MOLDED FIBER-REINFORCED PARTS- SPECIAL PROPERTIES AND INFLUENCING PARAMETERS

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Abstract

Composites, produced of different fiber reinforced plastic layers, offer the possibility to create light-weight structures with tailored non-isotropic properties. Natural fibers like flax, kenaf and cotton shoddy are combined with either thermoplastics or thermosettings. In the first production step fleeces as mixtures of natural and polymer fibers or out of fibers and resin powder are produced. In the second step the compression molding influences the properties like strength, young's modulus and also the acoustical absorption coefficient. The used technology for heating, molding and cooling has also a major impact on the economics.

Introduction

The variety of natural vegetable plant fibers is abundant. The different fibers come from different kinds of plants (dicotyledons and monocotyledons) and from different parts of the plant. Fig. 1 gives an overview of the diversity of natural fibers.

For technical products based on natural fibers a great variety of fibers can be found in nature. In the plant fibers are fulfilling special functions, for example as structural components or for protecting the seed or fruit. Nature optimized fiber properties can be utilized for technical application. With the view on bionic engineering we can learn a lot from biological structures. It is important to know the function of the fiber in the plant before working with them in technical products.

Composites reinforced by natural fibers are an emerging area in polymer science. There are some advantages using plant fibers in composites: the production is nearly CO_2-neutral, the fibers are biologically degradable, they are cheap and have interesting mechanical properties. As described there are many different plant fibers with totally different functions in the plant. For composites, as shown in fig. 2, fibers with high strength and low elongation properties are needed.

As shown in fig. 3 especially fibers like Ramie, Hemp, flax, Nettle, Sisal, Jute and Cotton are well suited for reinforcing polymers. The use of natural fibers in polymer composites is on the rise, especially in the automotive industry. In addition to reduced weight and cost, and improved safety, natural fiber-reinforced polymers offer increased recycling capabilities over conventional polymers used in the automotive industry. Natural plant fibers are incorporated into door panel trim, package trays, trunk trim, and other interior parts. But in the most cases a petrochemical polymer is used. With the view on reduction of the emission of carbon dioxide, it is important to find alternatives to conventional petrochemical polymers.

The comparison of wood-fiber/phenolic resin parts with car interiors made of flax/sisal-needle felt bonded by polyurethan is shown in fig. 4.

Using glass- and carbon-fibers for reinforcement offers the possibility to increase the stiffness. But because of the high flexibility of, for example, flax and cotton fibers and of the low weight the effect of these fibers are often at least comparable especially for special products, see fig. 5.

Most of the European automotive producers use already car interiors made of natural fibers. In Germany 1996 4.000 t of flax, sisal and jute were used for car interiors, 1999 this figure increased to 13.000 t. Not the absolute figure of the production is at the moment challenging, but the average annual growth, which is round about 50 %, is promising.

Round about 50.000 t wood-fibers are used in combination with phenolic resin. This figure is decreasing continuously because of the negative characteristics of the resin. The use of cotton shoddy, also mostly combined with phenolic resin, is today round about 50 – 60.000 t, see fig. 6.

Typical parts are presented in fig. 7.

The use of phenolic resin creates especially ecological problems, as the thermic disposal needs very high temperatures and as uncomplete combustion occurs at lower temperatures.

In fig. 8 the mechanical characteristics, the use of bonding material and especially the so called "fogging" is compared for different fiber/polymer-combinations.

Process Technology

For the production of reinforced materials different process technologies were developed. For processing the polymers the conventional methods, as injection molding, extrusion and so on are used or adapted for this special task, see fig. 9.

Mostly the processing takes place within two steps: one for the fibers and the other one for the polymer. One-shot-technologies would offer better economics, but mostly shorter fibers with reduced reinforcement capabilities are necessary. To use the high flexibility of the natural fibers the conventional nonwoven technology is mostly used. In the first production step, so called "hybrid fleeces" are produced, see fig. 10, 11 and 12.

Producing hybrid fleeces can be either done by a carding process or by an airlaid process, the last one offering better productivity.

The parameters which can be influenced by the carding or the airlaid process, are

- quality of the blend
- uniformity of the weight
- machine and cross direction
- strength of the fleece in machine and cross direction
- 3-dimensionality of the fleece
- shortage if fibers.

The needling process is necessary to reduce the volume for a better transport and also to increase their strength for automatisized compression molding process.

The needling process influences the following parameters of the hybrid fleece

- 3-dimensionality
- quality of entanglement
- shortage of fibers.

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National Cotton Council, Memphis TN

In a second step the flat hybrid fleece is heated mostly between two heated plates using a certain compression. Sometimes a pre-heating either using hot air or radiation is combined. The heat is necessary to melt the thermoplastic material or when using a phenolic resin, to start the reaction of this thermosetting material, see fig. 15.

The compressed sheets have different thickness, depending on the used pressure and temperature, see fig. 16. It is necessary to create fleeces with very accurate weight per area and a reproducible needling to achieve the same thickness and a porosity of the material. Both is important for the design, stiffness and acoustical characteristic of the finished product.

Sometimes a calibration device is used.

The figures 17, 18, 19 show SEM-pictures of a fleece with unmolten, partly and completely molten fibers.

