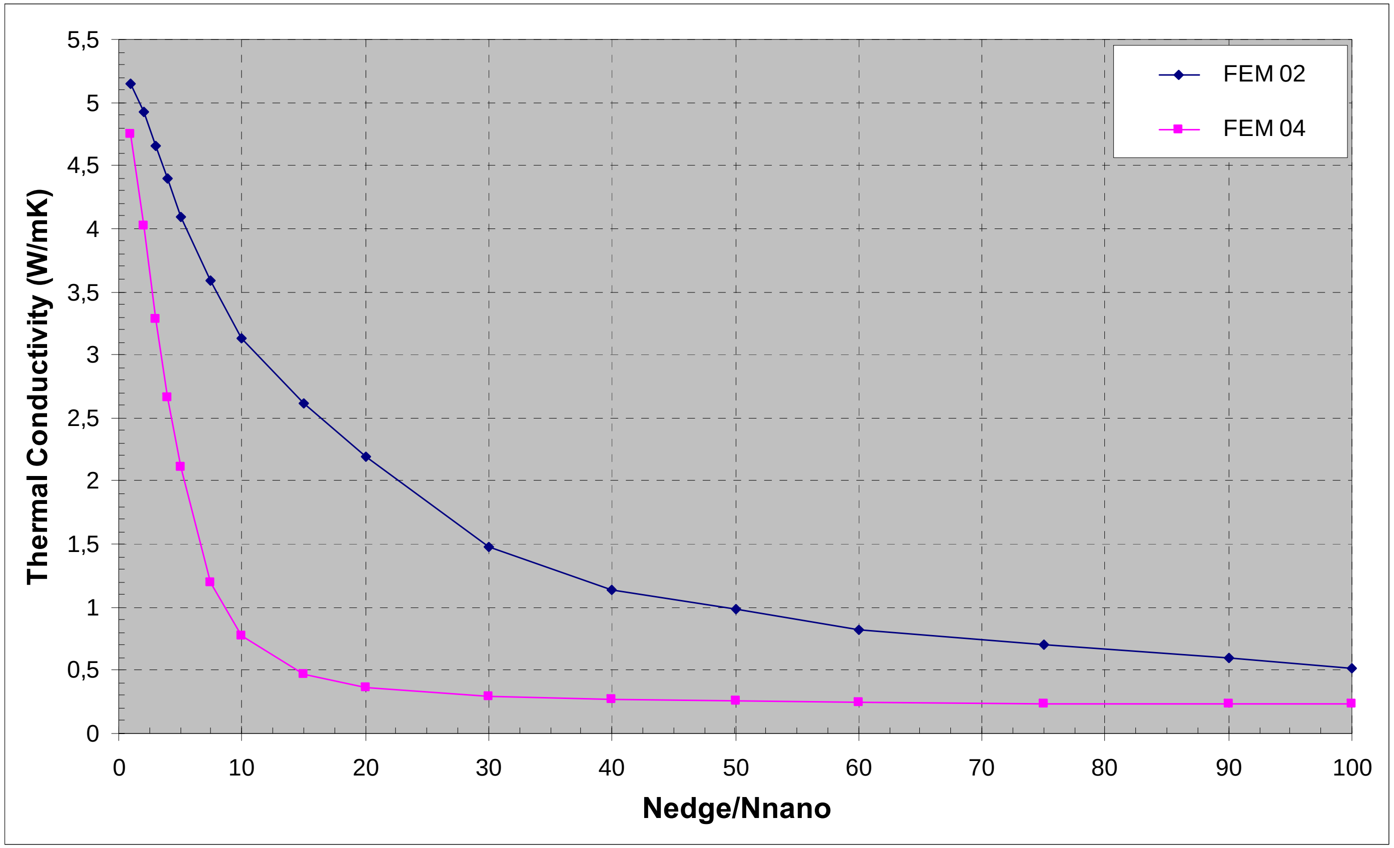
MODEL	K (W/mK)	
	FEM 02	FEM 04
WITHOUT AIR	5,15	4,75
1% AIR	5,10	-
10 % AIR	-	4,24



