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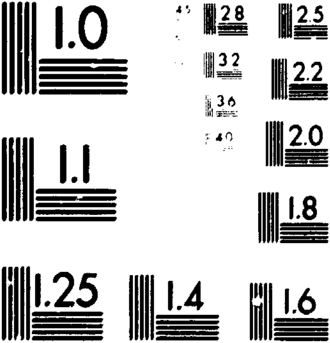

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NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
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AUTOCLAVE, COMPRESSION MOULDING*

by

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Autoclave and compression moulding are wellknown technologies in use for the fabrication of fibre composite structures. Aside of the general knowledge a lot of details has to be taken care of to ensure troublefree application.

This paper presents detail-information gathered with

- autoclave curing of extremely thin HM CFC (High Modulus Carbon-Fibre-Composite) face skin of space structures
- autoclave curing of thickness tapered HT (High Tensile) CFC skin of an AC taileron
- press curing of thick HT CFC rotorhub components
- and the use of an oven for vacuum bag curing

AUTOCLAVE - CURING OF EXTREMELY THIN HM CFC-SKINS

For the OTS (Orbital Test Satellite) and the INTELSAT V satellites CFC solar array structure have been developed and produced. For INTELSAT VI a hybrid CFC-AFC (Aramide Fibre Composite) solar array is beeing developed. A comon feature of those arrays are the thin face skins.

For example the skin of the INTELSAT V array structure has a nominal thickness of .16 mm only - see figure 1.

The skins are produced by winding Thornel 75 S on a large mandrel. The uncured laminate is cut off the mandrel and carefully placed on a steel plate.
With curing there is a high risk of damage due to, a, difference of coefficient of thermal expansion of the cured CFC skin and the metal plate and, b, due to memory-effects and coefficient of thermal expansion of auxiliary materials.

The difference of coefficient of thermal expansion becomes effective in the cooling phase. The plate on which the skin is cured contracts and compressive load is introduced to the skin. With the respective material data (table I) it can be calculated. Unfortunately the low expansion material "Invar" is expensive and does have long lead time. Therefore a set up using mild steel plate was used for INTELSAT V (see figure 2).

The experience was, that the shrinking of the metal tool did contribute to compressive load on the very thin skin and that the skin failed with local instability. The problem was overcome by reducing the curing temperature from 120°C to 80°C with vacuum applied until cooling down to 65°C.To cure the resin completely, a 3 hrs 120°C post cure was used. Since that no more skins were cured to scrap.

Aside of the metal tool the influence of auxiliary materials like peel-ply and vacuum foil, bleeder lease and so on also must be considered. Production technology of all thermoplastic auxiliary materials includes stretching. At elevated temperature those materials shrink considerably.

Manufacturing trials with hybrid skins, 4 x 4 m wide, .14 mm Kevlar and .1 mm Carbonfibrefabric composite to evaluate the curing procedure indicated severe problems.

For handling reasons an aluminum plate was used with the intention to let the composite slip.
Therefore the auxiliary materials were not fixed to the plate.
The cured skin was scrap because of severe wrinkling.

Thermal behaviour of the materials used was investigated.
Both shrinkage of auxiliary material and very high coefficient of thermal expansion (table II) of fleece and peel-ply after curing of the picked up resin were found to cause the wrinkling. The problem was overcome by use of a "Kevlar-plate", about 2 mm thick and by fixing everything to this plate.

AUTOCLAVE CURING OF TAPERED SKINS OF AC TAILERON

In the recent years quite a lot of CFC usage for aircrafts concentrated on control surfaces. In the FRG a CFC taileron for the Tornado and horizontal and vertical CFC stabilizer for the Alphajet have been developed. The high concentration of load at the inboard end of the taileron and the service temperature of up to 135°C made the development a technologywise demanding task.

The curing technology to be used for such components does depend on a few major items: Use of bleeding or zerobleed prepreg and use of a flow controlled or not controlled resin system. For a fast flying aircraft a resin system with a high softening temperature should be used - for ease of production a flow controlled system is desirable. Unfortunately today's ingredients to control flow tend to reduce especially wet softening temperature (table III).

With a flow controlled system both for bleed and zerobleed an example is presented.
The lay up scheme for the taileron skin is shown in figure 3.
The curing set up for a bleeding system (6% resin bleed from 40 to 34% by weight) is shown in figure 4. It becomes evident, that carefull tapering of the bleeder lease layers is to be used to receive uniform resin content. The bleed technology results in low porosity on one hand, but also in high labour cost on the other hand. Therefore, zerobleed technology was investigated, too. The set up for curing the skin with zerobleed material is shown in figure 5, the simplification is evident.

Both examples shown make use of a flow controlled resin system (Ciba 914). Using a non flow controlled system - i.e. low viscosity - a completely different curing set up must be applied. A typical set up for the Fiberite 1076 system is shown in figure 6.

