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ECONOMICAL PROCESSING OF FIBER-REINFORCED COMPONENTS WITH THERMAL EXPANSION MOLDING

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ECONOMICAL PROCESSING OF FIBER-REINFORCED COMPONENTS WITH THERMAL EXPANSION MOLDING

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Title:
Economical processing of fiber-reinforced components with
thermal expansion molding

Abstract (technical-scientific neutrally oriented short overview)

The concept of economical fabrication of fiber-reinforced structural components is illustrated with an example of a typical control surface (aileron). The concept provides for fabricating struts, ribs, and a cover plate as an integral structure in a hardening device and then joining the closure cover plate mechanically. Thus in contrast to a metallic piece-by-piece construction technique a saving of about 65% in the number of joints is realized.

Fabrication of the integral structure is achieved by so-called "Thermal Expansion Molding, TEM" technique. The hardening pressure is produced by silicone rubber cores which expand under the influence of temperature. Final fabrication is done in a negative mold in an air-circulating oven. The test results are presented for several rubber materials as well as for various structural pieces, satellite structures, spoilers A 300 B.

The technique is demonstrated extensively in the power introduction area of an aileron, consisting of 5 ribs, struts, and cover plate. From economic considerations for a large-scale technical production of an aileron cost savings of 25% can be realized compared to those for a sheet metal structure.

Key words (search concepts):

fabrication technique of fiber-reinforced composite materials (CFK), rubber expansion technique (thermal expansion molding), fabrication of an aileron structure by CFK using integral structure techniques.

DGLR---

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Introduction /1*

The modern advanced fiber-reinforced composites, because of their good specific mechanical properties, offer the potential to fabricate highly-stressed aircraft structures with considerable weight advantages as contrasted to those fabricated from metallic materials. The development of many structural parts, as conducted by various aircraft manufacturers in the last few years, has demonstrated the performance capabilities of these composite materials, such as carbon-fiber reinforced plastics (CFK). The present status can be characterized by the fact that, for civilian as well as for military projects, structural parts made from composite materials in the area of wing and fuselage flaps as well as of control surfaces can be considered mass-production items whereby, naturally, the military side is ahead of the civilian. Wing boxes for fighter planes and rudder boxes for passenger (private) planes are the next goal and will be incorporated in the next generation of corresponding projects.

The use of fiber technology as a mass-production item necessarily raises the question of cost comparisons as compared to conventional structures. For the composite technique the very high material costs (about 300.-DM/kg) and sometimes also the expensive fabrication technique are a disadvantage so that in many cases the extreme savings in structural weight by the use of fiber composites are offset by increased costs compared to structural parts made from conventional materials.

Analogously there are limitations in the extent to which fiber-reinforced composites can be utilized in a given structure or in the entire airplane, resp.

The development task discussed here has as its goal to investigate a fabrication technique which makes possible a cost-effective production of certain structural parts with almost exclusive use of CFK. In accordance with the above discussion concerning the status of the use

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* Numbers in the margin indicate pagination in the foreign text.

of composite-material structural parts this technique is oriented toward typical components belonging to the group of control surfaces. We chose the aileron of a civilian airplane. Within the framework /2 of the test program that was conducted the practical tests concentrated on the power-introduction region of such a structure. The finished section is 500 mm wide. The depth of the aileron box is 470 mm, its maximum height is 150 mm and decreases to 50 mm at the rear strut.

The subsequently described investigations were extensively carried out within the framework of the ZTL-program (future-technology-air); additional experiences were gained in project-related applications in space travel or in the project A-300-airbus.

Concept

Conventionally such an aileron structure is built in parts, consisting of sheet-metal parts riveted together for skins, struts, and ribs. Fabrication of such a structural part consists of the following main operations:

- gluing: local reinforcements of skins and strut
- shaping: struts and ribs
- joining: connecting ribs, struts, and skins

Contrasted to this expenditure of effort one must consider lamination and hardening as well as joining of the fiber-reinforced composites whereby it is important, with an eye toward cost comparisons, to utilize the advantages of the composite technology. Additional simplifications of the overall structure resulting from the use of composites, such as fewer ribs etc. as the result of improved mechanical properties, will not be considered here, but are an important part of a total comparison of the composite- and metal technique.

The advantages of the "Advanced composite technology" with respect to specific questions have already been basically demonstrated for a long time by the use of carbon-reinforced plastic (GFK) materials. Glass-fiber reinforced plastics are used extensively in large-aircraft construction where they are used primarily for the fabrication of /3 fairing pieces because of their mechanical properties. The primary advantages of this system of structural assembly are the fact that the material can be easily shaped in an unhardened state and that, by subsequent hardening, structural parts or cross sections of the desired shape are obtained.

On the other hand the lamination process makes it possible to increase the thickness directly so that the hardening operation, which is indispensable for the resin system, and which in its cost can be basically compared to the cementing together of doublers in sheet metal systems, can lead to locally strengthened construction zones. If one succeeds in utilizing this gluing capability to join the various parts so that during hardening not only the part itself can be produced but also joined to other parts such as ribs and cover plate, then an economical advantage compared to sheet metal construction can be realized. Depending on design the number of mechanical joints are reduced considerably and the fitting problems are reduced to a minimum.

With regard to the example given, these concepts lead to a final fabrication and assembly operation where, after hardening, an integral structure consisting, e.g., of a cover plate, struts, and ribs results such that only the missing cover plate has to be joined mechanically, or in an extreme case, that the entire structure is produced in a hardening fixture.

In carrying out these ideas in practice one quickly encounters considerable problems. The starting material for the fabrication is prepreg which must be hardened under pressure and temperature to produce the actual construction material CFK. The usual fabrication procedure as practiced in autoclave techniques with pressure foils would require a very complicated assembly with individual pressure chambers etc. if a given integral structure with undercuts and exact positioning and shape integrity of the individual parts were to be produced. Such an expenditure is hardly attractive for a cost-oriented mass production.

Thus the basic idea of the program that was conducted was to investigate the possibility of a uniform pressure increase during hardening which would satisfy the described requirements, and to gain practical experience with this technique. The tests were conducted with the thermal expansion molding technique.

Thermal Expansion Molding Technique (TEM)

The thermal expansion molding technique (TEM) utilizes as pressure medium special silicone rubber mixtures which expand under the influence of temperature and which, when these expansions are prevented, such as in a vessel, will exert a pressure against the wall of the vessel that is proportional to the prevented expansion.

Various manufacturers offered numerous TEM rubbers. The silicone component is a viscous pouring compound which after addition of a small amount of catalysts (< 10%) enjoys a pot time of about 60 minutes in which it can be cast to a desired shape and which at temperatures of 20-60° C, depending on the system, hardens within 24 hours to a degree that a core of stable shape results. The final complete hardening of the rubber cores to produce their desired mechanical properties takes place in an oven at about 120-205° C for about 1-8 hours, depending on the rubber mixture.

The final shaping of the cores is done in the original hardening devices whereby the fiber laminates produced are simulated by suitable forming materials.

The hardening apparatus for this method is usually a negative mold that can be divided into parts. The further layout of the inner chamber of the construction part, e.g. for the integral structure of the aileron, is determined by the inserted rubber cores in the individual chambers.

