Power transfer in complex shape heated moulds or functional composites

In mould curing process or composite functionalization is concerned by power exchange limitations and often requires stretchable fatigue withstanding heating circuits, because of the repeated heat cycles dilatation constraints.

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It is now widely known that in-mould curing of composites is an extremely energy-efficient and flexible method compared to oven cure.

Inserting functional layers

The use of heating pouches, more particularly made of HT rubber or other type of flexible silicone, makes it possible to adapt to complex shapes (see Figure 1) without the need for bulky equipment that takes up space, both during use and in storage.

In the same way, inserting functional de-icing, heating or monitoring circuits within composite parts brings the heat energy closer to its point of use, enabling higher efficiency compared to mechanical or warm-air heating solutions.

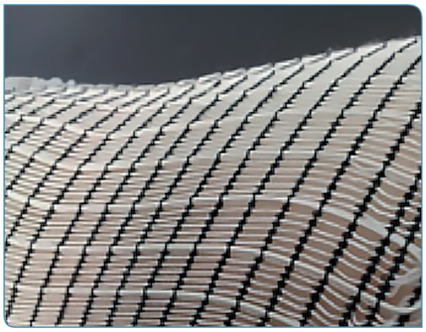

Fig. 1: Tibgrid-Stretch on complex shape

For a few years, Tibtech has been offering its Tibgrid® or Thermostretch flexible layer concept to manufacturers of composites or of heating pouches. The concept facilitates the layup of functional circuits on complex or deformable shapes. Besides the Thermotech heating yarns, these circuits can also include deformation monitoring filaments, optic fibres, and capillary networks to carry heat transfer fluids, in particular to cool and shorten the production cycles.

The three principal constraints

Within the specific framework of the composite materials treated here, we will retain only the principal constraints:

- ***fatigue strength***: the resistance to repeated bending of the heating filaments is essential in flexible composites and also very important in stiff composites. The stress of repeated expansion during the multiple heating/cooling cycles generates premature breaking of the layer's constituent filaments. A number of composite manufacturers using blankets based on thin copper alloy filaments have learned this through bitter experience. There is also a risk that hot spots form before complete rupture.

To solve this type of problem, Thermotech I filaments are designed with high intrinsic fatigue strength and are extruded into relatively thin, flexible insulating PTFE that is resistant to high temperatures and do not adhere to the final composite. This last point is essential: it allows creating a damping coefficient crosswise to offset the effects of expansion, keeping these effects from turning into a mechanical stress that could weaken the mould structure, as might occur in the case of filaments that are stiffer or adhering directly to the resin.

- ***dielectric constraints:*** for small size or functional composite, the supply voltage applied can be fairly weak (12-24 volts), with only moderate dielectric constraints. In this case, an only slightly insulated filament can be suitable within an insulating composite. But even with only 12 volts, a hot spot can be created by filament fatigue and cause

