# ACOUSTICALLY OPTIMIZED STRUCTURAL PARTS BASING ON HYBRID FLEECES

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## Abstract

Composite materials with a reinforcement of natural plant fibers have successfully proven their high qualities in various technical areas. One of their major field of application can be found in structural interior elements such as door trim panels or trunk trims in the automotive industry. With respect to driving comfort the acoustical properties of such structural parts are considered more and more important. The paper covers extensive investigations on the acoustical properties of such composites and presents material designs for acoustical optimized structures.

## Introduction

Composites reinforced by natural fibers have successfully proven their qualities in various fields of technical applications because of their excellent specific properties, e.g. high strength and stiffness, low weight, etc. One of their most important advantage, however, is the possibility of designing the material itself by arranging (long-) fibers in the direction of the applied forces in order to create lightweight structures with non-isotropic properties optimally tailored to each of the specific requirements.

Despite of ecological gains like less environmental impact of the later product within the formation, usage and disposal period further technical and economical advantages result from the utilization of natural fibers. In comparison to 'conventional' composites with a reinforcement of synthetic fiber materials like glass of carbon, such composites may lead to the following benefits /1/:

- lower weight with similar mechanical properties, leading e.g. to lower fuel consumption
- high strength and stiffness
- carbon dioxide neutrality of the fiber component by waste incineration with thermal dissipation
- at least partly integration of the product into natural cycles
- lower product costs
- higher operational and processing safety
- reducing the use of fossil resources
- meeting with steadily increasing environmental demands of legislative authorities

The variety of natural vegetable plant fibers is abundant as shown in fig. 1. The different fibers come from different kinds of plants (dicotyledons and monocotyledons) and from different parts of the plant.

The generation of composites requires fibers with high strength and low elongation (fig. 2). As shown in fig. 3 and fig 4 especially fibers like ramie, hemp, flax, sisal, jute and cotton are well suited for reinforcing polymers. Because of it's mechanical properties and high availability flax is the most commonly used natural fiber in technical applications in Europe.

The use of natural fibers in polymer composites is growing rapidly. One of the major area of application can be found 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. Referring to the polymer both thermoplastic and duroplastic resin are utilized /2/.

Meanwhile, almost all European automotive producers employ car interiors made of natural fibers. In Germany 1996 4.000 tons of flax, sisal and jute were used for car interiors, 1999 this figure increased to 13.000 tons as shown in fig. 5. Not the absolute number is remarkable, but the average annual growth of approximately 50 % is promising at present.

For the sake of completeness it has to be mentioned that furthermore approximately 50.000 tons of wood fibers are used in combination with phenolic resins. This figure is decreasing continuously due to negative characteristics of the resin. Also declining is the use of cotton shoddy combined with phenolic resin, which totals to approximately 50 to 60.000 tons at present.

## Process Technologies for the Manufactures of Reinforced Products

The production of reinforced products takes place within two steps (fig. 6). The first step covers the generation of a moldable semi-product, which is further processed to a composite part by thermal molding in the second step. One-shot-technologies would offer better economics, but mostly require shorter fibers with reduced reinforcement capabilities /3/.

In the first production step, utilizing the high flexibility of the natural fibers, conventional nonwoven technology is commonly applied to produce so called "hybrid fleeces" as semi- products. This takes place by blending natural and polymeric fibers and subsequent carding and needling. Alternative hybrid fleeces can also be produced by a so-called airlaid process, offering slightly better productivity than a carding process.

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, primarily reducing the volume, is required to simplify handling and transportation of the semi-product and also to increase it's strength for an automated compression molding process. The needling process influences the following parameters of the hybrid fleece:

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

In a second step the flat and pre-compacted hybrid fleece passes through a thermal molding process as shown in fig. 7, in which the thermoplastic polymeric material is plasticized and embeds the natural fibers when cooling down. The preheating is usually accomplished by means of contact heat using a certain compression. Sometimes either hot air or radiation may also be integrated. The heat is necessary to melt the thermoplastic material or when using a phenol resin, to start the reaction of this thermosetting material.

