ID-1231

# Composites in primary structures: Endurable and crash resistant bottom platform for a go-kart

Ir. E.Tromp/ Ir. W.D. Brouwer
*Delft University of Technology*
*Centre of Lightweight Structures TUD-TNO*

**KEYWORDS:** chassis structure, energy absorption, durability, safety, full scale impact tests, FEM-analysis

## 1. Introduction

Karting is a fast growing sport in Europe, the US and East Asia. The vehicle of this high thrill activity is characterised by its low-cost and simplicity. In fact the kart is not more than a steel tube frame with a seat, driving devices and a 'lawn mower' engine.
Originally practised by a small group of hobbyists, it is now a recreation where people with different skills, young and old, enjoy themselves. This asks for a new approach. The kart-tracks are now a recreational business where safety should have the highest priority.
Secondly, for a track-owner the karts are the source of income, they are exploited 10 hours a day, seven days per week. In other words, the structure should be durable, resist dynamic loads and heavy crashes.

At present the chassis is a frame, built up out of a large number of steel tubes welded together. Assembly is an laborious man-hour consuming process. This steel tube frame, however, is not durable enough. In recreational go-karting the chassis is involved in many collisions, causing unwanted deformations. Many maintenance hours are required to keep the go-kart in service. Thicker tubes improve durability, but cause poor driving properties because of lower flexibility.
Torsional flexibility is required in curves. The kart has a rigid rear-axle without differential which means that the rear wheels have the tendency to drive straight on. In order to take a curve, one of the wheels (the inner rear) should be lifted a bit, while the front wheels keep their grip.

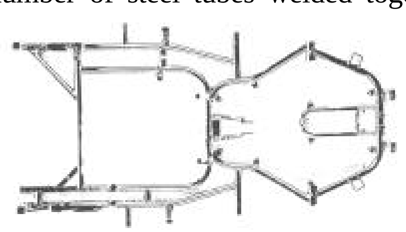


**Fig. 1: steel tube go-kart frame**

So, flexibility without permanent deformation is required. And this is one of the main fundamental differences between fibre reinforced plastics and metal. In the stress strain curve of composites and metals it can be seen easily that the ability of absorption of elastic energy is far better for composites because yield strength is better, while stiffness is lower.

The possibilities of composites were recognised by one of the bigger kart builders in Europe. In a two years R&D program, the Centre of Lightweight Structures [CLS] developed a composite chassis structure with the kart builder, experts on crash, ergonomics and styling and (end-)users. The program was funded by the European Commission and was called CHARMIC, an acronym of Chassis structures Resistant to Multiple Impact and Crash.

**Fig. 2 : conventional recreational go-kart**

## 2. Objectives and Requirements of the Improved Composite Chassis

The go-kart has grown from a hobby vehicle into a serious consumer product. In spite of that, requirements on production and durability and standards on safety did not keep in pace with that. The objective is to develop a new kart chassis improved on following items:

- **Safety.** During a crash the accelleration of the driver should be as low as possible.
- **Durability.** The life-cycle of the present kart is restricted to only 1,5 to 2 years because of frequent crashes on the crowded race-tracks that often result in deformation of the chassis.
- **Ergonomical and bio-mechanical properties.** Adjustment of seat, steering wheel and pedals to different sizes of people is a must.
- **Economic production.** The construction of the present kart is an assembly of many parts and joints. A more integrated body structure would decrease the cost.
- **Driving properties.** Also recreational, amateur drivers are becoming more critical on the driving behavior of the kart in fast curves. Secondly, the steering must be light to become less tiring.