For lamination the fiber laminate is usually placed on the rubber core and this assembly is placed in the mold. During heat addition one differentiates basically between three zones of pressure increase, such as is shown schematically in figure 1. At the beginning, when the rubber is free to fill the volume and thus can expand without restriction, no pressure is exerted on the prepreg. When the laminate has reached the outer wall and the resin flow starts, a pressure rise develops up to the gelling temperature of the particular resin used which corresponds to the flow restrictions of the resin just as in an autoclave operation. At the end of the gelling phase the structure allows no further expansion of the rubber. Because of the temperature rise up to hardening temperature the pressure thus increases proportionally to the properties of the rubber used.

Thus the exact pressure ratios are determined by the various factors such as the geometry of the cores, the physical and mechanical properties of the rubbers, their setting capabilities, the flow of resin and the thermal expansion of the laminate and the suction gauze, the tolerances in the assembly, the hardening and gelling temperature of the resin system and the expansion with heat of the apparatus and the mold, resp.

The hardening in the TEM process can take place in a simple air-circulating oven; the greater expenditures required for autoclaves, etc. are not needed here so that, even in this connection, more cost-effective conditions are reached. Depending on the shape and size of the construction part, one could even consider direct heating of the mold without an oven for the hardening process in which case heating cartridges could easily be poured into the rubber cores.

After the hardening the final shaping of the core is made easier because of the much greater thermal expansion of the expansion rubber compared to that of the construction part and the mold. The core shrinks about ten times as much as the other components and, therefore, can be easily removed after cooling. If the cores can be suitably divided into parts, then undercuts can be made in the finished products without any great problems.

3.1 Physical Investigations

In general the TEM technique is characterized by two physical parameters of the expansion rubber material:

- thermal expansion coefficients α (degree^{-1}) /6
- compression modulus K(N/m^2)

The thermal expansion coefficient determines the increase in volume of the core due to temperature increase and is the basis of all calculations of the described 3 pressure regions encountered in the fabrication process. The compression modulus, a characteristic quantity describing the elastic behavior of the TEM rubber, is the computing link between the body pressure generated and the change in volume that is prevented corresponding to the third zone of the hardening cycle.

The thermal expansion coefficients were measured in the investigation with cubes with sides 50 mm long in a temperature range from RT (room temperature) to 180° C. The results, figure 2, show almost equal values for all systems investigated in the order of magnitude of $\alpha = 200 \cdot 10^{-6}$(degree^{-1}). The cubic expansion coefficient α^1 can with sufficient accuracy be expressed by 3α. A purely mathematical determination cannot be made since the transverse contraction number ν is not known with sufficient accuracy for the rubber.

The determination of the compression modulus K is more complicated. Thus K must be determined experimentally. The methods described in the literature where cubes with one open face are allowed to expand and this expansion is counteracted by a power-controlled piston, were not satisfactory with regard to test procedures and measurements. Thus, within the framework of the test program, a simpler measuring technique was developed. The measurements were made in a hydrostatic pressure chamber filled with oil (figure 2). Volume changes of the sample rubber because of temperature changes produce proportional reactions on the sealing piston of the chamber such that the power-controlled return to the starting position gives a direct measure of the pressure forces.

For hydrostatic relations the following are valid:

$$P = \frac{K \cdot \Delta V}{V_o} \qquad (N/mm^2)$$

$$K = \frac{P \cdot V_o}{\Delta V} \qquad (N/mm^2)$$

P = pressure
K = compression modulus
V_o = initial volume f (T, α)
ΔV = change in volume f (T, α)

In the actual tests the rubber samples are compressed at various temperatures by pistons and pressure media where the piston travel and pressure forces are measured. For the geometric relations the required values P and ΔV can be obtained by calculations from the measured values so that pressure/contraction curves can be established for the various temperatures.

The change in volume (ΔV) due to heat increases can be obtained from the thermal expansion number; the pressure/contraction curves thus obtained determine the pressure values P corresponding the values of ΔV so that, from the above expression, the compression modulus can be computed for the desired test temperatures. Figure 4 shows a working diagram from which, for a known relative change in volume due to heat addition, the pressure changes can be picked off.

Figure 3 shows an overview of the results of the measurements made with various rubber systems. There are only small differences between the materials tested; for all types the K modulus decreases with increasing temperature because of softening in the amount of 25 - 40%.

The measurements that were conducted show (figure 4) that in the pressure phase III of the hardening operation considerable pressures can develop (figure 4). If one desires to carry over these realities into actual practice for the fabrication of structural parts, then /8 it can be seen basically that the control of the final pressure in the ranges up to 7 bar, customary in autoclaves, can hardly be achieved in the TEM process since in the third phase of the hardening operation even small values of ΔT can produce very high pressures.

In line with these considerations a practical fabrication concept was established which, in addition to the questions of core fabrication and handling, should investigate the problem of pressure control and the properties of the construction parts thus built.

3.2 Final Fabrication

In the practical conduct of the tests it is worthwhile to calculate the thickness of the rubber for the individual construction parts directly based on the required expansion up to gelling temperature. The necessary expansion path is determined essentially by the setting curve of the laminate assembly, consisting of starting material (prepreg) and suction gauze. On the average the final thickness of the assembly decreases by about 25% because of the resin flow during the hardening cycle. Based on the temperature difference up to gelling temperature and on the expansion coefficient of the core the required amount of rubber can be calculated. Thus during initial heating a pressure develops in phase II which is determined by the flow resistance encountered by the resin; similar to conditions in autoclaves. The subsequent temperature increase toward hardening temperature then produces a steep pressure rise caused by the restriction of the expansion of the core as already described. The pressures that are normally developed lie in the range of 50 bar although in certain construction part zones locally higher pressures of > 100 bar can be obtained. The exact pressure in the various zones of the construction assembly cannot be determined with satisfactory accuracy. For the fiber composites this is of little importance since all reactions occur far above the lower critical pressure limits and since no adverse effect of higher pressures on the properties could be observed. The deciding conditions are those which are required for the layout which is to be designed for the order of magnitude of the pressures that are expected.

As a rule rubber thicknesses are obtained which are not sufficient to fill the entire volume of the structural part. As additional filler material aluminum cores are then added which, in addition, exert positive influences on the total assembly. They stiffen the rather soft core in the laminating phase, improve heat transfer in the mold and, if needed, can accept heating cartridges etc. During the course of the fabrication development they also offer the possibility to change the rubber thicknesses in iterative steps from the inside in order to decrease local pressure peaks without altering the required outer contour.

If these high pressures cannot be tolerated during the construction, then there is the possibility to deviate from the pure TEM technique and to combine the rubber with pressure bags or possibly with the autoclave technique. This does not mean that the advantages of the TEM technique are sacrificed; however, in certain planes maximum pressures can thus be limited. In contrast to the pure TEM technique, however, this results in a more complicated and expensive hardening process. This technique was also investigated by VFW- Fokker, but is not the object of this report.