Flexible Conductive or heating yarns			family	Reference identification	Resist./m	color	count	outerwall	1 st insualtion	2nd insulation	max. temp.	max. volts	flexibility	water tight	fatigue with-standing
INSULATED WIRES	Fully insulated wires	"I" insulated	conductib	**C-Ie-0,12** Vi -XE0 - T2,6 -1,0 MF	0,12Ω	violet	2,6 g/m	1,0 mm	PTFE	-	240°C	250V	++	yes	++
				C-Ic-0,16 Gn - XC0 - T1,8 - 0,9 MF	0,16Ω	bottle green	1,8 g/m	0,9 mm	PVC	-	100°C	250 V	++	yes	++
				C-Ip-0,35 Bl-XP0 -T1,0 -0,8 HF	0,35Ω	white or black	1,0 g/m	0,8 mm	PVC	-	100°C	48V	+++	yes	++
				C-Ie-0,48 Gn - XE0 - T0,8 - 0,6 MF	0,48Ω	green	0,85 g/m	0,6 mm	PTFE	-	240°C	250V	++	yes	++
			Thermotech Hc	**T-Ie-1,8** Rd-XE0 -T3,0 -1,25LF	1,85Ω	red	3,0 g/m	1,25mm	PTFE	-	240°C	380V	+	yes	++
			Thermotech	**T-Ie-3,6** Wh-XE0 -T3,4 -1,35HF	3,60Ω	brown	3,4 g/m	1,35mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ie-4,6 Tr- XE0 -T2,6 -1,35HF	4,60Ω	translucent	2,6 g/m	1,35mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ie-7,0 Bu- XE0 -T2,3 -1,10HF	7,00Ω	blue	2,3 g/m	1,1 mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ie-9,0 Tr- XE0 -T1,4 -0,82HF	9,00Ω	translucent	1,45 g/m	0,82 mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ie-13 Gy- XE0 -T1,1 -0,80HF	13,0Ω	grey	1,1 g/m	0,8 mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ie-14 Bl- XE0 -T1,6 -0,90HF	14,0Ω	black	1,6 g/m	0,9 mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ip-23 Wh- XE0 -T0,9 -0,70HF	23,0Ω	yellow	0,9 g/m	0,7 mm	PTFE	-	240°C	250V	+++	yes	+++
				T-Ip-30 Wh- XP0 -T0,8 -0,90HF	30,0Ω	white	0,8 g/m	0,9 mm	PES	-	120°C	48CV	+++	yes	+++
		"IW" double insulation	Thermotech I-Wg	**T-IeWg 3,6** Wh-XE0 -T3,4 -1,35HF	3,60Ω	brown	3,4 g/m	1,35mm	PTFE	Glass	230°C	250V	+++	yes	+++
				T-IeWg 4,6 Tr- XE0 -T2,6 -1,35HF	4,60Ω	translucent	2,6 g/m	1,35mm	PTFE	Glass	230°C	250V	+++	yes	+++
				T-IeWg 7,0 Bu- XE0 -T2,3 -1,10HF	7,00Ω	blue	2,3 g/m	1,1 mm	PTFE	Glass	230°C	250V	+++	yes	+++
				Thermotech Type I + glass over-braiding	on special request , all the Thermotech Insulated yarns can be glass overbraided for use with higher power										
	semi-insulated yarns	"W" type wrapped yarns	Thermotech N-w	**T-NWg-0,9** Wh-WG-N7,9-0,9 MF	1,32Ω	white	7,9 g/m	0,9 mm	glass/gl.		280°C	?	++	no	++
				T-NWg-1,3 Wh-WGG-N7,9-1,3 MF	1,32Ω	white	7,9 g/m	3,20 mm	glass/gl.		400°C	?	++	no	++
				T-NWg-2,0 Wh-WGG-N8,8-2 MF	2,0 Ω	white	8,8 g/m	2,80 mm	glass/gl.	Glass	400°C	?	++	no	+++
				T-NWp-14 Wh-WP0-N0,54-0,7HF	14,0Ω	white	0,54 g/m	0,70 mm	PAM		120°C	48 V	++++	no	+++
				T-NWp-30 Wh-WP0-N0,26-0,4HF	30,0Ω	white	0,26 g/m	0,40 mm	PAM		120°C	48 V	++++	no	+++
