Mechanical Parts made of Thermoplastic Matrix Composites

H.J. Gysin

High performed industrial components made of Thermoplastic Matrix Composite Materials require special manufacturing techniques according to their economical and technical "environment". The availability of complex shapes in the design, the outstanding dimension on stability, the guaranteed mechanical strength in long terms and the competitive prices of the parts are crucial. In exception to their limited properties, most of the requirements can be met by todays common stampable materials and their processes. These processes can principally be applied on advanced thermoplastic composites with a very high fibre content. Considered the more limited flow of the fibre- material, the geometrical design is restricted to additional rules. Starting from tailored designed preforms, the press- forming of Advanced Thermoplastic Matrix Composites, results in adequate mechanical parts. A general presentation of applications completed by the description of flow phenomenas during the processing of these examples are outlined.

Keywords : moulding, material flow, thermoplastic, advanced composites, mechanical applications

INTRODUCTION

Current and future demands of engineering and manufacturing with modern thermoplastic composite materials call for new methods of design in their development and in their production. Corresponding to customer demand, it is important to invent instruments which allow new construction of components, which will in turn lead to a higher level of economical success without sacrificing quality.

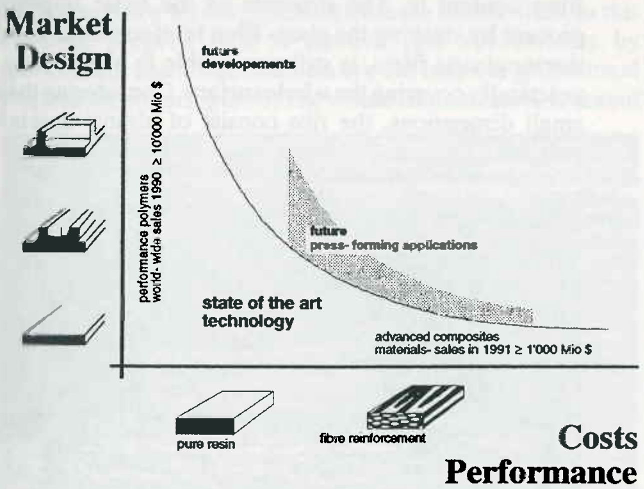


Figure 1 developments in technical polymer -products -market and -manufacturing

The main energy spent on new developments in industry is directed to achieve evolutionary improvements in existing products by lowering the manufacturing costs as well as increasing the technical performance. The future market therefore, requires either higher performance for the same design, or an improved design with the same performance. Press- Formed Advanced Composite parts may offer to meet both targets for many applications. Although their technology is remaining in an embryonic industrialised stage, a wide range of further improvements may be achieved.

Press- Forming of Advanced Thermoplastic Composites introduce an extensive material flow under high pressure and leads to an advantageous stage of high- speed processing with instationary thermal conditions. Both effects are considered to have an important impact on the quality of the end product. The controlled material flow allows to design economical production of high performance parts with more complex shapes than ever before. Laws and restrictions in flow of fibres impregnated by a matrix are investigated in many fundamental and applied research works , especially with glass- mat reinforced stampable materials. The Press- Forming of preforms with a high volume fibre reinforcement almost consisting of a lay up from uni- directional prepreg- tapes or BRUD- rods demands additional effort in research. However, it is obvious that any flow of material perpendicular to the fibre- axis is far less constraint than the flow parallel to the fibre- axis. As shown in the samples (Figure 2) the uni- directional layers squeeze perpendicular to their fibre direction, while the GMT- material which is reinforced by continuous strand mat glass- fibres squeezes continuously in all directions.

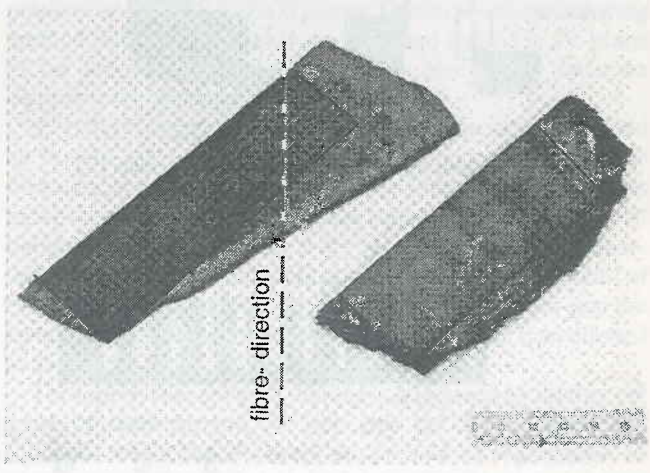


Figure 2 squeeze- flow of in a compressed platen of a uni- directional (left) and a strand- mat laminate (right)

