Preliminary Studies for the Design of a Composite Material Valve to be Integrated into PWR Circuits

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1. INTRODUCTION

In order to solve corrosion problems, some of the piping in PWR plants has been made of plastic or composite materials. However, at present, only small diameter valves in thermoplastic able to function at ambient temperature and under little pressure (a few bars) are to be found on the market.

The EDF (French Electricity Company) and the CEA are collaborating in order to carry out a study program designed to investigate the feasability of a valve made of new materials having characteristics adapted to most PWR circuits. The first part of this program was focused on a feasability study of the body of this valve which is in plastic reinforced with long fibres.

This study comprised the following stages :

- an inventory of existing valves in a PWR plant with an analysis of their characteristics in order to choose the operating field of the studied valve body ;
- an analysis of piping loads sustained by the valve body installed on a metallic circuit as well as on a composite circuit ;
- a preliminary mechanical calculation of the valve body supposing the material to be isotropic, and the fabrication of mock-up using this dimensioning ;
- mechanical tests on these mock-ups comprising pressurization and deformation tests under external loading effects ;
- the characterization of the composite material and a calculation of the valve body deformations in order to interpret the preceding tests.

2. PRELIMINARY STUDY

2.1 Inventory of the valves in a PWR plant

An investigation was made for the FLAMANVILLE 1 (1300 MWe) using the GMC data-file (Plant Materials Management) of equipment division of E.D.F.

The data-file contained 9774 valves among which 5699 were taken into account. Table 1 sums up their coresponding operation fields. It clearly shows that the $T \leq 110°C$, $P \leq 25$ bars, field covers 3717 valves, that is to say 65% of the whole.

The field considered corresponds to 74 elementary systems. Ten among these group 49% of the whole with a high proposition on the :

- SAR : Compressed Air Distribution System (325)
- SED : Demineralized Water Storage and Distribution (316)
- JPD : Fire-fighting Water Distribution (279)
- TEP : Primary Effluent Treatment System (176).

A study of their distribution by size showed that 85% of the valves had a nominal diameter of between 15 and 100 mm.

Finally for the greater part, the fluid transported is water or gas.

Consequently, for the follow-up, a typical valve corresponding to the following specifications was focused up on :

- Fluid : water or gas,
- Temperature : 110°C,
- Operating pressure : 25 bar,
- Diameter : ND 70 mm,
- Water flowrate : 45 m^3/h.

2.2. Mock-up dimensioning

Using the above data, a T-shaped mock-up was dimensioned in plastic reinforced with long glass fibres, representing a valve body.

A first calculation of a typical line was able to show that during its mounting, due to piping unalignment, the valve body could be subject to :

- bending effort of up to 25m daN ;
- torque of up to 70m daN.

In addition to these forces, mock-up dimensioning also took into account :

- an internal pressure of 170 bars corresponding to twice the pressure peak due to an 85 bars water hammer ;
- stamping due to the internal mechanics of a gate valve through a loading force of up to 1000 daN.

For these calculations, the following geometrical constraints were, moreover, imposed :

- equal inner diameters for both horizontal and vertical legs : 70 mm ;
- load length of horizontal leg : 200 mm ;
- load length of vertical leg : 150 mm.

The geometry resulting from this dimensioning is shown in Figure 1.

3. TEST PROGRAM

3.1 Mock-up fabrication

In order to obtain a composite material having good long-term resistance at 110°C in the presence of water, a vinylester DERAKANE matrix was chosen. It was decided that long E glass fibres would be used for reinforcement. The fibers were used in the form of quasi-isotropic braids with fibers orientations of 0, +60°, -60°.

For the fabrication, low pressure injection into a metallic mould first filled with 5 layers of braids laid on to a removable core was chosen ; this sort of fabrication, of industrial type, should enable good reproductivity to be obtained and does not demand costly tooling, eventually valve manufacturers will thus easily be able to launch the fabrication of various short lines.

Several problems were encountered during fabrication :

- some difficulty in piling up the braids owing to their rigidity due to their three-directioanl wearing ;
- the forming of bubbles networks in certain areas of the product, the injection front area in particular ;
- cracking due to shrinkage after the highly exothermal polymerisation of the resin.

3.2 Mock-up testing

3.2.1 Test definition

For pressure resistance tests, the mock-ups was plugged at its ends and was connected to a charging pump.

For loadings, the mock-up was set up on a frame. Figure 2 shows the test apparatus for bending. The other configurations tested were torque and stamping.

The instrumentation set up allowed measurement of :

- loading parameter ; pressure or applied forces ;
- displacement ;
- strain.