To improve the economics higher pressure is often used to shorten the heating time and also higher temperatures of the contact plates would have the same influence. On the other hand the reduction of porosity and perhaps the influence of higher temperature at the outside of the parts could decrease characteristics of the polymers itself. Therefore, careful tests are necessary to investigate the polymer flow inside the material. Fig. 20 demonstrates this effect. The figure shows how fast a temperature of this example 200 cC can be achieved using different pressures having surface temperatures at the context plates of 220 cC.

Fig. 21 shows the required heating time for different core temperatures.

A very interesting comparison is – regarding the ecological data – the accumulated energy which is necessary for the production of a car interior. In this example two door trim pads one produced out of ABS and the other one out of hemp/epoxy resin are compared, demonstrating the advantages of a reinforcement by natural fibers. The major part of the energy for the production of the hemp/epoxy resin compared is used for processing the resin itself, see fig. 22.

The fiber reinforced materials substitute products formerly produced out of polymers or wood-fiber/resin/compounds. Today also the acoustical behaviour becomes more and more important and, therefore, not only the strength or the Youngth's modulus is important for the comparison of products quality but also the damping parameters and the absorption coefficients.

One major car interior part is the headliner having the function to reduce the vibrations and noises which are produced by the motor, by air turbulences and by the tires.

The principle design of a headliner is shown in fig. 23.

Some alternatives were designed and checked, see fig. 24. All these design changes had the target to reduce the foam thickness, thus creating a better moldability. As fiber-reinforced products may have either open or closed pores, high quality damping characteristic can be designed.

Fig. 25 shows complete new concepts where the foam should be eliminated and the fleeces having a lot of pores should provide this noise damping function.

The better absorption coefficient can be achieved by reducing the amount of PP-fibers as the bonding between the natural fibers and the polymer is then reduced.

When having a Polyurethane as a foam it is necessary to add a Polyamid-fleece between the Polyurethane and the hybrid fleece (PP-natural fibers) to achieve a better bonding between both materials.

The acoustical behaviour was classified by measuring the absorption coefficient, which is depending on the frequency, see fig. 26 - 29. The use of longer and shorter fibers and the design across the thickness of the part and the amount of pores and so on influence especially the absorption at certain frequencies and therefore, it is very often difficult to judge which design is the better one.

In this investigation many problems occurred to achieve the quality of the existing material having a thick foam. Combining this thick foam with the so called gradient fleece meant that a better absorption was got also for higher frequencies.

Also the moldability was checked with the test mold, see fig. 30. The bonding was excellent, but the molding is very difficult in certain parts, where the foam is changing the thickness because of the geometry. This is especially the fact along sharp corners and edges.

Summary

Car interior parts can be built up out of natural fibers together with polymers and they are a better alternative e.g. to glass fiber reinforced composites.

By the different process technologies especially the polymers can be influenced and the production time can be reduced. Better heating devices are necessary to improve the economical situation. The behaviour in respect of acoustical parameters of this material is similar to sandwich parts built up out of glass fiber composites and PU-foam and also the moldability can be improved by reducing the foam.

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Literature

Dupont, A. 1999: *Zukunftschancen harzgebundener Naturfaser-Formpressteile.* Veranst.: nova-Institut, Vortrag zum Seminar: Verbundwerkstoffe: Märkte und Ökonomie, (Wolfsburg: 26. Mai 1999) im Rahmen des EU-ADAPT Projektes Marktinnovation Hanf, MIH-Fachvorträge: http://www.naturfaser-wirtschaft.de.

Harig, H. / Muessig, J. 1999: *Heimische Pflanzenfasern für das Automobil.* In: Harig, H. / Langenbach, C.J.: Neue Materialien für innovative Produkte - Entwicklungstrends und gesellschaftliche Relevanz. Berlin: Springer Verlag, 1999 (Wissenschaftsethik und Technikfolgenbeurteilung Bd. 3), (ISBN 3-540-66063-1), p. 235 - 251.

Karus, M. / Kaup, M. / Lohmeyer, D. 2000: *Studie zur Markt- und Preissituation bei Naturfasern (Deutschland und EU).* Gülzow: 1. Auflage, März 2000, Hrsg.: Fachagentur Nachwachsende Rohstoffe e.V. (FNR), Gülzower Fachgespräche, Studie des nova-Institut.

Knothe, J. 1997: *Herstellung und Eignung von naturfaserverstärkten Kunststoffbauteilen für die Automobilindustrie.* Internationales VDI-MEG Kolloquium Nr. 22 (Bonn 6. - 7. August 1997). Kromer, K.-H. (Hrsg.): Erzeugung, Aufbereitung und Verarbeitung von Naturfasern für nichttextile Zwecke Bonn, 1997, 1. Auflage, (ISSN 0939-3048), p. 136 - 144.

Mueller, D. H. 1997: *Herstellung biologisch abbaubarer Faserverbundwerkstoffe aus Faservliesen.* 7. Chemnitzer Textilmaschinentagung / „Textilmaschinenbau und Textilindustrie - Synergien für die Zukunft.“ (Chemnitz 05. - 06. Oktober 1999). Veranst.: Förderverein Cetex, Tagungsdokumentation: Vortrag Nr. III/4, p. 113 – 121.