With such a system only flat components can be autoclave cured with a rigid mould on one side only. If there is any remarkable vertical extension a second rigid tool surface must withstand the hydraulic pressure of the resin.

Aside of the differences in the technology of vacuum set up, mould concepts are very important for cost effectiveness. For composite components with a thickness about equal or exceeding 2 mm mild steel or electroformed nickel are appropriate materials for the mould. In the recent years the technology of coldforming of mild steel has improved considerably.
The mould shown in figure 7 was produced to the close tolerances specified in the drawing. Moderatly double curved shapes also can be made.
In Europe the prices for moulds produced with the technologies mentioned before, are about 3000.--DM/m² for mild steel and 6000.--DM till 8000.-- DM//m² for nickel, respectively, and therefore far below those of NC-milled moulds.

COMPRESSION MOULDING OF THICKWALL CFC-COMPONENTS

The fixed wing utilization of CFC normally leads to thin to medium thick wall components. Rather thick components out of composites are used for rotorhubs, for example for the wellknown "Starflex". Whilst this is a glassfibre design most of today's composite hub design use carbonfibres. Experience gained with the development of a carbon Fibre composite Elastomeric (FEL) bearing rotorsystem is tabled.

The structural components of this hub are two plates, each 55 mm thick, made out of C fabric-prepreg Fibredux 913C-815-40 (fig.8). For cost effectiveness machining was to be reduced to the minimum possible, a plate thickness of 55 $_{-0,5}$mm after curing was requested, also uniformity of fibre volume fraction. To reach this objective the following production sequence was developed:

- Production of 136 oversized single layer cuts
- Presscuring of each 8 cuts to a thickness of 3,2 mm at 85°C for three hours. This treatment consumes about 22% of the exotherm reaction energy.
- Cutting of the partially cured 8 layer prepreg by means of steel rule die to final dimension - .3 mm.
- Laying of the 17 partially cured cuts into the mould (fig.9).
- Curing in the closed steel mould - pressure to completely close the mould 5 - 8 bars, curing cycle see fig. 10.
- Removal of hot tool from press, disassembly of bolts to prevent the tool from shrinking onto the component.

Dimensional control:

Since second part the thickness of the plates varies from 54,5 to 54,8 mm, the requirements are met.

The experience to be drawn from this R+D program is:

- Curing of thick prepreg laminates requires special methods to avoid overheating - steel rule dies are very cost effective for medium quantity precision prepreg cuts up to about 5 mm in thickness
- With appropriate tool design conical walls can be avoided
- Rather close thickness and fiber volume tolerances can be met.

ADVANCED CURING CONCEPT

Cost effective utilization of autoclave curing in aerospace industry always creates logistic problems. Small autoclaves are not cost effective in serial quantity production, large ones need to be filled up to be so. Turn around time of individual moulds to produce a given number of parts per day can be manifold of that required if the tools could be used continously. The general tendency, therefore, is to try to make use of curing in an oven with vacuum applied to the laminate.

The MBB-Laupheim facility has installed one of the most advanced production lines for vacuum-oven curing of composite structures. The equipment is used for glass- and aramide phenolic prepregs now but also can be used for carbon fibre components.

The most important features of this productionline are: Computer controlled transportation system, a continuous furnace, four axis adjustable working places for manual prepreg application and a powder-primer spray - and cure equipment. Production is started by feeding into in the computer the drawing number of parts, the number required and the dates when the parts should be completed. The computer then defines the sequence for the moulds to be taken from the store and controlls their transport to the primer application unit. The moulds are coated with powder primer, the powder is cured in approximately 2 min by both infrared radiation and hot air circulation. At the same time the prepreg - pre cuts necessary for each individual part are assorted into in steelwhire baskets. These baskets are attached to the coated moulds, which are transported to the intermediate store. From there, again in a sequence defined by the computer, transportation to laminating place becoming free is done. After application of prepreg, peel-ply, release foil and so on a reusable silicon rubber mask is assembled to the mould. The set up is leak proof tested.

During transportation to the intermediate store before the continuous furnace and during storage vacuum is maintained by special vacuum valves which don't allow air to flow in the bag after lines have been cut off. During curing in the continuous furnace movable vacuum lines are connected to the moulds. After curing moulds are automatially transferred to demoulding and mould cleaning stations. Then release is applied and moulds are brought back to the mould store again.

The computer controlled transportation system does provide good traceability in the laminating shop. Calculation of piece work based salaries is eased also.

Although the investment was in excess of 10 Mio DM an average 30% reduction in cost per part was achieved by installation of the equipment described above.

The paper presented gives an overview only. The author will be happy to give detailed verbal information on request.