3.2.1 Hollow Sections

In its simplest version the TEM process offers means for fabricating hollow sections. The first practical experiences were thus gained in the production of suitable construction parts having different cross sections. Here in the production of the cores several discoveries were made: the mixing of the system components must be done very carefully where special attention has to be paid to the vacuum in order to avoid air inclusions into the rubber which, otherwise, could lead to subsequently local low-pressure zones in the fiber composite structural part. Equal care must be exerted in the pouring of the core since the very thick, viscous rubbers are relatively difficult to process, and since, again, air inclusions cannot be completely avoided in this step. After the /10 core has been hardened, however, there are chances to repair the defective areas. Defective sections can be cut out with a knife so that they can again be filled with new material. In any case the finished core can be worked to a certain degree. Cutting, drilling, and grinding can be done successfully.

Figure 5 shows the construction of a tube of 64 mm diameter, a wall thickness of 1 mm and a length of 500 mm. Corresponding to this model, tubes of various diameters and wall thicknesses as well as cross-sectional shapes such as rectangles, squares, and triangles and of various layer construction were produced and tested. We were able to ascertain that, despite the pressure problems described, the construction part laminates were of uniform quality such as one might expect from autoclave technology.

In the course of developments for world space travel this technology was already tested in the fabrication of tubes for various applications in satellite construction by the firm of VFW-Fokker/ERNO. For several extremely thin, multi-layer laminate assemblies "prepreg" materials with an effective thickness of 0.05 mm were successfully processed by the TEM technique.

Figure 6 shows an application from space travel technology. For the test program then in existence 10 tubes were fabricated from one core without any trouble using a 175°C hardening system. Test tubes, cut into sections, fulfill the requirements with regard to stiffness and strength. The complicated shape tube end pieces made of CFK were also fabricated separately by the TEM technique. From one core 75 shells were fabricated without any problems.

Based on the good experiences with this fabrication technique several components of the CFK spoiler developed in 1978 by VFW-Fokker for the Airbus A 300 B2/B4 were fabricated by the TEM technique and were tested successfully in structural part- and component tests.

Figure 7 shows a view of the structural part about 2 m^2 in size /11 and shows the two most important TEM components. One is the U-shaped frame which is glued into the structure and forms the inner closure of the sandwich body in the area of power introduction and to which the mid fixtures used for transverse power connection are joined mechanically. The frame is fabricated in one piece by the TEM technique such that, in different areas, sections of varying wall thickness and varying layer construction are laminated.

The second TEM part consists of the exterior bearing brackets where the basic body as well as the closure sections are fabricated separately and are completed during assembly.

The basic body shown, partly hollow sections and partly angle sections, is fabricated in a fixture with a divided rubber core. The front reinforcements are inserted into the TEM assembly as hardened laminates. As mentioned before these components have proven their worth within the framework of the structural part tests. Four of these spoilers have been in operation since February or March resp. of this year in two Lufthansa aircrafts.

4. Demonstration Structural Part

As already described, the structural part to demonstrate the usefulness of the fabrication technique consisted of the power introduction section of an aileron. The concept for the economical production of this component is based on the already described basic considerations: almost the entire structural part is hardened in one operation as an integral structure. The assembly must be such that it is possible to again remove the TEM cores after hardening in which case there are several possibilities: e.g., the main strut can be drilled such that the separable cores can be removed and that the entire structure can be made in one operation. Or, in another case, a component such as a strut or a cover plate, is hardened between separation foils so that it can be removed for the removal of the cores. For the final assembly this component must then be fastened mechanically where, compared to differential sheet-metal structures, a considerable number of riveted joints are eliminated and, in addition, only minimum fitting problems are encountered. /12

For the demonstration part, a box with struts, cover plates and 5 ribs where 2 ribs are pure support ribs, 2 ribs are used as lower-stressed CFK power introduction system ribs and one is the main rib for the central power introduction. After consideration of several alternatives a method was chosen in which the integral structure was fabricated without a bottom cover plate. The open box thus can be easily inspected after hardening and the fittings for the center connections are easily attached to the rib from inside the structure (trunk corners). Even in service the cover plate can be removed for inspection. All ribs are U-shaped. It can be seen that the CFK power introduction ribs are thickened in steps where the various steps are laminated wet and are hardened during the course of the TEM hardening process.

In contrast to the hollow sections described till now, the fabrication of an integral structure requires laminate hardening solely between two rubber cores while until now the core served to shape the laminate at the steel wall, i.e. supported from only one side. Thus, as a preliminary step for the construction part fabrication I-shapes were produced by the TEM technique where the cross members were also hardened between two cores. Similar to the structural part, the sections had web heights of 150 to 50 mm and chord widths of 50 mm. During the course of the investigation various versions of web construction were compared. Basically there is the possibility to allow the web laminate to be butt-welded to the chord and to secure the joint by means of added small corner strips. The other possibility is to fold half of the web laminate over the lower part of the chord laminate and then to again laminate the second part of the chord structure on top of it. Both versions were employed successfully. The webs hardened between rubber were of the same quality with respect to resin content and /13 and geometry as the chord laminates. The comparability of the constructive solutions from strength considerations was demonstrated in tests of the structural parts. Figure 8 shows I-shapes in both versions with the power-introduction sections in place for the tests.

Figure 9 shows a view of the final fabrication device with the rubber cores and the aluminum fillers for the voids in the cores of the hollow sections.

After these preliminary tests the fabrication of the demonstration structural part was begun. The part is composed of 4 laminate types which, for mass production, can be laminated by machine into sheets of large surface. From these unhardened large laminates including the peel-ply layer the parts for the individual construction part components can be stamped or cut out, resp. Both are operations which can be carried out economically in mass production quantities. The individual cuts are then assembled in the TEM device to form the final structural part.

Figure 12 shows the finished integral structure of the aileron box next to the TEM device open on one side. For the assembly a side piece and the front piece at main strut are removed from the TEM base plate (figure 13). The first laminate to be inserted is the upper cover plate which is then folded over vertically at the back edge, thus, at the same time forming the rear strut. Then, from the side, rubber cores with the ribs laminated to them are inserted. The reinforcements at the power introduction ribs are then placed in the steps of the cores and are thus fixed. As in the other structures, the rubber parts contain aluminum cores for the previously-mentioned reasons. After the last rib has been inserted, the mold is closed on the side and the cover plate laminate is further folded over the ribs, such that the rear strut is laminated in its final form. The closure is formed by the main strut which is inserted into the device against the cores that are present.

On top of that an additional rubber core is placed to form the main strut and the front face of the device. After the mold has been closed and the thermocouples have been attached, the assembly is put /14 into the oven to be hardened without any additional operations. Figures 10 and 11 show various views of the finished integral structure.

The described operational procedure emphasizes that the total concept, in large-scale technology, offers possibilities for a cost-effective fabrication of composite structural parts. In addition, figure 13 shows that the required fixtures can be made very simple. Even the production of the cores should not be considered as a costly item so that the fabrication raw materials can fit well into the total concept from an economic standpoint. From these standpoints the question of continued use of the cores, which cannot be answered unequivocally, does not appear to be too important. Depending on the actual pressure conditions in the mold, permanent deformations of the cores can occur which, after a certain number of hardening operations (order of magnitude: 50 charges) can lead to the result that the expansion of the core is no longer sufficient and that the laminates are hardened at too low a pressure. Measurements made with samples do not produce representative answers: the final answer can only come from mass production. In view of the simple repair concept for the cores, one can visualize a core-monitoring and repair running concurrently with mass production.