The compressed sheets have different thickness, depending on the applied pressure and temperature. It is necessary to create fleeces with very accurate weight per area and a reproducible needling to achieve uniform thickness and porosity of the material. Both is important for the design, stiffness and acoustical characteristic of the later product. To improve the economics of the manufacturing process 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.

An 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 made of pure ABS and one of hemp/epoxy resin, are compared to demonstrate the advantages of a reinforcement by natural fibers. The major part of the energy required for the production of the hemp/epoxy resin is used for processing the resin itself, see fig. 8, /4/.

## Determination of Acoustical Properties

Lighter structures allow the reduction of weight but deteriorate the acoustical properties. Fleeces offer the possibility of different compression, different amount of polymeric fibers and by that the potential of better acoustical absorption. Combining different material components and constructing a composite made of compressed fleeces with slightly compressed fleeces offers a good structural stability and better acoustical properties. Especially for car interiors the characteristic is very important to reduce disturbing noises and to improve the speech intelligibility.

Two fundamental principles are applied to determine acoustical properties, the measurement of absorption and reflection. Both principles require different means of measurement.

Absorption coefficients can be determined by impedance tubes and a so-called Alpha cabin. The impedance tube primarily measures material properties by perpendicular sound while the Alpha cabins determines geometrical and surface influences by applying a diffuse sound field. The principle of an impedance tube is shown in fig. 9. Fig. 10 and 11 present the schematic and an inside view of an Alpha cabin.

Reflection properties are determined using the 'falling ball'- method as shown in fig. 12. The alpha cabin is used for the measurement of the frequency depending absorption coefficient within the frequencies between 400 Hz up to 10 kHz in a diffuse sound field. The measurement is taken at 5 different positions within the cabin. After integrating the decay curve the reverberation time was calculated.

Materials having a small absorption characteristic (absorption coefficient beneath 0.1) are mainly reflecting the sound and worsen the speech intelligibility and enlarge the basic noise.

Fig. 13 shows the absorption properties of an uncompressed PP/natural fiber fleece with a weight ratio of 50 – 60 within the diffuse sound field. The fleece was needle punched and had a thickness of 6 mm. The natural fibers were mainly flax (50 %) and additionally hemp (30 %) and kenaf (20 %). The weight was 1600 g/qm.

After compressing the same material to a thickness of 3 mm, the compressed layer shows the effect of intensive change of the absorption.

For the classification of natural fiber materials, they were compared with plates made of ply wood, chipboards and plates made of plastic material. Fig. 15 demonstrates the excellent parameters of fibrous materials. Even a chipboard with a thickness of 16 mm had only an absorption coefficient of approx. 0.1 and is therefore much worse than the 3 mm PP/natural fiber plate.

Within frequencies above 1 kHz only the 3 mm hybrid fleece plate has a good absorption coefficient.

Fig. 16 shows how by using the sandwich technology acoustical properties can be designed. Here a simple sandwich made of two layers was built. The layers have a thickness of 6 mm, being a fleece made of 40 % PP-fibers and 60 % natural fibers and the upper layer was built out of the same material, but compressed to 3 mm. Especially the improvement of the absorption below a frequency of 1 kHz can be realized. None of both layers show such a characteristic.

Compressing is one possibility to change the acoustical property, the other is using different amount of esp. PP fibers. This was demonstrated by using a 200 g/qm-fleece with 30 % PP fibers and 70 % flax and it was changed to just the amount of 70 % PP and 30 % flax. The absorption characteristic was measured with the fleeces which had a thickness of 20 mm and with compressed material with a thickness of 3 mm, see fig. 17, for the uncompressed fleeces and fig. 18 for the compressed material. The PP fibers have a very good acoustical characteristic and therefore the big amount is beneficial when having the fiber structure within the product. After heating and compressing this fiber structure is destroyed and therefore the behavior changes completely.

To demonstrate the amount of compression see fig. 19. PP natural fiber fleece with 40 % PP fibers and 60 % natural fibers was compressed to different thickness. With increased compression the absorption characteristic becomes worse. It is very astonishing, see fig. 19, that the curves of the 2.5 mm plate are very different to the curves for the 3.5 and 4.5 mm plates.