Muessig, J. 1998: *Hanf als Faser für Verbundwerkstoffe.* Stiftung Institut für Werkstofftechnik (Veranst.): Vortrag im Rahmen des Werkstoffkolloquiums Bremen an der Universität Bremen, 20. Oktober 1998.

Muessig, J. / Harig H. 2000: *Technical prod ucts based on natural fibres.* Munster Committee EXPO 2000 (Veranst.): 2nd International Symposium Biotechnology for Conservation of the Environment (Munster, Ger many, July 9 - 12, 2000). .- proceedings 1 / 3 / p. 1 – 3.

Scherzer, D. 1997: *Pflanzenfaserverstärkte Polyurethanschäume in industriellen Anwendungen.* Branchendialog „Neue Produkte aus pflanzlichen Fasern“ (5. Juni 1997 in Mainz). Bildungsseminar für die Agrarverwaltung Rheinland-Pfalz (Hrsg.) im Auftrag des Ministeriums für Wirtschaft, Verkehr, Landwirtschaft und Weinbau Rheinland-Pfalz, Emmelshausen, 1997 .- Tagungsband.

Stryjewski, D. / Kloecker, S. / Mueller, D. H. 1998: *Umweltverträgliche re Produkte aus nachwachsenden Rohstoffen.* VDI (Veranst.): Markt- und Kostenvorteile durch Entwicklung umweltverträglicher Produkte, Tagung, Fellbach, 9. - 10. Juni, 1998, VDI- Berichte, Band 1400 (1998), p. 213 - 228.

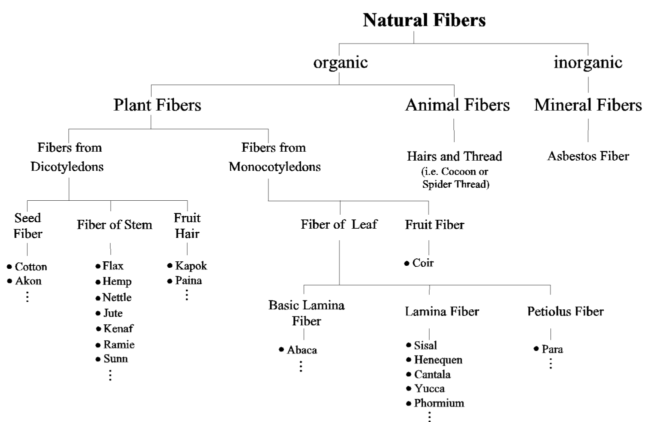

Figure 1. Overview natural fibers. [Muessig, Harig 2000]

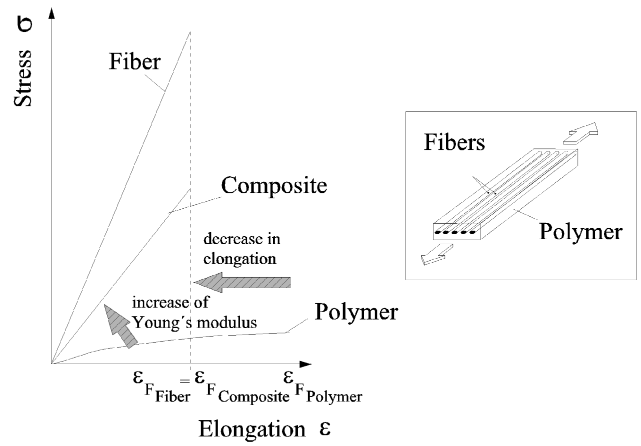

Figure 2. Natural fiber (NF) / polymer composites.

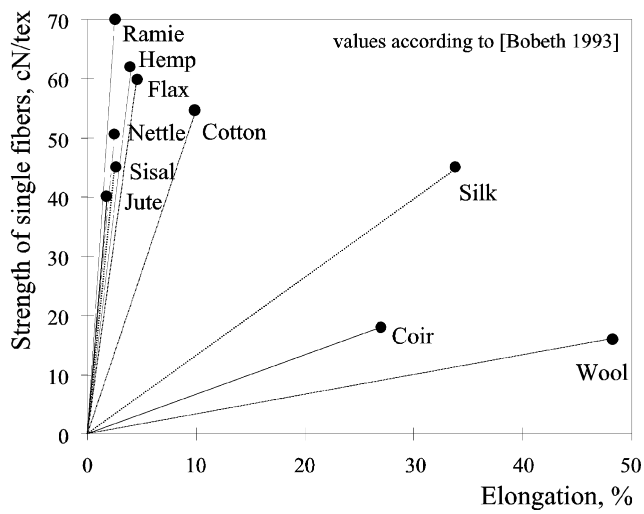

Figure 3. Correlation between strength and elongation for different NF. [Muessig 1998]

		Woodfiber/ phenol resin	Flax/Sisal/PU	Flax/Sisal/PU vs. Woodfiber/phenol resin
Mass (thickness 2mm)	g/m^2	2200	1700	1,3
Absorption of water	%	35	15	2,3
Swelling	%	20	3	6,7
Bending strength	N/mm^2	50	72	0,7
Modulus	N/mm^2	400	3100	1,3
Notched izod impact strength	kJ/m^2	8	23	0,05
Burning rate	mm/min	15	15	1
Fogging	mg	> 5	1	> 5

