SYNTHESIS REPORT

FOR PUBLICATION

CONTRACT N° : **BREU-CT91-0454**

PROJECT N° : BE 4125

TITLE : Design manufacturing and recycling of advanced thermoplastic composite automotive parts

PROJECT COORDINATOR : BMW Technik GmbH

PARTNERS :
Linde y Wiemann SA
Heckler &Koch GmbH
Branson Ultraschall
Ilma Plastica SpA
Krauss Maffei Kunststofftechnik
Technische Universiteit Delft
Inst. f. Kunststoffprfg. Universität Stuttgart
Deutsche Forschungsanstalt f. Luft- u. Raumfahrt e.V.

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NAMES AND ADRESSES OF ALL PROJECT PARTNERS

Firma	Name	Addresse	Telefon	Fax
BMW Technik GmbH	H. Hippke	Hanauer Str. 46, D-80992 München	089-14983-167	089-14983-198
Branson Ultraschall	H.Tillmanns	Waldstr.53-55, D-63128 Dietzenbach 2	06074-497-864	06074-497-750
DLR	H. Costa[as	Pfaffenwaldring 38, D-70569 Stuttgart 80	0711-6862-360	0711-6862-227
EG-Technik	H. Tokamanis	Rue de Montoyer 75, B-1049 Brüssel	0032-2-295-9565	0032-2-295-8046
HIK Präzisionstechnik	H. Mayer	Neckarstr. 1, D-78727 Oberndorf	007423-79-2736	07423-79-2750
(P	H. Schafer	Pfaffenwaldring 32, D-70569 Stuttgart 80	0711-685-2667	0711-685-2066
.MA Plastica Spa	H. Tentori	Via Unione 2, I-21 026 Gavirate (Varese)	0039-332-731050	0039-332-730330
Krauss Maffei KT	Dr. Bürkle, H. Klotz	Krauss-Maffei-Str. 2, D-80997 München 50	089-8899-2799	089-8899-3742
inde y Wiemann	H . Schönleber	Aparto 18, Zona Industrial KE 08530,	0034-3-8714096	0034-3-8715850
		La Garriga (Barcelona), Spanien		
W-Composite	H. Schönleber	Postfach 155, D-35665 Dillenburg	02771-392-490	02771-392-489
U-Delft	H. Brouwer	P. O. Box 5058, NL-2600 GB Delft	0031-1578-2463	0031-1578-1822

ABSTRACT

Application of lightweight structural car parts made of new developed advanced composite materials with a thermoplastic matrix system might lead to a dramatic reduction of car weight. To take advantage of these materials high speed and high volume process had to be developed. Therefore the final objective of the project is:

The installation of a laboratory production unit for advanced composite with thermoplastic matrix using the technologies: Compression Forming, cutting process, welding process and Advanced Composite Casting.

As a pilot part a back seat rest of a BMW 3series was chosen. In the running series this part is a two shell construction of steel and GMT. .
For the project a design for two composite shells was realized. The shells consist of Advanced Composite material with a thermoplastic matrix system.

In the beginning all available Advanced Composite raw-material were tested. To develope the necessary processes, test tools were built. Further research was made in the fields of:

- cutting of composite
- injection moulding with composite inserts
- recycling of Advanced Composite

Finally the composite material and all processes were determined.

The details of the process are:

The composite material is heated up by a circulating air oven. The hot composite material is handeled by a vacuum plate into the hydraulic press. In the press the composite material is moulded (Compression Forming).
The following step is to cut the pressed composite part by the use of water jet.
Then the two composite shells were welded together by the use of the vibration-welding process.
To reach the final shape of the part and to fix some elements the composite part was overinjected in an injection moulding process (Advanced Composite Casting). For the injection moulding scrap-material of the composite material was used. This supports the idea of a closed-loop-production.
A Quality Assurance concept supports all processes. Finally the Advanced Composite back-seat-rest was tested.

Project-partner and their tasks

IKP-University of Stuttgart (D)
Tasks: Recycling Concept
Recycling of Parts
Quality Assurance
Concept

Ilma Stampa Plastica (I)
Tasks: Design and
Toolmaking of the
Injection Moulding
Tool (ACC-process)

Präzisionstechnik (D)
Tasks: Engineering CF-Equipment
Engineering Cutting Equipment
Built up CF-Equipment
Toolmaking Cutting Tools
Cutting Parts

DLR - Stuttgart (D)
Tasks: Quality Control
of Raw-Material and
of Produced Parts

Linde y Wiemann (E)
Tasks: Engineering CF-Tools
Toolmaking CF-Tools
Manufacturing CF-Tools

Project Title
Design, Manufacturing and Recycling
of Advanced Thermoplastic Composite
Automotive Parts

University of Delft (NL)
Tasks: Material Section
Compression Forming
Process Developement

BMW Technik GmbH (D)
Tasks: Part Design
Part Testing
Planning and Coordination

Krauss Maffei Kunststofftechnik (D)
Tasks: Engineering the ACC-
Production Equipment
Overinjection of AC-parts
(ACC-Process)

Branson (D)
Tasks: Engineering Welding
Equipment
Engineering Welding Tools
Welding Tools

TECHNICAL DESCRIPTION

The following chapters will provide a description of processes, equipment and workprogram performed during the project.