When the objectives described above are translated into a structural design of a composite chassis, one can list the following structural requirements that have to be fulfilled:

- **Torsional flexibility**
  Experienced drivers have tested diffrent karts with steel frames and it turned out that frames with a relatively high torsional flexibility (but not too high) have good road-holding in a bend. This torsional stiffness is used as the refererence for the new composite frame.
- **Longitudunal stiffness**
  This is required to withstand vertical loads. When driving up a hill, the accelleration of the driver may not cause too much bending, since the chassis is hanging only 4 cm above the ground.
- **Frontal impact**
  The present kart has a plastic (PE) cover which is attached to the steel frame by bolts with some small rubber rings, so in a collision almost all energy is absorbed by the steel frame. This induces high loads and high accellerations on the driver. In the new concept an energy absorbing bumper system is preferable. The shape and strength of the chassis had to be designed in accordance with the bumper. Assuming a frontal crash of 20 km/h and an available stroke of 150 mm to absorb the energy, the frontal load will be up to 40 kN
- **Side impact**
  The present kart has a rotation moulded side protection, that can absorp a considerable amount of energy. Also the kart is surrounded by a 10 mm thick PP graze plate that distributes the loads. So, absorption of impact energy at the side is a smaller problem than on the front side
- **Other load introductions**.
  The chassis is subjected to many different high loads introduced by parts such as seat, engine, brakes, steering wheel, roll-bar, axle bearings and last but not least the front wheel suspension. Critical case for this is a sharp bend at high speed and driving up and down a steep slope.
- **Durability.**
  High peak loads as well as frequent lower loads must be considered. The complete load spectrum during 5 years (around 150,000 km) determine the required (fatigue) strength level of the chassis.

## 3. Conceptual Design of the Chassis

Main objectives that were relevant for the shape and general lay-out (conceptual design) of the chassis were the driving properties (torsional flexibility) and the way impact energy is absorbed.

The mechanical properties of composites are for both objectives in favour to those of metal, since the ability to absorp elastic energy is higher which can be seen in the stress-strain curve below: The absorped energy without any plastic deformation is given by the hatched area in fig. 3.

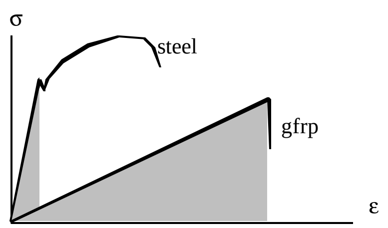
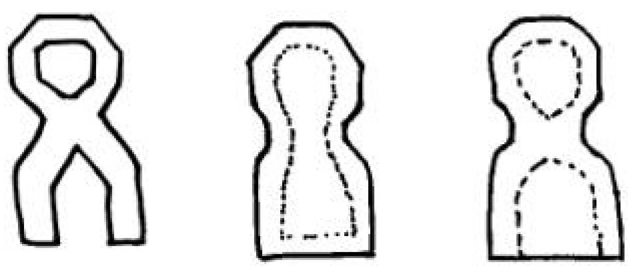



**Fig. 3 stress strain curve steel and composite**

The present steel frames can be built very flexible and it then has excellent driving properties, but these frames are very vulnerable. Any collision should be prevented.

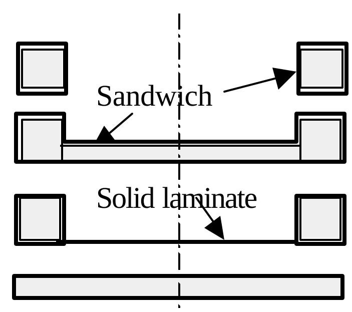
When defining the global shape of the chassis, it should be considered that stiff elements are required to provide longitudunal stiffness, impact protection and different load introductions. On the other hand torsional stiffness should not be too high in order to provide good driving behavior. Torsional flexibility can be obtained by making the chassis 'waisted'. The waist of the chassis has a smaller width and therefore less differential bending stiffness.

With this in mind, a number of conceptual designs of the chassis were made, in which the use of sandwiches, beams and solid laminates and their dimensions were varied:



X-type beam structure square-type shell X-type shell structure

**Fig. 4: chassis concepts (schematised)**




possible cross sections

**Fig.5 examples of cross sections**

Although the shell type concepts are stiffer in torsion, they have the advantage that they are provided with bottom panel which is required to protect the driver's feet. Also the open beam concept is probably more expensive to manufacture.

