The drapability of multi-axial materials and the use of laser-transmission welding

Eva-Maria Falk, Cetex Chemnitzer Textilmaschinenentwicklung gGmbH, Chemnitz/Germany

The subject-matter of this article is the three-dimensional drapability of multi-axial materials. Two purpose-developed methods of draping were investigated. Laser transmission welding was utilized for a partial and geometrically adjusted separation of fixing stitches.

The manufacture and the processing of geometrically superior light construction parts made of fiber composite materials in three dimensional geometries serves as a response to needs of the automotive, transport, mechanical engineering, and air industries for textiles with higher drapability.

Effective laser treatment parameters enable fold-free draping in a basic geometric shape up to the diameter capacity of a hemisphere. This is achieved through delicately finished, two-layered, multi-axial, carbon fiber material with PET threads for fixing and uniform separation of the PET stitches.

For this, two methods of draping were utilized both with defined fixing points and as a modified hand application. In the hand application process, fiber-composite parts could be produced in convex or concave shape. Possible applications relate to airplane production for windows and areas featuring slight curvature, for the afterbody of the Airbus and slightly curved parts of the outer-surface of helicopters. Unwanted folds and overlapping can be avoided in many applications. Identical strength of the components provides for a light weight.

Problem analysis

Methods and processes for the manufacture of preforms from textile fabrics are somewhat costly. The desired product quality: high strength in the main deforming area, fold-free and seam-free drapability, no build-up in the polymer matrix and weight reduction are only partly or not at all achieved; thus, possibilities of implementation are still limited. Simply curved geometries could be achieved in costly processes with the use of unidirectional materials. Complex geometries can be achieved utilizing winding with an optimal fiber layer, but only for convex shapes. This is generally due to damage of the multi-filament [1-4].

Use of these materials provides challenges particularly related to their three dimensional design during fiber protective manufacturing and lubrication [5]. New and specific possibilities of draping in the molding of simple three-dimensional geometries of semi-refined materials using a fractionally geometrically fitted cutting of thread stitches will be investigated. It is intended that the fiber layers will maintain their forms.

Testing process

A 50 W diode-laser (LM 50 with a fiber coupling, and wavelength of 808 nm) was used for an extended length of time to separate the PET fibers.

An advantage during laser welding, the black carbon fibers absorb radiation which is transferred through thermal conduction to the white PET fibers. These fibers, which are not affected by the laser, but have a lower melting temperature than the carbon fibers conduct this heat and melt on top of the black fibers [6]. Advantages of laser use are high productivity, reliability, and minimal thermal stress on the area due to the precise, local and contact free application of heat. Damage to the surrounding material also remains low.

Experimental parameter tests

For trial tests [5], a two-layer multi-axial material was employed of +45°/ -45° 800 tex. Carbon from the company Toray, with fiber 76 dtex f 24 PET, textured, with a yarn count of 5 F, stitch length of 2.5 mm, structure, pillar stitch and a mass per unit area of 410 g/m^2.

A thermo gravimetric analysis during laser testing demonstrated that a separation of the PET fibers without waste-residue, and without damage to the carbon fibers or their lubrication was possible at working temperature from 240 °C to 270 °C.

The complexity of the temperature parameters, speed, time, output, heat dissipation from the base-layer, separation width, radiated surface, laser profile, the capacity of the unit and operating efficiency all have an effect on the separation results:

- Successful separation of PET fibers occurs at low temperatures with low speed, structure, and geometrically specified continuous laser exposure.
- A base-layer that removes heat less than steel, such as a PET heat-web, achieves less output in melting and in using lower temperatures, less reaction on the surface and bottom-side of material.
- An enlargement of the laser beam through defocusing resulted in greatly improving the progress: shorter processing time, higher operating efficiency and large separation widths.
- There are two limitations of the unit: Defocused laser work in the processing area is non-uniform and the round laser beam results in a less heated outer-area than in the center and a higher procedural speed minimizes the melted area.