Another possibility to measure the absorption is done by the impedance tube. With this tube small material samples can be checked within a frequency from 50 Hz up to 6,4 kHz. The measurement is only done with perpendicularly sound impact. A microphone creates a noise within the tube and the reflected sound is measured. The reflection is influenced by the material itself and therefore the absorption coefficient can be measured by comparing both sound pressures, see fig. 20. As in the impedance tube the coefficient is measured only under perpendicularly sound impact, it is not possible to compare both coefficients as within the alpha-cabin. The sound impact comes from all directions, see fig. 21.

A further example demonstrates the advantage of sandwich materials, built out of soft PP/natural fiber core and compressed plates at the surface. This development was made for floor covering which shall compete against parquet floor cover and laminate, see fig. 22. The conventional floor covering show a very bad absorption coefficient being under 0.1. The 3 mm compressed PP natural fiber fleece has above 1.5 kHz better absorption characteristic than all other conventional floor covers.

By using the sandwich technique even a further improvement can be achieved.

A very important other material and property is the reflection. Reflecting surfaces disturb the acoustical surroundings . The understanding will be disturbed. For the characterization of the reflection the A-weighted sound pressure levels are measured

to get a good adjustment to the auditory sensation of the human ear, as identical sound pressure levels of different frequencies are realized in a different volume and comfort.

The advantages of the compressed PP natural fiber fleece measured already in the alpha cabin, are proven with this measurement.

Fig. 23 demonstrates that the reflected A-weighted sound pressure level has the smallest figure comparing them with all other materials. The difference is 8 dB lower than the sound pressure level of the coated plywood with a thickness of 4 mm.

See also fig. 24. Here again the plywood has the worst figures and the compressed hybrid fleece the best value.

## Summary

It was demonstrated that hybrid fleeces made of PP and natural fibers have excellent characteristics regarding the acoustical behaviour. Furthermore the potential is enormous when changing the amount of PP fibers and changing the compression. By combining different layers with different either PP amount or compression, a much better absorption coefficient can be achieved which was proven with the diffuse sound field and also by a perpendicularly sound impact.

Also the reflection of the sound impact was measured and it was proven that the disturbing influences of the material can be avoided.

These advantages are for all parts, products etc. beneficial where human beings live or work. Not only for the automotive industry this material is used but also for floor coverings of buildings, cabins on exhibitions etc.

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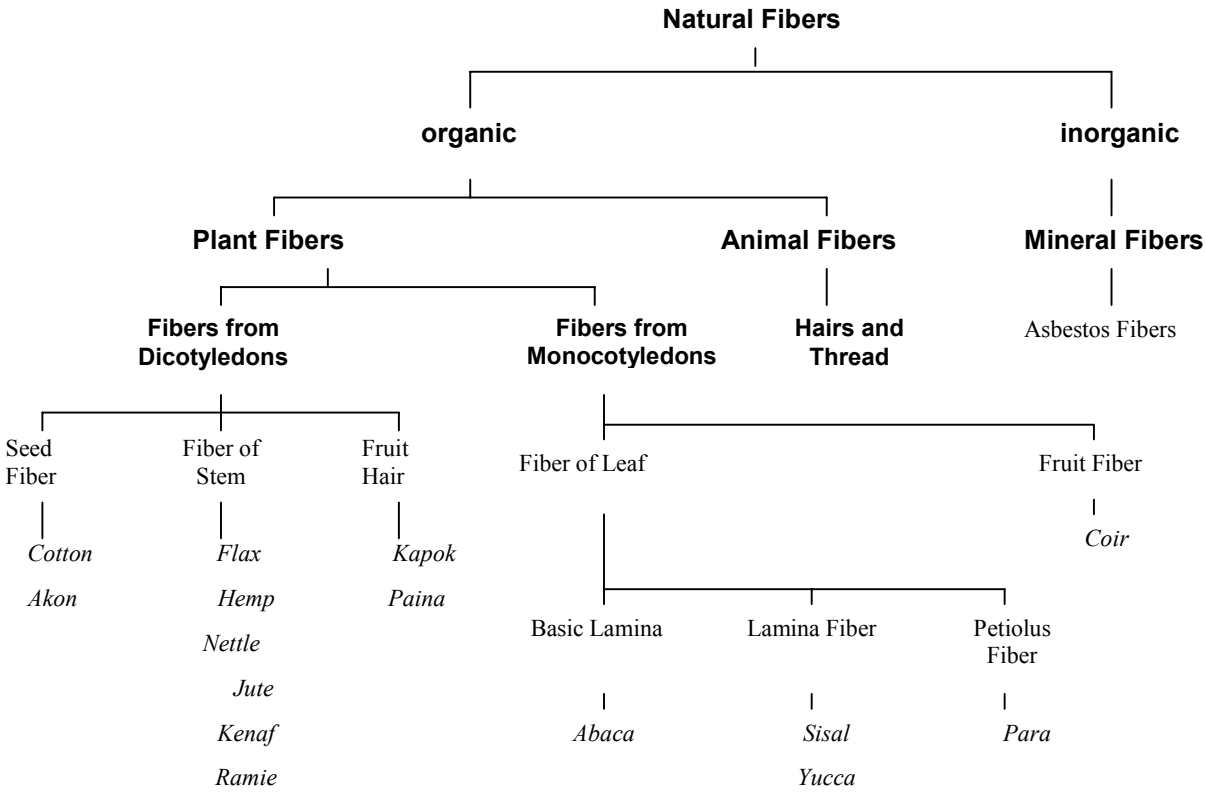