Influence of lack of dispersion on the thermal conductivity

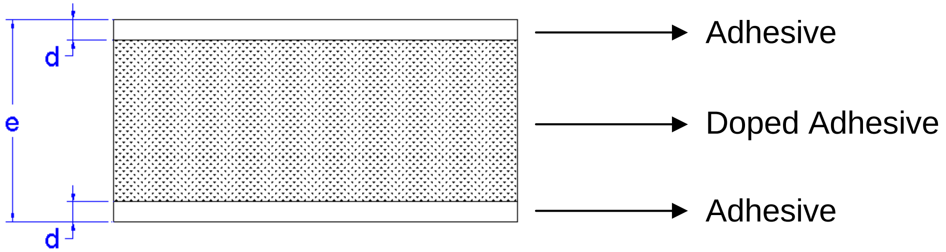


Nedge Nnano	K (W/mK)	
	FEM 02	FEM 04
1	5,15	4,75
2	4,93	4,02
3	4,66	3,29
4	4,39	2,66
5	4,09	2,12
7,5	3,59	1,20
10	3,13	0,77
15	2,61	0,47
20	2,19	0,37
30	1,48	0,30
40	1,14	0,27
50	0,98	0,26
60	0,82	0,25
75	0,71	0,24
90	0,59	0,23
100	0,52	0,23