If the square- and X-type shells are compared, the X-type is stiffer in torsion since its cross section in the centre is high. This and some other considerations were the reason that the square type shell was chosen for the basic geometry of the chassis. The shell is a built up from a solid laminate in the middle surrounded by foam filled sandwich beams, as can be seen in the cross section below:

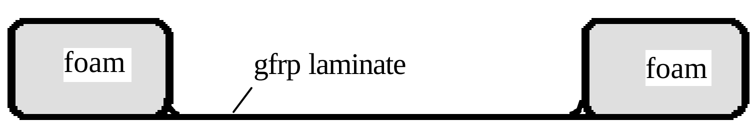



**Fig.6 selected cross section of the chassis**

The cross-section of the beams is a symbiosis of structural (moments or inertia), functional (bumper suspension), manufacturing (draw angle) and styling aspects. The bottom plate is a solid laminate web, that is shaped for a seat position as low as possible and contains form elements for easy placement of the seat and guiding elements for lengthwise-adjustable pedals.

High stress levels in the material should be prevented. Since the impact during a collision is a given fact, it means that the way in which energy is absorped is the key issue. The energy absorbed can be written as the acting force times its stroke.
In other words, the chassis concept should incorporate possibility to deform in order to provide length along which energy can be absorbed. It is obvious that chassis deformation only is not enough and would cause too high accellerations on the chassis and driver. Additional bumper systems have to be added in order to increase stroke and to decrease forces. The design of the bumper is described in section 4.4.

## 4. Structural Design of the chassis

Strength and stiffness properties of the chassis have to be calculated. Objective is a frame with the same diagonal stiffness and bending stiffness as a well-driving, flexible steel tube frame. Secondly, in the critical load cases, stresses have to remain below the critical design stresses.

### 4.1 Design process

In the development of the go-kart use was made of results of theoretical crash analysis and tests as input for structural analysis. The design process is visualised in the flow diagram of fig.7.