PART DESIGN

Basis for the design of the back seat rest are the requirements of the serial 3-series-part, a steel/GMT construction. The main task of the back seat rest is to protect passengers in the case of an accident from loaded parts in the trunk. The main BMW test for back seat rests are simulated impact-tests to prove the parts quality.

According to this data a FEM-analysis was realized as basis of the design.[1]

Additional design requirements and boundary conditions are:

- position of the whole part corresponds to serial conditions
- wall thickness 2 mm
- double wall (two shell) construction
- overinjection frame at the edge
  - inner profile of this edge identical with the serial product
- taking up or, if unfavorable, modification of the serial insert
  - position of the insert corresponds to serial conditions

Necessary pre-conditions of the design with influence of the production processes:

- in the welding process the rear shell is fixed
  - nesting of the insert on the rear side of the front shell (alignment included)
  - vibration welding (front shell vibration part, rear shell fixed part)
  - insert has to be fixed at intended position until the overinjection process takes place
- overinjection process (ACC)
  - overinjection frame at the edge
  - overinjection of the turning
  - filling cavities in the area of the insert

The design of the back seat rest can be described in the summery:

- modified beam courses (former: rib course) according FE-analysis
- wide flange, appropriated to the requirements of overinjection tool
- smallest radius used 5 mm
- taking-over the serial turning and fixing it by total overinjection
  - additional cramping by slots in both shells
- additional cramping by slots, staggered gaps etc.alongside the frame
- data available for tool design
  - upper left comer of rear shell (utilized for testing tool)

[1] chapter annexes, fig.06

- complete rear shell (rear side described), welding rib not included
- complete front shell (front side described), welding rib not included
- ACC-frame
- assembly

COMPRESSION FORMING PROCESS

The installation of a lab production unit for this process is a key objective of the prograrn.[2]

The basis for the CF-process was a lab-equipment installed at TU Delft. This constrained of an usual hydraulic presses with conventional heating systems. The moulds were in most cases made of materials with a good thermal conductivity e.g. aluminium in solid construction. The moulds were slowly heated up to process temperature by plate heat excharger or by external oilheating appliance, and cooled down after the process by air, CO_2 or water.

Because of its thermoplast nature, the AC-material must be heated up either prior to the pressing process or within the pressing mould. With respect to the AC-materials using unidirectional or woven fibre-structures the matrix material defines the treatment temperature. In addition the density of the fibres and their arrangement define the possible transformable geometry.

Several methods for the temperature management are already available e.g. those for heating up thermoplastic foils or GMT-materials. GMT-materials are usually preheated in a continuously or discontinuously working oven. Thermoplastic foils are mostly preheated using infrared irradiation or sometimes microwaves. Within the program it has to be defined which preheating method for the AC-materials is the most effective.

Preheating-methods incorporate the risk that the AC-material does not contain enough thermal energy for the pressing process in the cold mould. Longer heating rates or higher preheating temperatures might result in partly melting the material, delaminating, oxidation of the surface or cracking of molecules.

To solve the above mentioned problems TU Delft assisted by DLR performed preliminary tests to determine the process parameters.

Based on the test results Heckler& Koch designed and built the CF-equipment.
Depending on the AC-material it became necessary not only to heat up the AC-material but also to dry it before processing. For this reason Heckler & Koch developed a special patemoster-circulation air oven. The AC-material transfer from the oven-exit to the hydraulic press was solved by a vacuum-plate. If the AC-material is heated up to the temperature level to form it in the press, the thermoplast matrix is nearly melted. Such a soft material can not be handled.
For this handling reason the paternoster-circulation-air-oven heated the AC-material up to a level below the melting temperature.
To adapt the missing energy an additional infrared-heating system became necessary. This heating unit is integrated in the traversing feed arm which gets the formed part out of the CF-tool.

[2] chapter annexes, fig. 02

The single worksteps areas followed:

- material feed into the paternoster-circulation air oven
- material heating (under melting point of the matrix) .
- material transfer into the press (by vacuum-plate)
- additional R-heating
- Compression Forming process
- taking the pressed part out of the CF-tool

The CF-tool was designed and built by Linde y Wiemam, based on the part design from BMW Technik GmbH and the experience of the project partners, especially the already existing lab-installation at the TU Delft. The mould was built in steel and has the option to be heated or cooled.