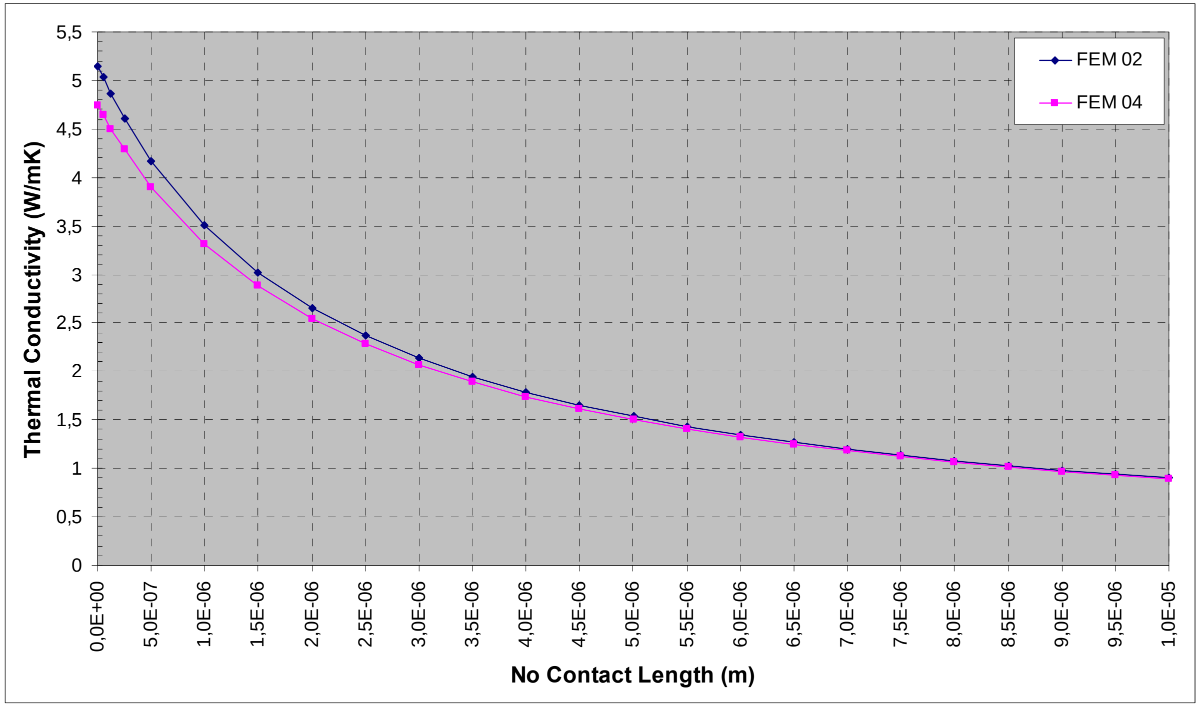


Influence of no contact on the thermal conductivity

NO CONTACT BETWEEN THE NANOELEMENTS AND THE ELECTRONIC COMPONENT

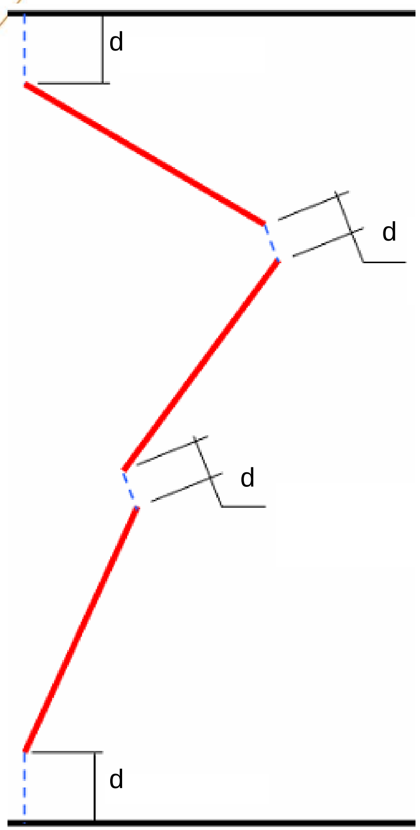


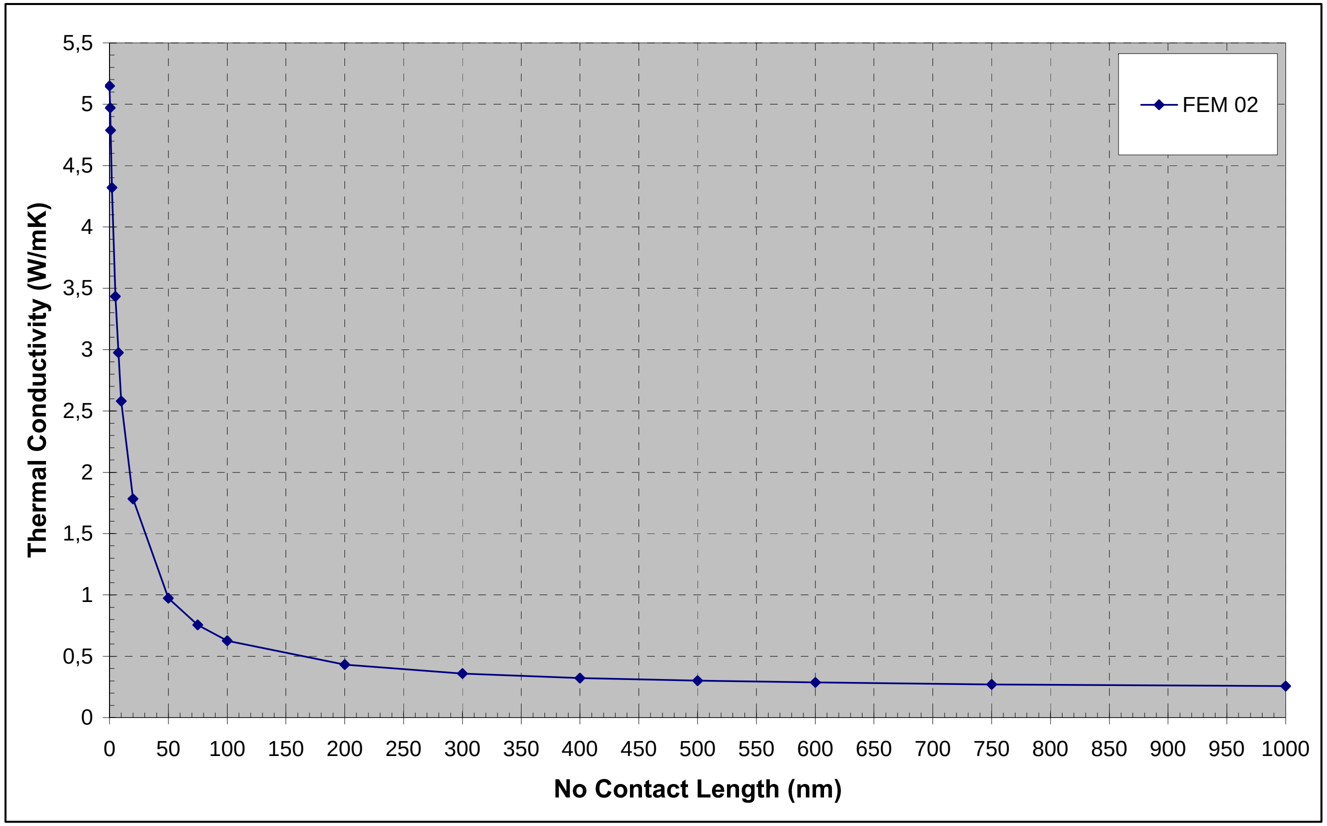
d (m)	K (W/mK)	
	FEM 02	FEM 04
0,00E+00	5,15	4,75
1,00E-06	3,50	3,31
2,00E-06	2,65	2,55
3,00E-06	2,14	2,07
4,00E-06	1,79	1,74
5,00E-06	1,54	1,50
6,00E-06	1,35	1,32
7,00E-06	1,20	1,18
8,00E-06	1,08	1,07
9,00E-06	0,98	0,97
10,0E-06	0,90	0,89