Effective parameters enable uniform melting of the PET fibers at the temperature of 240 °C with a separation width on th esurface (~2,500 mm^2/min) and on the backside.

Effect of parameters related to bending

The effect of optimal parameters on bending variables of material layers with epoxy resin matrix, after laser fiber separation, demonstrated a tendency to decrease in bending (Modulus E), a limited increase in strain, distortion, toughness, and break stress at 240 and 280 °C. Impact tests did not show a clear relationship between damage and test treatment. The minimal differences suggest few disadvantages of use at either temperature. Without sewing threads, penetration of the matrix utilizing hand lamination is better [5].

Attempts using a three-dimensional draping test rig

Using basic geometric forms fit to a hemisphere, in the x, y coordinate system the separation of the largest symmetrically formed surface with limited line spacing was achieved through laser treatment. The effect of laser treated forms in fold-free draping was tested using two reproducible methods with specially developed devices. In multi-axial materials, draping is only possible through shearing.

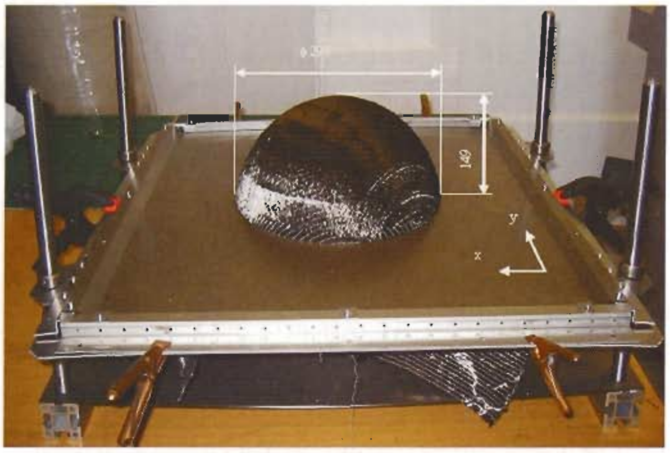

Fig. 1 Draping test rig and fold-free draping by geometrically adjusted separation, maximum diameter: 298 mm, draping height: 149 mm

Strain and fiber stretching is reliable in high performance fibers.
Tests on the Draping Test Rig (Fig. 1) with a glass swivel as a draping form, a stentering frame for square material, perforated sheets at diameters of 274, 292, 298 mm to support draping and a gauge for a draping height of 90, 119, 149 mm as well as driving spindles to support equal weight distribution show in the circular basic form:

- Stretched, untreated or laser treated materials result in a draping height of only 75 mm as shearing causes a definite retightening of the material.
- In un-stretched and untreated material, a fold-free drape of up to 90 mm (Diameter 274 mm) is possible. Moreover, up to six folds result (Fig. 2).
- Un-stretched, laser treated material develops, due to geometric separation, up to 7 folds. Symmetrical geometries promote symmetric and uniform laser treatment.
- For fold-free draping through shearing (Fig. 1) up to a 298 mm maximal diameter of the glass swivel and a draping height of 149 mm, both a defined point by point fixing parallel to the y- and x-axis outside of the stretching area and a uniformly laser treated, circular formed inner area, an extra 2 cm, that corresponds to the degree of bend of the hemisphere are required.

Fixed, the material will not return to its original state. Disadvantages of the draping test state were fiber tears and damage caused by the perforated sheet.

Trials without a test-rig for deformation utilizing manual stretching served as a temporary technology suited to a variable process of hand application. A newly developed cutting layout for a modified hand application process where the carbon fibers lay parallel to the edge of the material square saves on material and lowers costs. Laser treated, a squarer with edge lengths corresponding to the degree of bending in draping is 2 cm longer. The trials demonstrate:

- The manual and incremental stretching of diagonals consecutively at 90° shifted to right and left in two opposite directions brings about a nearly accurate distortion.
- Shearing of multi-axial material is made when material is homogenously lasered over a large surface.
- The preform can be applied to the form stabily and without folds.
- The deformation described is two-dimensional (Fig. 3a, b) with local main axial directions of the deformation tensor set in diagonal (stretching direction) and perpendicular directions. The deformation is defined by a cross expansion and length stretch.
- Fold-free draping is possible with a maximum hemisphere diameter of 298 mm and a height of 149 mm.