				T-NWp-30 Wh-WP0-N0,28-0,4HF	30,0Ω	white	0,28 g/m	0,42 mm	PAM		120°C	48V	++++	no	+++
				T-Wp-60 Wh-WP0-N0,15-0,2HF	60,0Ω	white	0,15 g/m	0,20 mm	PAM		120°C	48V	++++	no	+++
			N yarns	Thermotech Type N + over-braiding	on special request , special wrappings or braiding can be made on all our non insulated yarns . Warning: the braiding is not watertight, except with special treatments										
NON INSULATED YARNS	hybrid		Thermaram	**H-N-0,7** Ye-000 -N0,36 -0,55 MF	0,7Ω	yellow 4c	0,36 g/m	0,38 mm			280°C	n insul.	++	no	+
				H-N-1,2 Ye-000 -N0,20 -0,35 MF	1,2Ω	yellow 2c	0,20 g/m	0,35 mm			280°C	n insul.	+++	no	+
			Copernic/ aram	**H-N-1,1** Ye-000 -N0,20 -0,35 MF	1,1 Ω	yellow 6c	0,22 g/m	0,35 mm			280°C	n insul.	++	no	++
				H-N-1,2 Ye-000 -N0,20 -0,35 MF	2,2Ω	yellow 3c	0,20 g/m	0,35 mm			280°C	n insul.	++	no	++
			Tibdata	**H-N-4** Br-000-N0,10 - 0,18 HF	4,0Ω	brown	0,10 g/m	0,18 mm			100°C	n insul.	+++	no	++
			data-Stretch	**H-NS-5** Bl-000-N0,10 - 0,18 stretch	5,0Ω	black	0,15 g/m	0,20 mm			100°C	wrapped	+++	no	++
			Polynox	**P-N-200** Wh-000 -N0,20 -0, MF	200 Ω	White 4i	0,36 g/m	0,35 mm			100°C	n insul.	++	no	++
				P-N-400 Wh-000 -N0,20 -0,35 MF	400 Ω	White 2i	0,34 g/m	0,35 mm			100°C	n insul.	++	no	++
				P-N-1000 Wh-000 -N0,20 -0,40 MF	1000 Ω	Silver 3	0,3 g/m	0,40 mm			100°C	n insul.	++	no	++
	N type		Copernic	**H-N-1,1** Gy-000 -N0,18 -0,29 MF	1,1 Ω	copernic 6	0,18 g/m	0,29 mm			450°C	n insul.	++	no	+
				H-N-2,2 Gy-000 -N0,24 -0,29 MF	2,2 Ω	copernic 3	0,24 g/m	0,29 mm			450°C	n insul.	++	no	+
				H-N-11 Gy-000 -N0,04 -0,11 MF	11 Ω	copernic	0,04 g/m	0,11 mm			450°C	n insul.	++	no	+
			conductib	**C-N-0,19** Gy -000-N0,86 -0,45MF	0,19Ω	light grey	0,86 g/m	0,45 mm			280°C	n insul.	+++	no	++
				C-N-0,35 Gy -000-N0,86 -0,45MF	0,35Ω	light grey	0,86 g/m	0,40 mm			280°C	n insul.	+++	no	++
			Thermot. Hcw	**T-N-1,8 Gy**-000 -N1,7 -0,70 LF	1,85Ω	grey	1,70 g/m	0,70 mm			600°C	n insul.	+	no	+
			Thermotech N	**T-N-3,6 Gy**-000 -N1,9 -0,70 HF	3,60Ω	grey	1,90 g/m	0,70 mm			600°C	n insul.	+++	no	+++
				T-N-4,6 Gy-000 -N1,5 -0,55 HF	4,60Ω	grey	1,48 g/m	0,55 mm			600°C	n insul.	+++	no	+++
				T-N-7,0 Gy-000 -N1,0 -0,50 HF	7,00Ω	grey	1,02 g/m	0,50 mm			600°C	n insul.	+++	no	+++
				T-N-9,0 Gy-000 -N0,75-0,40 HF	9,00Ω	grey	0,75 g/m	0,40 mm			600°C	n insul.	+++	no	+++
				T-N-14 Gy-000 -N0,51 -0,25 HF	14,0Ω	grey	0,51 g/m	0,25 mm			600°C	n insul.	+++	no	+++
				T-N-23 Gy-000 -N0,33 -0,20 HF	23,0Ω	grey	0,33 g/m	0,20 mm			600°C	n insul.	+++	no	+++
				T-N-30 Gy-000 -N0,24 -0,10 HF	30,0Ω	grey	0,24 g/m	0,10 mm			600°C	n insul.	+++	no	+++
				T-N-60 Gy-000 -N0,11 -0,07 HF	60,0Ω	grey	0,11 g/m	0,07 mm			600°C	n insul.	+++	no	+++