GLASS- REINFORCED-THERMOPLASTIC PRESSFORMING- SHEET- MATERIAL

The concept of these materials is to produce a fully impregnated semifinished product in the form of a sheet, typically ~ 5 mm thick. It is then heated and pressed or stamped. The process is considered to be more compatible with mass- production fabrication than the slower methods with thermosetting- resin- based materials such as sheet-moulding compound.

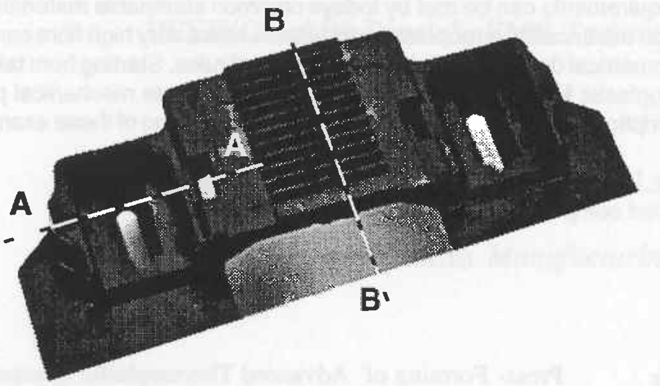


Figure 3 part for an electro- mechanical application in GMT PC/PBT

The inquired part for an electro- mechanical application is manufactured from GMT PC/PBT with 30%wt continuous strand mat glass- fibres, as this material is used in the automotive industry. A very high performance in the geometrical tolerances as well as solid electrical insulation behavior is specified due to the technical requirements. The material- sheets are pressed into the final shape according to suppliers instructions, except processing temperatures are increased. Suitable cut blanks are

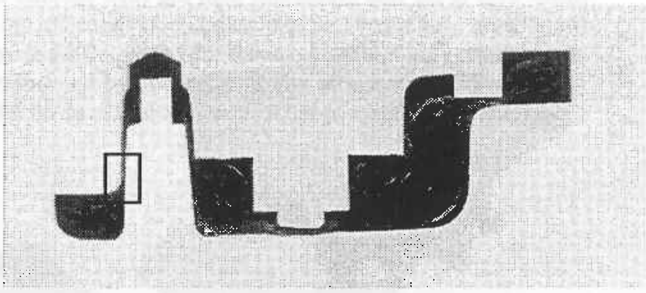


Figure 4 section A; slots and a cylindrical hole (scale 1:1)

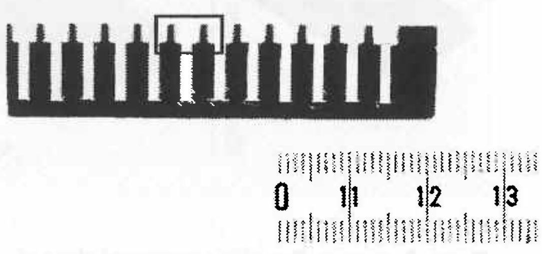


Figure 5 section B; row of cylindrical holes (scale 1:1)

