INFLUENCE OF THE SHEET FORMING TECHNIQUE ON THE DRAPABILITY OF LOW COST TEXTILE REINFORCED THERMOPLASTIC COMPOSITES

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INTRODUCTION : SPLIT-WARPKNIT PREFORM

As a thermoplastic is more suitable for composite production with short cycle times, weft-inserted warp knitting is applied to manufacture a novel thermoplastic textile, containing both non-crimp reinforcing glass fibres and thermoplastic PP matrix ribbons. The merit of this structure is the good drapability, high mechanical performance with a comparable low cost (figure 1). Moreover, the split-films have been fibrillated (figure 2) and varied in profile to enhance the melt distribution during the impregnation process [7][8][9].

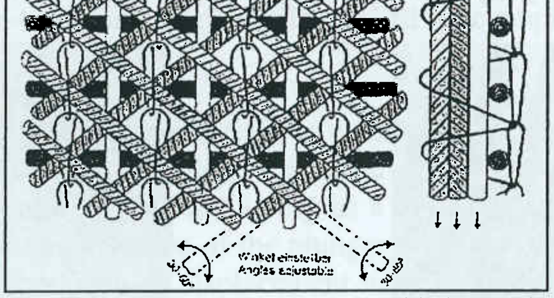

Figure 1: Multi-axial weft-inserted warp knitting with thermoplastic split-films

The split-films are inserted in the straigth yarns, along with the reinforcement rovings. The loops are hence exclusively consisting of a commercial PET binding yarn (figure 2). The hybrid split-warpknit textile allows for a more even fibre distribution because it is possible to bring the inlays closer together, as the binding yarn has a considerable lower count than the split-films and the volume between the rovings is kept low.

The composite structures are obtained by simple hot pressing the textile preform without any further addition of matrix. Special glass sizings and low viscosity matrix materials are developed to ensure a good wetting out of the reinforcement and an easy, thus fast impregnation.

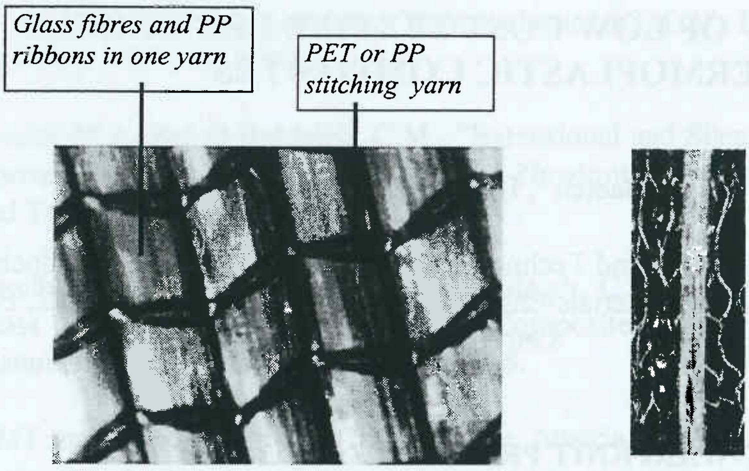

Figure 2: Mono axial **hybrid** split-warpknit

SHORT CYCLE SHEET PRODUCTION CONCEPTS

The thermoplastic split-film ribbons are severely stretched to guarantee sufficient tenacity during knitting. During the stretch operation, the polymer chains get a high degree of orientation. Free heating without the application of external pressure, increases the possibility for the molecular chains to return to their more natural state of random coil orientation. This will cause the film to shrink and may result in a deformation (in-plane contraction or curling) of the split-warpknit structure (figure 3). Due to the shrinkage of the ribbons upon heating, it is mandatory to support the textile throughout the heating phase, either by sideways clamping and stretching, or by applying a flat-wise pressure on the preform.

Figure 3: Shrinkage of the thermoplastic film: waviness and curling of the fabric

There are mainly two different ways of processing this new split-warpknit textile into a flat stable laminate <u>*prior to deep drawing*</u>:

- ***A full pre-consolidation*** of the textile into an organic sheet under high temperature and pressure (T=240°C, p=25 bar). Consequently, the pre-consolidated sheet is re-heated and formed during deep drawing. A classical *in-mould heating and cooling* method, where a loose stack of textile layers is placed in a cold mould, heated, pressed and cooled down is used. It is however very energy and time consuming and hence far too expensive for industrial use.

