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CHE and Related Stresses in GEM Foils

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Abstract

The “Coefficient of Hygroscopic Expansion” (herein α_{CHE}) of a GEM foil is simply computed assuming that the expansion is only due to the kapton layer that absorbs and retains the water vapor content of the moisture (or in general of any gas mixture) through the holes; that expansion is highly constrained by the copper layers and the resulting compressive (in kapton) and tensile (in copper) stresses can be easily estimated assuming that no other external loads are applied. It will be shown that the $\alpha_{CHE-GEM}$ in a GEM foil (2x5 + 50 micron) is 0.135 times lower than the $\alpha_{CHE-kapton}$ of the single kapton foil; then the effect of the Relative Humidity (herein RH) on the sag of the GEM foils is substantially negligible if the “kapton-free-to-expand” areas are small.

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The range of the $\alpha_{CHE-kapton}$ of kapton foils in GEM production is approximately from $9 \cdot 10^{-6}/\%RH$ (*type-E*) to $20 \cdot 10^{-6}/\%RH$ (*apical*) and more, that is there is a factor of about 2; the elongation ε_{free} due to an increase $\Delta\%RH > 0$ of RH of a kapton foil "free" to expand is:

$$\varepsilon_{free} = \alpha_{CHE-kapton}\,\Delta\%RH$$

That expansion depends of course on the "initial condition" of the RH (the RH plays the same role of the temperature: an increase of both of them respect to the "initial condition" gives an expansion while a decrease a contraction as it happens when a kapton foil is "glued" to protect or insulate a flat surface; in the present case the copper layer is deposited on the kapton foil in vacuum and the initial RH is simply null i.e. $\Delta\%RH$ can be replaced by $\%RH$).

In a GEM foil the kapton layer is not free to expand because the copper layers do not allow that; given $\%RH > 0$ then the resulting biaxial stress in the kapton layer is compressive while it is tensile in the copper ones as follows:

$$\sigma_{kapton} = -\frac{E_{kapton}}{1-v_{kapton}}\left(\varepsilon_{free} - \epsilon\right) < 0 \quad \sigma_{copper} = +\frac{E_{copper}}{1-v_{copper}}\epsilon > 0$$

where $\varepsilon < \varepsilon_{free}$ is the global dilatation (still unknown) of the GEM foil under $\%RH$ of the moisture (or equivalent water vapor content in any gas mixture) and it is the same for kapton and copper; the Young modulus of bulk kapton is $E_{kapton} = 3400\,MPa$ and that of bulk copper is $E_{copper} = 108800\,MPa$ (both 0.53 times lower considering the perforation) and $v_{kapton} = v_{copper} = 0.34$.

Since there are no applied external forces then the resulting stress in the "rule of mixtures" is null [1]:

$$\sigma_{uniform} = \alpha\sigma_{kapton} + (1-\alpha)\sigma_{copper} = 0$$

where $\alpha = 5/6$ is the volume fraction for the GEM foil; after replacing the dilatation ratio is:

$$\frac{\varepsilon}{\varepsilon_{free}} = \frac{5E_{kapton}}{5E_{kapton} + E_{copper}} = 0.135 \;\rightarrow\; \frac{\alpha_{CHE-GEM}}{\alpha_{CHE-kapton}} = 0.135$$

That ratio is the same if considering or not the perforation; then the dilatation of the GEM foil is 0.135 times the dilatation of the single kapton foil under the same $\%RH$.

As example if $\%RH = 50\%$, $l = 1m$ length and $\alpha_{CHE-kapton} = 9 \cdot 10^{-6}/\%RH$ (*type-E kapton*):

$\varepsilon_{free} = 0.00045 \;\rightarrow\; \Delta l_{free} = 0.45\,mm$ (*kapton "free" to expand*)

$\varepsilon = 0.00006081 \;\rightarrow\; \Delta l = 0.06081\,mm$ (*real GEM foil*)

$\sigma_{kapton} = -1.1\,MPa$ (*perforated kapton*)

$\sigma_{copper} = +5.3\,MPa$ (*perforated copper*)

All these values are doubled if considering the apical-type kapton; these stresses must be compared with the "equivalent uniform stresses" of a stretched foil, respectively $\sigma_{kapton} = +2.7\,MPa$ and $\sigma_{copper} = +86.5\,MPa$, for which the elongations in a biaxial tensioning is about 1 mm for a 1m length.

It follows that if $\%RH = 50\%$ then the strong variation of stress in the kapton layer (1.1/2.7=40.7%) is very well balanced by a small variation of stress in the copper layer (5.3/86.5=6.1%) and the resulting variations in the elongations are very small; it must be underlined that this conclusion is valid as far as there are no copper-uncoated tensioned areas of the GEM foil where the kapton is "free" to expand under RH variations; the resulting total elongations are as larger as the dimensions of these "uncoated" area; note that the kapton stresses may be negative for high $\alpha_{CHE-kapton}$ under great values of RH even in a tensioned foil.

References:

[1] G.Raffone (2010), *CMS Trapezoidal GEM Foil Stuctural Analysis*, LNF-10/20(IR) Note, September 20, 2010.