Uniformity of tension is essential to the quality of the draped surface. Without fixation, further deformations remain possible, which lead to build in the roving [4].

Results and Outlook

The process of defined separation using laser transmission welding is applicable in principal. In the hand application process, fold-free fiber composite parts were built on the concave and convex form of a half globe (Fig. 4). This concave form necessitates a separation of hand-application and deformation. Epoxy resin L20 with hard EPH 161 was employed as a matrix [5].

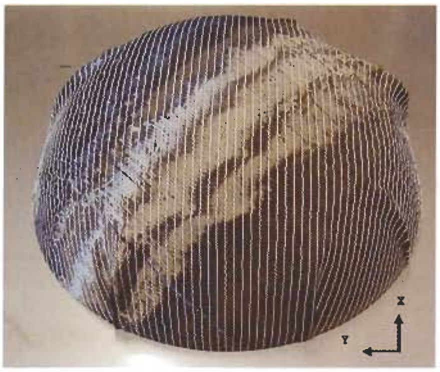

Fig. 2 Untreated fabric with threads with 6 folds at high diameters and draping heights

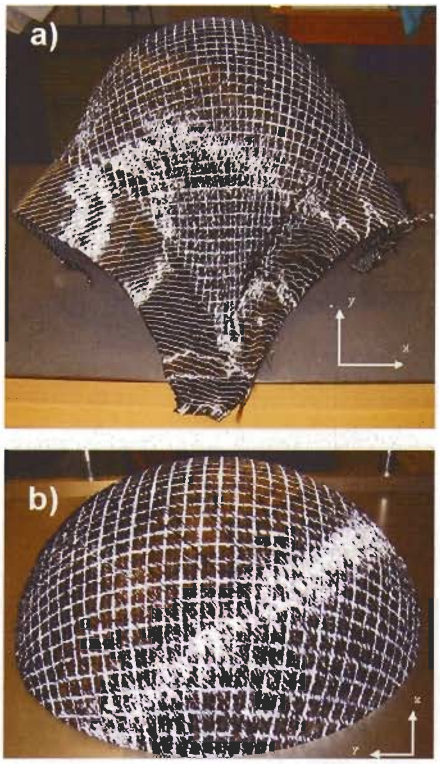

Fig. 3 a) Deformation behavior of the preform in x and y directions - 10 mm raster; b) Deformation behavior in x and y directions - 10 mm raster, draping zone is marked at a maximum diameter of 298 mm and a draping height of 149 mm

Fig. 4 Fiber composite (negative form - concave) with fold-free exterior, hemisphere diameter 298 mm, height 149 mm; hand laminate with epoxy matrix L20 and hardener EPH 161 with 4 layers of pre-draped multi-axial non crimp fabric

The fibers need to be more precisely melted through a more exact energy application. Waste residue free separation and the effects of residue need to be investigated. Fibers with a lower melting temperature are expected to produce a higher effectiveness by a factor of 2-3.
Further activity will take place in improvements to the technology through mechanization and ability of reproduction. The problem of back-deformation through release of restorative forces should be dealt with for quality improvement. Eventually, bunches and bends in the fibers, which cause poor hand application through build-up in concave forms, are to be improved. The ultimate goal is the improvement of hand application technology in order to raise the volumetric content of the fibers and ultimately, the strength in components [5].