- ➢ ***Impregnation and full consolidation*** press forming are combined. A ***pre-compaction*** at lower pressure and intermediate temperature (T=210°C, p=5.5 bar and t=5.5 min) is necessary for the relaxation of internal stresses and hence the elimination of shrinkage of the thermoplastic ribbons during free heating. During pre-compaction, a limited matrix infiltration of the fibre bundles is already achieved.
- ➢ A ***GMT based cold pressing method***, i.e. an external preheating and cold pressing, is applied on the pre-compacted laminates. The GMT parameter settings are as follows: preheating at 240°C for 4 min, pressing at 125°C for 1.4 min at 60 bar.

DEEP DRAWING INTO COMPLEX SHAPES

A deep drawing apparatus (figure 4), consisting of a mould with a built-in hold-down blankholder is designed. Flat laminates are re-heated in a hot air oven above the melting temperature of the thermoplastic matrix and formed with a cold stamp. To prevent the molten laminate to stick to the surface of the stamp, two polymeric foils are used during stamping [5].

Because straight continuous fibres can not lengthen nor shorten, the principal mode of deformation during stamping is compression and local shear deformation. However, significant compressive forces are induced during deformation. If these compressive forces exceed the critical buckling stress of the fibres, fibre buckling and wrinkling take place in the flange area. It is important to anticipate and predict wrinkling in a forming process because it results in an unacceptable surface appearance and a potentially weakened part [1]. By clamping of the laminate, a frictional force is additionally build up which prevents the laminate from slipping into the cavity and deformation during draping mainly occurs via inter-ply slipping and intra-ply shearing. Moreover, it keeps the laminate under tension as to avoid wrinkling. Substantial pre-tensioning is normally applied by clamps at the fabric edges (as a blankholder).

The preforms are subjected to a hemispherical or cylindrical plunger under semi-constrained boundary conditions. The preform sample size is square, 250 mm by 250 mm. The sample is clamped between two circular ring plates, acting as a blankholder. The plunger is mounted and moves upwards. The initial position of the plunger is set such that the plunger still has to move before touching the laminate. A displacement limit position is preset at 75 mm. When this displacement is reached, the plunger stops automatically. The displacement and load are recorded during the test. The forming energy is calculated. Since the forming energy is an effective measurement of the difficulty level of a forming process, it can be used as an index, evaluating the formability of preform fabrics.

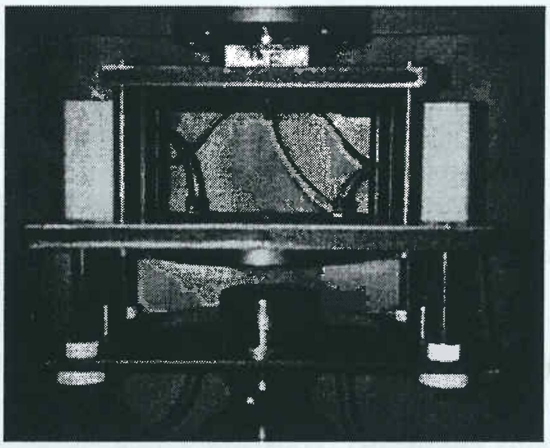

Figure 4: Deep drawing pilot plant

After a screening study of the deep drawing settings, the parameters are set at:

- Cylindrical or hemispherical stamp
- Re-heating temperature of 200°C in a hot air oven
- Stamping velocity of 12 mm/s
- Hold-down pressure of 0.08 MPa (6 bar)
- Stamp temperature of 50°C

EVALUATION OF THE DRAPABILITY

During deep drawing, the force-displacement curve is recorded. Formability refers to the level of ease or difficulty of forming certain materials into complex shapes. A material with a good formability needs less applied force, consumes less energy and can be formed in the required shape without failure [2]. To quantify differences in the formability of the laminates, five indices have been defined (figure 5):

- F40, this is the force at a displacement of 40 mm. It is a measure for the elastic deformation during draping (intra-ply shear and inter-ply slipping). A first plateau in the force-displacement curve is seen.
- F70, the force at a displacement of 70 mm, towards the end of the draping. This is a measure for the degree of out-of-plane buckling and hence the tendency for wrinkling.
- Slope 30-40, slope of the force-displacement curve, between a displacement of 30 and 40 mm. This is an indication of the ease of intra-ply shear and inter-ply slipping.
- Slope 60-end: slope of the force-displacement curve, between a displacement of 60 mm and the end (75 mm). This is more an indication of the degree of buckling.
- Forming energy to reflect the difficult level in a forming process [2]. The forming energy is defined as the integration of the force versus the displacement.