Figure 1. Natural fibers.

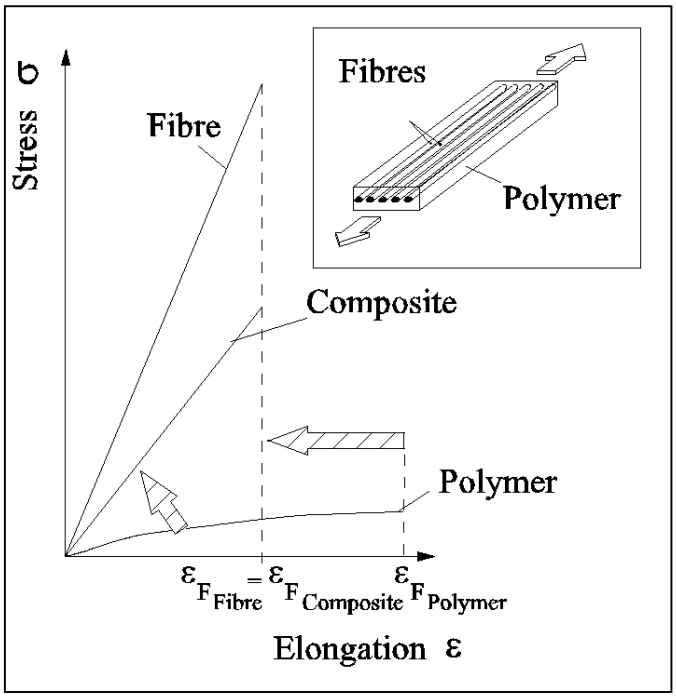


Figure 2. Natural fiber (NF) / polymer composites.

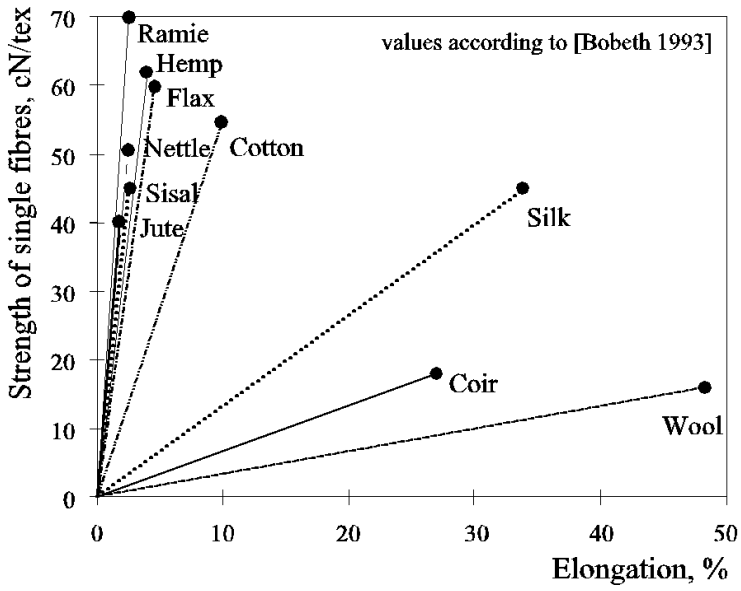


Figure 3. Correlation between strength and elongation for different natural fiber.

