Prediction of Mechanical Properties of Fabric reinforced GMT in Moulded Components

Fabric reinforced GMT has shown to be a material suitable for cost effective complex shaped parts with high mechanical performance (eg. bumper beams, power train components, impact protection shields, spare wheel wells etc). The mechanical data of moulded fabric reinforced GMT varies over the area and through the thickness of the component which has to be considered in the design of parts. Here is an attempt to describe these effects as an aid for studies on the mechanical properties of such components.

The blank is a combination of layers of fabrics and GMT. When the blanks are moulded by flow moulding, the GMT flows out and fills the tool. Since the fabrics cannot deform to any significant degree they stay in the blank inlay position. This results in “normal GMT” properties in the flow zone (into which the material flows) and properties in the inlay zone (where the preheated blanks are put into the mould) dominated by the fabric. This can be seen in Figure 1 where the lighter shaded area is a fabric on the surface and the darker shaded area is GMT.

Figure 1. A moulded component in fabric reinforced GMT. The inlay zone consists of combined layers of fabrics and GMT, whereas the flow zone consist of only GMT.

It is reasonable to assume in-plane isotropic properties in the flow zone of the component. The properties in the flow zone are actually to a certain degree non-isotropic due to fibre orientation during the flow, but in practice this effect can often be neglected in a mechanical analysis of the component as a whole (the effect is much smaller than for example in injection moulding).

The properties in the inlay region will depend on the following factors:

1. The properties of the GMT flow layers (see Table 1).
2. The properties of the fabric reinforcement layers (fibre structure, orientation and content).
3. The volumetric content of the fabrics and GMT.

The two first points can be measured on the individual materials, whereas the third point will depend on the blank lay out and the part geometry. It does require some experience to determine a proper blank lay out, if need be QPC can help in this process. Advice to a proper blank lay out is given in the “QPC processing guide lines” for GMT. For fabric reinforced GMT, a further point has to be taken into account: - where the additional reinforcement of the fabric is needed in the component to carry the loads to which it is subjected. This can be very local to reinforce a small part of the component, but it can also be almost the whole area of the part.

Properties in the moulded component
When the blank lay out has been determined, the volumetric content of fabric and GMT in the inlay region can be determined. The volumetric content of fabrics in the inlay zone is calculated by adding the thickness of the fabric layers and divide this with the part thickness according to

$$V_{weave} = \frac{n_{weave} t_{weave}}{t_{component}}$$

where V_{weave} is the volumetric content of weave in the inlay region, n_{weave} is the number of weaves through the thickness, t_{weave} is the consolidated thickness of the fabric layer and $t_{component}$ is the local thickness of the component. This can be used to calculate the volumetric average stiffness in the inlay region according to the following equation

$$E_{inlay} = V_{weave} E_{weave} + (1 - V_{weave}) E_{GMT}$$

where E_{inlay} is the stiffness of the inlay region (usually orientation dependent), E_{weave} is the stiffness of the fabric layer and E_{GMT} is the stiffness of the GMT flow moulding material. The stiffness calculation can be extended to strength values, supposed that the elongation to break is similar between the fabric layer and the GMT, which is usually the case if both consist of glass fibres and polypropylene. This type of volumetric calculation has shown to work in practice for several components and plates.

Calculation example
3 blanks of a GMT combined with two woven glass fibre fabrics in 5mm thick blanks which moulded on top of each other to a flat plate.

The properties of the fabric and GMT layers are given in the Table below:

Table 1. Input data for the example calculation

	GMT	Fabric (0°)	Fabric (90°)
t (mm)	-	0.6	0.6
E (MPa)	4500	24000	8000
σ (MPa)	70	500	180
ε (%)	2.3	2.3	2.3

Since the blank stack is 15 mm in total this is the maximum thickness of the moulded part (without flow). The minimum thickness is limited by the thickness fabric layers (6 x 0.6 = 3.6 mm). The maximum practical limit in such a case would be around 10 mm in the thickest sections. Putting in the data from table 2 into equations 1 and 2 gives the following diagram (figure 2) of thickness depending mechanical properties in the inlay zone.