MATERIAL	COEFFICIENT OF THERMAL EXPANSION /RT/ /K^{-1}/	MODULUS OF ELASTICITY /RT/ /kN/mm²/
MILD STEEL	11	210
"INVAR" *	1,2	200
75 S / CY 209 ∥ **	$-1{,}2 \times 10^{-6}$	298
⊥	40×10^{-6}	3
±45°	$-0{,}5 \times 10^{-6}$	11
T 300 / CY 209 ∥	$0{,}23 \times 10^{-6}$	132
⊥	29×10^{-6}	9
±45°	2,55	16

*Composition: Fe 63,1 %, Ni 36,2 %, Mn 0,4 %

** Composition: 60 Vol.-%

TABLE I: MATERIAL DATA

MATERIAL	SHRINKAGE 120°C, 4 hrs	COEFFICIENT OF THERMAL EXPANSION /K^{-1}/
PEEL-PLY	1,5 %	54×10^{-6} / 40 % *
TEDLAR	1,5 %	
PAN FLEECE	1,5 %	70×10^{-6} / 15 % *
PERFORATED FOIL 4500	3,6 %	

*percentage of resin picked up / per weight

TABLE II: AUXILIARY MATERIAL DATA

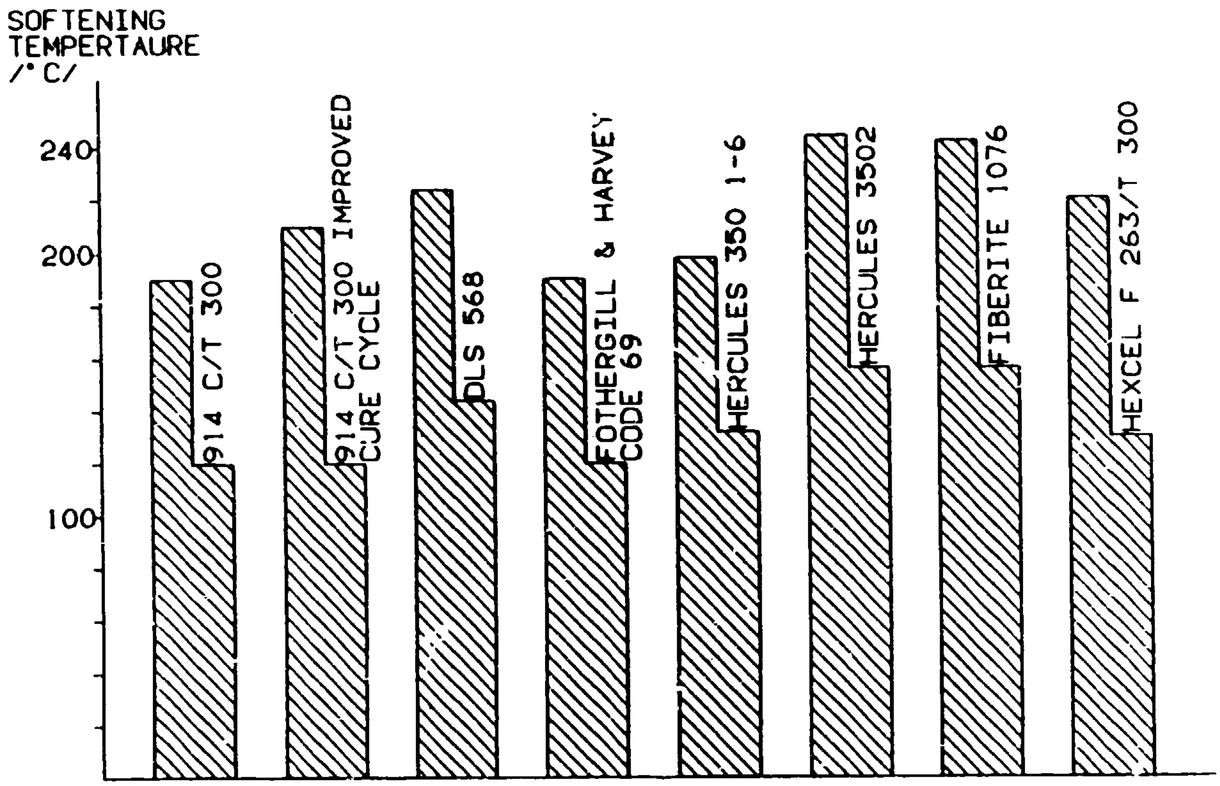
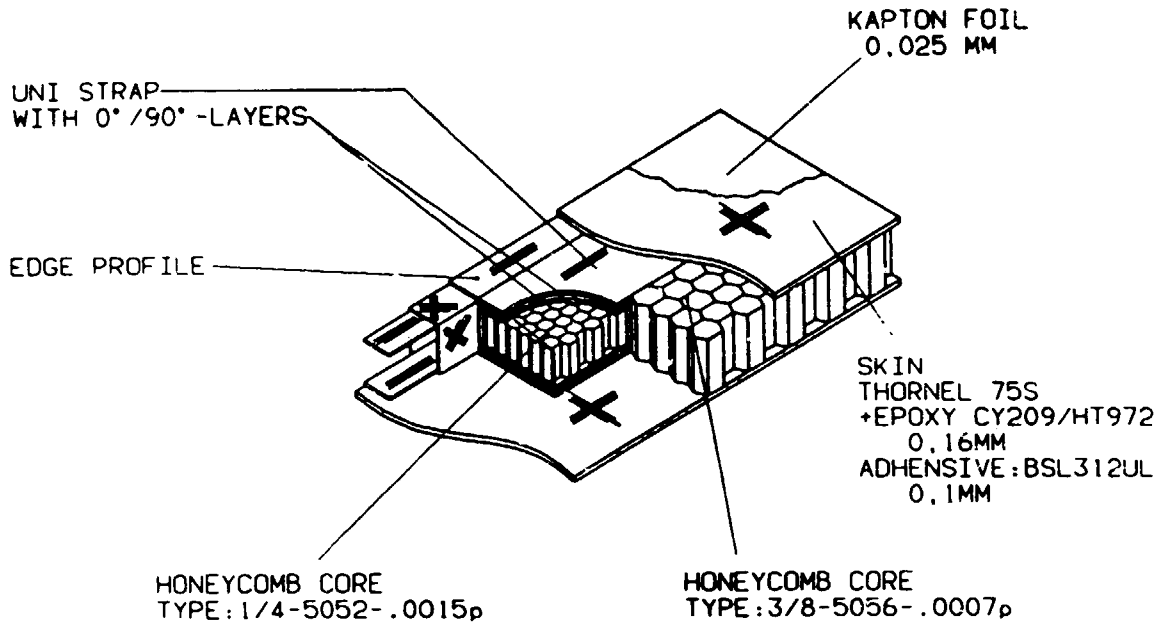
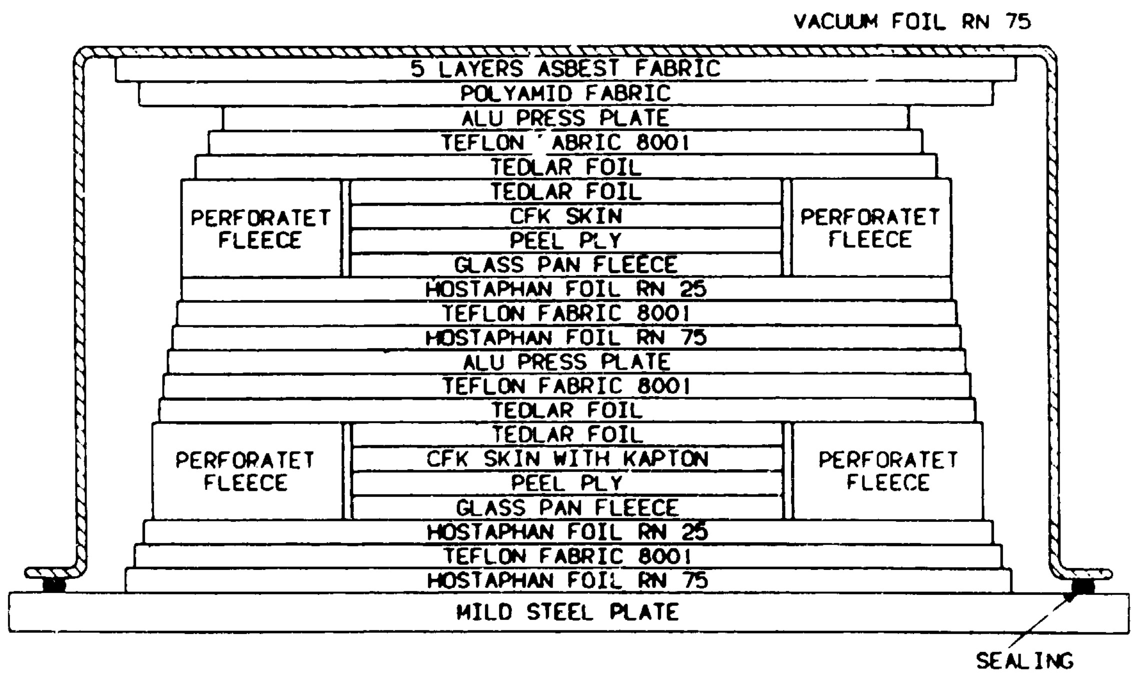