During the first tests, the CF-process parameters were defined. The tool-temperature is stabilized or cooled down during the production, so heating is only during production-start necessary.

Finally the two shells for the back seat rest were produced at Linde y Wiemann in spain with good results.

CUTTING TECHNOLOGY

First the raw-material had to be cut. This was done with a diamand saw, because it is possible to cut 100 shells in the same time without any 3-d-geometries or inner contours.[3]

After the CF-process the final geometry of the part had to be cut. General cutting technology can in principle fulfill this task. Following technologies were tested:

- High Speed Cutting with Milling Cutter
- Ultrasonic Knife Method
- Laser Cutting
- Water Jet Cutting
- Diamond Saw
- Classical Saw.

Because of the aim of this project to develop a rapid manufacturing process it was necessary to compare the a.m. possibilities with respect to the following aspects:

- Clear cut of the shells (e.g. no fringes, no deformation, no unacceptable temperature increase, no delamination)
- High speed (e.g. no manual methods like precutting by a conventional saw and then grinding by hand)

Prior to the final decision, a trade off study was carried out to compare those cutting technology. The preconditions for doing this were excellent, as the team member Heckler & Koch has a lot of experience on this subject. In either case the main equipment was available.

[3] chapter annexes, fig.01

For this task no basic investment was necessary for a cutting machine. In any case however special tooling became necessary.

The following program was carried out:

. Testing the cutting speed as a function of material and method
. Testing the cutting edge
• Testing the delamination
. Testing the temperature increase in the cutting edge
• Testing the deformation
• Handling methods prior and after cutting
. Cleaning and drying methods prior and after cutting.

After the CF-process, the shells had to be cut to its final contour. Following the pressing process, the shells are three dimensionally shaped whereas prior to the pressing the raw material is strictly two-dimensional.

Besides the cutting velocity the temperature in the cutting edge is very important especially if the matrix-material is a thermoplast. Thermoplast tends to mearing, if the cutting process causes temperatures close to or above the melting point.

The other important element is the fibre material. Glas fibres and carbon fibres are brittle, in contrast to e.g. Kevlar fibres.

Delamination might occure either because of too high impact e.g. using water jet, conventional saws or even diamond saws or eventually of high temperatures at the cutting edge caused by the laser. It is well known that punching quite frequently causes partial delamination.

Based on the results about different cutting technologies it was decided to use a water-jet unit for cutting the three dimensional shaped AC-material[4]. HK Präzisionstechnik did build the tool to cut the two shells for the beack seat rest.

WELDING PROCESS

Welding seem to be the most preferable joining technology since no additional material is necessary, This fact is very important in respect to the recyclability of the part. The welding technology must meet the following requirements:

- connection without any additive or adhesive
- fast and integratable process
- energy saving system
- low pollution technology
- reproducible process

[4] chapter annexes, fig.03

The vibration weldig was chosen by Bran son Ultraschall, as it belongs to the most economical processes.[5]
For the welding of AC-parts the welding know-how of thermoplasts was transfered to AC-material by Branson Ultraschall considering the following specifications:

- weldability of the AC-material with different wall thickness under the influence of the therrnoplast-matrix and the amount of fibres
- influence of the forming operation of the AC-material on the weldability
- define the weld structure and process parameters
- define the welding equipment
- define the necessary parameters for quality control

Branson Ultraschall carried out some preliminary welding-tests with a special designed test tool to investigate the necessary welding parameters and the geometry of the welding ribs.

The main result was that AC-material with woven glas material of about 50% content had onl y poor welding results. During the CF-process the glassfibres are pressed into the welding ribs. During the vibration-welding-process the glass prevented a satisfying welding.

According to this the decision was made to modify the AC-material. One shell got at both surfaces an extra layer of pure thermoplast. Tests proved that with this material good welding ribs without glas could be realized. To reach good welding results it was not necessary to modify the other AC-material for the second shell.

Based on the test results of the principal test program performed at Bran son Ultraschall the welding tool for joining the two shells of the back seat rest were designed and built. The shells were welded at BranSon Ultraschall laboratory.

ADVANCED COMPOSITE CASTING

Advanced Composite Casting (ACC) describes a process of injection moulding to realize flanges or the final shape of AC-parts by using the same thermoplast as the matrix of the AC-material[6]. This was the last step in the production of the back seat rest. The advantages of AC-parts produced in this technology compared to steel or aluminium constructions are described as follows:

- weight reduction for the same performance
- cost reduction
- high integration = reduction in the number of components

The technology of ovennjection inserts from different materials is “state of the art for about 30 years. ILMA Plastica has got a lot of experience and is producing injection moulded consumer products with overinjected metal inserts. For metal-inserts the bonding process works in general by form closure. For plastic insert the bonding system is more complex, as there is a mixture of form closure, chemical compatibility of the thermoplastics and the anchorage by melting the thermoplast.