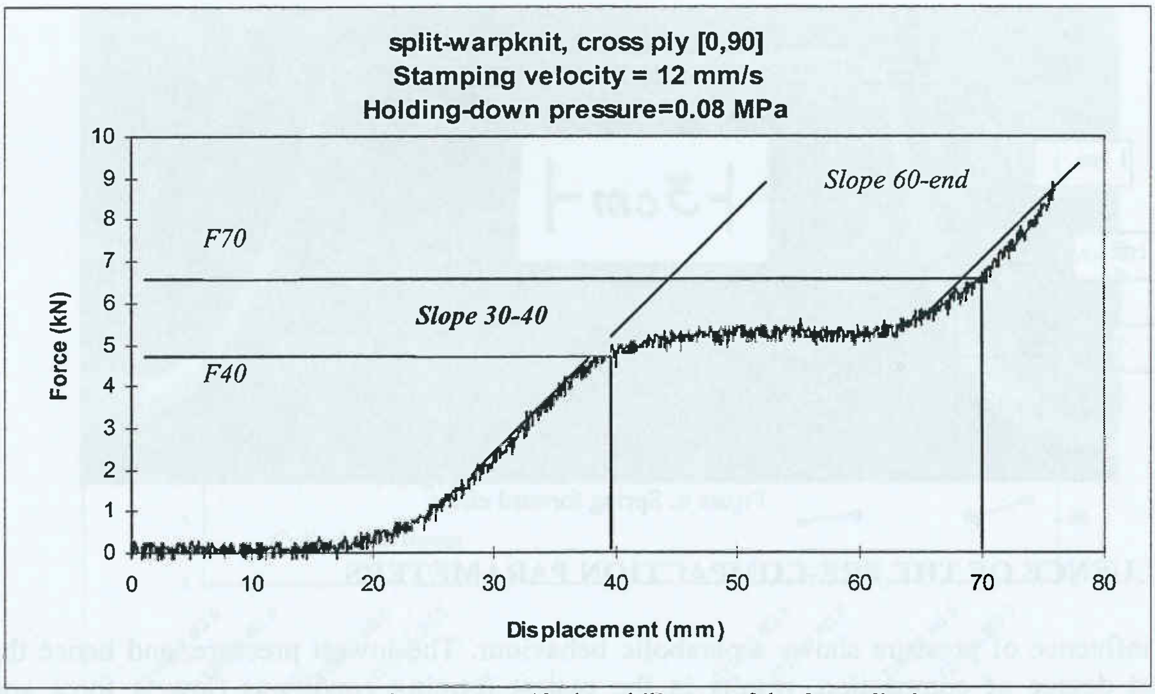

Figure 5: Different indices to quantify drapability out of the force-displacement curves

The shape conformity is studied by defining an **"index of drapability"**, comparing the *volume* of the formed composite part and the original cylindrical or hemispherical metal stamp. The more the part shows an open cup structure, due to the spring-forward effects, partially caused by thermal residual stresses, and partially caused by the mechanical built-in stresses by the limited formability, the higher the difference in measured volume and the lower the shape conformity. The so-called spring-forward effect in a product is a possible form of thermally induced distortion in the product. With spring-forward is meant that the final angle in a formed product is larger than the mould angle (figure 6). The deviation is induced during the cooling of the laminate and several causes are depicted in literature [3]. The anisotropy in thermal expansion coefficients of the constituents of the composite material is believed to be the most important: the in-plane coefficient of thermal expansion of a fibre reinforced material can be more than 40 times higher than the through the thickness coefficient.

To decide on the volume of the shaped parts, they are filled with sand and the weight increase is measured. The volume is determined at three different depths [*1 cm –2.5 cm –4 cm*] to study the cause of the volume increase in detail. Possible causes are defects in the shape, wrinkles and the spring forward effect, mainly seen for the measurement at higher depth.

The ***shape conformability*** is expressed as % drapability:

% drapability = 100 % - % volume difference (average of volume difference in percentage of the draped part to the metal stamp at different heights).