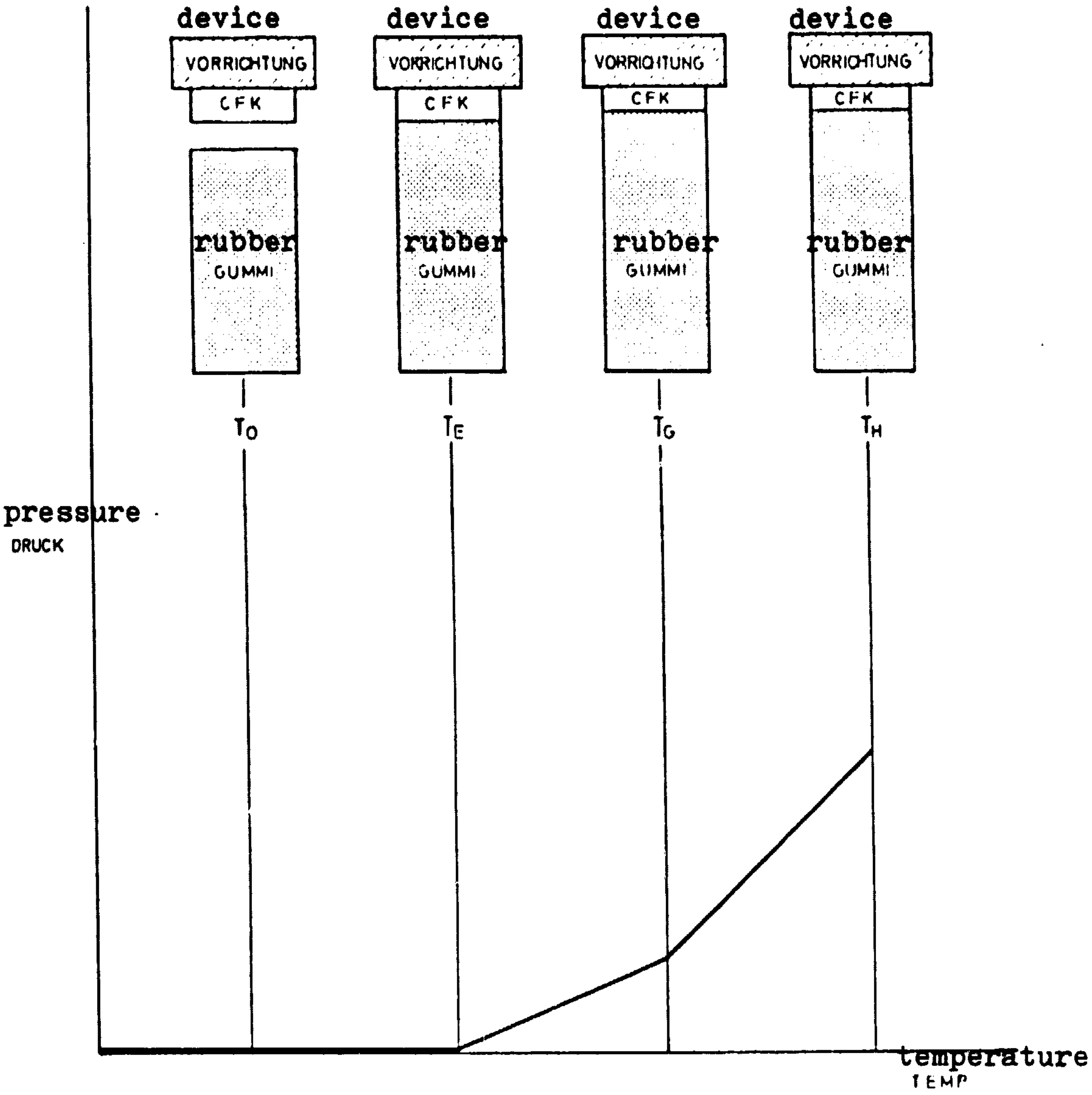
From a consideration of economics, the comparison of the sheet-metal part assembly technique and the composite integral structure technique shows considerable advantages, in total, for the new technique. The raw material costs for the fiber construction are considerably higher, but the integral technique has the advantage of requiring considerably fewer joints. The selected method makes possible, compared to the metal structure, to eliminate about 65% of the required rivet joints. Together with the conversion to CFK this produces a weight saving of about 22%.

A detailed economic analysis arrives at a cost saving for the /15 fiber integral-structure technique of about 25%, based on costs for the conventional structure. One-time costs have not been considered in this connection. The comparison is based on the cost of 100 metal pieces while in the fiber construction version, because of the lack of reliable learning curves for the CFK fabrication in the TEM process, data have sometimes been used which were obtained in the experimental fabrication phase. To lower the laminating costs, fiber fabrication depends on machine-operated, large surface and flat lamination operations from which the required parts can be stamped. To estimate the performance of laminating machines conservative data were used in this case so that altogether the cost estimate with regard to mass production must be considered conservative. The cost saving of 25% is based on the reduction of riveted joints required as well as the integrated fabrication of the CFK side assemblies and lower-cost production fixtures (ovens.)

Concluding Considerations

The results of the economic analysis emphasize the possibilities which this fabrication technique offers. The tests that were conducted with structural parts have proven that the TEM technique can be effective even for integral structures of the described assembly. Several construction parts were fabricated which fulfilled all expectations; some are still under test.

Thus it seems appropriate to investigate this technique further with respect to mass production whereby the key to these efforts must lie in the area of rubber development. Today's systems cannot be considered ideal. Primarily one should strive for a lower K modulus in order to reduce drastically the high pressures and thus to increase the life expectancy of the cores. It would also be desirable to find a higher thermal expansion coefficient and better workability properties of newly developing systems. If the efforts are successful in this respect, the TEM technique would offer an attractive alternative for the fabrication of future fiber structures.



T_O - Ausgangstemperatur initial temperature
T_E - Ende der freien Expansion end of free expansion
T_G - Geliertemperatur gelling temperature
T_H - Härtetemperatur hardening temperature