[5] chapter annexes, fig. 04
[6] chapter annexes, fig. 05

A special injection moulding test tool was built with the flange-geometry of the back seat rest to answer following questions:

- investigation of the connection between the AC-material and the injection moulding compound taking into account the influence of geometry and process parameters especially the thermal conditions (Krauss Maffei and DLR),
- positioning system for AC-parts in the injection moulds (ILMA Plastica, Krauss Maffei),
- determination of the optimal gating system (ILMA Plastica),
- determination of the influence of the mass-pressure on the deformation of the AC-part
- during the process, especially the filling stage (Krauss Maffei),
- reproducibility of parts.

After the tests and further research by DLR following general answer is possible: The overinjection of AC-material is possible. A good joining by the form closure works very well.

The results were basis for the design of the AC-part and the layout of the ACC-tool.
A further conclusion for the ACC-equipment was, that a vertical press unit combined with a horizontal injection moulding unit would bring the best results.

The production equipment of this process was obtained by modifications of an injection moulding machine by Krauss Maffei. The design and built up of tools was performed at ILMA Plastica.

The production of the ACC-parts was realized at a partner of Krauss Maffei with satisfying results.

RECYCLING PROGRAM

During the production of the AC-composite parts waste material occurs caused by the different cutting processes, as the preproduction cut of the raw material, the final cut of the flanges after the production process, scrap parts from production and parts which could not pass the quality control.

Since all the scrap material is a composite with a thermoplastic matrix system regrinding and reuse of the material for injection moulded parts would be the easiest way of recycling.

According to the project delay and the late deliver of the AC-raw material from a supplier it was not possible to use regrinded scrap material for the ACC-process. But IKP prooved the feasibility of this process under lab-conditions. For the ACC-process virgin thermoplast granulate will be used. Additionally the ACC-process offers the opportunity to recuperate the scrap of the cutting operations in the production part itself. The integration of the material recuperation is part of the production process.

But this kind of material recuperation has never been tested in a ruining production process. Therefore a test' program was performed to obtain a basic know how in this subject.

This test program was performed at the University Institut IKP with following main elements:

- collection of material
- cleaning
- regrinding and mixing with virgin material
- production of test specimen
- material tests.

One important element in the program was the definition of the optimum mixture rate between virgin and regrinded material, for overinjection. For comparison the same test program was performed with virgin material. The test specimen was regrinded and moulded again up to four times for investigation of the material degradation due to repeatedly processing.

As a result of the test program it was possible to define exactly the influence of material recuperation on (details see in chapter „Annexes of the partners"):

- material properties
- part performance.
- processability

According to the project delay and the late deliver of AC-raw material from a supplier it was not possible to use regrinded material for the production of back seat rests by the ACC-process. But the feasibility of the process was proved under lab conditions. For the ACC-process virgin therrnoplast granulate was used.

QUALITY ASSURANCE CONCEPT

Since the manufacturing processes and the materials are relatively new and have not been used for production, a quality assurance concept did not exist. Thus the definition of a QA-concept was part of the project. The QA-concept was defined by IKP.

The main problem by defining the QA-system was, that the most critical parameters of the whole manufacturing process were new,.

It was decided to establish the manufacturing process first and after having gained some experience and a more detailed knowlege of the process identify the relevant parameters for the QA-system.
Therefore the quality measurements was reduced to a minimum. The aim of this measurements was to identify only deviations of part quality. The following tests were made:

- incoming goods inspection
- Check of dimensions, form and weight of the parts after every production step.

This checks could only help to get a first idea about part quality and could not provide any relationship between process parameters and part quality. But based on the experiences made during part production, the definition of a quality assurance concept was possible. In this concept the baseline parameters and the philosophy of a quality assurance system was provided (for details see annex of IKP).

RESULTS AND CONCLUSION

The general statement about the project is positive. All main tasks were worked off and the planned components of the lab-production equipments and tools were realized.