Fig. 2: THERMOTECH conductive or heating yarns withstanding thermal fatigue effect (insulated or not)

a fire (furthermore, this is one of the most important issues with heated seats in the automotive industry).

On the other hand, as soon as high power or large surfaces are required, the famous P=UI crops up. For example, to reach a power of 1200 watts/m² (which is the power usually required to heat a mould for thin parts to 80°C), for 12 volts, you would need 100 amperes to heat a single square metre. Some manufacturers of heating fabrics or grids have made that choice, often to enable working with thin, highly conductive alloy-based filaments, although this requires having the capacity to provide and manage this type of intensity in large power transformers.

In most cases, the power requirements will entail the use of 230 or even 380 volts, and this comes with the absolute need to have good dielectric materials on the heating filaments. There are standard solutions, of course, but they often result in thickes wires and successive insulating layers that make the whole thing stiffer, limiting the drapability on complex shapes and the heat conductivity. This in turn leads to overheating and weakening of the filaments inside their insulation. With its range of Thermotech yarns specifically designed for this type of application, Tibtech can offer a broad range of flexible, resistive wires with single or double insulation (see Figure 2).

More information

Specific case of carbon or conductive composites

In the case of carbon composites, which of course are inherently conductive, Tibtech developed a heterogeneous double insulation for the highest voltages: Thermotech IWg wires. The core generally consists of the Thermotech I filaments with the previously mentioned advantages, plus a flexible overbraiding that can be impregnated. The filaments are flexible to facilitate placement in complex shapes. Then, once in place (in the form of Tibgrid mats or wires) and impregnated with the resin or thermoplastic in the composite, they become stiff, establishing the complementary dielectric material, which becomes integral with the composite itself. After hardening, a dielectric channel is created in which the standard Thermotech I filaments can expand.

Note: Care is required in the case of doped resins or thermoplastics/elastomers (e.g. carbon black or conductive fillers, aluminium or other oxides): the stresses on the dielectric material are even higher, as the reinforcement material is inherently conductive, and the conductive fillers create valence zones that turn the structure into an actual semiconductor within the composite material. Unlike the carbon reinforcement, this type of impregnation could penetrate the sheath and compromise the double insulation properties of the Thermotech IWg filaments – so be on the lookout for short circuits. In this specific, highly restrictive case, Tibtech can propose solutions whereby the outer braiding is already preimpregnated with a flexible insulating material that is high-temperature resistant.