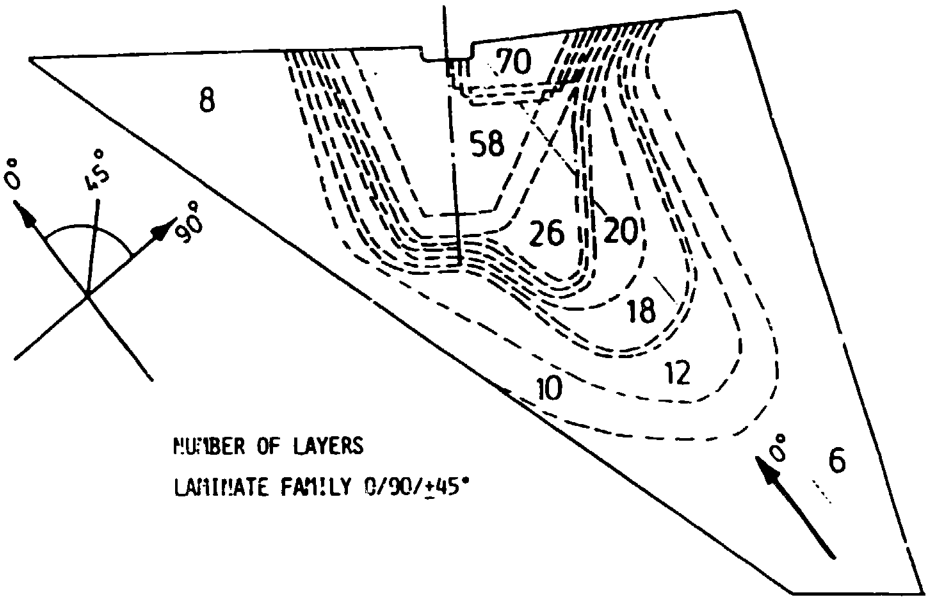
TABLE III:: SOFTENING TEMPERATURE, DRY AND AFTER STORAGE AT 70°C 75% REL. HUMIDITY/TORSION PENDULUM TEST



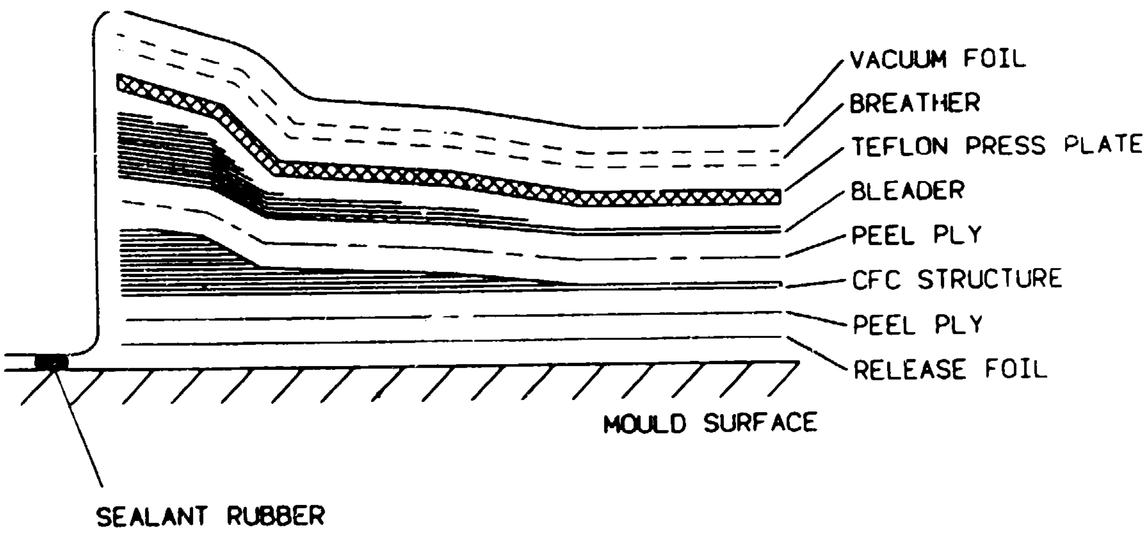
INTELSAT 5 SOLAR ARRAY STRUCTURE | **FIGURE 1**



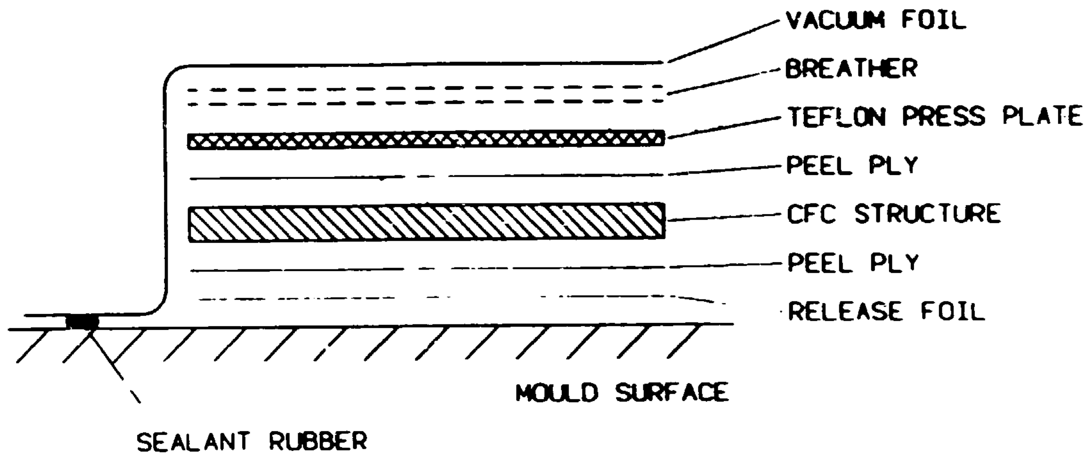
INTELSAT 5, SKIN CURING VACUUM SET-UP | **FIGURE 2**