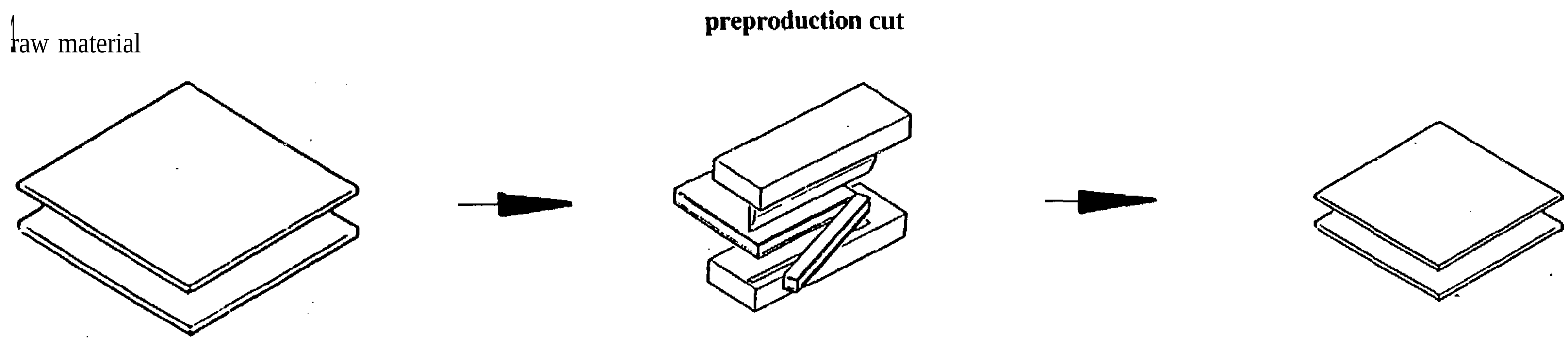
Some assumptions at the project start were rather optimistic and caused a project delay. The project was started on the premises that the AC-raw material was developed by different suppliers and to be available. For this reason no material supplier became partner of the project, because different materials were planned to be used. But during the project, a lot of developments had to be done to modify the AC-raw-material according the required quality.
The finally choosen supplier was not able to deliver sufficient material to produce the demanded quantity of parts.

A comparison between the objectives at the starting point of the project and the results at the project end leads to following results:

- All components for a lab-production line for high speed manufacturing of Advanced Composite parts were realized.
- The reutilisation of scrap material was proved under laboratory scale. The use of regrinded material for the overinjection of the AC-part (ACC-process) was not possible, as there was not enough material available
- The feasibility of a mass-production was proved
- The economic benefit for the user on a system level of the used AC-raw material is not proved.
  A positiv sign in this field are new AC-products, which came lately to the market with less expensive thermoplast "matrix systems. Some partners of this project have already started on their own costs to continue the project and to investigate the new materials. It is planned to transform new AC-materials in the existing CF-equipment and tools.

Furthermore there are some tasks left, which will be finished after the project end. The main task is the impact test for the back seat rest. This result will not be part of this report.

