Summary

Fibre Reinforced Composites (FRC) have gained in importance for the past several years. Due to its high specific strength this material group offers great potentials in weight reduction. Not only metals, like steel or aluminium, but also wood or plastics can be substituted by FRC. The advantages of fibre reinforced composites range from low specific weight, chemical and corrosion resistance, adjustable electrical, acoustic and thermal properties to integration of functions by integral design.

Composites are separated into thermosets that can be cured, and thermoplastics that can be melted and thermoformed. Thermosets can not be recycled by preheating and forming, pressing or injection moulding like thermoplastics. Especially in view of the regulation concerning the disposal of wrecked cars the possibility to recycle Fibre Reinforced Thermoplastics (FRT) should increase their applications and sales.

Large sales volumes are achieved using Glass Mat reinforced Thermoplastics (GMT) or Long Fibre reinforced Thermoplastics (LFT). This material is utilised in the manufacturing of parts like front ends and underbody protections for the automotive industry. But GMT and LFT have lower mechanical properties than fabric reinforced thermoplastics, so-called organic sheets.

These fully impregnated organic sheets consist of reinforcement up to 50 Vol%. The semi-finished material is manufactured in double belt or static presses. In a second step the sheets or laminates are formed to the desired shape by heating them in an infrared-heater, then transferring them into a press for quick forming. After the temperature of the component has dropped below the recristallisation temperature it can be removed and trimmed. The cycle time of the forming step is very short and can be reduced to 20 s with a fully automated manufacturing line. For applications like side tail units a welding or glueing process follows.

Organic sheets have a homogenous thickness. When a part is designed, the logical way is to have more material in areas of high stresses and less material in areas of no or low stresses. For material with high specific stiffness and strength, material thickness is also an important factor for an optimisation of weight and cost reduction. For other processes like Liquid Composites Moulding (LCM), GMT or Sheet Moulding Compound (SMC) part manufacturing with differing wall thickness is state of the art.

A one step technology to manufacture load and weight optimised parts has been developed by bringing in stiffened elements locally for force introduced parts like bearing places or inserts. Plain sheets, profiles or force introducing are practicable as joining parts to increase the stiffness of the main sheet. This so-called Tailored Blank Technology (TBT) is discussed in this thesis.

Tailored Blank Technology means forming and joining in one step. Therefore, a special tool with three beads and four inserts was manufactured. Three of the inserts have the geometry of plain sheets or L-profiles and one insert has a round shape. Cylinders are fixed within the female mould, applying pressure to the inserts. The hydraulic pressure system is adjustable. An insulation is placed between the female mould and the additional sheets or inserts. Without insulation it is not possible to heat the inserts above melting temperature.

The Tailored Blank Technology works as follows: The organic sheet is positioned in the transportation frame. The inserts are placed in the female mould. Then the organic sheet is heated in an external infrared-heater and the inserts are heated by an infrared-heater, which is positioned in the press between the mould halves. Sheets and inserts are heated at the same time, but the inserts are heated from the top surface only. After reaching the desired laminate temperatures the infrared-heater in the press is removed and the organic sheet is transported into the press. After forming the organic sheet comes in contact with the inserts and is joined together. During transportation the laminates cool down at the surfaces. While forming the organic sheet, it contacts the inserts and the laminates reach their contact or bonding temperature. Then the temperature of the laminates adapts because of the heat flow from one sheet to another. The whole cycle requires the same amount of time as the simple forming step without joining.

First, thermodynamical investigation to determine the contact temperatures of the organic sheet and the inserts was made. The following conditions were assumed: The laminate size is very large compared to the laminate thickness, therefore heat is only transferred into the top or bottom surface of the laminates. The heat at the sides is negligible. These conditions are locally constant for the heat flow process. Thus a one dimensional heat flow in direction of the laminate is considered. For reflection of the transient heat flow the specific heat capacity, the density and the coefficient of conductivity of the laminates were determined.

The result of the thermodynamical investigation is comparable with the experimental data. The temperatures of the laminates must be above melting temperature of the polymer matrix. If the insert top surface is at room temperature or below melting temperature, the heat flow from the organic sheet into the insert is insufficient for a good bonding quality. The temperatures should be as high as possible for the forming process to work at optimum as well. A navigation diagram for the laminate temperatures of different polymers is given.

The experimental investigation concentrated on the following process parameters: organic sheet temperature, insert temperature, bonding pressure and press time. In addition to the variation of process parameters two different matrix materials with different fibre volume content were selected: Glass Fibre reinforced Polypropylene (GF/PP at 35 Vol%) and Carbon/Glass Fibre reinforced Polyamide 12 (CF/GF/PA12 at 50 Vol%). The laminates were impregnated and consolidated in a double belt press. Another diversification was to increase the bonding strength with pure matrix. The process parameters were investigated in the above given order, whereas the other parameters were kept constant. Later the optimised process parameters were used.

The shear strength test (DIN EN 1465) was found to be the best test for investigating bonded sheets. The bending test (DIN EN ISO 14125) was not sensitive enough.

The organic sheet temperature selected should be as high as possible without having too high thermal oxidative degradation. For inserts with a lower reinforcing content it is sufficient to reach the melting temperature. For higher fibre volume fractions the temperature should be the same as the organic sheet temperature. The bonding pressure of CF/GF/PA12 material does not need to be higher than the simple forming. In contrary the GF/PP material, only needs a three times lower pressure, which is due to the different fibre volume content. The fabrics of the highly reinforced CF/GF/PA12 are lying tight one upon the other and need more pressure to prevent delamination. The press time - means the time the press is closed - differs again with different fibre content. GF/PP shows nearly no difference in shear strength values. In contrast, CF/GF/PA12 looses half of the strength, when the press is opened too soon. After the recrystallisation process the press can be opened and the parts can be removed. If the closing time is too short recristallisation is not complete and the bonding line or the laminate itself delaminates when the press is opened. This effect is more obvious with CF/GF/PA12 material, where the fabrics are packed very tight. Because of the high influence of the fibre volume content on the shear strength the bonding area of CF/GF/PA12 was enriched with

matrix. The shear strength increased up to 25 % adding two Polyamide 12 foils. Also the scatter of the values dropped about 50 %.
For comparison with Tailored Blank Technology, samples were manufactured using the vibration and induction welding technology as well as an autoclave technology. As expected the autoclave samples reached the highest values, followed closely by the Tailored Blank Technology and vibration welding. The induction welded samples had the lowest welding strength. These experiments demonstrate the excellent feasibility of this new one-step-process.

In order to calculate the economic efficiency a static cost analysis was realised which shows advantage of the Tailored Blank Technology process. The manufacturing cost of a side tail unit with 16 add on profiles was less than the costs of vibration and induction welding processes. A 100 % workload and therefore quantities of 25.000 parts per year in one shift production with Tailored Blank Technology and vibration welding was assumed. Including the material cost, the cost advantage of TBT is minimal compared to the vibration welding dependent on the selected material. Induction welding is only cost effective in low quantities.