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Stress State Estimations for the Premodule of Tilecal

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1 Introduction.

A 306 mm thick premodule of the tile calorimeter should be appropriately rigid, what means, when it is transported or it changes the position after rotating, lifting, or laying it down any permanent deformation cannot occur. During such technological position changings the premodule can be supported or suspended from some points, lines, or surfaces. External loadings to which this premodule is subjected are those coming from its weight and, in addition, from accelerations when lifting or laying it down on a supporting structure.

Let us assume that the weight of the 306 mm thick premodule is about $W_s = 9\,000\,N$. Moreover, we assume that during lifting or laying it down absolute values of accelerations are not bigger than $1/3\,g$ (g - the acceleration due to gravity). For this reason, the additional dynamic load should not reach a value of $W_d = 3\,000\,N$.

To determine whether the premodule resists such loads without any permanent deformation, stress states for different position of the premodule should be defined. This is why, we will consider three cases of the premodule position together with different methods of supporting. It seems that for each of these cases stress states between master plates and spacers should be checked whether it is not dangerous for loosing integrity of the premodule.

Finally, it should be noticed, that in the presented below methods of stress estimating any loosing of contact or sliding between master plates and spacers is not permitted.

2 Estimations of stress states

The first case of premodule positions and methods of supporting is as follows. All the master plates are positioned vertically. The whole premodule is supported or suspended from two opposite sides (see Fig.1). The total reaction force of the supporting structure applied on each side of the premodule is about $R = 1/2(W_s + W_d) \approx 6\,000\,N$ (two forces equal to $R/2$) as it is shown in Fig.1. Different types of the supporting structure can produce differently distributed reaction forces. The total force can be uniformly distributed along a line, over an area or be a rather concentrated force acting on a very small area.

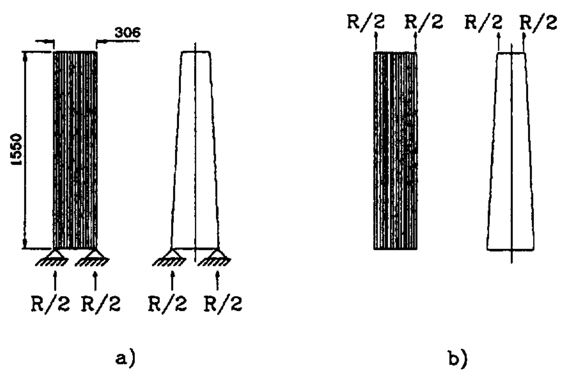

Figure 1: The first position of the premodule.

In each case the total shear force between one master plate and all the spacers which are joined to one side of the plate, is not higher than $T = 6\,000\,N$ (Fig.2). Assuming that the total shear force is uniformly smeared over the area of spacers, the maximal value of shear stresses would be below $0.03\,N/mm^2$. But, as it is shown below, the distribution of the shear stresses is not uniform. The maximal value of shear stresses and their distribution can be estimated in the following way.

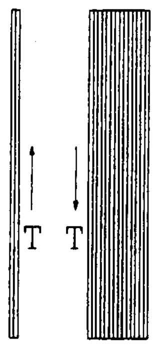

Figure 2: The total shear force.

Let us consider an half space which is subjected to a single force (Fig.3a) or to a force uniformly distributed along a straight line, that is, along the "z" coordinate (Fig.3b). The first case is a axisymmetric problem and the second one is the plane strain problem. Analytical solutions of these problems are well-known [2,3].

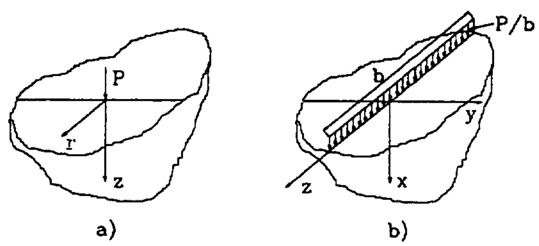

Figure 3: 2-D problems; a) the axisymmetric problem; b) the plane strain problem.