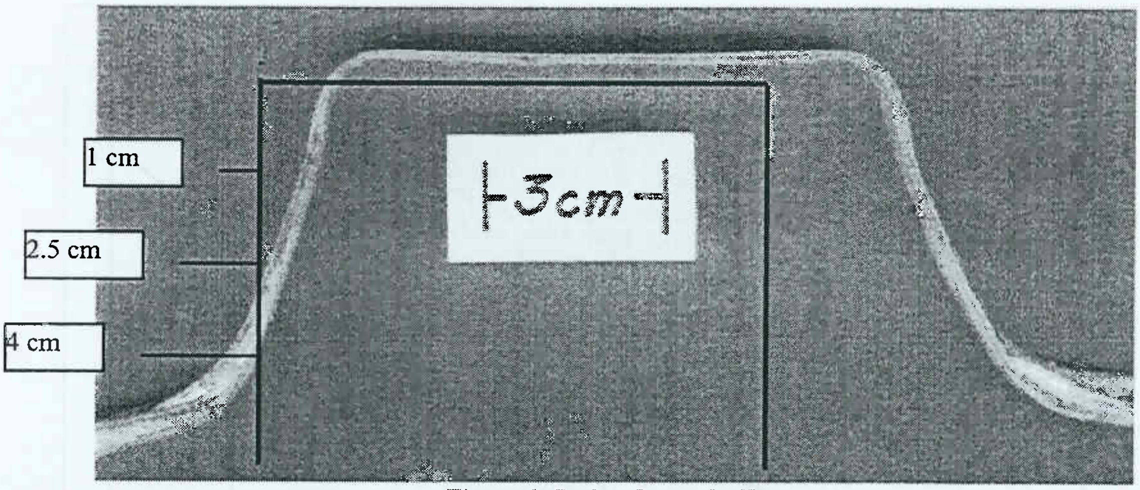

Figure 6: Spring forward effect

INFLUENCE OF THE PRE-COMPACTION PARAMETERS

The influence of pressure shows a parabolic behaviour. The lowest pressure, and hence the lowest degree of compaction, results in the easiest forming conditions (lowest force and energy). Due to the low compaction, the layers can act individually and inter-ply slipping and rotation is facilitated (figure 7). The easiest draping is obtained for the pre-compacted laminate with a low pressure and short time. This is again due to the lower compaction quality and hence the easier inter-ply slipping.

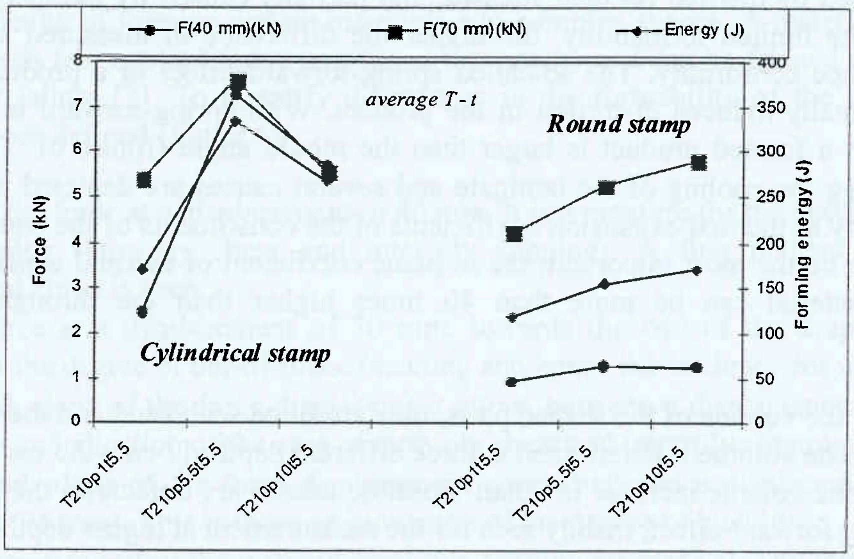

Figure 7: Influence of the pre-compaction pressure on the ease of draping

The influence of temperature is clearly seen in figure 8. The higher the temperature during pre-compaction, the higher the forces and energy needed during draping and hence the less easy the forming. The forming is hence more difficult because of the better compaction, limiting inter-ply slipping and rotation.