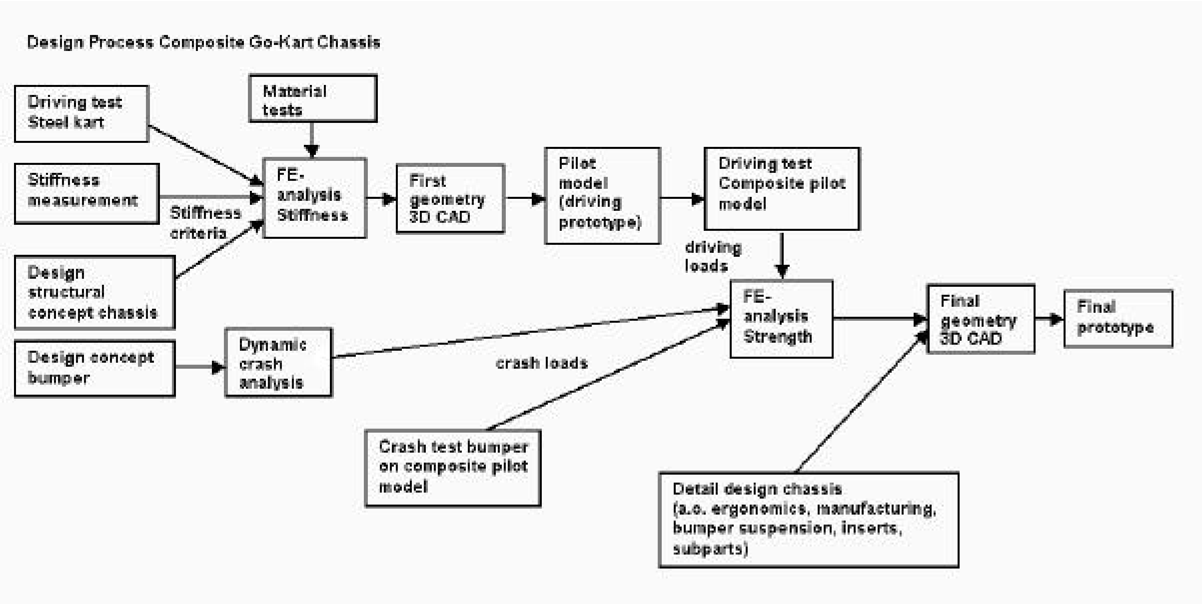



**Fig. 7: schematised design process composite go-kart chassis**

### 4.2 First geometry and FE-analysis

Based on the structural concept the simplified geometry of the kart chassis was modeled in 3D CAD. This model was used as initial geometry model for the FEM-analysis, and modified to fit the stiffness requirement. The design torsional rigidity has been derived from measurements of a steel kart chassis with very good driving properties.
Within the FEM analysis the torsional flexibility of the platform is tuned by reducing the width at the midsection of the platform, and the heigth and width of the sandwich beams. The fibre orientation in combination with cross sectional area balance the torsional rigidity (cross sectional area and shear modulus) and the bending stiffness (moment of inertia and Young' s modulus). Design stress data were derived from samples of the material as was used for the construction of the driving prototype.

**FEA load case 1: torsional rigidity**

The test set up, used for the measurements, is simulated in the FEM-model. A load of 40 kg is applied on the left front wheel, and the resulting maximum deflection of the front wheel suspension is taken as a criterion.

The sandwich chassis will be modeled as a hollow box, thus neglecting the contribution of the core. This simplification leads to a slight underestimation of the stiffness of the panel of approximately 20%. A modeled deflection of 12mm was taken as a target.

The first geometry was found to be too rigid. Tailoring of the chassis, or reducing the beam height at the waist, resulted in a weak center section. It was found that a tapering of the beam at the midfront was very effective: the deformtion was spread more evenly, whereas before it was more concentrated at the waist of the chassis. Fig 8 shows the effect of the tapering.

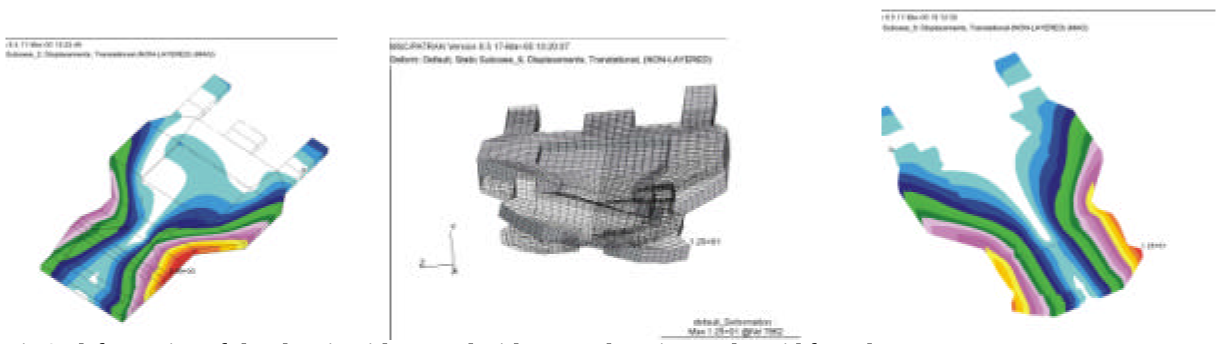


**Fig 8: deformation of the chassis without and with tapered section at the mid front beam**

This way, the stiffness of the chassis was reduced effectively, without reducing the strength of the areas of high loads, i.e. the waist area and the wheel suspension.

Other load cases investigated consider the deformation of the chassis when a person enters the go-kart and steps with one foot on the side beam.They were found to be not critical.

The resulting geometry is shown in fig.9 and 10 .The same 3D CAD model as was used for geometric input for the FE-analysis was used for production drawings for mould construction for the manufacturing of a driving prototype.This model does not yet include details regarding styling, ergonomic features or bumper attachment.