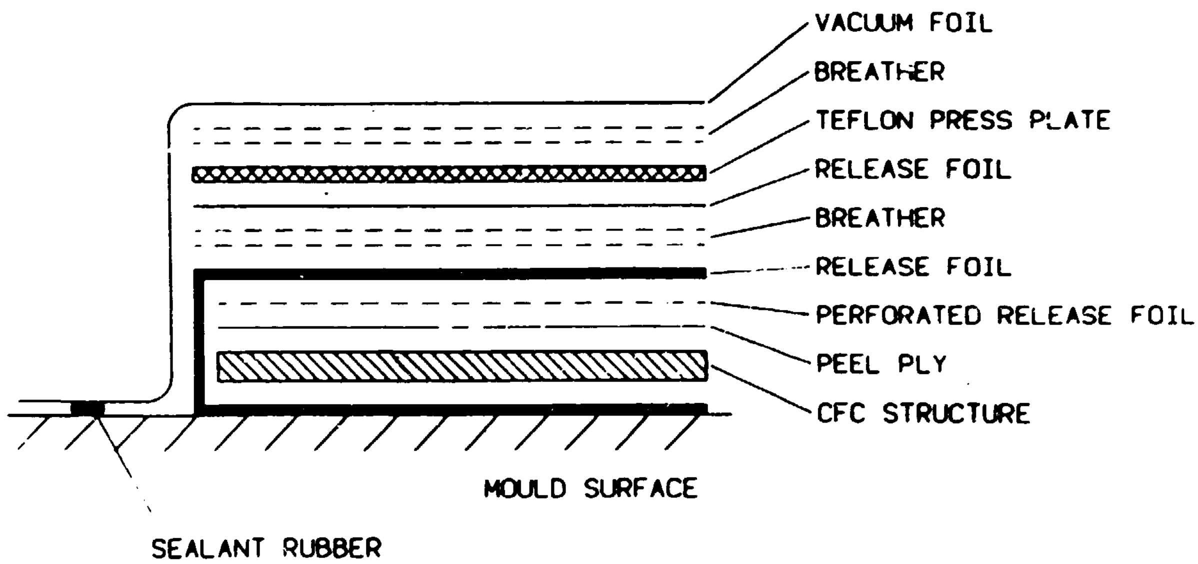
LAY-UP SHEME OF TAILERON SKIN FIGURE 3



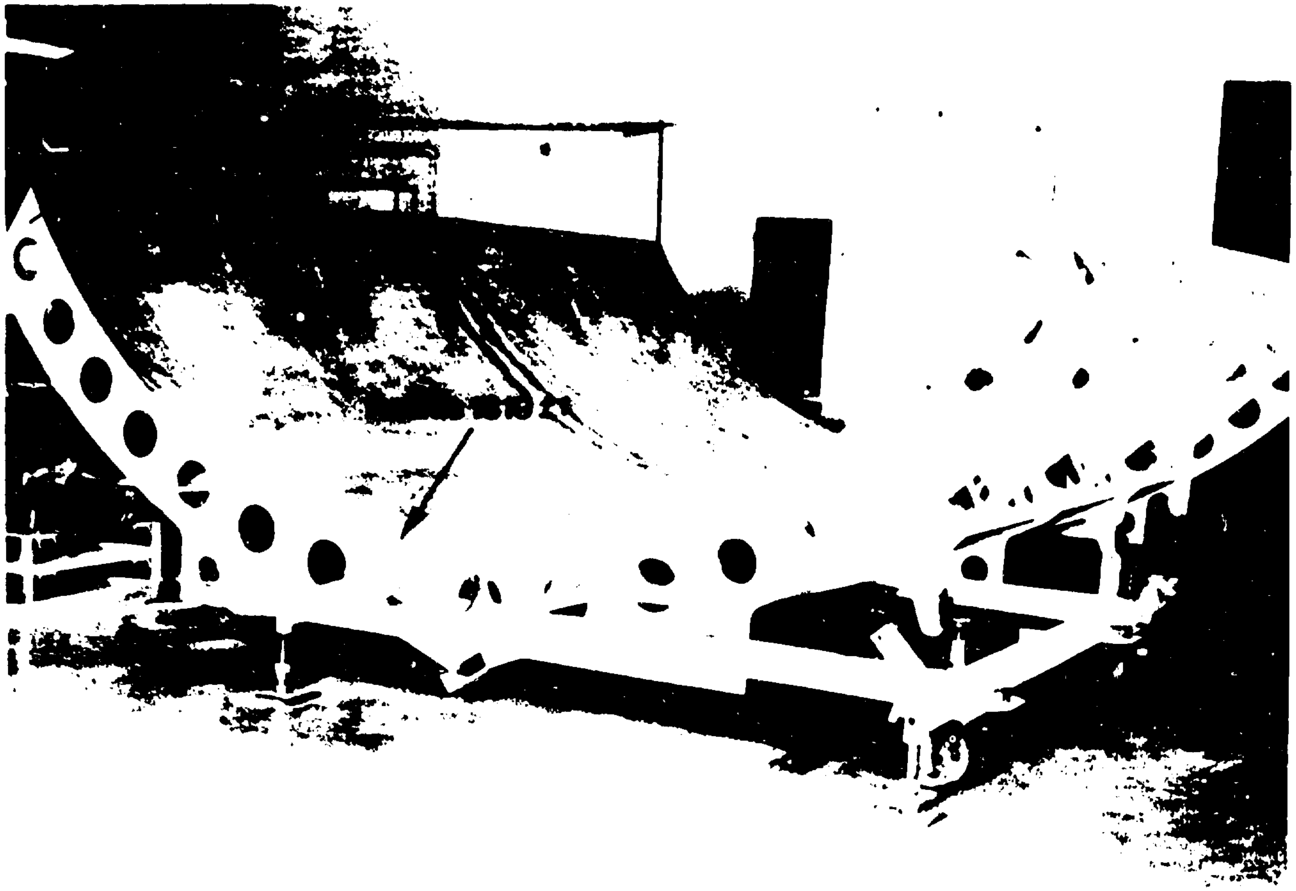
CURING SET-UP FOR BLEEDING SYSTEM FIGURE 4