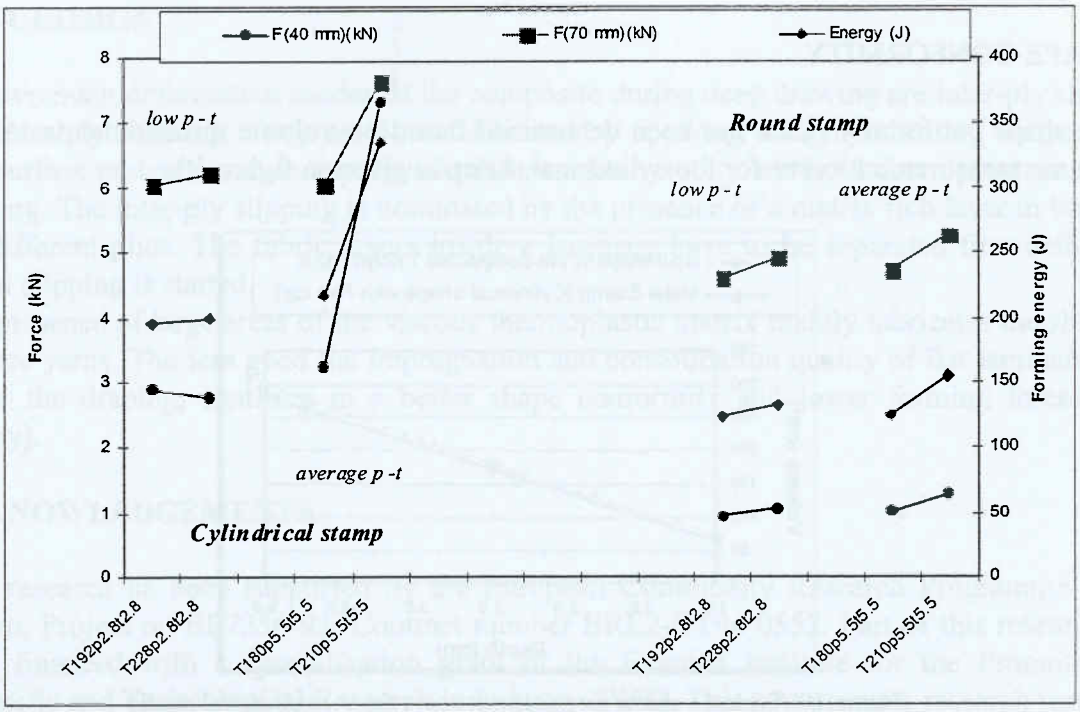

Figure 8: Influence of the pre-compaction temperature on the ease of draping

INFLUENCE OF SHEET PRODUCTION TECHNIQUE

The influence on the formability of the GMT cold pressing after pre-compaction depends on the pre-compaction paremeters. If the pre-compaction settings are optimal for deep drawing (low forces and forming energy), the GMT cold pressing does not seem to give any improvement. If the forming of the pre-compacted laminates is difficult (higher forces and higher energy needed during deep drawing), the GMT cold pressing can however increase the ease of draping and hence decrease the forming forces and forming energy. The pre-consolidation laminate shows an average drapability (figure 9).

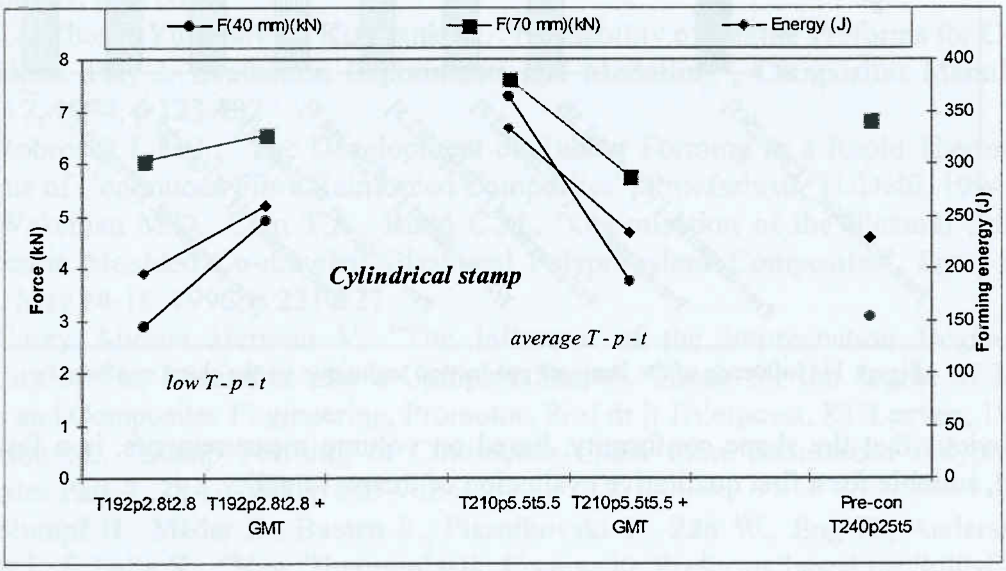

Figure 9: Influence of the sheet production technique on the ease of draping

SHAPE CONFORMITY

The shape conformity index has been determined based on volume measurements. A typical volume measurement curve for the cylindrical stamp is given in figure 10.