Figure 4. Properties of woodfiber/phenol resins- and Flax/Sisal/PU-composites. [Scherzer 1997]

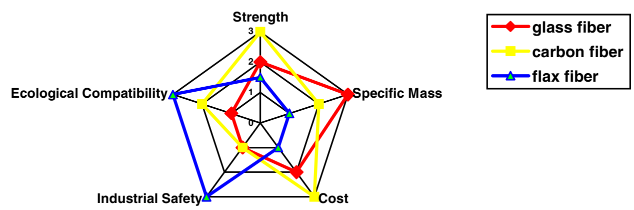

Figure 5. Properties of Flax and other reinforcing fibers. [Knothe 1997]

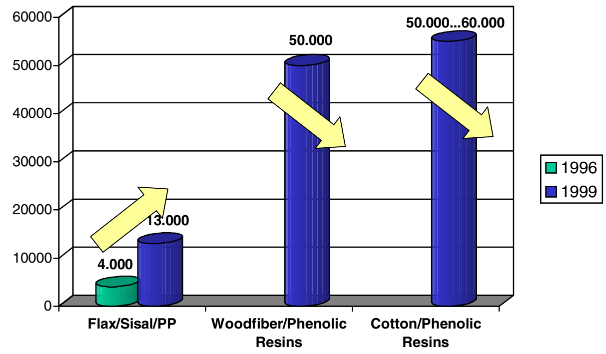

Figure 6. Consumption of NF/polymer composites for the production of car interiors in Germany. [Karus et.al. 2000]

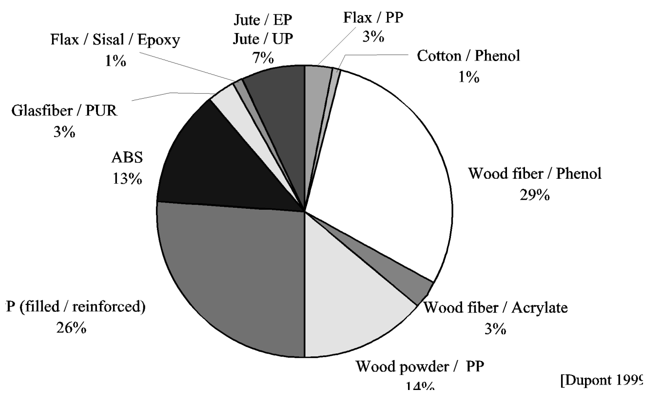

Figure 6b. Material use for door panel trim in Western Europe 1997 (ca. 13 Mio. cars / year). [Dupont 1999]

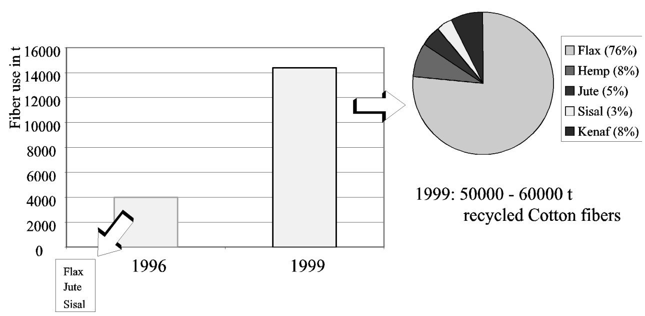

Figure 6c. Use of natural fibers in automotive industrie(Germany, without Cotton and Wood). [Karus et.al. 2000]

Type of Fiber	Type of Polymer	Type of Reinforcement	Part
Wood	PF	Fleece	Dashboard, Door trim
Jute	UP	Needle Felt	Door trim
Flax, Sisal	PUR	Needle Felt	Door trim
Flax, Sisal	EP	Needle Felt	Door trim
Flax	PP	Fleece, Needle Felt	Dashboard, Backrest
Cotton	PP	Fleece	Trunk trim
Cotton	PES	Fleece	Sound absorption at bottom areas

Figure 7. Typical parts made of NF/polymer. [Harig, Muessig 1999]

Fleece or Needle Felt made of...	Price Level	Mechanical Properties	Compatibilizer	Absorbency	Fogging
Cotton shoddy	++	--	--	-	+
Flax	+/-	+	+	+	+/-
Jute	+	+	+	+	+/-
Jute *	++	+	+	+	--
Sisal	+	+/-	++	++	++
Sisal *	++	+/-	++	++	--
Flax/Sisal	+	+	+	++	+

*: from wrenched sacks

++ : very good **-- : very poor**

Figure 8. Valuation of fleeces and needle felts for use as car interior. [Scherzer 1997]

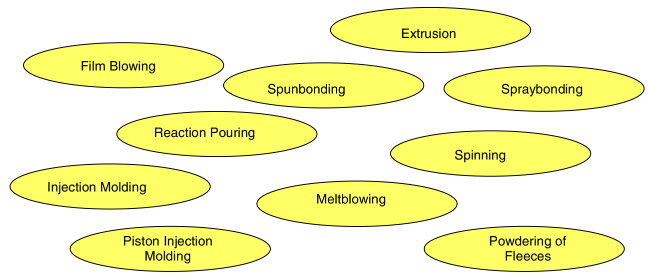

Figure 9. Processes technologies for polymeric materials.