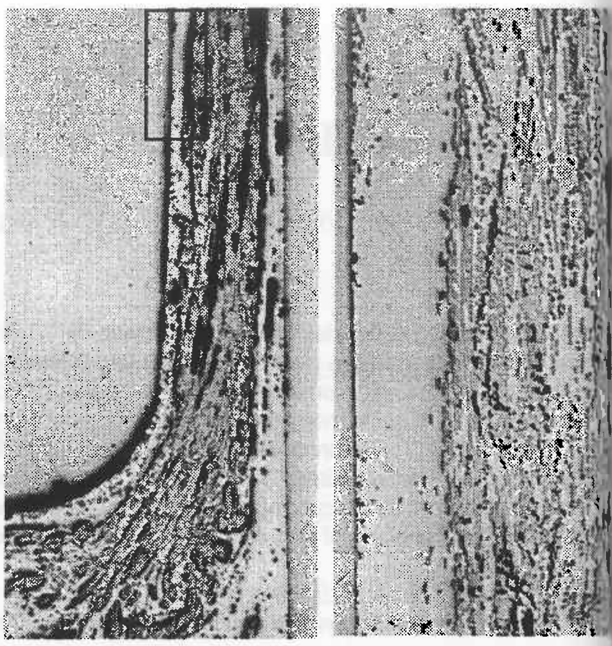


Figure 6 details of section A; fiber flow and resin rich surface (scale 10:1, 50:1)

oven heated to melt the polymer and then quickly transf into a match- dies tool under a 150 ton press. The mate flows between the dies to fill the cavity, "freezes" within a f seconds and the formed product is then ejected. While surfaces are net- shape formed, a few machining operati are required merely to finally open the holes.

As shown in the micrographs, the fibres flow easily arou the pins, thus forming the cylindrical- holes, whilst the fib are consolidated to a maximum, due to the sharp corne inserts which form the slots. The convex corners are fil with segregated polymer; the sharper the corner, the less fibre content is. The structure of the basic impregnat process by stacking the glass- fibre reinforcement inbetw thermoplastic films, is still perceptible in a pure resin la practically covering the whole surface. Considering their v small dimensions, the ribs consist of almost unreinfor polymer.

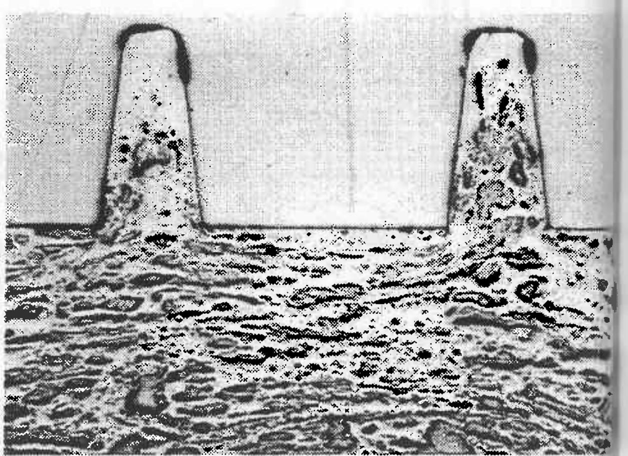


Figure 7 detail of section B without holes (scale 10:1)

Polymer- blends as PC/PBT tend to shrink during cool from the molten phase into the solid phase, which could l to cracking in the unreinforced resin rich areas. Neither whole part, nor the ribs, due to their small thickness, or convexial corners, due to their unstraint forming in the t showed any signs of cracking.

SQUEEZE FLOW OF A STACK OF PREPREG

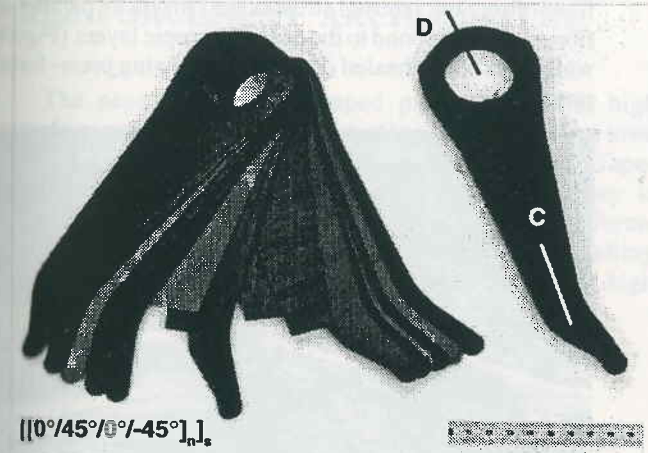


Figure 8 picking- leaver for weaving machinery application and its prepreg- stacking sequence

Carbon- fibre prepreg- tape is used to manufacture high performed parts by tape- laying, pressforming or autoclaving. The laminat is built up by stacking as close as possible to the final fibre- architecture of the part. These stacks might be reshaped after, or during first consolidation by diaphragma-forming, or folding operations. Shear- deformations between the layers allow the primary flat stack to become a shell geometry.