| Fiber | Density [g/cm$^3$] | Tensile Strength of Single Fiber [cN/tex] | Strain at max. Tensile Force [%] | Young's Modulus [kN/mm$^2$] |
|---|---|---|---|---|
| Cotton | 1,52 | 55 | 48,0 | 11 |
| Flax | 1,48 | 60 | 4,0 | |
| Hemp | 1,47 | 62 | 4,0 | |
| Ramie | 1,55 | 70 | 2,5 | 7 |
| Jute | 1,49 | 40 | 1,5 | 10 |
| Sisal | 1,45 | 45 | 2,5 | |
| Polyester | 1,39 | 60 | 50,0 | 50 |
| Aramid | 1,45 | 270 | 3,0 | 150 |
| Glass | 2,54 | 138 | 4,0 | 77 |
| Carbon | 1,80 | 167 | 1,0 | 250 |

Figure 4. Mechanical properties of natural and synthetic fibers.

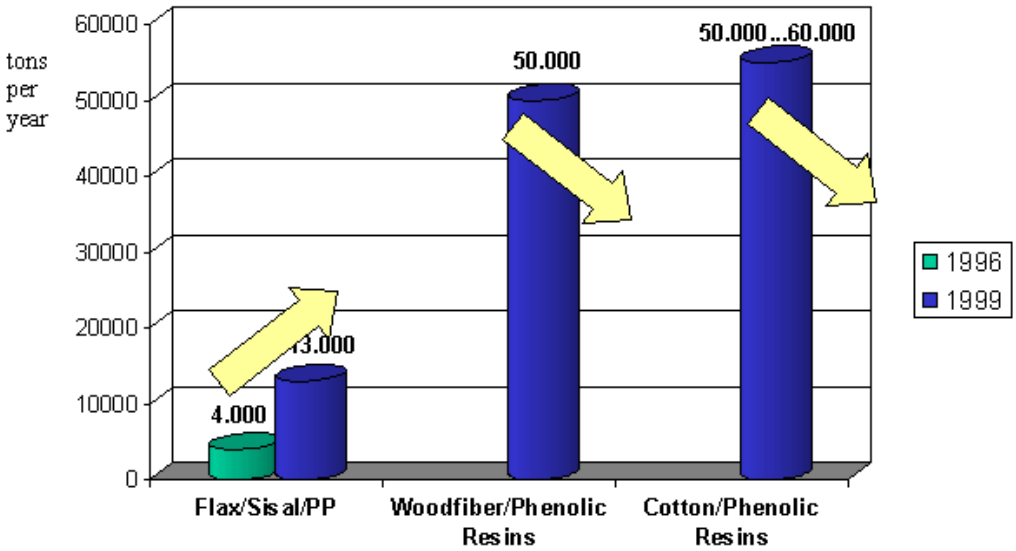


Figure 5. Consumption of NF/polymer composites for the production of car interiors in Germany.