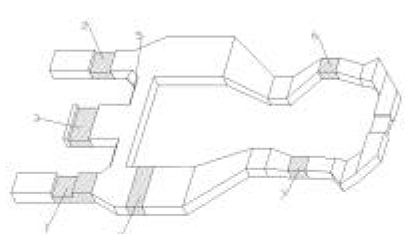


**Fig. 9 geometric model with main inserts**

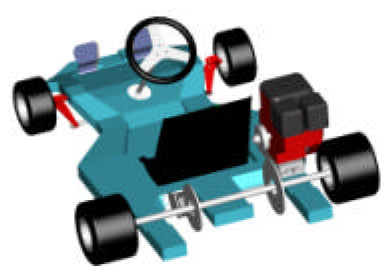


**Fig 10 3D CAD model**

## 4.3 Pilot model and drive tests

A pilot model was produced with RTM. This model is used to investigate the driving properties (design verification) and to measure the actual driving loads, to be used in load case 2 of the FEA.

The driving loads are derived from driving tests on a representative go-kart circuit. The track included a large number of sharp curves and a viaduct, causing high loads especially on the front wheel suspension.

During the driving test, the loads on the chassis were measured using strain gauges and a datalogger. Highest loads were found to occur at the waist and at the frontwheel suspension.

A spectrum of the driving loads is shown in figure 11.

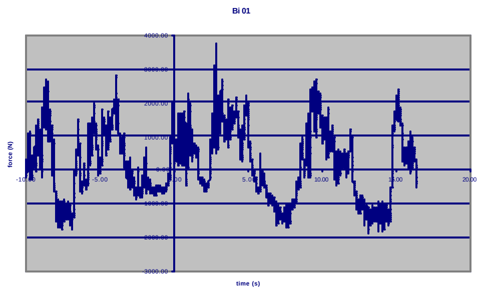


**Fig. 11 typical load spectrum**


**Fig.12 go-kart with strain gauges**

The peaks are the high loads when taking a turn. The occuring strains were compared to the torsion test measurements, and the FE-analysis. From this an estimate of the load on the front wheel is made. The maximum strain levels are around 0.2 , which indicates that fatigue is unlikely to occur.

### 4.4 Bumper design and Dynamic Crash analysis (Madymo)

For the drivers safety it is important to keep his accellerations as low as possible during a collision. Secondly, it is preferred that energy is dissipated, and not elastically returned by spring back. If the kart would bounce back directly, accellerations would take longer and there would be a bigger risk of head injuries. There are several ways to dissipate energy without permanent deformation or failure, i.e. by friction, by hysteresis of material deformation or by hydraulic/pneumatic valves. A proven concept based on friction can be a cylinder with an oversized rubber piston. Energy absorption through hysteresis can be obtained with resiliant foams.

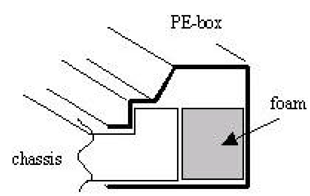


**Fig. 13 Bumper concept**

For the kart bumper simplicity and low-cost are required, therefore it was decided to use the resiliant foam concept. A foam filled box structure was designed as shown in fig. 13. The PE-box will be made by rotation moulding, for the prototype the box was welded out of PE-sheets.

To further study the effect of the bumper on the response of the go-kart and the pilot, use was made of dynamic crash software:Madymo, a multi-body simulation program. The improved bumper system resulted in less jump-up of the chassis and lower peak accellerations of the pilot.