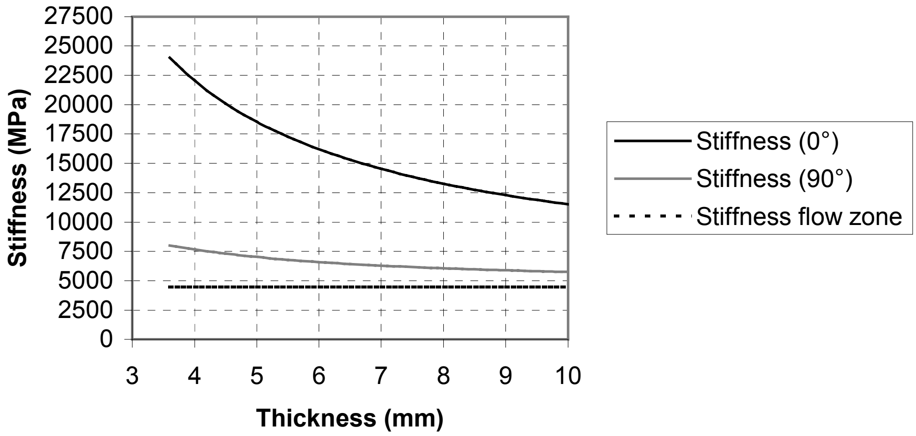

Figure 2. An example of calculated stiffness as a function of the plate thickness.

Since the elongation to break is the same between the fabric reinforced layers and the GMT, the same calculation can be done for the strength of the composite, the results are shown in figure 3 below.

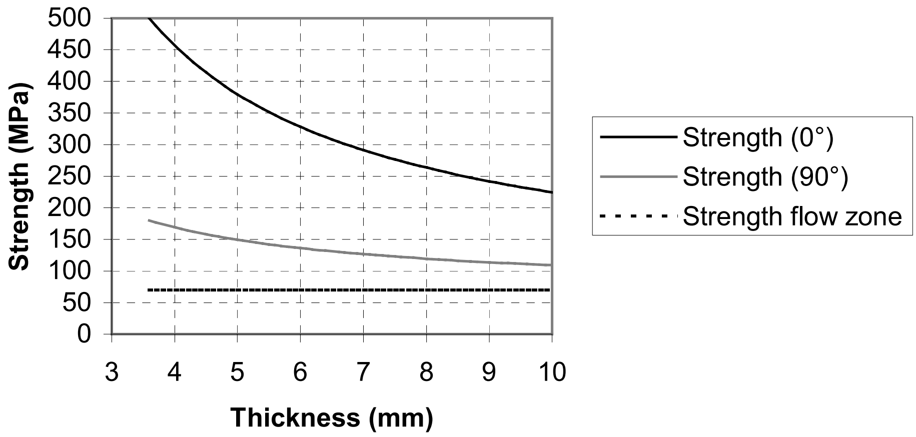

Figure 3. An example of calculated strength as a function of the plate thickness.

As seen in figures 2 and 3 above, the properties in the inlay zone depend strongly on the degree of flow in a part. To help in the design of components in fabric reinforced GMT, the mechanical data needed for these calculations can be given on demand.

Sandwich effect – flexural properties

The flexural strength and stiffness will just as the tensile properties depend on the fabric type, degree of compression etc. but it will also be affected by sandwich effect. The bending properties depend on the distance from the neutral plane in the bent specimen. The stiffness can be calculated for a layered material according to Steiners rule. Practically, the stiffness contribution from a fabric to the bending stiffness of the composite part increases with the square of the through-thickness distance between the fabric and the centre of the part. This effect can be very strong when segments of a component are loaded in bending.

Typical data

The most commonly needed data for these calculations are given in the tables below.

Table 2. Typical tensile properties of GMT with different fibre content

Fibre content	Stiffness	Strength	Elongation at brake
Wf (%)	E(MPa)	σ (MPa)	ε (%)
30	4500	70	2.3
40	5800	96	2.3
50	7600	130	2.3

Table 3. Typical tensile properties of consolidated fabrics in QPC standard fabric reinforced products.

Weave type	Orientation	Stiffness	Strength
Description		E(MPa)	σ (MPa)
1/1-90°	0°	13600	315*
	90°	13600	315*
4/1 – 90°	0°	24000	500*
	90°	8000	180*

* Usually not attained in practice, a safety factor of 0.8 is recommended.

Note that these calculations can be used to give an indication about some effects that occur in components moulded from fabric reinforced GMT. Even though gives a course approximation, it is practical for a first approximation of mechanical data for calculation of the components mechanical characteristics.