Bild Nr. 1 TEM - Technik
Schematische Darstellung der Druckaufbringung

Figure 1 - TEM technique; schematic representation of pressure rise

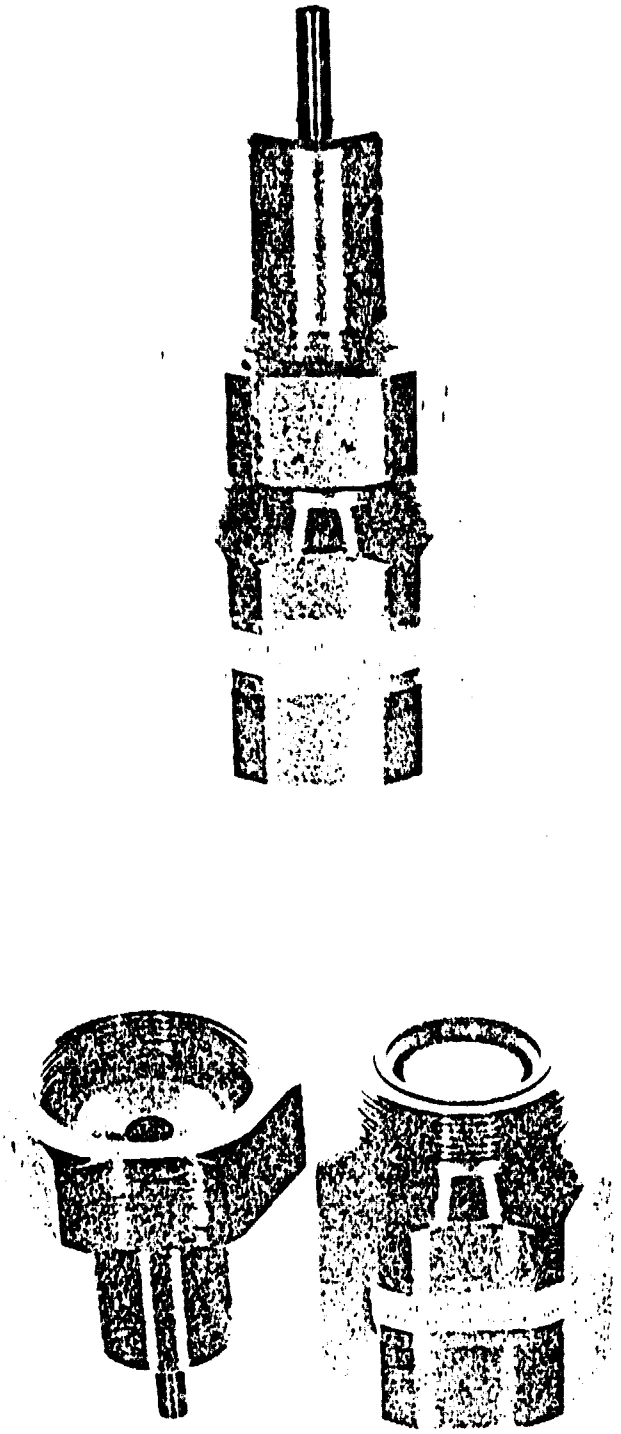


Bild Nr. 2 Bestimmung des Kompressionsmoduls
Hydrostatische Kompressionskammer

Figure 2 - Determination of compression modulus;
hydrostatic compression chamber

Product PRODUKT	**temperature** Temperatur [°C]	**expansion coefficient** AUSDEHNUNGSKOEFFIZIENT α [1/~~grad~~ degr.]	**compression modulus** KOMPRESSIONSMODUL K [daN/mm^2] *
DAPCOCAST Nr.1	43	$231 \cdot 10^{-6}$	13 000
	80		11 000
	120		9 000
	160		7 000
DAPCOCAST Nr.52	40	$193 \cdot 10^{-6}$	14 000
	80		12 000
	120		10 000
	160		9 000
MOSITES 2701-F	40	$205 \cdot 10^{-6}$	11 000
	80		10 000
	120		9 000
	160		8 000