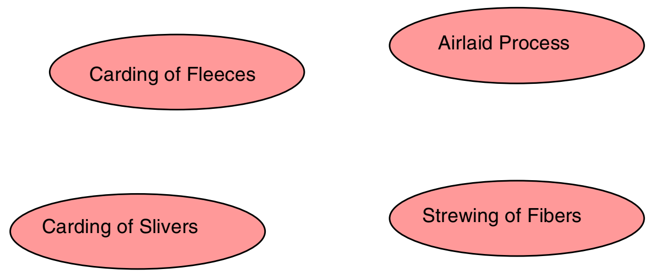

Figure 10. Process technologies for natural fibers.

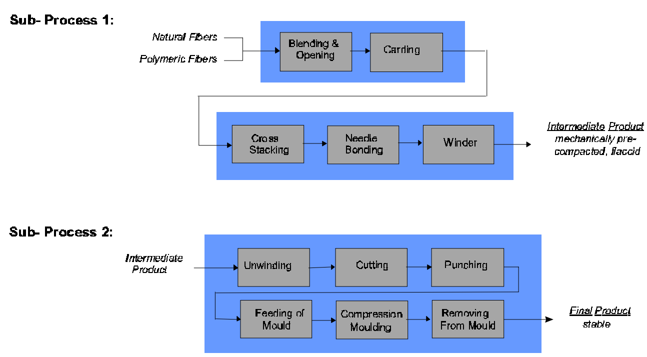

Figure 11. Process technology with hybrid fleeces.

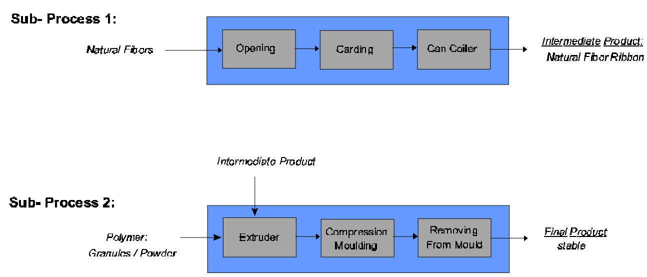

Figure 12. Process technology with slivers.

- Quality of the blend
  - Uniformity of the weight
    - Machine and cross direction
      - Strength of fleece in machine and cross direction
        - Three- dimensionality of the fleece
          - Shortage of fibers

Figure 13. Characteristics influenced by the carding process.

- Three- dimensionality
  - Quality of the entanglement
    - Shortage of fibers

Figure 14. Characteristics influenced by the needling process.

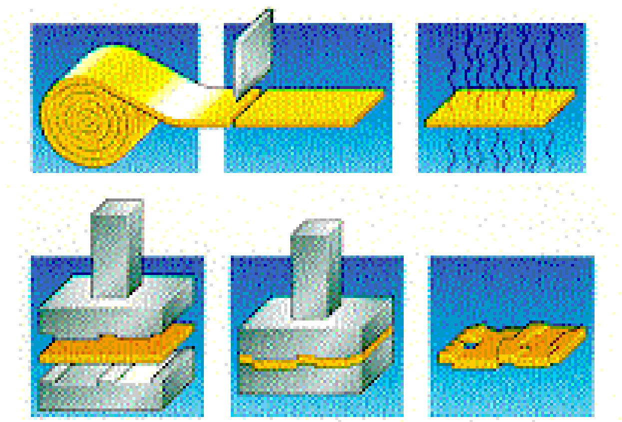

Figure 15. Schematic of a compression molding process.

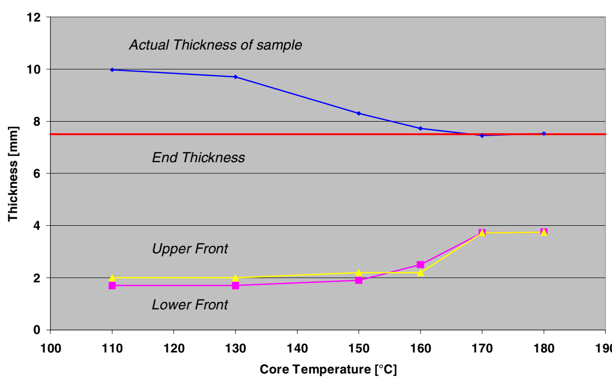

Figure 16. Thickness of a sample and heat flow during the compression molding process.

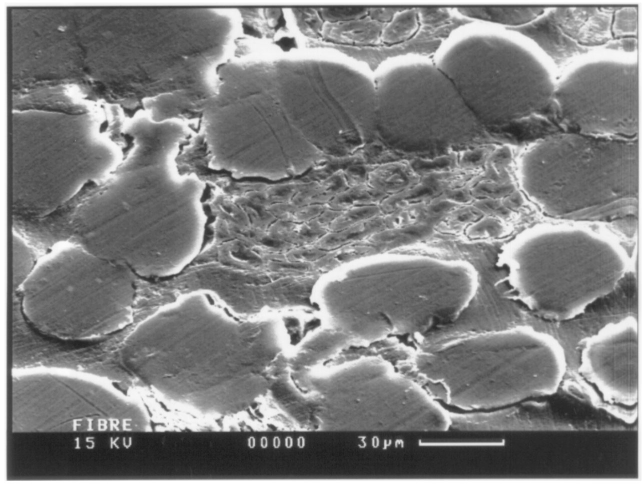

Figure 17. Photomicrograph of an unmolten flax/PP sample.