Influence of the no contact on the thermal conductivity

NO CONTACT BETWEEN THE NANOELEMENTS

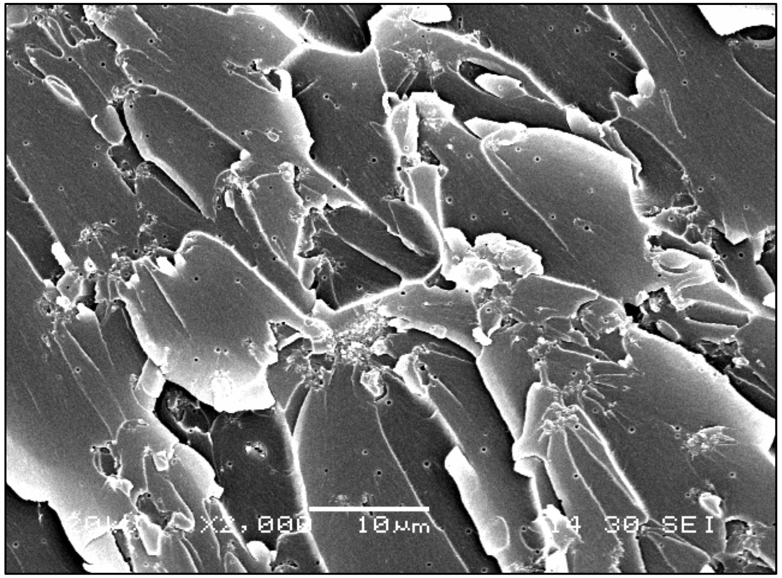




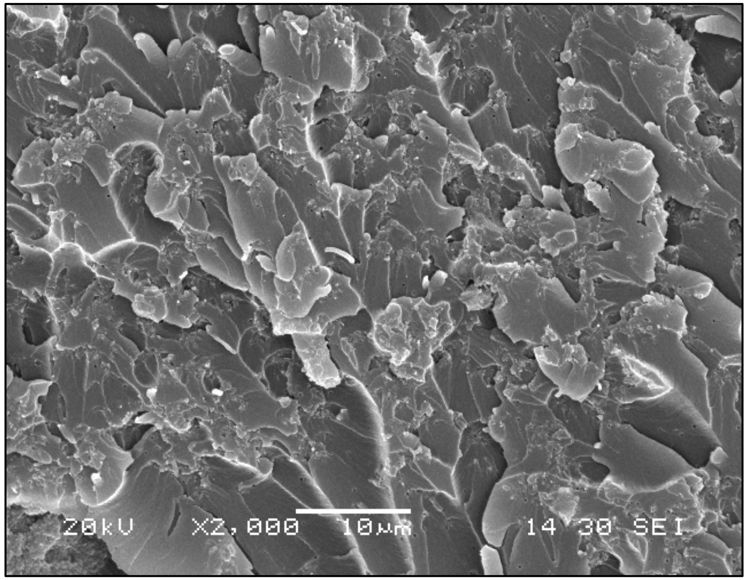
Strategies to improve thermal conductivity. Synergic effect

Boron nitride + fibrous nanomaterials (CNF)

$$K_{Boron\ nitride} = 600 \frac{W}{mK}$$



EPOXY+BORON NITRIDE



EPOXY+CNF + BN

Conclusions

1. A methodology has been establish to predict K for doped adhesives and a FEM program has been written.

2. In the fibrous shaped nanomaterials (CNF, MWNT and SWNT), the efficiency depends mainly on the orientation of the nanoparticles, as well as the thermal conductivity of the nanomaterials.

3. Good CNF dispersion into the polymeric matrix was achieved using the three roller mill device.

4. Thermal conductivity increases to 0.5 W/mk using 2.5 wt% of CNF. This result is in concordance with the simulation in which the main condition is that no contact between the nanoelements takes place.

5. Adding boron nitride the contact among conductive elements was increased (SEM images), therefore the thermal conductivity could be increased.

6. **New and promising results are being obtained that assure succesful final for the project**

Thanks for your attention!