Frequently Asked Questions About CarbAl™

1. What is a general description of the two CarbAl material types: CarbAl-G & CarbAl-N

Graphite is well known in the industry to have great thermal properties, but is also very brittle, making it useful for only a limited number of applications. Applied Nanotech has developed two novel graphite composite materials incorporated into CarbAl™ family:

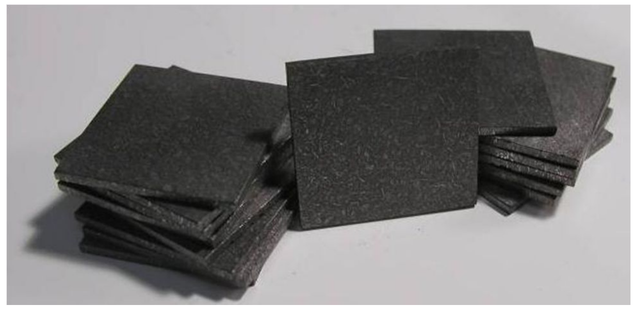

Figure 1: Samples of CarbAl™-N thermal management material. (80% graphite / 20% aluminum).

a) **CarbAl™-N**, a composite of graphite and aluminum shown in Figure 1, which leverages the benefits of the thermal properties of graphite with the mechanical stability and robustness of aluminum, at a cost suitable for use in high volume consumer electronics. , CarbAl™-N is a porous graphitic matrix which is impregnated with a specially doped molten aluminum alloy at high pressures to create a smooth thermal interface between the graphite and the aluminum. The impregnation of the metallic component into the pores of the graphite matrix is achieved by a proprietary process that we have developed, utilizing specially designed custom manufacturing equipment, capable of injecting molten metals at high pressures into the pores of graphitic materials. Special additives are used to secure a compatible nanometric thermal interface between the aluminum in the filled pores and the surrounding graphitic material.

b) **CarbAl™-G** is a designed thermal management material based on a graphite matrix. CarbAl™-G has a good combination of physical and chemical properties at a much lower cost. Furthermore, prime materials for CarbAl™-G are available now in substantial volume. ANI can provide CarbAl™-G presently at a quantity up to 8 tons per year.

2. What is the physical composition of CarbAl™?

The graphite matrix is an integral part of CarbAl™ family products. The graphite is manufactured from high quality needle coke materials that align the crystalline structure preferentially in one direction under high pressure and temperature. By using graphite with plate thicknesses in the range of 50nm to 100nm, we maintain the thermal properties of graphite at a cost that is suitable for the high volume consumer markets. The orientation of the graphitic plate gives the directionality of the most efficient heat transfer.

3. What is the method of construction for CarbAl™

- CarbAl-G is made from graphitic material by an extrusion method in the form of cylinders of desired length and diameter of 450 mm.
- CarbAl-N is manufactured started with CarbAl-G and then infused with molten aluminum at high pressure (Figure 2).

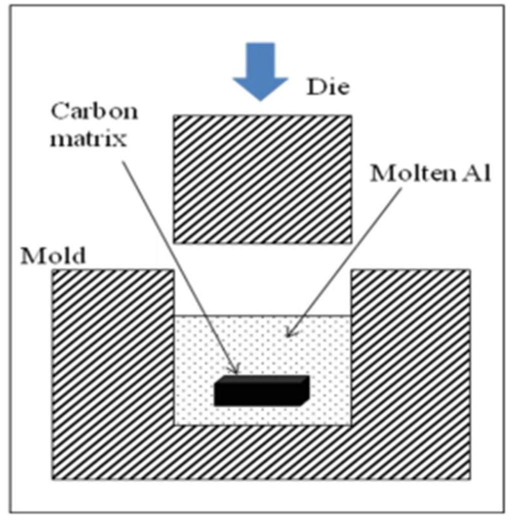

Figure 2: Process for infusing molten aluminum into the CarbAl™ carbon matrix.

4. What are the material properties of CarbAl™?

Thermal Conductivity

CarbAl™ has a preferred direction for highest thermal conductivity.
- CarbAl-N = preferred direction = 425-450 W/mK , perpendicular to the preferred direction 200 W/mK.
- CarbAl-G = preferred direction = 350-400 W/mK , perpendicular to the preferred direction 180 W/mK.

Below is the table that compares CarbAl properties with the properties of other thermal management materials.