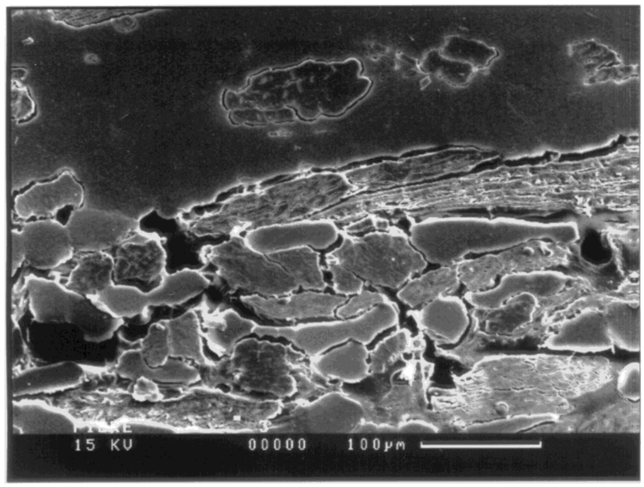

Figure 18. Photomicrograph of a flax/PP sample with melting front.

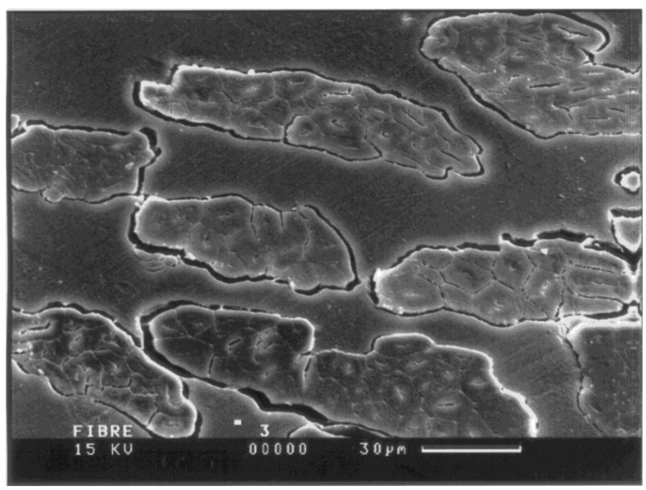

Figure 19. Photomicrograph of a flax/PP sample with completely embedded fibers.

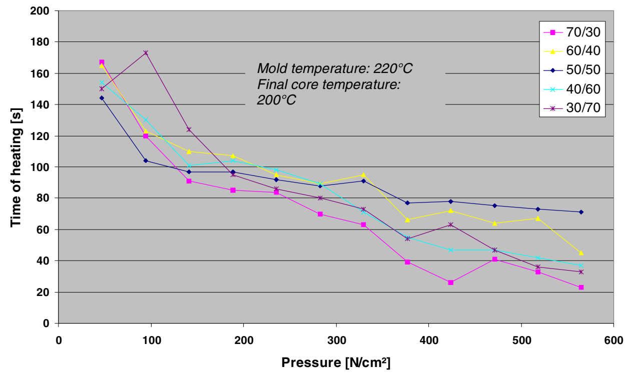

Figure 20. Time of heating vs. pressure for flax/PP composites with different compounding rates NF/polymer.

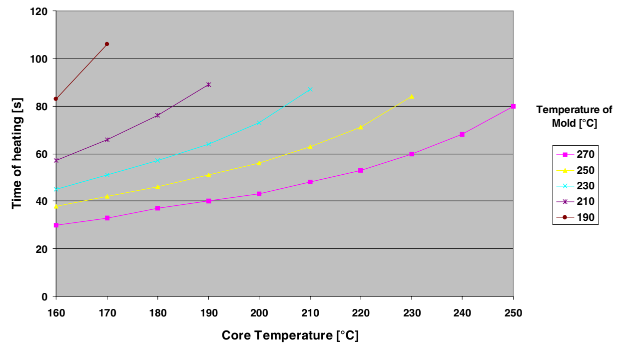

Figure 21. Required time of heating vs. core temperature for a flax/PP (70/30) composite.

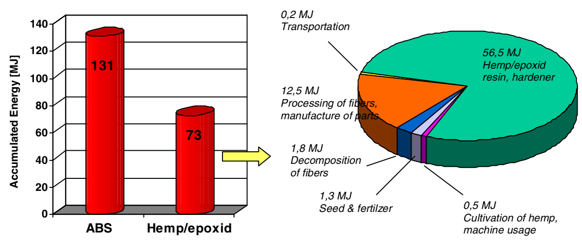

Figure 22. Accumulated energy for the production of a car interior.

Part	*No. of Sample*	*Fleeces* *Type*	*Weight*	*Thickness*
Conven-tional Part	1	*Hybrid fiber fleece*	1800 g/m^2	4 mm
		PU- foam		13 mm
		Covering foil		
Alternativ es	2	Hybrid fiber fleece	1800 g/m^2	4 mm
		PU- foam		6 mm
		Covering foil		
	3	Hemp / PP	1200 g/m^2	3,5 mm
		PU- foam		13 mm
		Covering foil		
	4	Hemp / PP	1200 g/m^2	3,5 mm
		PU- foam		6 mm
		Covering foil		
	5	Cotton / phenolic resin	2400 g/m^2	8 mm
		PU- foam		6 mm
		Covering foil		
	6	Cotton / phenolic resin	1200 g/m^2	5 mm
		PU-foam		6 mm
		Covering foil		

Figure 23. Principle design of a headliner.