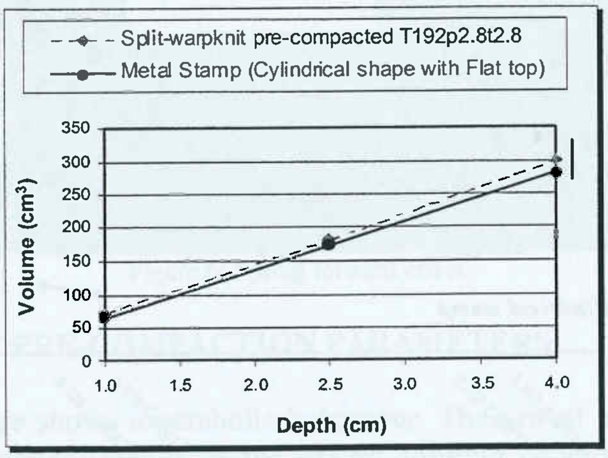

Figure 10: Typical volume measurement curve for the cylindrical mould

The effect of the laminate production technique is shown in figure 11. The GMT cold pressing [T=240°C for 4 min, T=125, p=60 bar and t=1.4 min] does not have a significant influence.

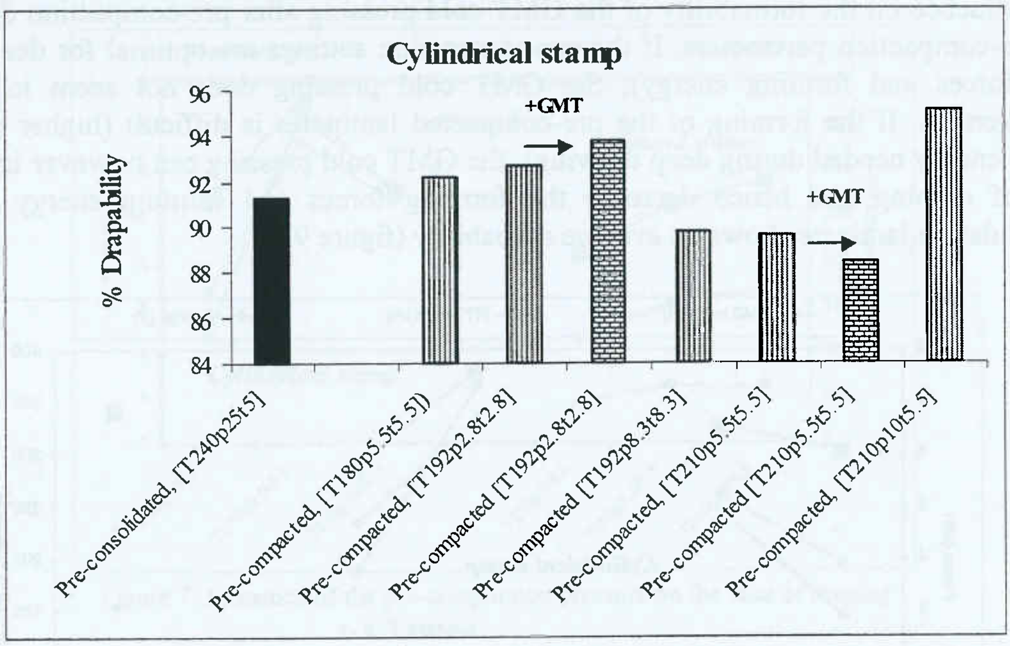

Figure 11: Influence of the laminate production technique on the shape conformity

It is obvious that the shape conformity, based on volume measurements, is a fast and easy method, suitable for a first qualitative evaluation of the part quality.

CONCLUSION

The two main deformation modes of the composite during deep drawing are inter-ply slipping and intra-ply shearing. They are both facilitated by applying a high re-heating temperature, low surface pressure and an appropriate deformation velocity and hold-down pressure during forming. The inter-ply slipping is dominated by the presence of a matrix rich layer in between the different plies. The fabric layers inside a laminate have to be separated first before the actual slipping is started.

The presence of large areas of the viscous thermoplastic matrix mainly lubricates the shearing of fibre yarns. The less good the impregnation and consolidation quality of flat laminates, the easier the draping, resulting in a better shape conformity and lower forming forces (and energy).

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