Material	Density (g/cm^3)	CTE (ppm/K)	Thermal Conductivity (W/m-K)	Thermal Diffusivity (cm^2/sec)	Bend Strength (MPa)	Young's Modulus (GPa)	Relative Cost
AlSiC	3	7 - 9	170 - 200	0.88	450	290	$
CuW (10-20% Cu)	15.7-17.0	7 - 8	180 - 200		1172	367	$$$
CuMo (15-20% Mo)	10	7 - 8	160 - 170			313	$$$
Cu	8.96	17.8	398	1.1	330	131	$
Al	2.7	23.6	238	0.84	137 - 200	68	<<$
SiC	3.2	2.7	200 - 270	0.5	450	415	$$
AlN	3.3	4.5	170 - 200	1.47	300	310	$$
Beryllia	3.9	7.6	250		250	345	$$$
Poco Graphite	0.9	1.02	245	-	2.7	-	$$
KFoam	0.48	0.69	220	0.48	2.1	-	$$
CVD Diamond	3.5	1 - 2	500 - 2200	10.5			$$$$$$
CarbAl™-N	**2.1**	**7**	**400-450**	**2.78**	**40**	**12**	**$**
CarbAl™-G	**1.75**	**2.0**	**180- 400**	**2.9**	**24**	**-**	<<$

Coefficient of Thermal Expansion (CTE)

- CarbAl-G 2 ppm/K
- CarbAl-N 7 ppm/K

Operating temperature range

As graphite we do not see any issue in the temperature range between -50° C and 500°C (still need to check moisture absorption and freezing).

Modulus

The Young modulus for CarbAl-N is 12 GPa.
Observations: in some applications, when mechanical strength is necessary, we can laminate CarbAl with aluminum or copper (Attachment 4).

Poisson's ratio

Not available.

Density

- GarbAl-G - 1.75 g/cm3
- CarbAl-N - 2.1 g/cm3

Specific heat

Measured by a customer, 0.75 J/gK
m. Flammability
Not flammable.

Electrical resistivity

The electrical resistivity is like a graphitic material, approximately 10(-5) ohm-cm, but in any case lower than 5 µohm-cm.

The material should be considered a conductor, not an insulator. For applications that need an electrically insulating surface, a thermally-conductive, electrically-insulator coating is available.

What are standard CarbAl thickness and sizes?

CarbAl ™ is easily machined. Due to some porosity, the lowest thickness we recommend is:
- CarbAl-G - 1 mm
- CarbAl-N - 0.75mm

Related to cross-section:

- CarbAl-N – The maximum physical dimensions are limited by the size of the blocks we received from our subcontractor. For CarbAl the size is 6"x8"x10".
- CarbAl-G does not have the limitation above, larger sizes are available.

What are CarbAl environmental conditions

In thermal cycle testing whereby we ramped the temperature continuously from -35°C to 85°C for 100 cycles, the samples did not change their morphology and did not show any signs of delamination.

Below are the temperature-dependent properties of CarbAl-G where the properties such as diffusivity, specific heat, thermal conductivity were measured from 25°C to 150°C. In the preferred Z direction the thermal conductivity was 366 W/mK showing a drop of 28% at 150°C.

Temperature	X-direction			Y-direction			Z-direction		
	Diffusivity	Specific Heat	Thermal Conductivity	Diffusivity	Specific Heat	Thermal Conductivity	Diffusivity	Specific Heat	Thermal Conductivity
(°C)	(cm^2/s)	(J/gk)	(W/mk)	(cm^2/s)	(J/gk)	(W/mk)	(cm^2/s)	(J/gk)	(W/mk)
25	1.21	0.88	200	1.07	0.91	198	2.52	0.78	366
50	1.07	0.91	183	0.94	0.92	178	2.20	0.85	340
75	0.96	0.94	168	0.85	0.95	164	1.96	0.88	312
100	0.85	0.99	157	0.76	1.01	157	1.76	0.94	300
125	0.77	1.01	146	0.69	1.04	146	1.58	0.97	276
150	0.7	1.05	137	0.62	1.07	136	1.43	1.01	262

What are the machining properties of CarbAl?

Instruction for machining CarbAl

Machining CarbAl-G

1. In principle no lubricant is necessary
2. If one wants to use lubricant to clear work piece, a lubricant can be used.
3. The material is porous, so, if lubricant is used, it must be flushed out of pores.
4. Need to use either vacuum or blow-off to clear work piece.
5. Can use high Spindle speed.
6. Can use higher feed speed than the one used for Al materials.
7. Cuts similar to light plastics.

Machining CarbAl-N

1. In principle no lubricant is necessary
2. The material is less porous but some pores are present.
3. If one wants to use lubricant to clear work piece, a lubricant can be used.
4. Need to use either vacuum or blow-off to clear work piece.
5. To reduce pull-outs of Al from the composite one must use high Spindle speed.
6. For the same reason use lower feed speed similar to the one used for Al materials.
7. Cuts similar to light plastics.

Can CarbAl be coated?

ANI has successfully developed new materials and new processes for depositing or coating these materials on CarbAl™-G such as ceramic, polymeric insulating layers, anodized aluminum films, etc. (Figur 3 shows some examples of CarbAl™-G functionalized by a number of proprietary films and processes). Furthermore, ANI has successfully metallized CarbAl™-G surfaces by metal plating ensuring in such a way CarbAl™-G compatibility to the standard soldering processes (Figur 3 (C)). The combination of excellent thermal properties of CarbAl™-G and the effective functionalization approaches of ANI offers a number of advantages for a wide variety of thermal management applications such as for LEDs, batteries, automotive engines, integrated circuits, among many others.