Acknowledgement
We would like to thank the BMWA, Berlin for financial support and the project managing company FhS Fraunhofer Services GmbH Berlin/Germany for advisory support. Further, would like to acknowledge Karl Mayer Malimo Textilmaschinenfabrik GmbH, Chemnitz/Germany, for support and testing materials, scientists at the Instituts für Polymerwerkstoffe e.V. and Prof. E. Straube, at the faculty of Physics at the Martin-Luther-Universität Halle/Wittenberg/Germany, for analyses, suggestions and discussions during the experimental and theoretical work process. Additionally, we would like to thank Strukturleichtbau e.V. at the TU Chemnitz/Germany for help in inquiries and operations.

Empa: fiber reinforced polymer composites for construction

Carbon fiber reinforced polymer (FRP) composites are frequently used today to strengthen buildings to make them suitable for new applications and uses, as well as to prevent them suffering earthquake damage. The success of this modern material is due to its ease of use and its lightness. New products, however, must be handled with a certain degree of caution. In mid-January 2007 experts from all over Europe gathered at Empa, Dübendorf/ Switzerland, to discuss their experiences involving novel applications with these fiber composite materials.
Today it is impossible to imagine the building industry without carbon fiber reinforced composites, the two main reasons for this being that these materials are extremely light and resistant to corrosion. Initially the high price was counterbalanced by the ease of handling and use. Increased demand and resulting greater production rapidly brought down the purchase cost of FRPs. And demand is bound to continue to rise, because ever more applications are coming to light as more and more elderly concrete building become due for renovation. In such cases the use of carbon fiber reinforced composites is often the most economic solution - why demolish an old building and replace it with an expensive new one when it could be economically repaired using these modern materials?
For example *Kypros Pilakoutas* of the University of Sheffield/UK and his colleague *Marco Di Ludovica* of the University of Naples/Italy described their work in constructing two and three storied buildings on shaker platforms and then subjecting them to high levels of acceleration. Even at these loads the structures strengthened with carbon fiber reinforced composites suffered little damage, while those which were not so equipped would have rapidly collapsed.
In addition one of Motavalli's coworkers, *Christoph Czaderski*, presented a newly developed method which allows carbon fiber reinforced strips to be placed under tension before being attached to the building structure in a "prestressed" state using adhesive without any permanent anchorages. Prestressed strips have the advantage that, for example, the strengthened structure shows smaller distortions and cracks.
An interesting variation on the theme of fiber reinforced material comes from Greece. *Thanasis Triantafillou* of the University of Patras replaced the modern carbon fibers with textile-based ones, using standard mortar as a binder instead of polymer. Even if laboratory tests showed that his materials did not quite achieve the same high values as the high-tech materials, the textile composite materials do have certain advantages. One decisive plus point lies in its cost-effectiveness - while it is true that the textile fibers must be specially made, and are therefore not significantly cheaper than carbon fibers, the mortar used costs practically nothing when compared to the polymer binder. Another is that "normal" building workers are capable of carrying out the reinforcing work with the "low-tech" material, obviating the requirement to employ expensive specialists.

Wirktechnik für 3D-Textilien in matrixgebundenen Bauelementen

Technische Entwicklungen zur Fertigung räumlicher Gewirkestrukturen, die den besonderen Bedingungen ihrer Weiterverarbeitung entsprechen und hinsichtlich lastaufnahmefähiger, direkt orientierter Systeme auf spezielle Anwendungsfälle im Hochbau zugeschnitten sind, waren Gegenstand der hier beschriebenen Untersuchungen.