The enquired part for textile machinery application is manufactured from PEEK/C- fibre prepreg with 61%vol fibre content. The wheigt is some 100g per piece and the thickness varies from some 6.5 to 9.5 mm. The edges are kept sligthely conical to allow an easy ejection from the match- dies. In this example prepreg tape is stacked into sublaminats by spotwelding and these laminats are cut into the geometrical shape as shown in Figure 8. The whole laminat- stack is heated

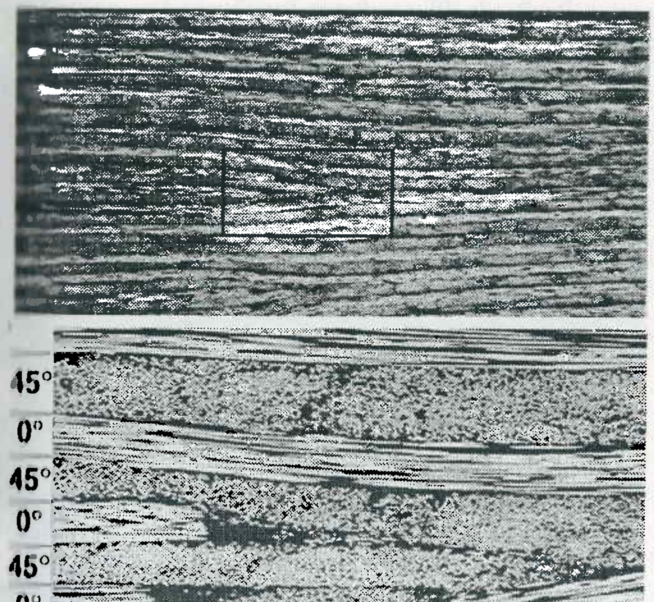


Figure 9 section C; consolidated prepreg- stack (scale 10:1, 50:1)

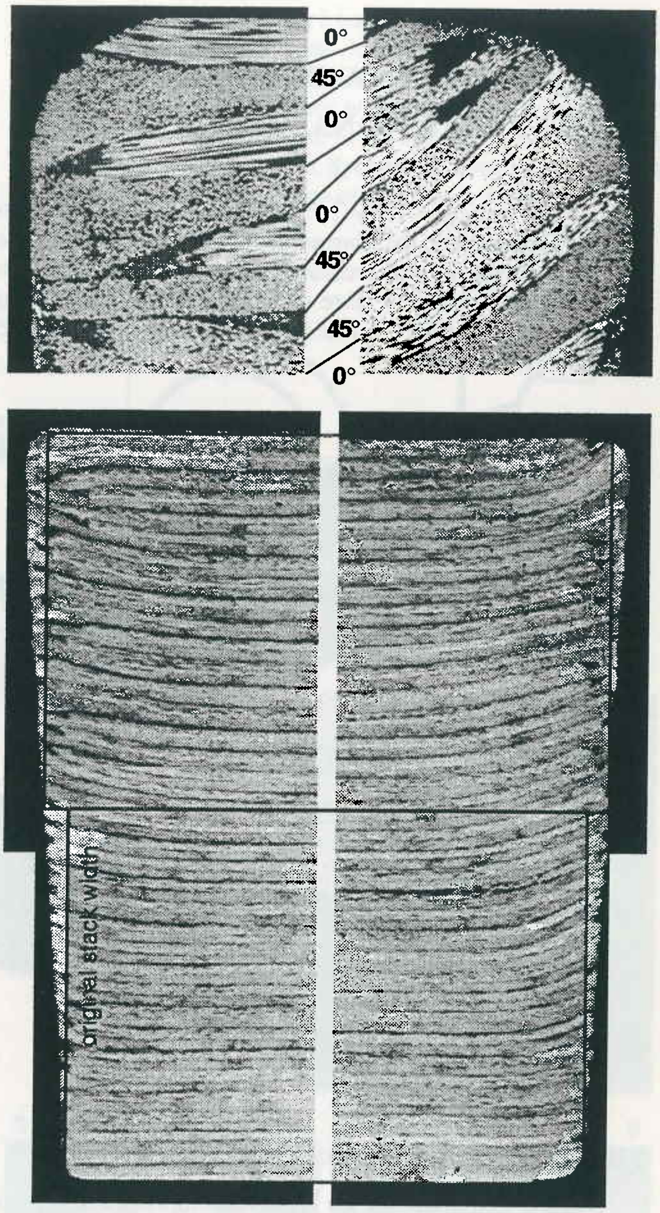


Figure 10 section D; consolidated prepreg- stack (scale 10:1, 50:1)