* Werte abgerundet
values rounded off

Bild Nr. 3 TEM - Gummikerne
Ergebnisse der physikalischen Messungen

Figure 3 - TEM rubber cores
Results of physical measurements

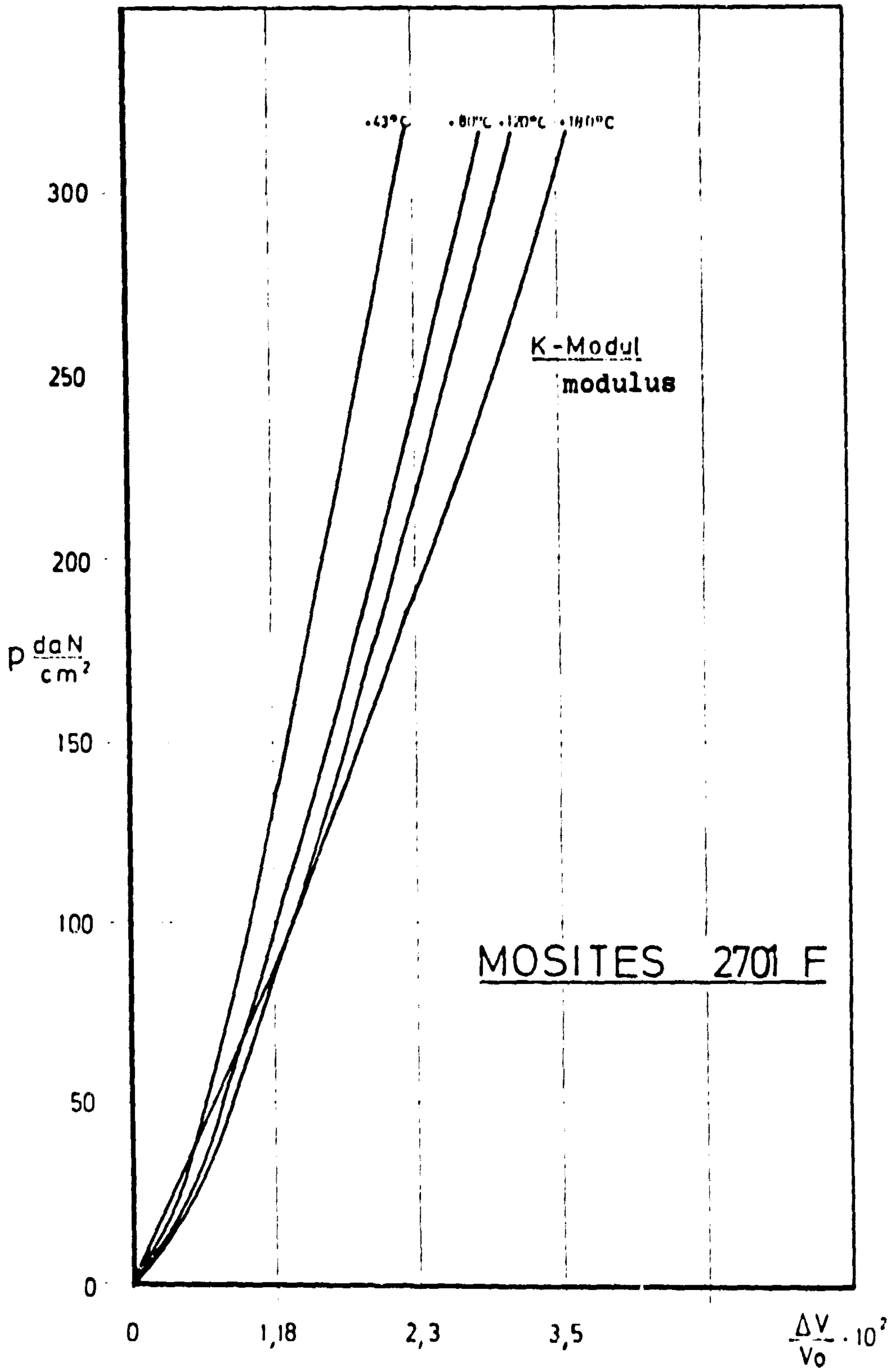


Bild Nr. 4 TEM - TECHNIK Druck - Expansionskurve

Figure 4 - TEM technique; pressure-expansion curve

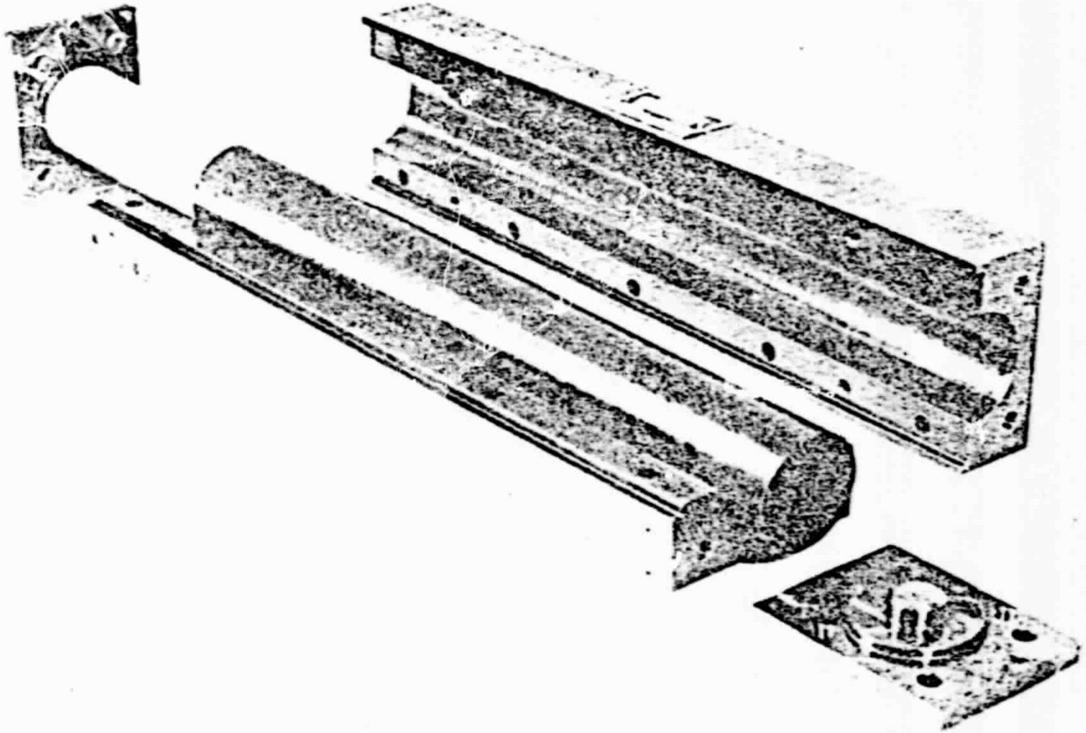


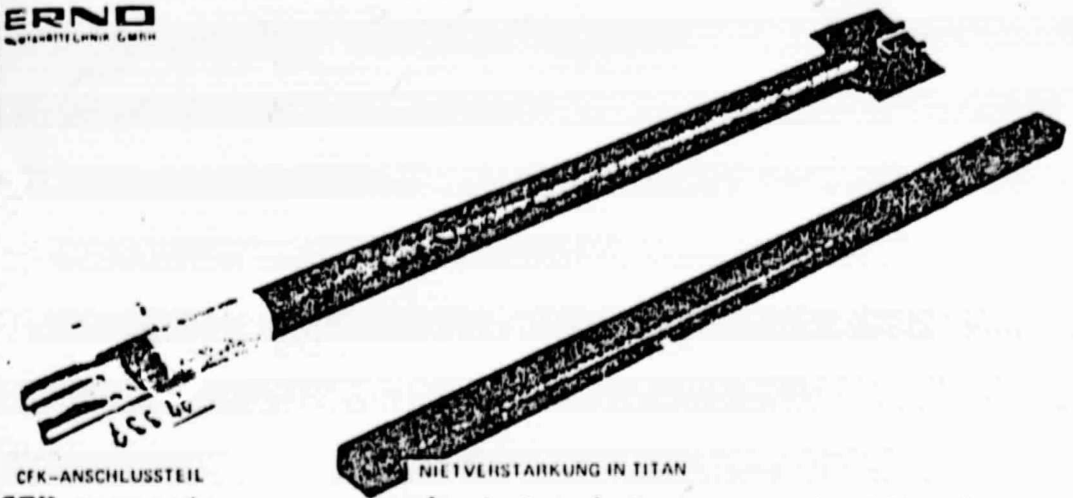
Bild Nr. 5 CFK - Rohr (d = 64 mm/ t = 1,0 mm/ l = 500 m) Multidirektionaler Aufbau mit TEM - Vorrichtung

Figure 5 - CFK tube (diameter = 64mm; thickness = 1.0 mm; length = 500 mm) Multi-directional assembly with TEM device

tubular strut and rectangular shape for ZSK position control module

ROHRSTREBE UND RECHTECKPROFILE FÜR ZKS-LAGEREGELUNGSMODUL

ERNO



GEWICHTSERSPARNIS GEGENÜBER AL: 1008 g ODER 46 % weight saving compared to Al

STEIFIGKEITSZUWACHS ca. 40 %

DRUCKFESTIGKEITEN 38,9 daN/mm² FÜR VIERECKPROFILE for rectangular shapes

64,7 daN/mm² FÜR ROHRPROFILE for tubular shapes

increase in stiffness

compressive strength

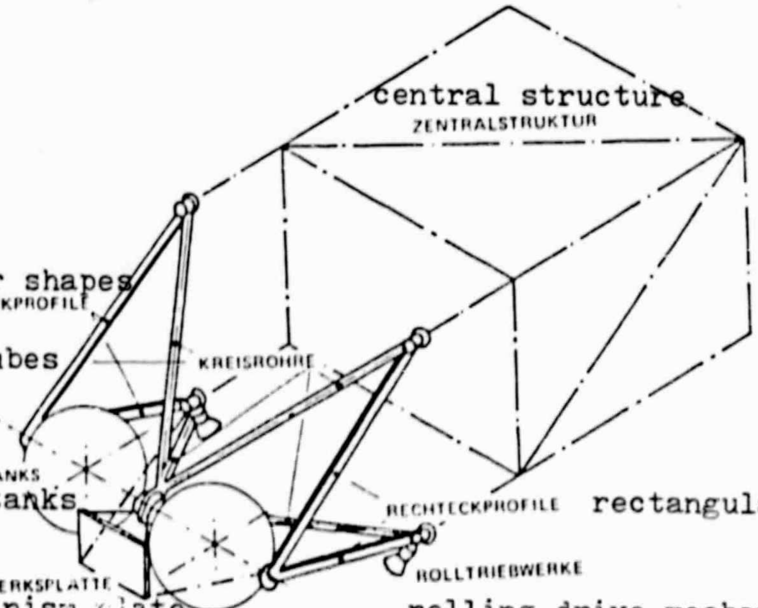
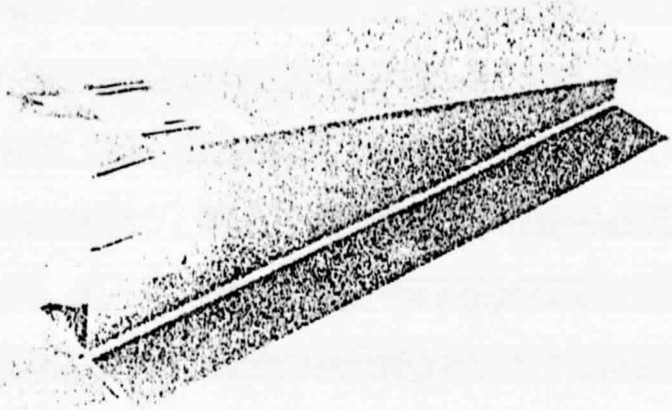