For the axisymmetric problem, shear stresses can be calculated from the following relation

$$\tau_{rz} = \frac{2G}{1-2\nu}\left[[2\nu c_2 - (1-2\nu)c_1]\frac{r}{R^3} - 3(c_1 + c_2)\frac{rz^2}{R^5} \right],$$

where

$$c_1 = \frac{\nu(1-2\nu)}{2\pi}\frac{P}{G},$$

$$c_2 = \frac{(1-2\nu)^2}{4\pi}\frac{P}{G},$$

$$G = \frac{E}{2(1+\nu)},$$

$$R = \sqrt{r^2+z^2},$$

in which E is Young's modulus, and ν is Poisson's coefficient.
Assuming that $\nu = 0.3$, the above formula leads to

$$\tau_{rz} = -0.48P\frac{rz^2}{R^5}.$$

From this solution we get a value of the maximal shear stress equal to

$$\tau_{rz}^{max} = -0.14\frac{P}{z^2}.$$

For z=const this maximal value occurs when $r = z/2$ (see Fig.4).

For the plane strain problem, the solution for shear stresses is of the form

$$\tau_{xy} = -\frac{2P}{\pi b}\frac{x^2y}{\hat{R}^4},$$

in which

$$\hat{R} = \sqrt{x^2+y^2},$$

and where P is the total force and b is length of the line along the "z" coordinate on which the force is distributed uniformly.
The latest relation gives the maximal value of shear stresses equal to

$$\tau_{xy}^{max} = -0.21\frac{P}{xb},$$

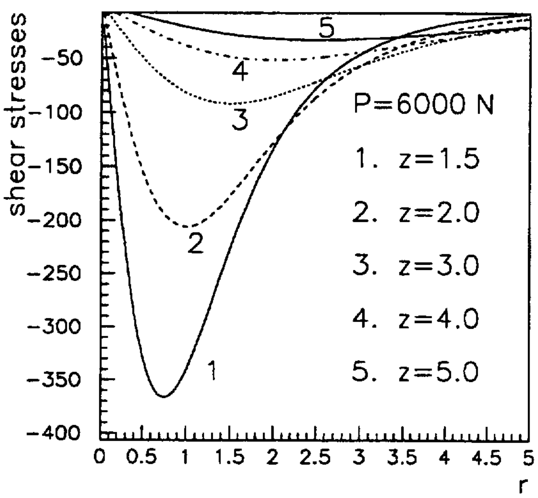

Figure 4: Shear stress distribution for the axisymmetric problem.

which occurs at $y = x/\sqrt{3}$. The distribution of these stresses in the both directions "x" and "y" is shown in Fig.5.

If the supporting line is on the edge (see Fig.6), shear stresses are defined by

$$\tau_{xy} = -\frac{P}{b}(0.275\frac{x^2y}{\hat{R}^4} + 1.239\frac{xy^2}{\hat{R}^4}).$$

Distribution of these stresses is shown in Fig.7.

Making use of the above relations we can draw conclusions that to limit the concentration of shear stresses we should not support the premodule directly on supporting points but rather on lines or through appropriately thick plate.

Normal stresses coming from tension between master plates and spacers are smaller than those in the other cases of the premodule position.

In the second position of the premodule which is to be considered, master plates are positioned horizontally. In the similar way as before, the premodule is supported from two opposite sides (see Fig.8). Shear stresses can also be estimated by the formulae just presented. Again, normal stresses between master plates and spacers are much smaller than those in the other position of the premodule.

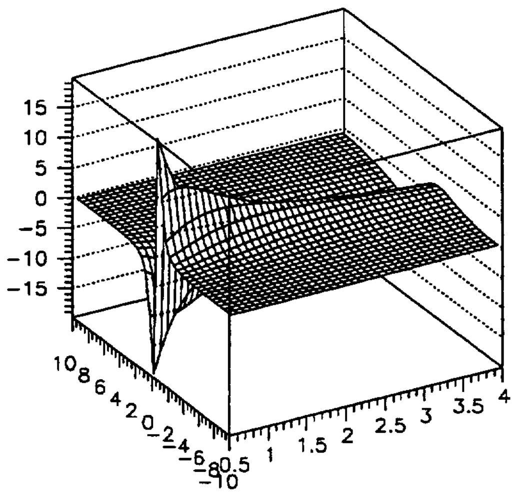

Figure 5: Shear stress distribution for the plane strain problem.