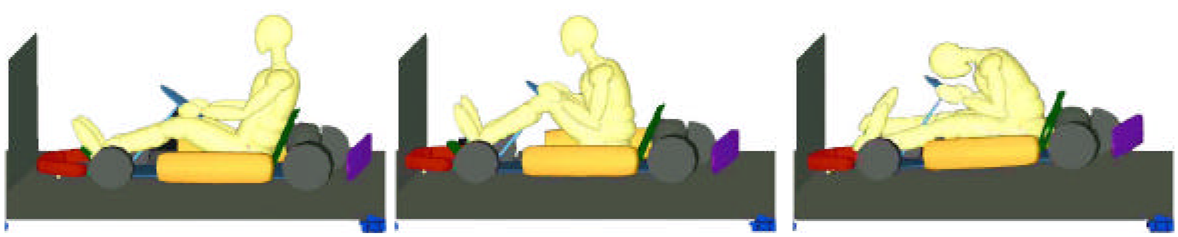


**Fig.14: Madymo- frontal impact analysis**

From this model, the peak loads acting from the wall on the chassis were derived and used as input for the FE-analysis. An impact of 20 km/h against a solid brick wall was taken as a reference. With the optimised bumper, a compressive peak load of 40 kN was found. This load case is equivalent to a collision at much higher speed (40 km/h) into a flexible track side wall , such as a wall of tyres.
In this model an infinitely rigid chassis is assumed. The effect of the flexibility of the chassis was derived from the FE-analysis, and corrected for in the bumper deformation.

The performance of the bumper was tested for both the side bumper as the front bumper.Fig. 15 shows the bumperprototypes in the test setup for the side impact test.



**Fig. 15 side bumper impact test and bumper prototypes**

The bumpertest was done with a second geometric pilot model. Both the side and front bumper were tested. The kart chassis was mounted on a carriage, and launched by a spring mechanism at a speed of around 25 km/h. Near the impact wall the chassis (with balance weight) is ejected, such that it can move freely. High speed camera's, load cells and strain gauges were used for data collecting.
The response of the chassis is used for model verification of the Madymo analysis (accellerations and loads on the chassis) and the FE-analysis (occurring strain levels at maximum frontal load). The chassis did sustain the test succesfully.

### 4.5 Strength analysis : 2$^{nd}$ FE-analysis

For the same geometric model, a more detailed strength analysis was performed, using loadcases derived from the tests and crash simulation.

**Load case 2: driving loads**

A single vertical load is applied to one of the front wheels, whereas the other three wheels are kept in place. The occurring strains must be below the fatigue level of 0.4. The force on the front wheel was derived from the driving tests. Fatigue was found to be not critical. Still, fatigue tests will be performed to prove the durability of the chassis.

**Load case 3: impact**

The loads on the chassis are derived from the Madymo analysis that was used for the design of the bumper. From the bumpertest, a peak value of 47 kN was found. This load case is the ultimate load for the strength analysis of the chassis. Due to the curved shape of the front of the kart, high bending moments are introduced at the wheel suspension. At this area high normal stresses are found. Which is seen in fig.16.

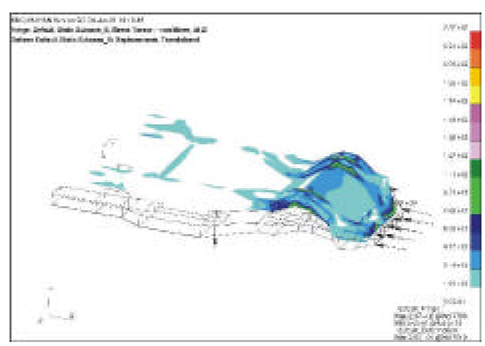


**Fig.16: frontal impact: von Mises**

It is noted that the high stresses are partly due to the simplified geometry and inaccurecies in the model. In the real product, round offs will reduce peak stresses. Also at the front wheel section a strong insert is present for introduction of the vertical wheel loads, which is not included. To improve the strength of the chassis at the front wheel suspension the beam height at the front section will be increased. Such local increase in stiffness will not affect the driving properties. Secondly, the front beam of the kart will be elevated. This way, the front bumper will be supported more symmetrically, and the bending moment on the beam of the front wheel suspension is effectively reduced.