CarbAl™ can be plated or coated for direct solder attach.

Threaded inserts can be used.

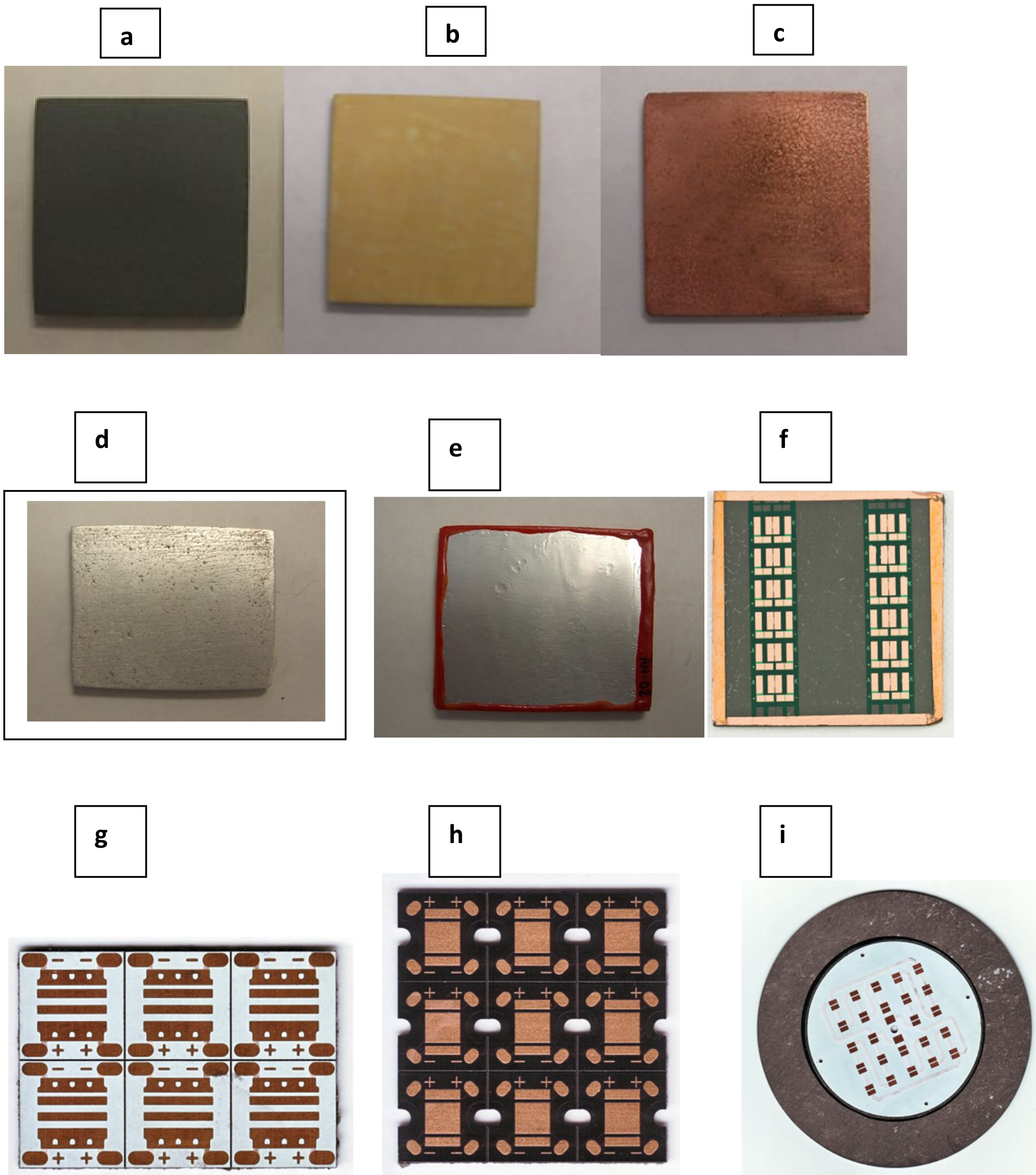

Figure 3: (a) Ceramic dielectric layer on CarbAl™- G. (b) Polymeric dielectric layer on CarbAl™- G. (c) Cu plated on CarbAl™-G. (d) Al layer evaporated on CarbAl™-G. (e) Anodizes Al layer (insulating Al oxide layer) on CarbAl™-G. (f) Fully integrated CarbAl™-G with dielectric layers and Cu metallization for packaging 12 LEDs. (g) CarbAl™-G LED printed circuit board (PCB) using copper on ceramic layer. (h) CarbAl™-G LED printed circuit board (PCB) using copper on epoxy dielectric layer. (i) CarbAl™-G printed circuit board (PCB) for multiple LEDs on ceramic having a disc shape.