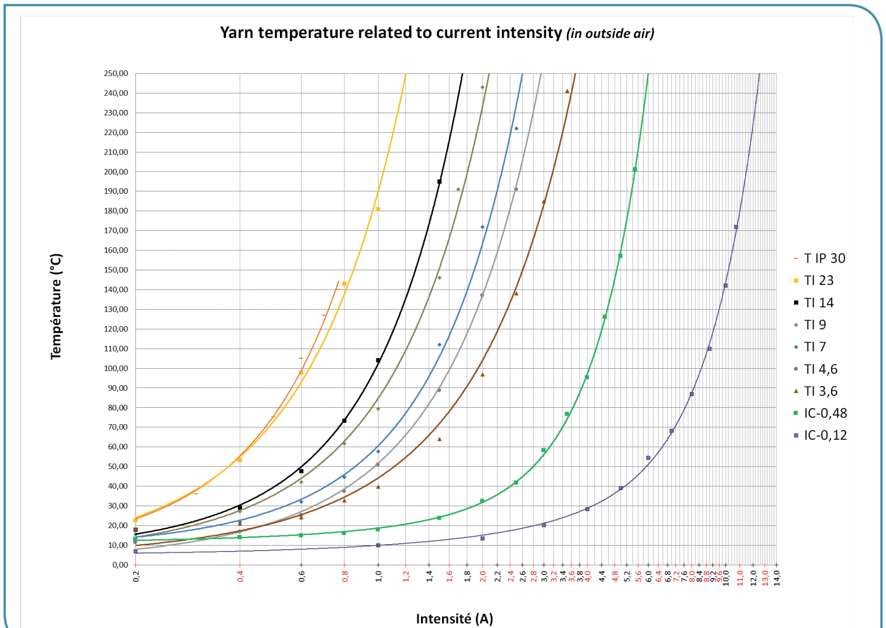

Fig. 3: Thermal behavior of Thermotech yarns related to current intensity

- heat exchange: First of all, it is important to know the characteristics of the heating yarn in a standard environment (in the open air). The table below (see Figure 3) shows the evolution of the surface temperature for some insulated Thermotech yarns as a function of the intensity.

What we are talking about, then, is the capacity of each of these wire to dissipate the Joule effect heat into the air at ambient temperature.

The equilibrium between the heat added and the heat dissipated depends on the exchange surface between the filament and its environment. Of course, the capacity of the environment to rapidly dissipate this heat is essential. The insulating material's specific exchange surface and thermal conductivity will therefore have a strong influence on this capacity to rapidly dissipate the added heat into the environment. The equilibrium is established more or less rapidly as a function of the insulation. Of course, each heating yarn is characterized by a maximum operating temperature.

Note that the design surface effect for Thermotech "Nu " yarns makes it possible to almost double the specific exchange surface compared to an equivalent round filament with the same cross-sectional surface (corresponding to the sum of the cross-sectional surfaces of the fibres).

In this example of Thermotech I filaments, the maximum operating temperature of 240°C is due to the high-temperature resistance of its core material. So, to continue with our example, the Thermotech I 3.6 yarn (the brown line in the diagram) will have a theoretical maximum heat capacity in open air at ambient temperature that corresponds to a maximum intensity of 3.8A, lowered to 3.6A for safety reasons. When the wire is inserted into a composite material of a given thermal resistivity (and this is something that needs to be factored in), the higher the temperature of the composite that constitutes the filament's environment, the lower the heat diffusion will be. Therefore, it will be advisable to progressively limit the amperage when working at temperatures that are close to the maximum heat capacity.

The Tibgrid calculator below (see Figure 4, which can be downloaded from the company's website) serves to determine the maximum heat capacity per unit of surface of the heating mat: e.g. for a 100-mm-wide Tibgrid mat, with a 20-mm pitch and the Ti 3.6 Ω/m heating yarn (limit amperage: 3.6A). In 230 volts, the maximum equivalent power per square metre will be 1450 watts/m^2 for a relatively short mat length of 4.10 m. The Ti 3.6 will be able to deliver a maximum power of RI^2 = 3.6 X (3.6)^2 per linear metre. The Pmax in open air at ambient temperature for Ti 3.6 is 46.6 watts per metre of filament.

For a filament based on higher conductivity alloys, e.g. Ti 0.48Ω/m, as shown by the green line in the above diagram, the limit amperage is 5.8 A. The advantage here is a greater useful length, which makes it possible in the preceding example to cover a greater useful area using only two connections (giving a mat length of 13.8m); on the other hand, the filament's maximum heat capacity will be 0.48 x (5.8)^2 = 16.1 watts/m, which is relatively low. This can be explained by the incapacity of the filament to dissipate enough heat per unit of length.

To obtain the same resulting output, one would have to add more circuits in parallel or shorten the pitch. Using parallel networks complicates the connections, and especially the layout on 3D complex-shape parts, because each filament must have the same resistance and therefore the same length (even if the paths are different). One also have to be careful to avoid potential delamination of the composite or the cure pouch when inserting a mat with a very dense network of conducting filaments.