in the tool above melting temperature and then moved under the cold press where it is fully consolidated within minutes. This type of processing was especially designed for an annual production of 3000 to 5000 pieces. Due to the manufacturing method polymer and fibers are squeezed almost in the plane of the prepreg to fill the dies cavity completely under an equipressure of some 150 bar.

The step in the width of the prepreg- stack becomes equalised by flow of resin and fibre (Figure 10). The more parallel the fibres are to the edge, than better they flow. Layers having an axis perpendicular to the edge are squeezed to segregation of the matrix. In section C the ± 45° layers show the most flow-deformation. Due to the friction of material on the sidewall of the tool during consolidation and leckage in the dies- gap the layers edges are bent upwards than higher the layer is positioned in the stack.

The tapered variation in thickness is induced by cutting off some of sublaminates. In this area the ± 45° layers are squeezed while the 0° layers are pressed to segregation of matrix material to fill the gap inbetween. As shown in the micrographs of section C (Figure 9) the laminat is free of any voids as its is all over the remaining part.

SQUEEZE FLOW OF AN ALMOST UNI- DIRECTIONAL LAMINAT

The squeeze flow in advanced composite material perpendicular to the fibre axis is of high interest, because it is the least energy and pressure consumable flow direction and introduces the least fibre damage. Taking fluid dynamical laws into considaration the flow is easiated the thicker the uni-directional layer is.

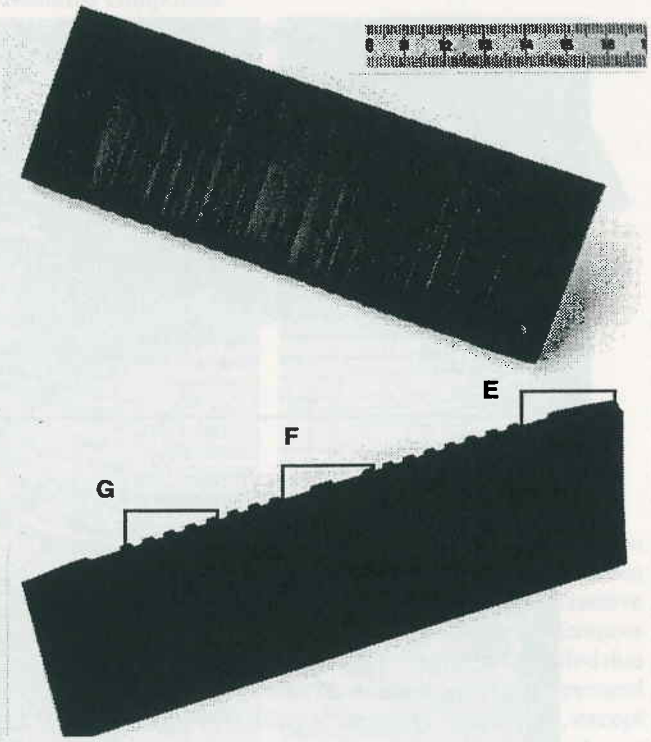


Figure 11 segmented labyrinth- sealing

The enquired part for a piston compressor application is manufactured from PEEK/C- fibre prepreg with 61%vol fibre content. It is one of the segments of the labyrinth sealing system of a piston. The preforms are consolidated in flat platten- laminats, reheated above melting temperature, transfered into the warmed tool (150°C) whereby they are placed under a 50 ton high speed press.