Bert Böhme, Hans-Jürgen Heinrich
Cetex Chemnitzer Textilmaschinenentwicklung gGmbH, Chemnitz
Frank Helbig
Institut für Allgemeinen Maschinenbau und Kunststofftechnik, TU Chemnitz,

Ausgangssituation und Forschungsziel

Technische Textilien, die in Verbindung mit fest oder elastisch abbindenden Matrices zu Anwendungsprodukten gebracht werden, bildeten die Basis für die Forschungsarbeit. Im Vordergrund standen grundlegende technische Entwicklungen, deren Realisierung die Fertigung räumlicher Gewirkestrukturen ermöglichen. Sie sollen den besonderen Bedingungen ihrer Weiterverarbeitung entsprechen und hinsichtlich lastaufnahmefähiger, direkt orientierter Systeme (D.O.S.) auf spezielle Anwendungsfälle im Hochbau zugeschnitten sein.
Zahlreiche Untersuchungen und textile Entwicklungen zu speziellen Anwendungserzeugnissen verdeutlichen die Notwendigkeit, die zunehmend geforderte technologische Flexibilität der Verarbeitungstechnik durch Adaption oder Implementierung mechatronischer Komponenten und Systeme zu erreichen. Vorhandene Wirkmaschinen wurden im Rahmen des Projekts entsprechend ausgestattet, um Funktionalitäten und Anwendungspotenziale bezüglich ihrer praktischen Relevanz zu untersuchen.

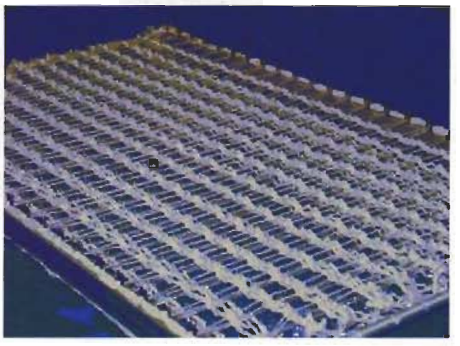

Bild 2
Detailansicht des gitterförmigen, beidseitig 0°-90°-verstärkten 3D-Gewirkes

Forschungsergebnis

Zur Herstellung textiler Muster mit D.O.S. in netzförmigen Oberflächen wurde die Doppelraschel HDR-DPLM mechanisch umgebaut und dabei im Funktionsumfang erweitert. Sie besitzt sechs Grund-Legebarren, von denen zwei als Abstandsfaden-führende Legebarren betrieben werden können, sowie zwei Einrichtungen für Einzelfaden-Umkehrschuss (Bild 1). Ein zentraler Antriebsmotor erzeugt in herkömmlicher Weise über Exzenterwellen die Grundbewegungen der Wirkwerkzeuge. Alle legungsabhängigen bzw. bindungsabhängigen Bewegungen werden mittels Einzelantrieben realisiert und können somit auf einfache Weise durch Parametrierung der Steuerungssoftware beeinflusst werden. Das betrifft den Legebarren-Versatz, den Einzelfaden-Umkehrschuss und den Warenabzug. Für die Versatzbewegung der Grundlegebarren wurden Linearmotoren verwendet. Rotatorisch arbeitende Servomotoren erzeugen über ein Zahnriemengetriebe die Linearbewegung für den Schusseintrag. Ebenfalls rotatorische Antriebe sind für den Warenabzug und die beiden Exzenterwellen vorhanden.
Die komplette Überarbeitung der Steuerungssoftware führte zu einer wesentlichen Neuerung: Die Berechnung aller Kurventabellen zur mustergerechten Achskopplung aus Daten, erfasst in wirkereitechnologisch orientierter Notation, erfolgt im Steuerungsprogramm.
Mit den genannten Änderungen und Erweiterungen steht eine Doppelraschelmaschine zur Verfügung, deren musterungsabhängige Bewegungsabläufe vollständig durch mechatronische Komponenten erzeugt werden und damit allein durch entsprechende Parametrierung der Software beeinflussbar sind.
Unter Einsatz der mit mechatronischen Komponenten technologisch flexibilisierten Doppelraschel wurden zur Verwendung in einem Transferprojekt diverse gitterartig offene 3D-Gewirke gefertigt (Bild 2).
Die räumliche textile Konstruktion soll neben einer ausreichenden Drucksteifigkeit gegenüber einer in der Weiterverarbeitung zu erwartenden Belastung möglichst an allen Rändern zusätzliche Elemente enthalten. Diese sollen als mechanische Aufnahmen verwendet werden, um das 3D-Gewirke über die Ebenen der beiden Oberflächen aufzuspannen, ohne dabei die gitterförmige Geometrie der Verstärkungsfäden zueinander zu beeinträchtigen (Bild 3).