In short, a filament with greater conductivity makes it possible to manage larger surfaces, but with lower heat exchange capacities than for a more resistive filament, and often with lower mechanical or fatigue resistance. You have to find a trade-off between these aspects based on the specific application, which is why it is important to have a broad range of yarns in terms of different resistivities, geometries and alloys.

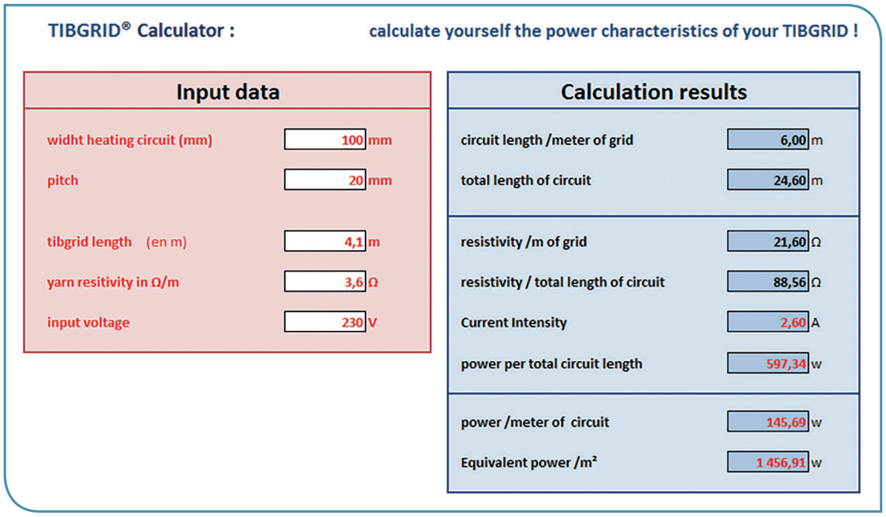

Fig. 4: TIBGRID heating grids calculator , loadable from TIBTECH web site

Micromesh for safety and to regulate the thermal gradient

For building composite heating moulds, Tibtech recommends adding a flexible conductive mesh like Tibmesh, or even better, an elastic one like Stretchomesh. This should be inserted between the heating mat and the internal mould surface, separated by one or two plies of reinforcement. The mesh fulfils three purposes:

- safety: by earthing the mesh, the power circuit can be broken immediately in case the pouch or the heating mould is accidently damaged;

- regulation of the (small) thermal gradient between each circuit pitch during heating;

- increasing heat diffusion within the material by improving the heat exchange between heating mat and inner mould surface, which makes it possible to use a higher effective power (this purpose can also be fulfilled by doped conductive resins, although there is always the risk of lowering the global dielectric, and therefore of limited input voltage, especially when the filament diameter must be limited).

Tibgrid® circuit for high-capacity requirements

For large composite structures, it is difficult to bring in enough power without also increasing the maximum heat capacity, and therefore, the wire diameter (and this is often impossible due to the risk of delamination or losing structural resistance) or, as an alternative, increasing the number of circuit connections in parallel, which complicates matters and greatly increases the cost.

To open up possibilities and eliminate the need to handle and place the micromeshes, Tibtech developed the Tibgrid® Interface mesh concept. These are Tibgrid® mats to which are added very thin, but fairly dense networks of heat transfer filaments that enable the heating yarns within the mat to maximize their heat exchange capacity without sacrificing their elasticity. Maintaining their elasticity means that they are able to cover complex-shape or 3D surfaces. And since no conductive filaments are used in the warp direction, the risk of a hot spot developing in case of partial rupture is minimized.

In certain conditions, the Tibgrid® Interface concept can be used to more than double the maximum heat dissipated by the same yarn and pitch on a given surface. ■

More information:
www.tibtech.com