## 5. Insert Design

Crucial aspect of a composite structure is the way in which high loads are introduced.
The first step in the design is to define the magnitude and direction of the loads and to decide which path in the composite structure will be followed in order to realise a reliable load introduction.
In case of a composite shell structure with sandwiches incorporated, following considerations are important when introducing loads:

- Laminates should be subjected to loads in their plane only. In this way, high bending moments in the laminate are prevented. It is obvious that fibres are preferably oriented in the direction of the principle stresses, which means a +/- 45° orientation in case of shear.
- In plane load introduction should take place along a certain length or surface of the laminate in order to prevent high local compression and shear stresses in the laminate.
- Loads perpendicular to the laminate should be carried by flanges (laminates perpendicular to the shell) or by the core in case of a sandwich. Here it is also required to introduce the loads along sufficient surface.
- A bonded joint should carry shear loads only, peel stresses should be prevented.
- A hole in a composite laminate can carry bearing load but only under certain conditions:
  1) The laminate around the hole must have a quasi-isotropic orientation.
  2) The hole must be reamed to a perfect fitting to prevent high local compression stresses. This can also be done by an injection with resin after assembly
  3) The laminate should be clamped in order to prevent brushing (local failure under compression)
  4) The distance between the hole and the edge of the structure are another hole must be at least 3 times the diameter of the hole.
  If these conditions cannot be fulfilled, an insert is required. In a sandwich this can be for example a solid block of wood or metal that replaces the foam core. In case of a single laminate one would choose for a metal ring or flange bonded to the surface in order to transfer loads through shear instead of bearing.

Especially the front wheel suspension is a part of the chassis where high, dynamic loads occur. Its design is mainly determined by the vertical load with its resulting moment along the X-axis.
The vertical load has to be transferred from the wheel and the stub axle to the outer vertical flanges of the composite beam strucure, while the moment is carried by both the inner and outer flange.
From a manufacturing point of view it is preferred to keep the foam core in one piece, therefore it was decided not to use a solid block in the beam as an insert. Instead, two steel parts were used for load introduction. One steel C-profile bonded around the outer vertical flange of the beam, and one internal steel plate besides the inner vertical flange. See figure 17.

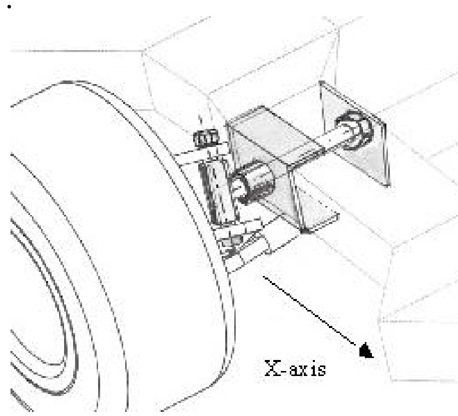



**Fig. 17 insert at the front wheel suspension**

## 6. Manufacturing

### 6.1 choice of technique

The foreseen series production of up to 10,000 pcs. is determining for the technology. Techniques like SMC (sheet moulding compound), GMT (glass mat thermoplastic) and RTM (resin transfer moulding) would be suitable.

Both SMC and GMT are techniques where a prepreg is moulded under high pressure. SMC uses a thermoset resin while GMT is thermoplastic. Typical products are shell structures with limited 3D geometry. Product area is often restricted to around 1 $m^2$ since heavy pressing machines are required. The flow of the prepreg has to fill the mould, therefore fibre volume content ($V_f$) is restricted to 25%.

If sandwich sections and/or inserts have to be integrated, and if a certain mechanical level is required, RTM is a more appropriate technique. Applied pressure is low (up to 8 bar) the product size can be larger and no pressing machine is required. The technique is not as fast as the pressing techniques, since fibre reinforcements are often put into the mould manually. But the $V_f$ of the composite can be higher (up to 40% with fabric, up to 30% with CSM).

From the beginning it was likely that the chassis needed many inserts and a high mechanical performance, so RTM was the first choice of technique.