3.2.2 Results

3.2.2.1 Pressure resistance

On the 2 first mock-ups, a skrinkage cavity that appeared during fabrication in an area of highly varying thickness caused a beginning of cracking. Afterwards, this problem having been solved, weeping occurred randomly in various points of the mock-ups. This always happened, however, in areas where the presence of bubbles, which had appeared during fabrication, had already been observed.

The last mock-up was made of an epoxy resin so as to see whether these bubbles were due to the presence of styrene in the vinylester resin,but the same defects were observed. The injection process should then be improved.

The maximum tightness pressure obtained during these tests was 71 bars.

3.2.2.2 Application of load

Only the linear behaviour of the mock-up was of interest here, and that before the appearance of damage.

The results obtained, on the most significant gauges, are shown in Table 3, line 2, for the bending configuration which is taken as example. The values given here are the stress/strain curve slopes inasmich as linear behaviour was observed for the near totality of the gauges. The only gauges that presented non-linearity were those whose measured value remained low (that is to say below 5% of the values obtained for the other gauges).

3.2.2.3 Characterization

The mechanical characterization of the product was performed on plates obtained by low pressure injection of epoxy resin into a pile of open and unfolded braids. Using these plates it was possible to verify that the measured characteristics were close to those calculated by the Puck's formulation, supposing that there is a pile of one-directional layers : 0, +60°, -60° ; the values calculated for the reinforcement rates of the valve bodies were therefore retained for the continuation of the study.

4 NUMERICAL INTERPRETATION

4.1. Modelling

Test modelling was carried out with the TALMA 2000 finite element code, which is an adaptation for multi-layer, anisotropic structures considered as thin shells of the code developed by the CEA, CASTEM 2000.

The principle of this code is a classic for composite materials : it uses a homogenization method by summing layer stiffness in proportion to their thickness, and takes into account the coupling between membrane and flexion stresses.

The mesh presented in Figure 3 comprises 1800 elements and 900 nodes. The location of the gauges is also shown.

Each braided layer was considered to comprise three under-layers orientated respectively at -60°, 0 and +60°. Each of these layers was made of the same material.

The basic mechanical characteristics that were taken into account were those obtained by the mechanical characterization. In addition, a possible dispersion on the fibers fraction, quite frequent with this type of materials, was also taken into account ; this brought us to the characteristics given in Table 2.

4.2 Results

The results obtained for the bending loading appear in Table 3, where they are compared with the tests results.

Figure 4 represents the superposition of the initial mesh and the deformed structure.

5. DISCUSSION AND CONCLUSION

An analysis of Table 3 leads to the following comments :

- the correlation between the calculations and the tests is fairly satisfactory. Discrepancies of less than 10% were obtained for displacement and of less than 25% for strains ;
- these results are logical if one considers the non-homogeneity of the material : for displacement, the global stiffness of the structure is the essential factor, and this term, is correctly calculated through the homogenization method chosen. For strains, the local stiffness of the material is the main factor. This term is subject to variations corresponding to multi-layer composition variations (% of resin or fibers orientations, for example) ;

- the greatest discrepancies were noted in the area where the strain gradient was itself very high : near the embedding. An uncertainly on gauge location then intervenes significantly (gauges J4, J5, J6, J9). This result will certainly be improved with new calculation on a more refined mesh.

In conclusion, one can say that the fabrication process used for the realization of the mock-up needs to be refined. Nevertheless, the comparison between the experimental results and the calculations shows that the mechanical behaviour of such a complex structure, as much from the aspect of shape as from that of the material variations (layers piling, fibers orientations, resin fraction), can be calculated with the TALMA 2000 computer code with quite good accuracy.

The feasability of a valve body made of composite materials will be demonstrated as soon as this problem of fabrication will be solve.

Table 1 : Operating conditions of 5700 among 9800 valves of FLAMANVILLE 1 (PWR)

T (°C) / NP bar	20-110	111-370	TOTAL
6<NP<10	364	19	383
16<NP<25	3 353	266	3 619
40<NP<400	647	1 050	1 697
TOTAL	4 364	1 335	5 699

Table 2 : Characteristics of materials

Composition : glass/resin	35/65	45/55	55/45
E_X (// fibers) (MPa)	27500	34500	41500
E_Y ($\perp$ fibers) (MPa)	6561	8442	11347
nu	0.35	0.33	0.32
G_{XY} (MPa)	2497	3144	4081

Table 3 : comparison calculations/tests for the bending loading (45% of glass) (results in μdef/daN for gauges and in μm/daN for displacement)