Bild Nr. 6 ROHRSTREBE UND RECHTECKPROFILE FÜR ZKS-LAGEREGELUNGSMODUL

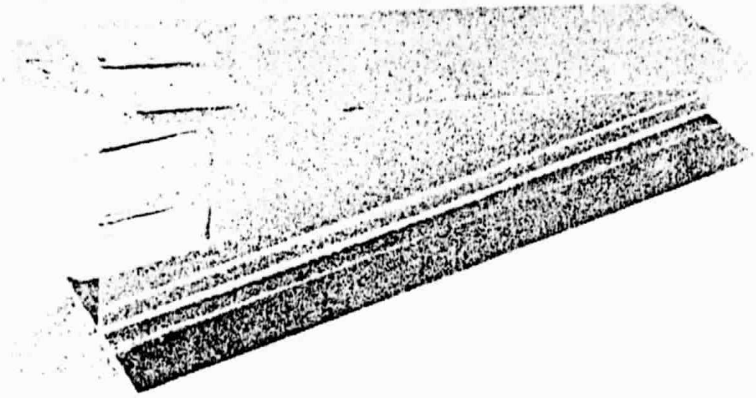
Figure 6 - Tubular strut and rectangular shapes for ZKS position control module

Bild Nr. 7 CFK - Spoiler A 300
Lage der wichtigsten TEM-Komponenten des Bauteils

Figure 7 - CFK spoiler A 300
Position of most important TEM components of structural part



Version: Geteiltes Laminat für Steg und Gurte
Modification: Separated laminate for web and chord



Version: Laminat- und Stumpfstöße mit Zusatzecken
Modification: laminate and butt-weld joints with reinforcement corners

Bild Nr. 8: I-Profile aus CFK. Fertigung im TEM-Verfahren Bauteile mit Krafteinleitungen für statische Versuche.

Figure 8 - I-shapes made by the CFK technique; fabrication with TEM process; construction parts with power introduction for static tests.

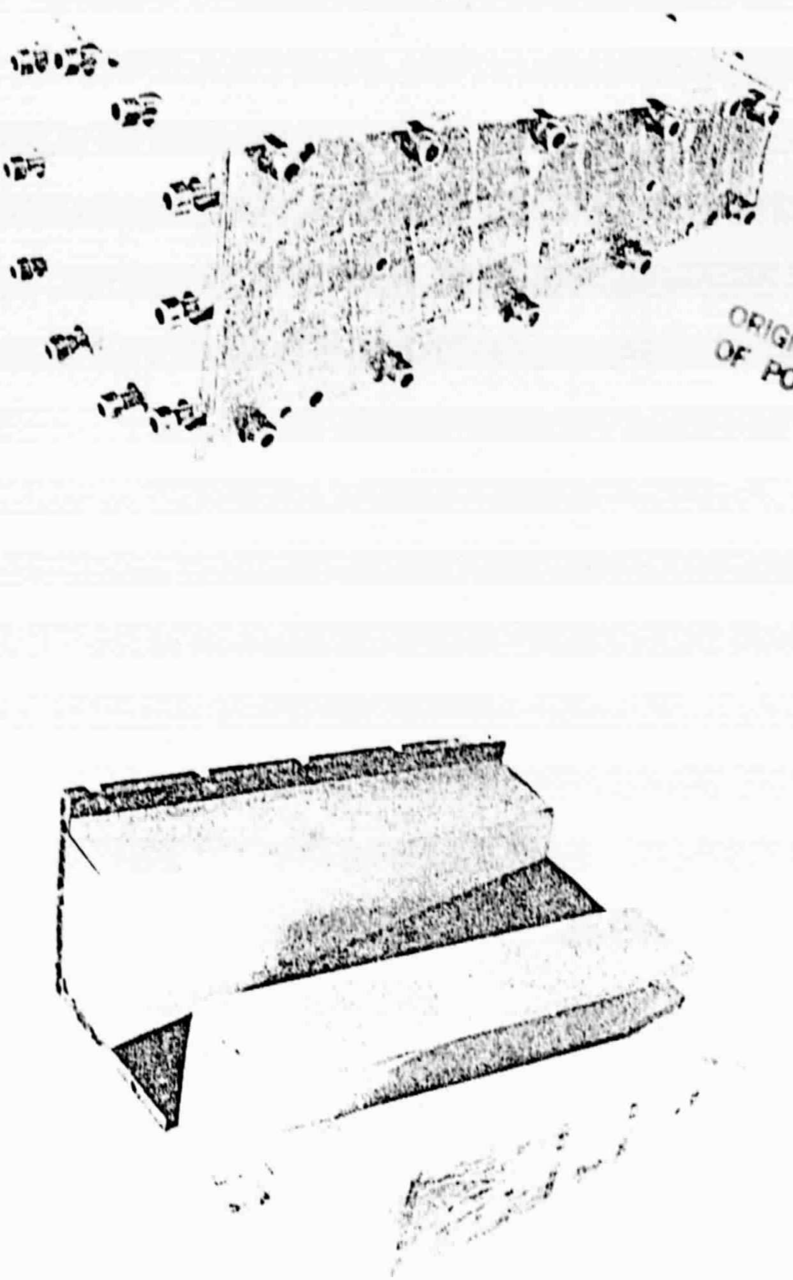


Figure 9 - I-shapes from CFK; fabrication using TEM process; hardening mold with rubber cores and aluminum fillers.

Bild Nr. 9: I-Profile aus CFK. Fertigung im TEM-Verfahren Härteform mit Gummikernen und Al-Füllstücken.