It should be noticed that in the latest considerations holes for scintillator tiles which exist in the real premodule have not been taken into account. Nevertheless, as can be seen from numerical calculations (ANSYS code [4]), shear stress distributions around such holes are not differed very much in comparison with those defined by the analytical solutions(see Fig.5 and Fig.9).

In the third position of the premodule, master plates are positioned vertically. The whole premodule is supported on two opposite edges as it is shown in Fig.10.

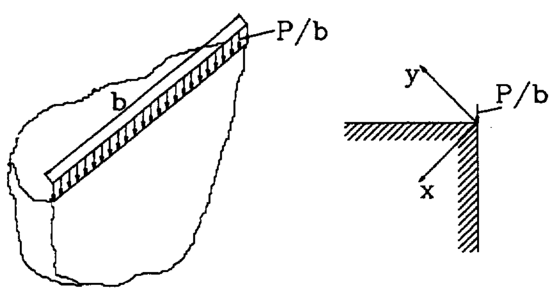

Figure 6: The plane strain problem with a force applied on the edge.

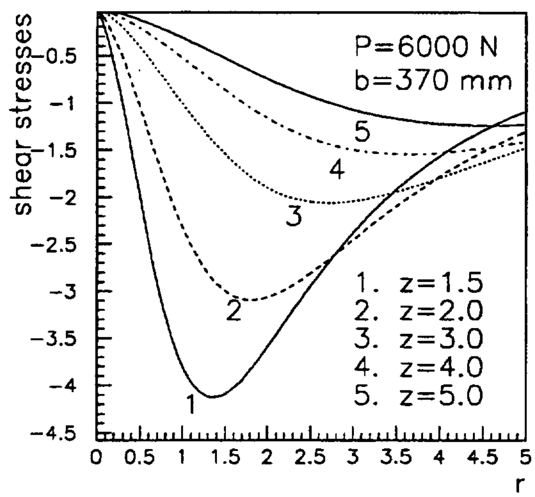

Figure 7: Shear stress distribution for the plane strain problem with a force applied on the edge.

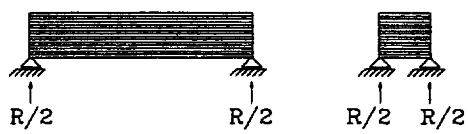

Figure 8: The second position of the premodule.

Values of shear stresses and the total shear force are not higher than those in the cases described above. However, normal stresses between master plates and spacers are now rather important and should be taken into account. This type of stresses are caused by bending moments. The total reaction force applied to one side of the premodule is equal to $R = 6\,000\,N$, so the maximal bending moment acting in the "yz" surface is about $M_y = 0.46 \cdot 10^6\,Nmm$ (see Fig.10). The highest tension stresses between master plates and spacers occur at the bottom of the premodule in the middle of its length (point A in Fig.10b).

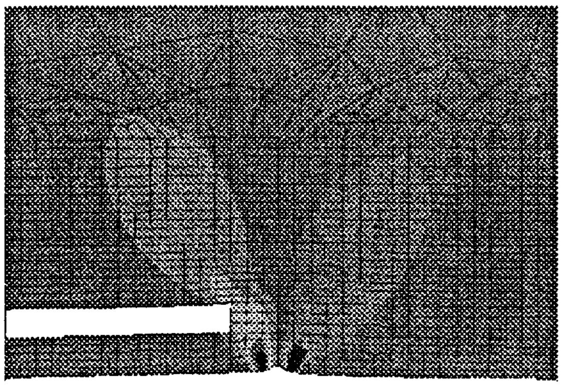

Figure 9: Shear stress distribution for the premodule with holes for scintillator tiles.