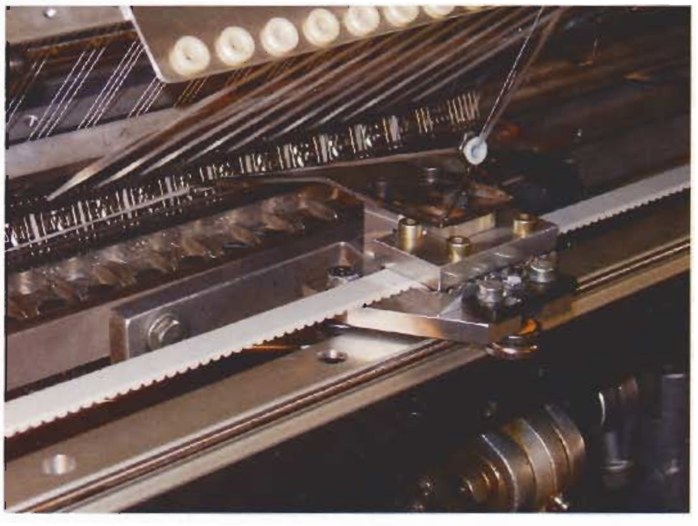

Bild 1
Einzelfaden-Umkehrschuss

Die Optimierung der textilen Konstruktion unter solchen Vorgaben und Bedingungen erfolgt durch die Erarbeitung spezieller Legungskombinationen, die sich aus der Verwendung von 6 Grund-Legebarren und 2 Einzelfaden-Umkehrschuss-Systemen ableiten lassen, sowie durch deren systematische praktische Umsetzung an der Wirkmaschine. Die weitreichenden Möglichkeiten der technologischen Parametrierung auf Basis der mechatronischen Komponenten erlaubten eine effiziente, strategische Entwicklungsarbeit.

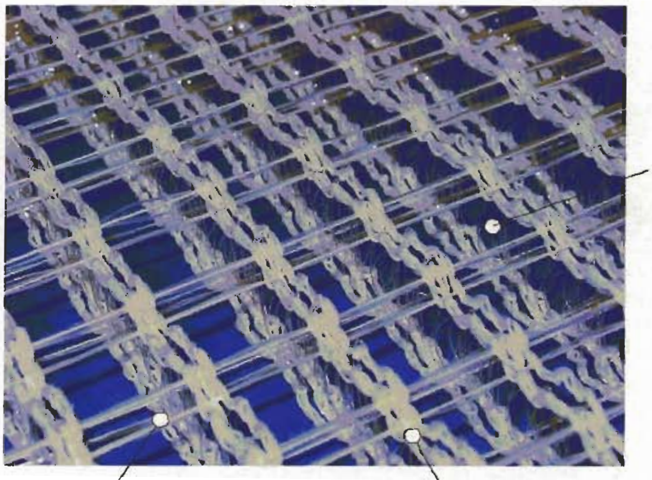

Bild 3
Ebenen-parallel aufgespanntes 3D-Gewirke

Anwendung und wirtschaftliche Bedeutung

Durch die konsequente Anwendung mechatronischer Grundsätze bei der Entwicklung spezieller, maschinentechnischer Lösungen sind allgemeingültige Konzepte in Form von Komponenten und Systemen ableitbar, die hinsichtlich ihrer Struktur und ihrer technologischen Flexibilität im Vergleich zu klassischen technischen Lösungen zu bewerten sind. Dabei bleiben die möglichen technischen Ableitungen nicht auf die RR-Raschelmaschine zur Herstellung von Abstandsgewirken beschränkt. Vielmehr liefert das Forschungsprojekt grundlegende Hinweise für die Weitentwicklung und Entstehung innovativer Textiltechnik für das gesamte Spektrum der barrentragenden Textilmaschinen.