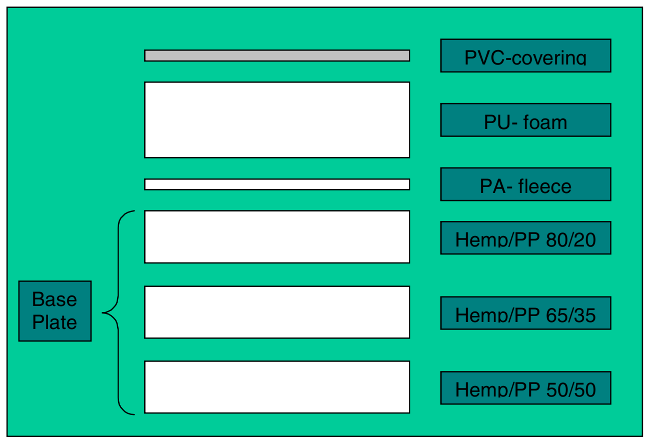

Figure 24. New headliner design.

No. of Sample	Fleeces		
	Type	**Weight**	**Thickness**
00/43/2	Hemp/PP 50/50	2100 g/m^2	
	PA	24 g/m2	
	PU- foam		13 mm
	Covering foil		
Final thickness after cool pressing: 7 mm			
00/43/3	Hemp/PP 50/50	600 g/m^2	
	Hemp/PP 65/35	470 g/m2	
	Hemp/PP 80/20	420 g/m2	
	PA	24 g/m2	
	PU- foam		13 mm
	Covering foil		
Final thickness after cool pressing: 7 mm			
00/43/4	Hemp/PP 50/50	600 g/m^2	
	Hemp/PP 65/35	470 g/m2	
	Hemp/PP 80/20	850 g/m2	
	PA	24 g/m2	
	PU- foam		13 mm
	Covering foil		
Final thickness after cool pressing: 7 mm			
00/43/4	Hemp/PP 50/50	600 g/m^2	
	Hemp/PP 65/35	470 g/m2	
	Hemp/PP 80/20	850 g/m2	
	PA	24 g/m2	
	PU- foam		13 mm
	Covering foil		
Final thickness after cool pressing: 10 mm			

Figure 25. New concepts for acoustical optimized parts.

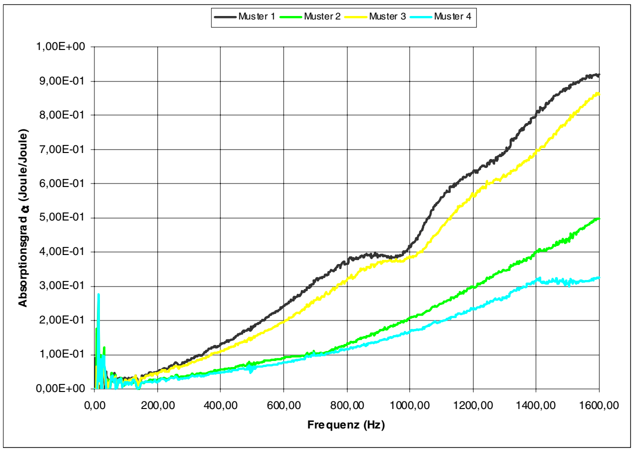

Figure 26. Acoustical behavior of samples 1 - 4 (upper frequency range).

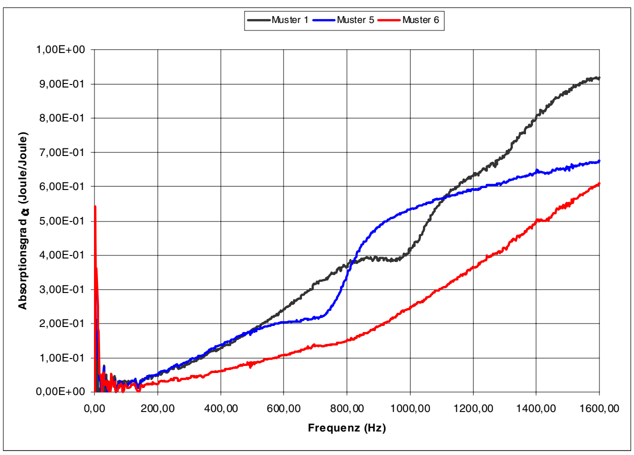

Figure 27. Acoustical behavior of samples 1, 5 and 6 (upper frequency range).