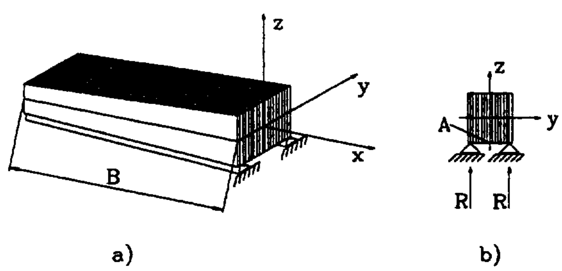

Figure 10: The third position of the premodule.

3 Stress states in the premodule with master plates and spacers joined with glue

According to specifications for Araldite AY 103, average strength for shearing or tension is not lower than $9\,N/mm^2$.

Since the total shear force between master plates and spacers is about $T = 6\,000\,N$, an average value of shear stresses in glue would be below $0.06\,N/mm^2$, assuming that only 50 % of the area of spacers is joined by glue with a master plate. As it was stated before, shear stresses between master plates and spacers are strongly depended on the method of premodule sup-

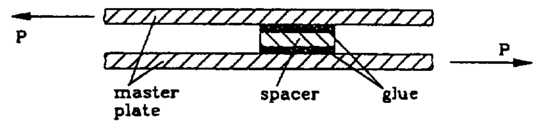

Figure 11: Two master plates and a spacer jointed with glue .

porting or suspension. To keep these stresses below the limit the premodule should always be supported rather along lines than on points.

To establish the stress concentration coefficient of shear stresses caused by different mechanical properties of master plates or spacers and glue, the following calculations are carried out.

Let us assume that two master plates are glued with one spacer in between as shown in Fig.11. A value of the maximal shear stress can be calculated using the following relations given in [5]

$$\tau^{max} = \frac{PC}{2b},$$

where P is an applied force, b is the width of the glueing area, and

$$C = \sqrt{\frac{G}{Eth}},$$

in which G is the shear modulus of glue, E is Young's modulus of master plates, t is the thickness of glue layer, and h is the thickness of a master plate.
Assuming that $P = 6\,000\,N$, $b = 200\,mm$, $G = 1.3\,GPa$, $E = 207\,GPa$, $t = 0.01\,mm$ or $0.05\,mm$, and $h = 5\,mm$, the equation above leads to

$$\tau^{max} = 5.3\,N/mm^2 \qquad for \quad t = 0.01\,mm,$$

$$\tau^{max} = 2.4\,N/mm^2 \qquad for \quad t = 0.05\,mm.$$

As can be noticed, for such an exceptional case the maximal values of shear stresses in glue are by far below the allowable limit.

Tension stresses in third position of the premodule can be estimated by the following relation

$$\sigma_y = \frac{6M_y}{H^2B},$$

where H is the thickness of the premodule in the "z" direction (see Fig.10), and B is the width in the "x" direction (see Fig.10a).
Assuming that $H = 200\,mm$, and $B = 710\,mm$, we get

$$\sigma_y^{max} = 0.1\,N/mm^2.$$

If we use only 50 % of the spacer area by reducing the width in the "x" direction, the maximal tension stress will be two times higher than that presented above. This is still below 3 % of the allowable value.

4 Conclusion

The loads described in Section 2 lead to shear stresses and normal stresses between master plates and spacers. In order to fulfil the condition of not occurring the permanent deformation when the premodule is transported, these stresses cannot cause any sliding or loosing contact between plates. The premodule has to be deformed only elastically.

The maximal value of the total shear force between a master plate and all the spacers joint to one side of the plate is not higher than $6\,000\,N$. If this force is smeared over the whole area of spacers, values of shear stresses would be below $0.03\,N/mm^2$. In the neighbourhood of supporting points or supporting lines shear stresses are much heigher. To reduce the stress concentration, an area of the supporting elements on which the premodule is laid should be rather big. If we want to support the premodule only on few points an appropriately thick plate should be used between the premodule and these supporting points.

Moreover, the connection between master plates and spacers should be strong enough to resist not only shear stresses but simultaneously tension stresses coming from the bending moment equal to $0.46 \cdot 10^6\,Nmm$.

The premodule with master plates and spacers joined by glue fulfils the condition of not sliding and not loosing contact between master plates and spacers so, it can be transported, rotated, lifted or laid down.

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