The chassis is a construction of laminates, foam cores and inserts. With RTM, the foam core and inserts are manufactured in advance and are then placed together with the dry fibre reinforcements into one of the two moulds. The set of moulds is then closed and resin is injected. For small series (prototyping) the foam core could be manufactured manually, but in series production it is economical to injection mould the foam pieces. So, in that case a seperate set of moulds is required

### 6.2 process development and mould design

Some manufacturing aspects had to be taken into account and determined the chassis design:

- Mats of chopped strands (CSM) are applied to improve the permeability.
- The shape is smooth and drapable with fabric and dischargable from the mould.
- Sharp corners must be avoided in order to place fibre reinforcements easily into the mould. Sharp corners had to be rounded off.
- The foam core and inserts were designed in a way that the foam core of the complete chassis is in one piece only. It means that only one injection mould for the foam is required.

Below, pictures are shown of the material placement and the RTM mould set:

**Fig. 18 material stacking**

**Fig. 19 RTM mould set**

The applied pressure during injection is around 4 bars. With a product size of 1,2 x 0,8 m it means that the moulds have to be stiffened thoroughly. This stiffness is obtained through the grid of steel flanges.

### 6.3 process

After glass reinforcement, inserts and foam core are placed, the moulds are closed and clamped together by bolds at the edges. The top mould is provided with a number of threaded holes, that can be used for both inje ction gate as well as overflow gate.

The resin is injected into one of the holes and the other holes are checked carefully upon overflow. If an overflow gate releases resin, it is closed with a bolt. To obtain a regular filling of the mould without any entrapped air an injection startegy has been determined, which means injecting the mould at specific places for a specific time. This action is shown on the picture on the right.

**Fig. 20 RTM injection**

After all overflow gates show resin, the injection is ready, and all holes are closed with bolts. The injection process itself takes not longer than around 5 minutes.

After that the mould is placed in a oven for a few hours (depending on the resin type) in order to cure the resin.

### 6.4 assembly

The composite chassis structure can be assembled easily with other parts to a complete kart. Compared to the present assembly with a steel frame there are three important advantages:

1) Less man-hours required for assembly
2) The composite chassis is cheaper than the steel one
3) The composite chassis has a well-defined shape, whereas the steel frame has large size tolerances caused by the welding during its manufacture.

Pictures of the complete assembly of the first prototype are shown below:

**Fig. 21: assembled pilot model**

**Fig. 22: racing pilot model!**

## 7. Results with the Prototype

The first pilot models of the composite kart have been tested on the go-kart indoor track and in the advanced crash test facillities of TNO Automotive, Delft , The Netherlands .

During rides on the track, driven by experienced go-kart racers, it was concluded that the driving properties were very satisfying. The longitudinal stiffness was enough while torsional stiffness was not too high. The kart had a good grip during in the bends. Durability and stiffness preservation of the chassis are also satisfying so far. After a few hundred driving hours, the torsional stiffness of the chassis was measured. This test showed no loss of stiffness of the pilot model chassis so far.

The bumpers were tested seperately in a crash laboratory. The front bumper was attached to the composite frame and this was put on the drive train of the crash simulater. The chassis and bumper collided with the wall at a speed of 25 km/h. The chassis sustained the test without any damage.
The mechanical behavior of the bumper, especially the compression characteristics of the foam blocks and the acting forces on the chassis were investigated. It turned out that it corresponded to the calculated expectations very well.


## Acknowledgements

The work described in this paper was performed by the Center of Lightweight Structures, Delft, The Netherlands, as part of the CRAFT research programme funded European Commission, in cooperation with the following parties:

- Joos Boxoen Kartsport [JBK], Kortrijk, Belgium
- Stratime Cappello Systems Villers Cotterêts, France
- IDN Concepts, Delft, The Netherlands
- TNO Automotive , Delft, The Netherlands
- DenHartog_Musch human product design engineering, Arnhem, The Netherlands