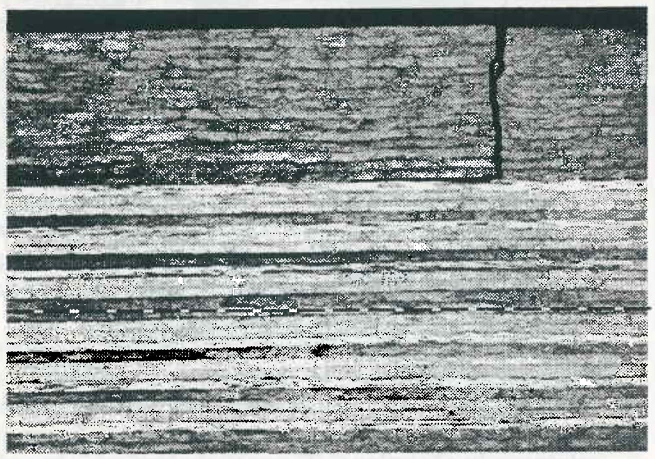


Figure 12 preconsolidated laminat- crack due to internal stresses micrograph (scale 10:1)

The preform- platten is 6.75 mm thick. It is built from layers uni- directional laminat parallel to the labyrinth both surfaces and inbetween 24 layers of quasi- isotr laminat. Due to the high thickness of the uni- directio layers and their increased shrinkage perpendicular to t fibre- direction, internal stresses lead to cracks parallel to fibres and in the bond to the quasi- isotropic layers (Figure which can not be healed during the following press- formi process.

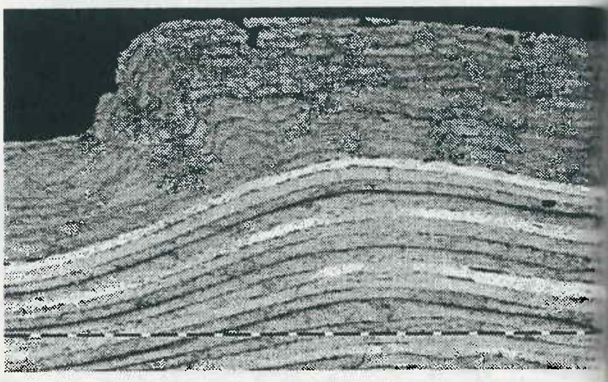


Figure 13 section E, squeeze flow of uni- directional laminat waves in the mid- plane quasi- isotropic material (scale 10

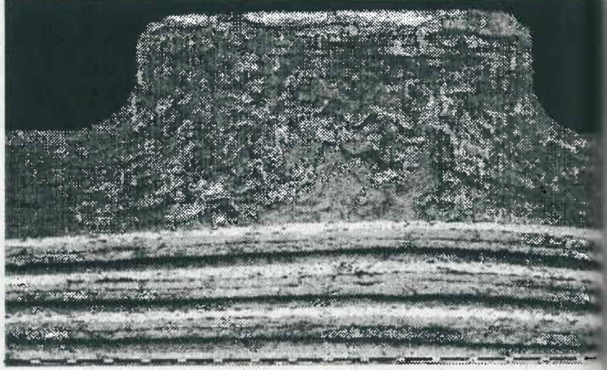


Figure 14 section F, squeeze flow of uni- directional laminat waves in the mid- plane quasi- isotropic material (scale 10

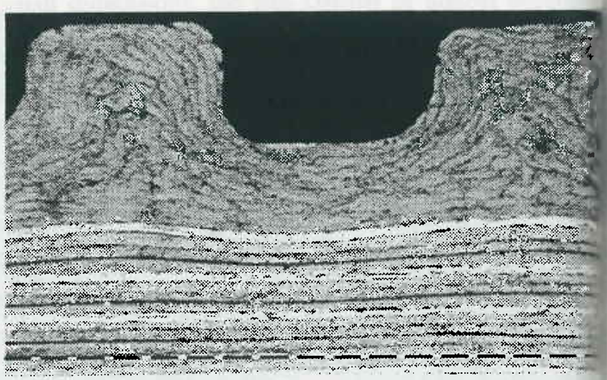


Figure 15 section G, squeeze flow of uni- directional laminat waves in the mid- plane quasi- isotropic material (scale 1

The ribs and slots of the labyrinths are formed by within all layers of the laminat. The outside uni- directi layer is formed to the net- shape surface which has the deformations. Considering a locally higher pressure i slots the inside uni- directional layers material sqeezes these areas too, which results in an inbetween wavy q isotropic layer . The wave- amplitude increases wit length, or the width of the slots respectively. No segreg of fibre and matrix can be found.