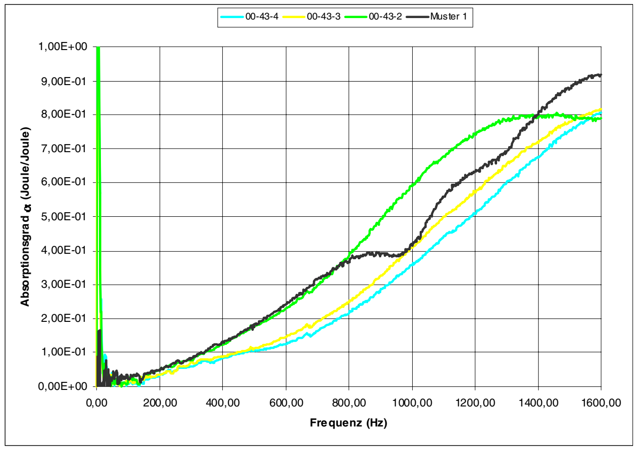

Figure 28. Acoustical behavior of gradient sample (lower frequency range).

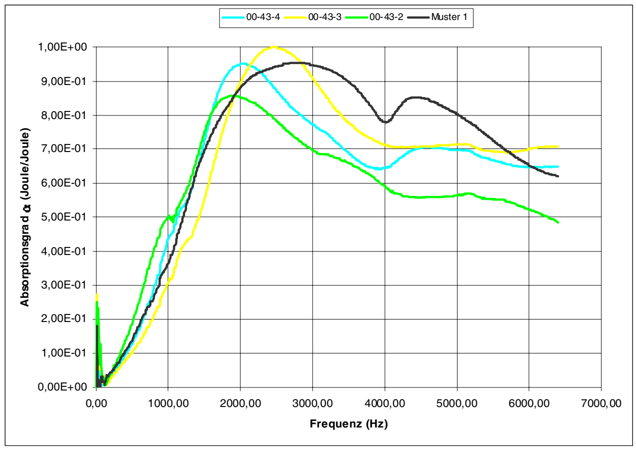

Figure 29. Acoustical behavior of gradient sample (upper frequency range).

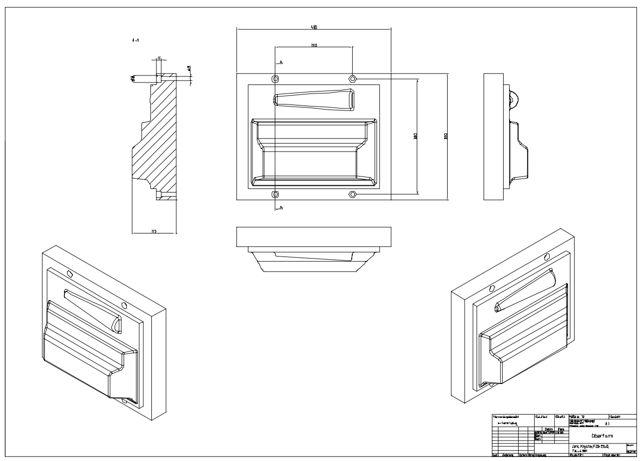

Figure 30. Test mold for the production of three-dimensional samples.

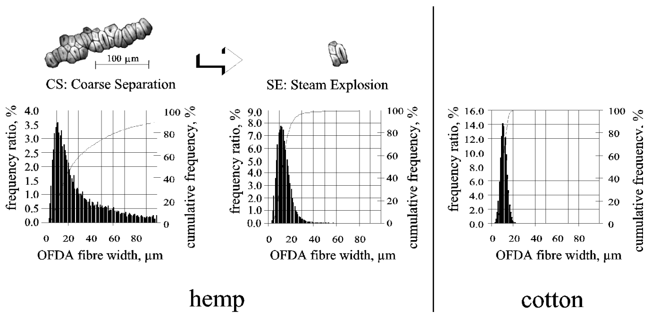

Figure 31. Fiber (bundle) width measured with OFDA.

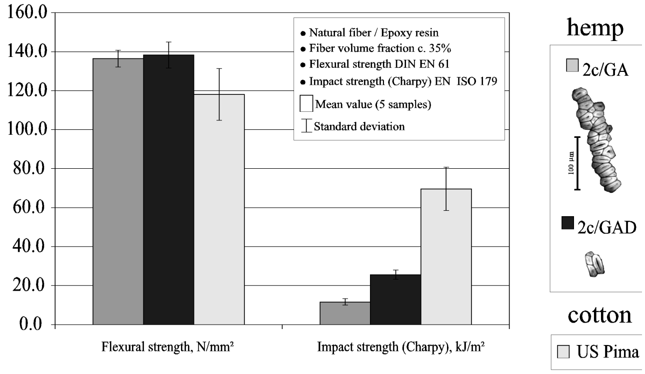

Figure 32. Composite properties depending on fiber fineness.

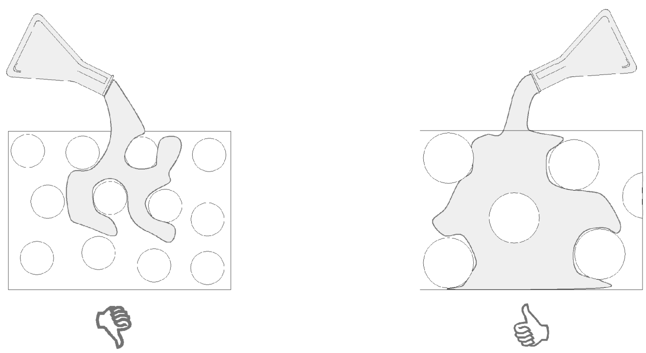

Figure 33. Consumption of resin and Impregnation properties depending on fiber fineness.