VACUUM SET-UP FOR ZERO BLEED PREPREG — FIGURE 5



VACUUM SET-UP FOR NON FLOW CONTROLLED PREPREG — FIGURE 6



SHEET METAL MOULD

FIGURE 7

ROTOR HUB - PLATE

FIGURE 8

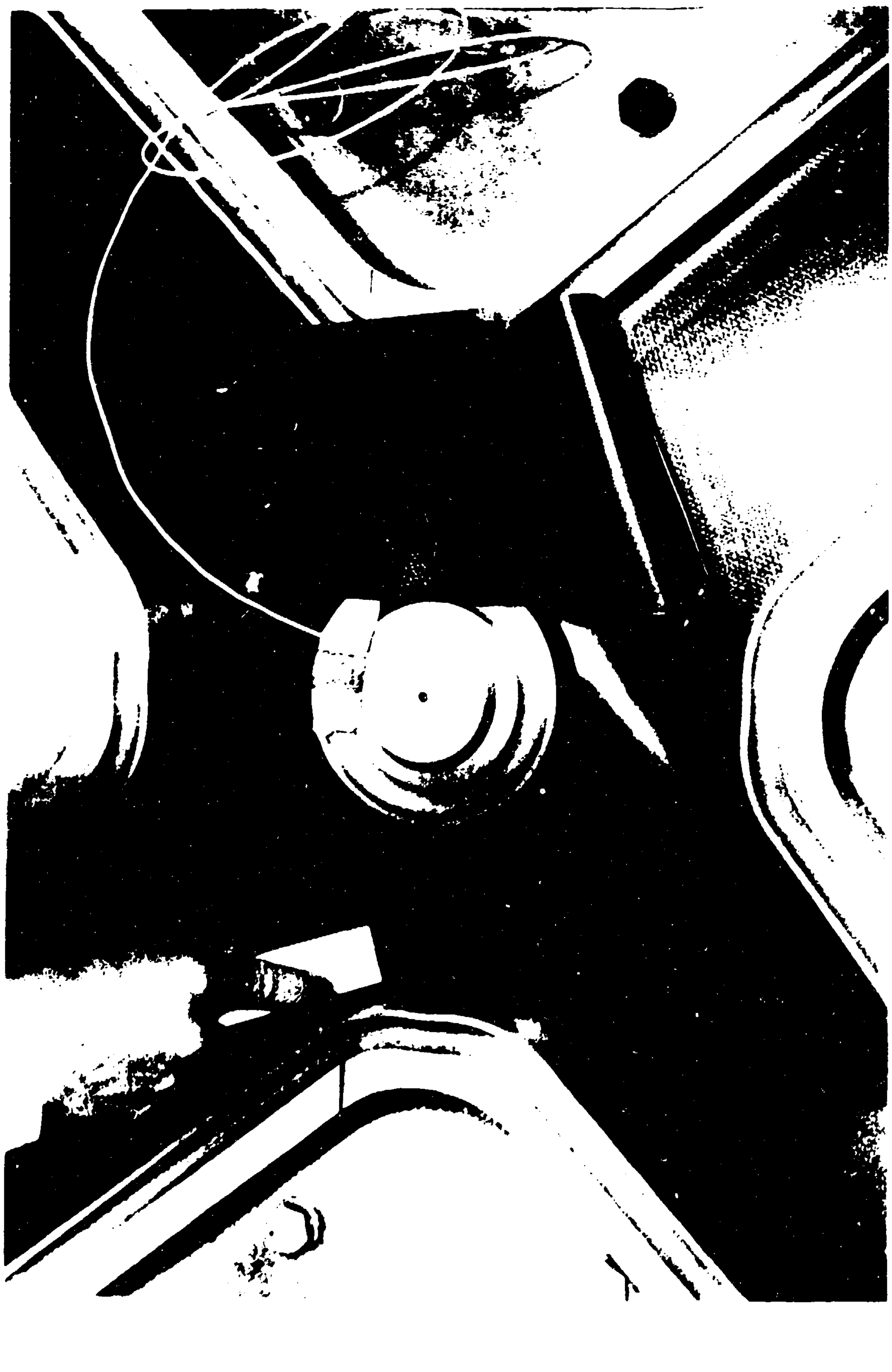
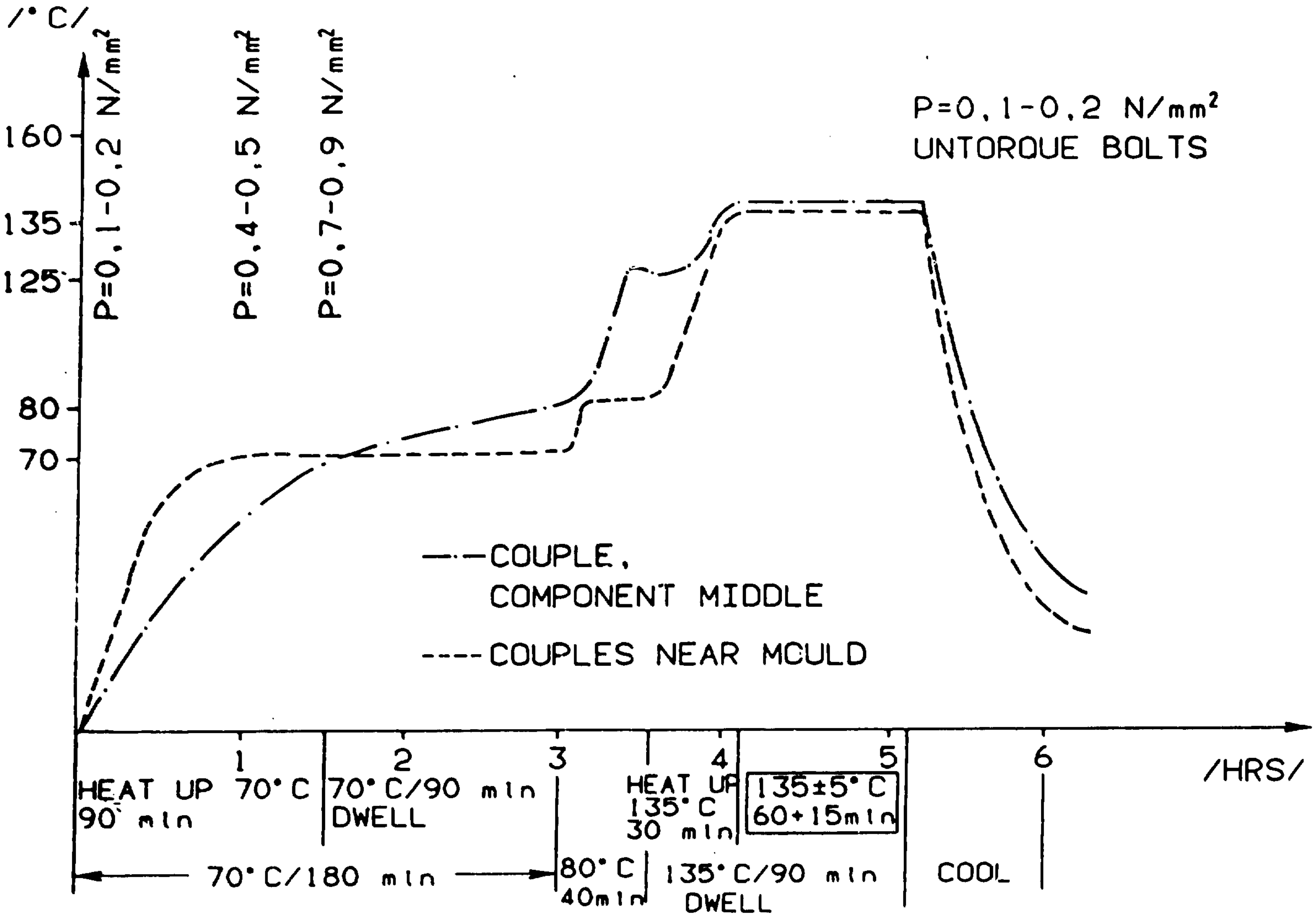


FIGURE 9

MOULD OF HUB - PLATE



CURING CYCLE

FIGURE 10