SQEEZE FLOW OF A UNI- DIRECTIONAL LAMINATE WITH AN ADVANCED REINFORCEMENT ARCHITECTURE

The need of complex shaped parts made from high performance materials could be met in a laydown of fibre tows which is optimised against the structural demand. Tape-laying is a high productive process where efficiency is depending upon the complexity of the form. Simple preforms manufactured by tape- laying can be heated above melting temperature of the polymer and then squeezed under high pressure in dies into the final shape.

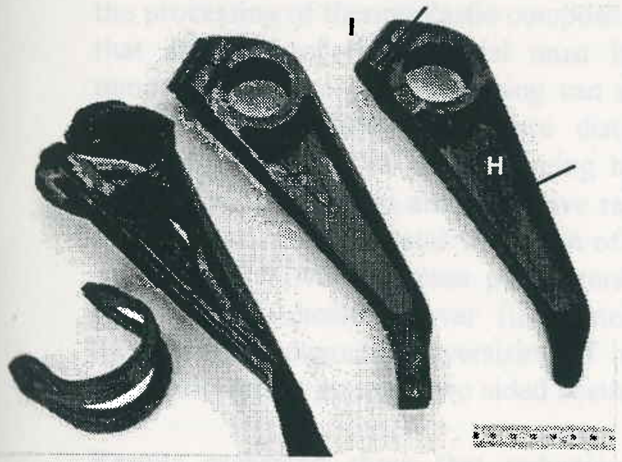


Figure 16 picking- leaver for weaving machinery application and its preforms made from slit prepreg

The enquired part for textile machinery application is manufactured from PEEK/C- fibre prepreg with 61 %vol. fibre content. The weight is some 125g per piece. Prepreg- slit is heated in bundles and then wound around a preliminary forming- tool where it is cooled. This preform is reheated in a fixation and transferred together with the fixation into warmed dies where it is fully consolidated. The material is squeezed in the perpendicular direction to the fibre and the slit bundles are stretched due to this deformation.

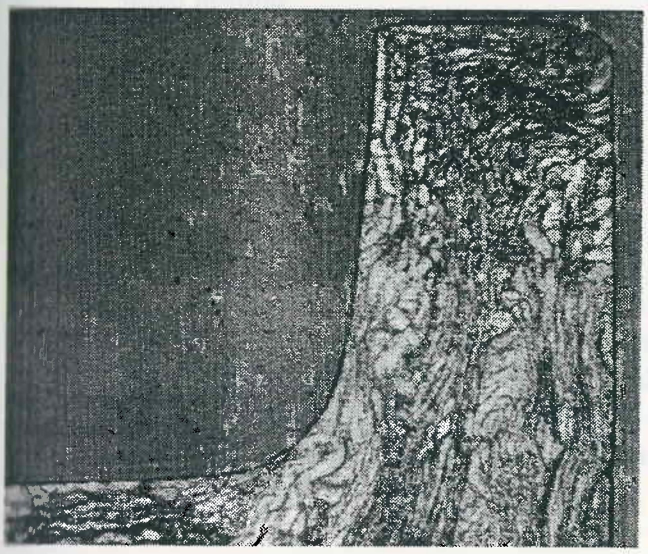
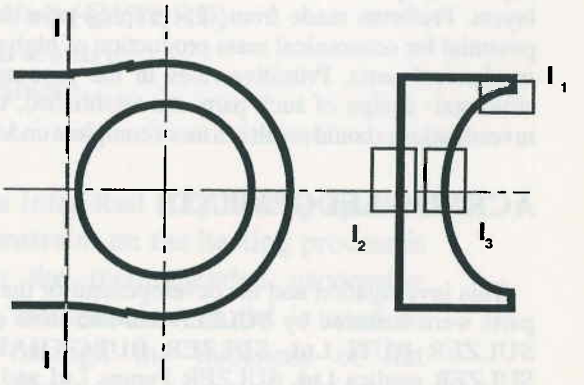


Figure 17 section H, squeeze flow of uni- directional laminat (scale 10:1)

In the design of such parts it has to be considered that all the fibre- bundles have the same length. This means the fibre bundles have a constant intersectional area along their full size.To prevent voids (Figure ww) the geometry of the tool has to have the negative form to the intersectional area of the slit bundles in every position. Special attention has to be spent on bifurcations and crossings of bundles.