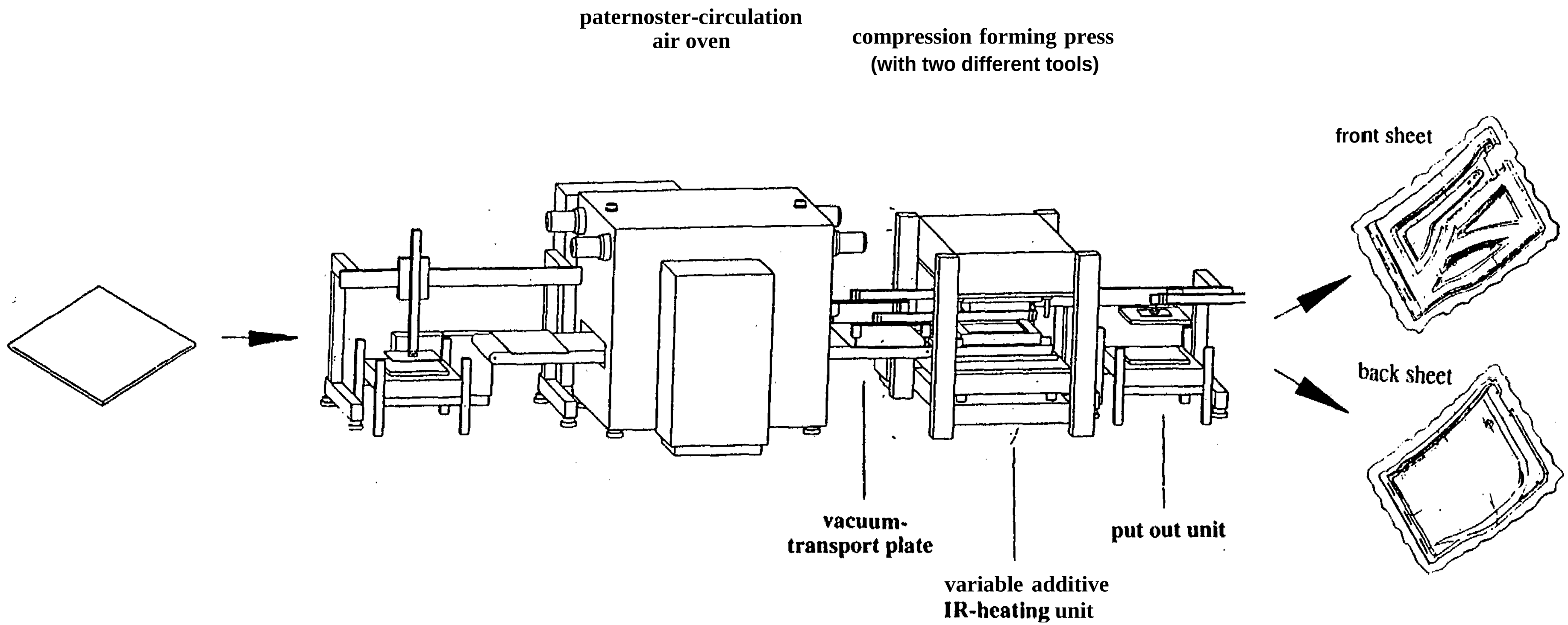
BRITE EURAM 4125: Preproduction Cut



Process Cycle

BE- Fig 01

BRITE EURAM 4125: Compression Forming

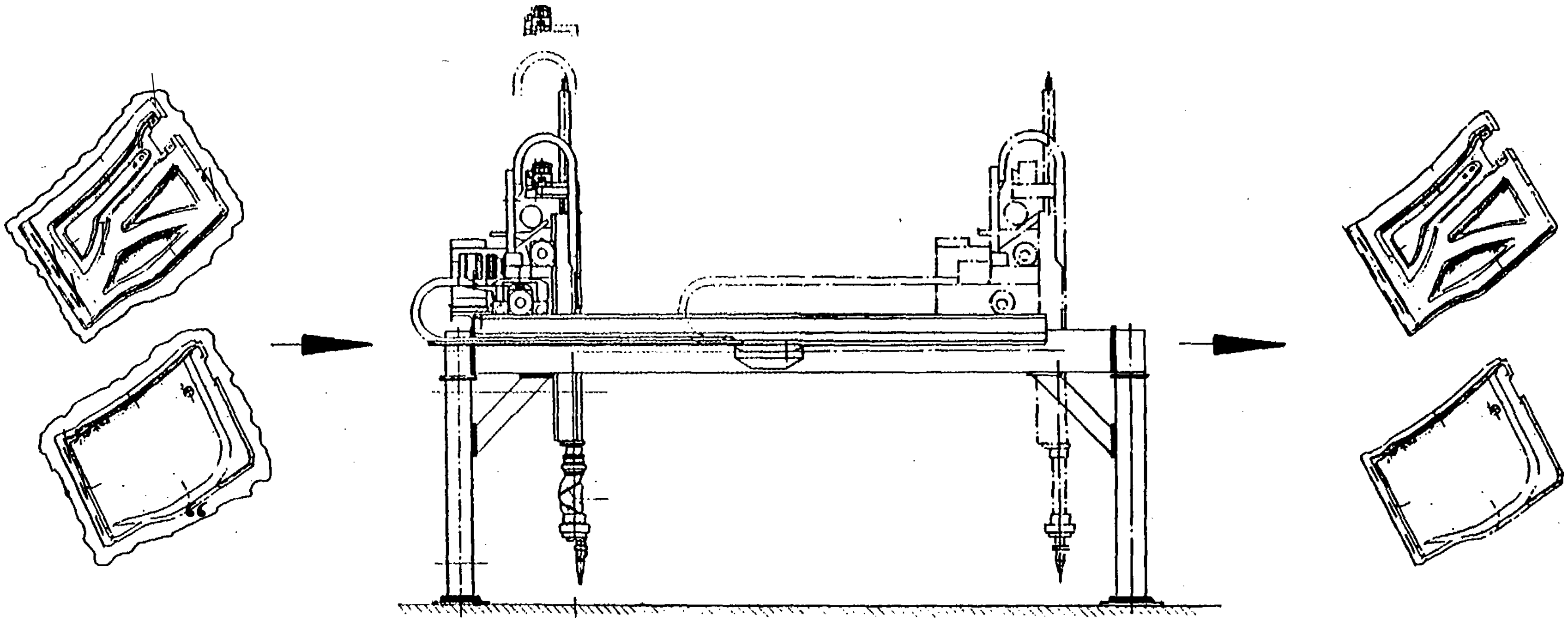