Netzwerk: experimentelle Stickerei

Das Projekt INTERREG III A-Projekt der Westsächsischen Hochschule Zwickau soll als Impulsgeber dienen sowohl für eine Vertiefung der grenzüberschreitenden Zusammenarbeit bei Ausbildung und Qualifizierung auf dem Gebiet der Stickerei, als auch bei der Entwicklung der vorhandenen regionalen Ressourcen auf dem Gebiet der Plauener Spitze und Stickerei.

Partner sind die Westsächsische Hochschule Zwickau (WHZ), Fachbereich Angewandte Kunst Schneeberg, Studiengänge Textildesign und Textilkunst, Fachgruppe Textil- und Ledertechnik, Reichenbach i. V., die Technische Universität Liberec, Fakultät Textil, Lehrstuhl Design und der Verein Vogtländische Textilgeschichte Plauen e.V., Schaustickerei Plauener Spitze, Plauen.

Neue Produkte sollen entwickelt werden, die später unter industriellen Bedingungen hergestellt werden können. Die Technologie des Stickens ist integraler Bestandteil der studentischen Ausbildung der Fachgruppe Textil- und Ledertechnik der WHZ und wird ausgebaut in Richtung Sticken für technische Anwendungen. Der Fachbereich Angewandte Kunst Schneeberg steht für das gestalterische Potenzial hinsichtlich Form und Farbe. Die Schaustickerei Plauen ist eine Werkstatt für Experimente textilgestalterischer Art und verfügt über traditionelle Maschinen sowie einen umfangreichen Fundus historischer Spitzen. Die experimentellen Leistungen können auf historischen und modernen Maschinen trainiert werden, ein Mehrkopf-Stickautomat mit entsprechender Punchsoftware konnte durch die WHZ erworben werden. Die Technische Universität Liberec kann durch die Integration in dieses Projekt die Stickerei als neue Komponente in ihre Ausbildung einbeziehen.

Wesentliche Bestandteile des Projekts waren das Erlernen der Stickereitechnik und das Umsetzen von Entwürfen im Rahmen von Praktika in der WHZ, in der Schaustickerei Plauen sowie in vogtländischen Stickereien im Rahmen von experimentellen Wochen bzw. Workshops (Bild 1). Die Auswertung des Projekts erfolgt im Rahmen eines Kolloquiums. Im April 2008 wird die Vergabe des Designpreises stickstich 008 den Abschluss des Projekts bilden.

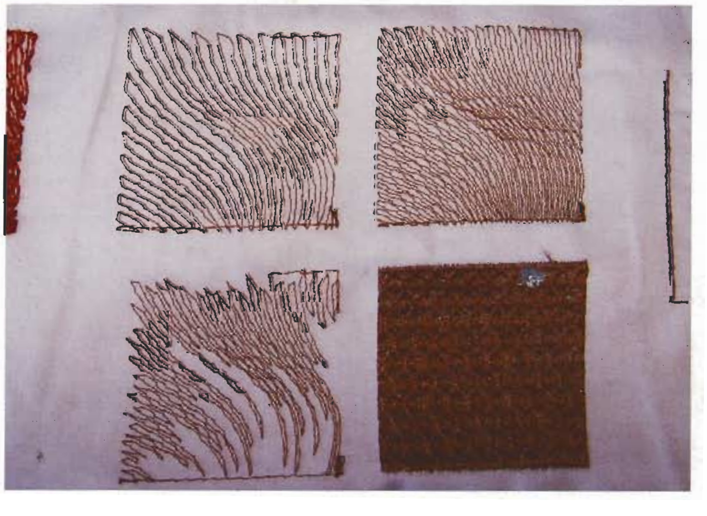

Bild 1
Experiment mit Stickkopf für Kordelstickerei auf verschiedenen Materialien