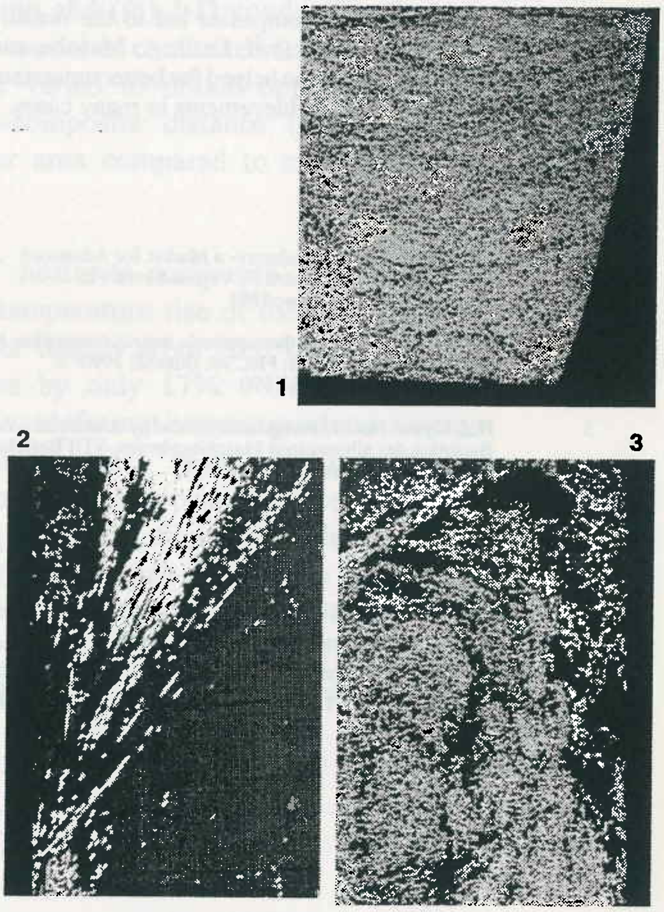


Figure 18 section I, squeeze flow of uni- directional laminat around a hole; voids and segregation of matrix- polymer (scale 10:1)

This type of processing is especially designed for high production rates. The equipressure in the dies exceedes almost 500 bar. The part is almost pressed net- shape, but the holes have to be grinded on tolerance as the tip has also to be mechanically machined. There is very little waste of raw-material compared to the traditional prepreg- cutting state of the art.

CONCLUSIONS

Preforms of advanced thermoplastic matrix composite material can be squeezed into a cavity of match- dies under high pressure. The flow behavior of the material is mainly depending upon the fibre orientation and the thickness of the layers. Preforms made from slit- prepreg-tape have a high potential for economical mass production of high performed mechanical parts. Primitive rules in the process- and the structural- design of such parts are established, but further investigations should result in a more complete understanding.

ACKNOWLEDGEMENTS

This investigation and the developement of the presented parts were financed by SULZER Ltd and their enterprises SULZER RÜTI Ltd, SULZER BURCKHARDT Ltd, SULZER medica Ltd, SULZER Pumps Ltd and SULZER INNOTEC Ltd. The shared skills of many Engineers and Researchers within these companies led to the result. The complementary research of Prof. Dr. J. A. Manson and his team at the EPFL in Lausanne helped for better unterstanding and interpretations of the achievements in many cases.

REFERENCES

1 **H.J. Gysin** Machine Industry- a Market for Advanced Thermoplastic Composites ? ; Verbundwerk'91; Wiesbaden 9- 11 October 1991

2 **H.J. Gysin** Advanced thermoplastic matrix composites in mechanical applications; FRC'90; IMechE 1990- 3; Liverpool 27- 29 March 1990

3 **H.J. Gysin** Hochleistungsfaserverbundwerkstoffe in Bauteilen des allgemeinen Maschinenbaues; VDI Bericht 734; Tagung in München, 6./7. März 1989

AUTHOR

H.J. Gysin is within SULZER INNOTEC Ltd, the central research and developement staff organisation of SULZER Ltd, where he is the leader of the Advanced Composites Group since 1988; KoSt 1524, PO Box, 8401- Winterthur, Switzerland.