	$\epsilon_{1/F}$	$\epsilon_{3/F}$	$\epsilon_{4/F}$	$\epsilon_{5/F}$	$\epsilon_{6/F}$	$\epsilon_{9/F}$	$\epsilon_{10/F}$	$\epsilon_{11/F}$	$d_{1/F}$
Tests results	-2.68	≃0	-2.38	-5.99	-3.00	+5.00	-2.75	+2.19	-4.20
35% glass	-3.50	+5.89 10^{-2}	-3.91	-9.52	-3.91	+4.69	-4.05	+2.68	-5.70
45% glass	-2.83	+4.29 10^{-2}	-3.17	-8.82	-3.17	+3.76	-3.27	+2.15	-4.50
55% glass	-2.27	+3.82 10^{-2}	-2.54	-6.18	-2.54	+3.04	-2.63	+1.74	-3.70
Δ%	+6	≃0	+33	+47	+6	-25	+19	-2	+7

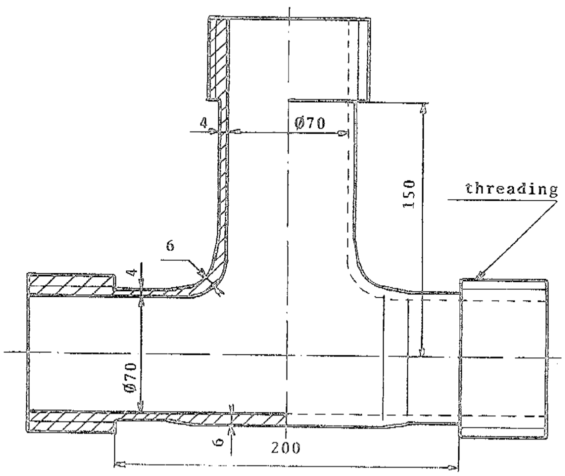

Fig. 1 Geometry of the mock-up representative of a valve body

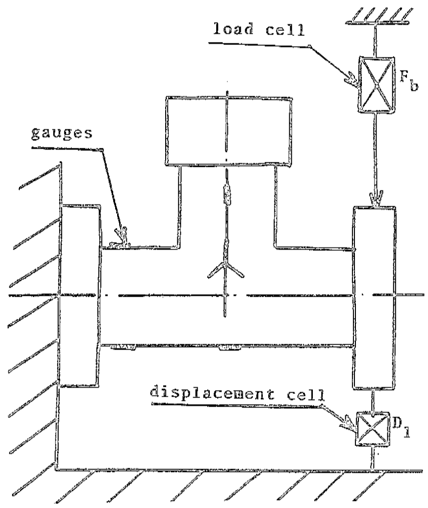

Fig. 2 Bending loading configuration

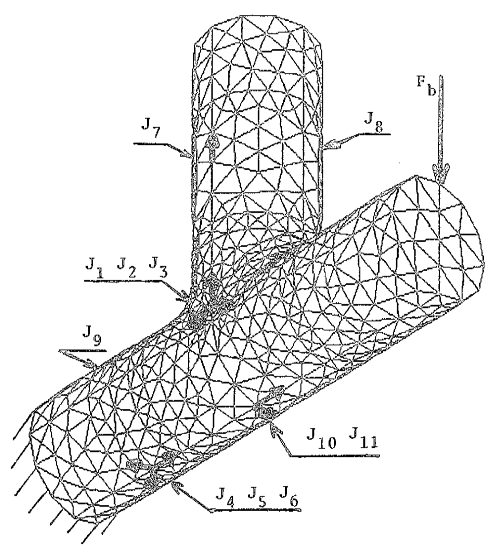

Fig. 3 Mesh of the mock-up with loading, boundary conditions and position of the gauges.

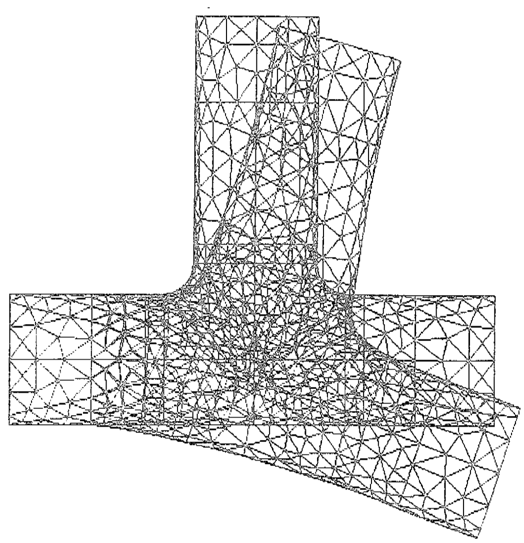

Fig. 4 Superposition of the initial mesh and the deformed structure for the bending loading.