Process Cycle

BE- Fig 02

BRITE EURAM 4125: Waterjet Cutting

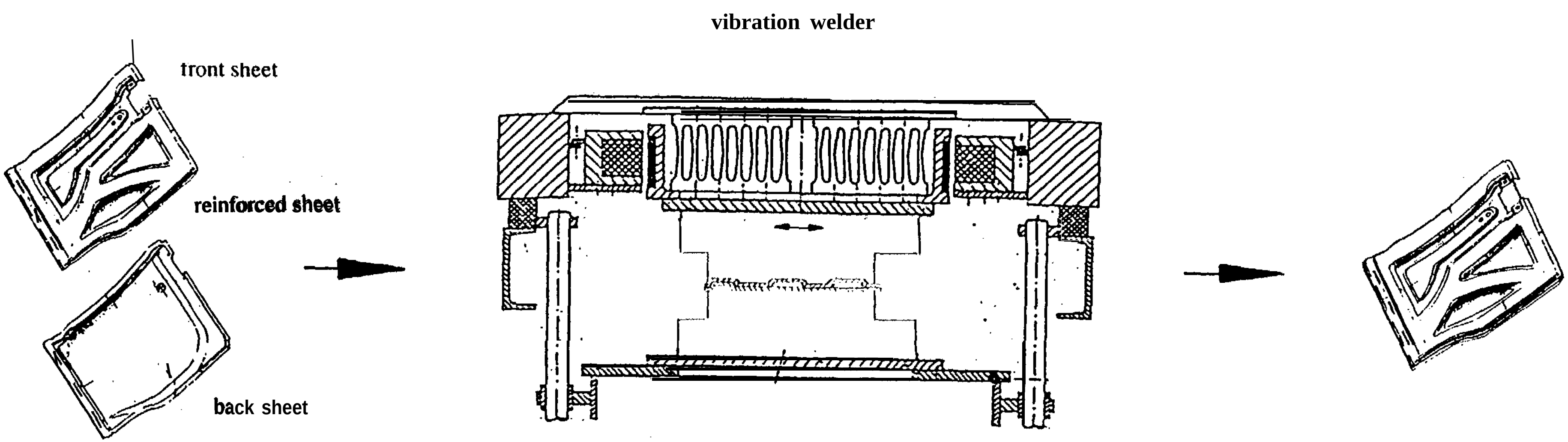
waterjetsystem



Process Cycle

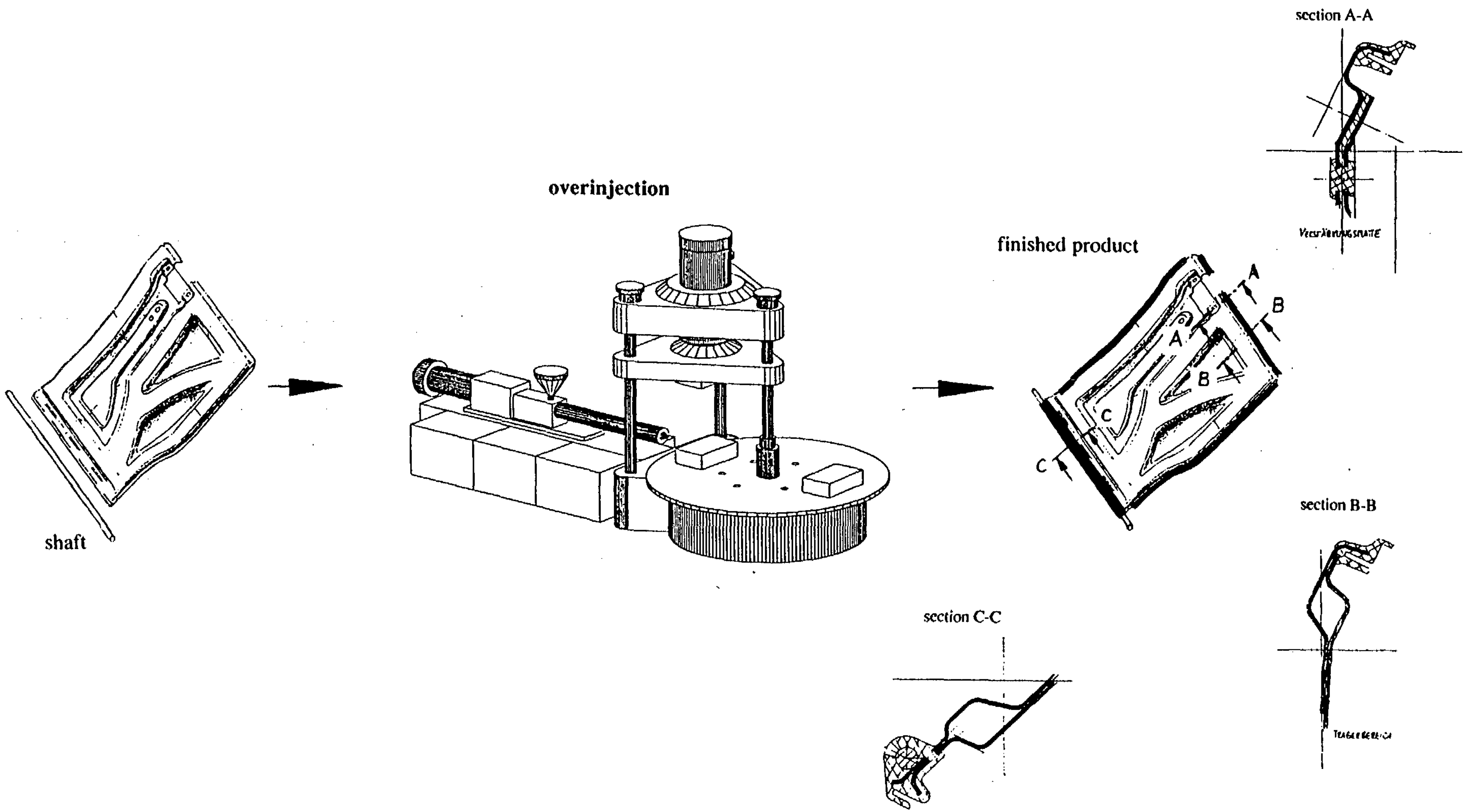
BE- Fig 03