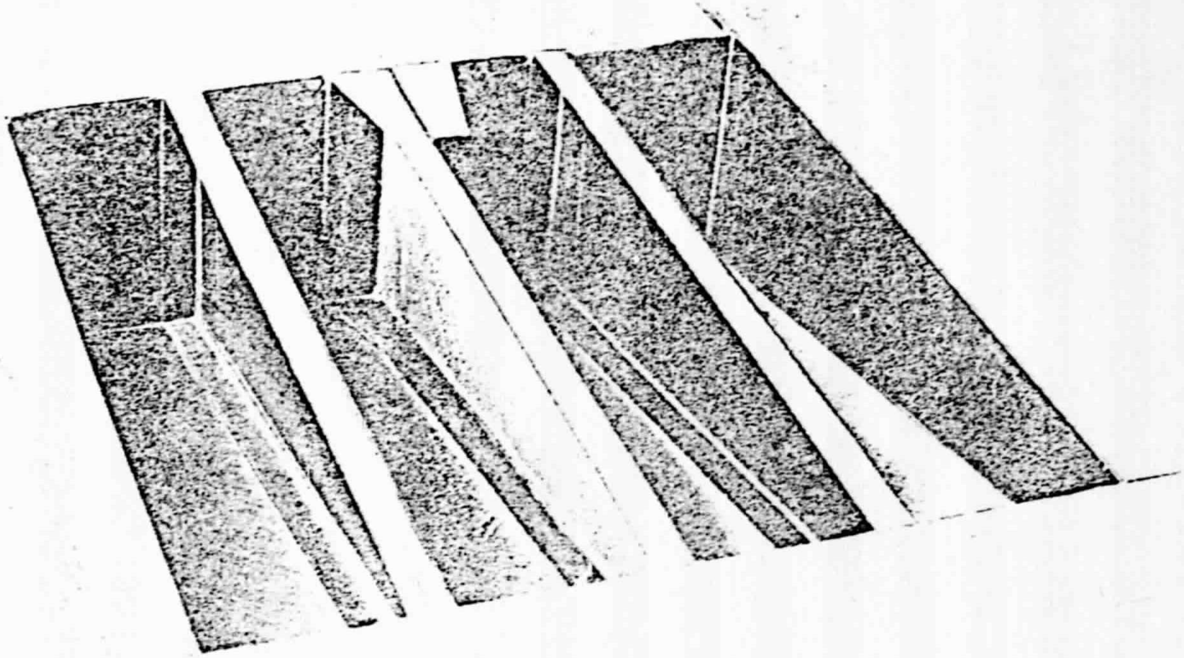


Bild Nr. 10 Demonstrationsbauteil -
Krafteinleitung Querruder Integralbauteil CFK Unterseite

Figure 10 - Demonstration structural part; power introduction for aileron; integral construction part CFK - bottom side

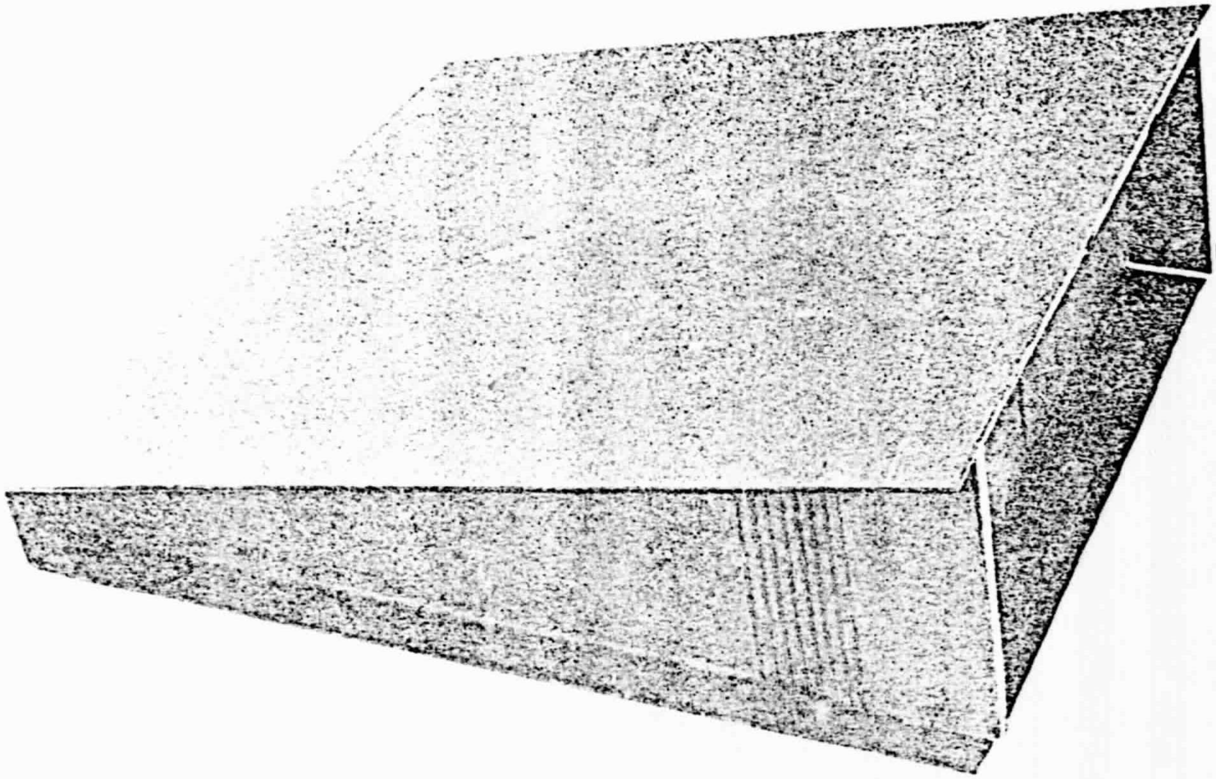


Bild Nr. 11 Demonstrationsbauteil Krafteinleitung Querruder Integralbauteil CFK Oberseite

Figure 11 - Demonstration structural part - power introduction to aileron-integral construction part CFK - upper face

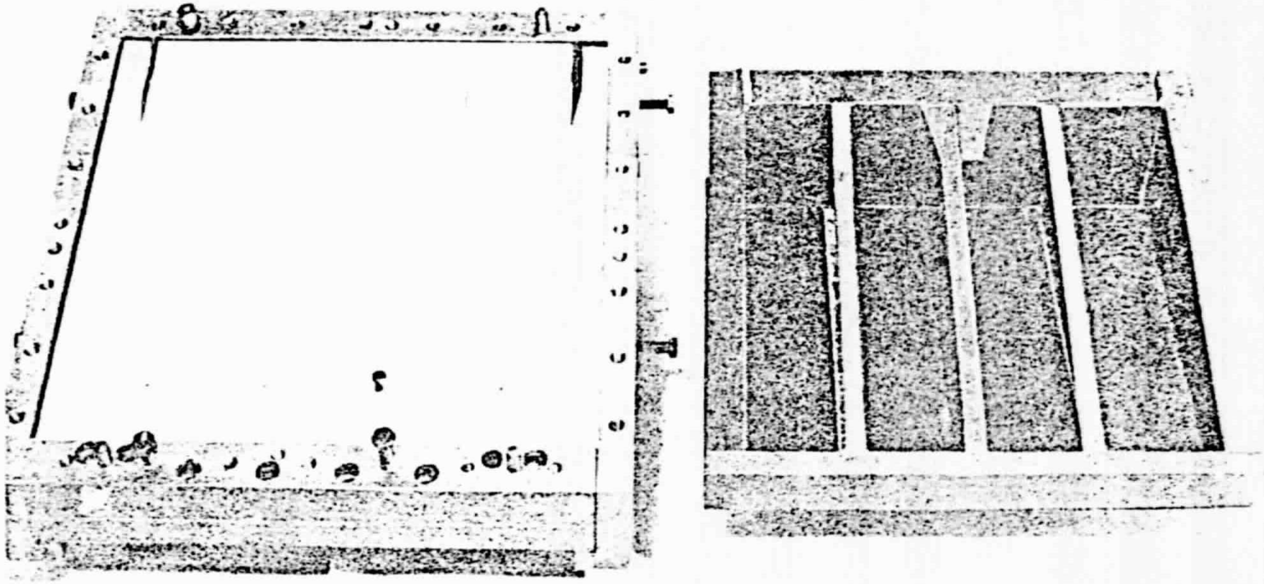


Figure 12 - demonstration construction part- power introduction to aileron-
TEM mold and integral construction part from CFK

Bild Nr. 12 Demonstrationsbauteil - Krafteinleitung Querruder
TEM - Form und Integralbauteil aus CFK.