BRITE EURAM 4125: Welding Process



Process Cycle

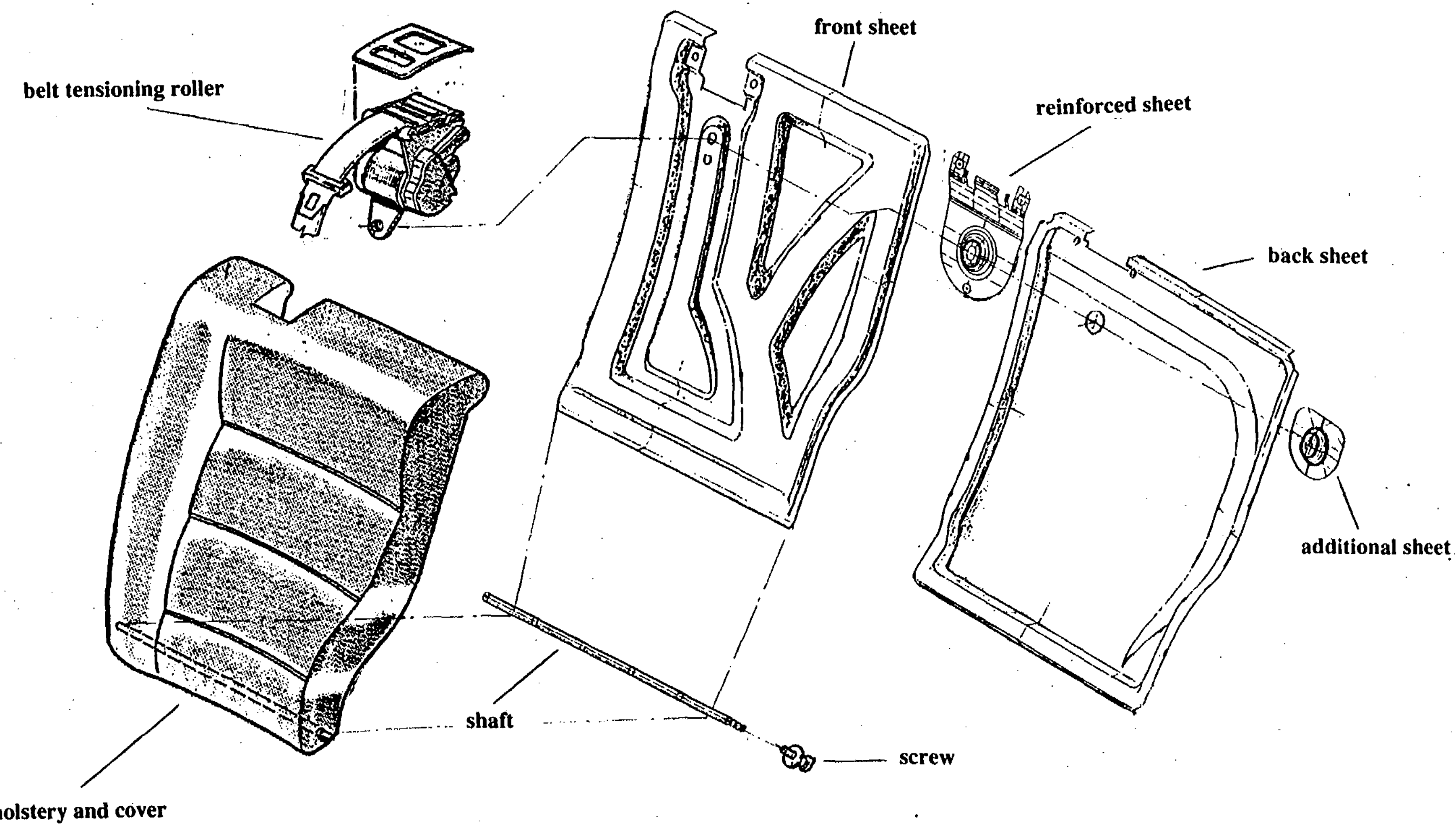
BRITE EURAM 4125: Overinjection



Process Cvcle

BE- Fig 05

Brite Euram 4125: Backseat Rest



Lavout

BE- Fig 06