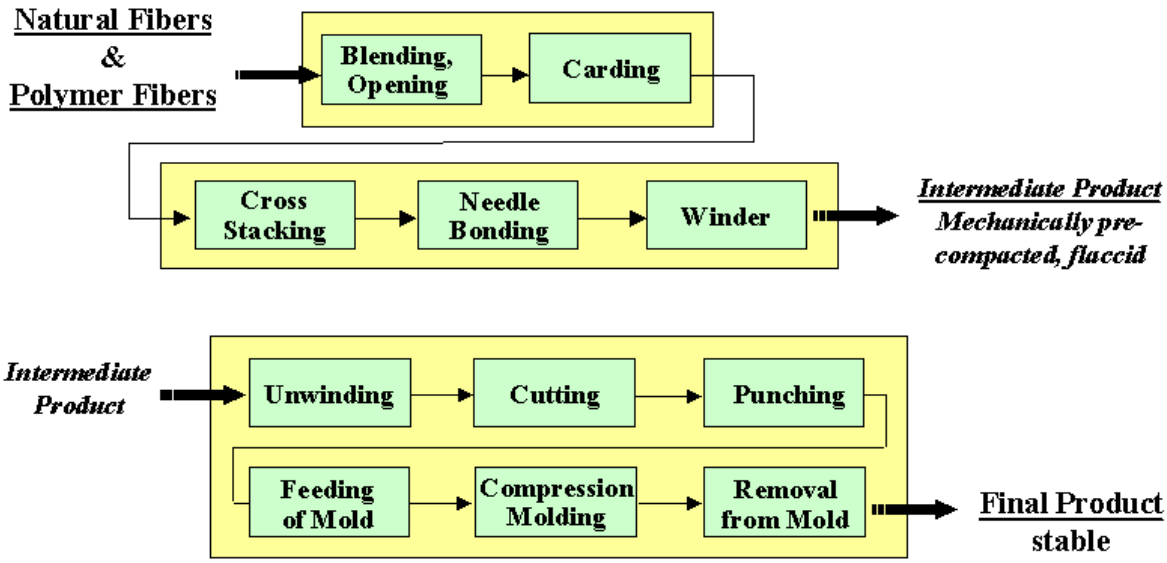


Figure 6. Process technology with hybrid fleeces.

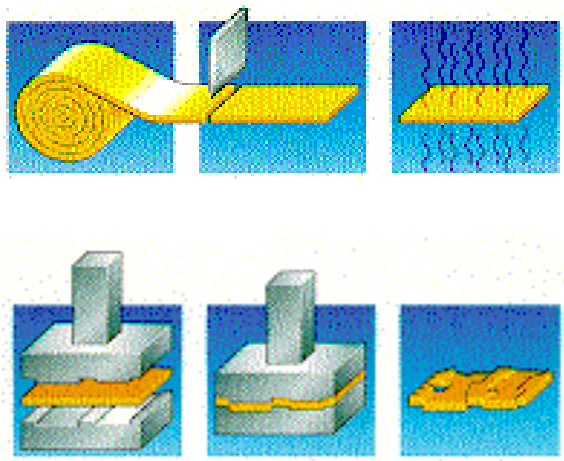

Figure 7. Compression molding process for the production of composite parts [6, modified illustration].

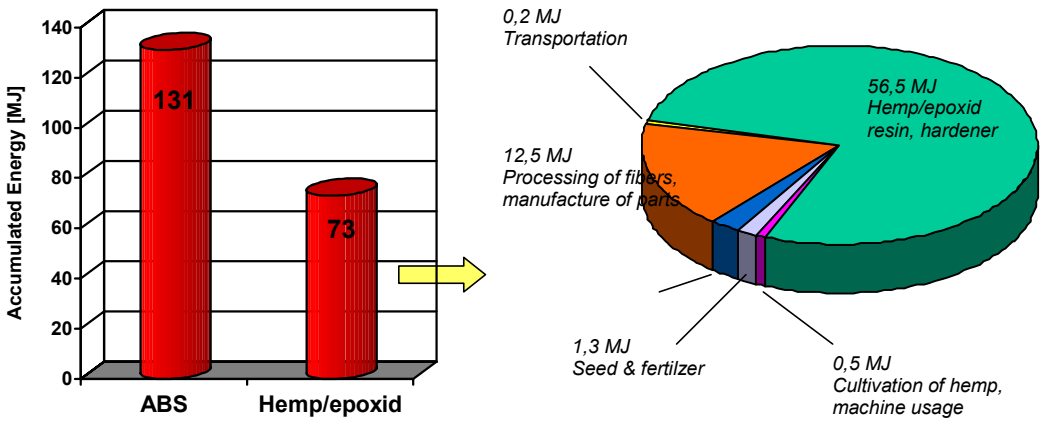


Figure 8. Accumulated energy for the production of a car interior.

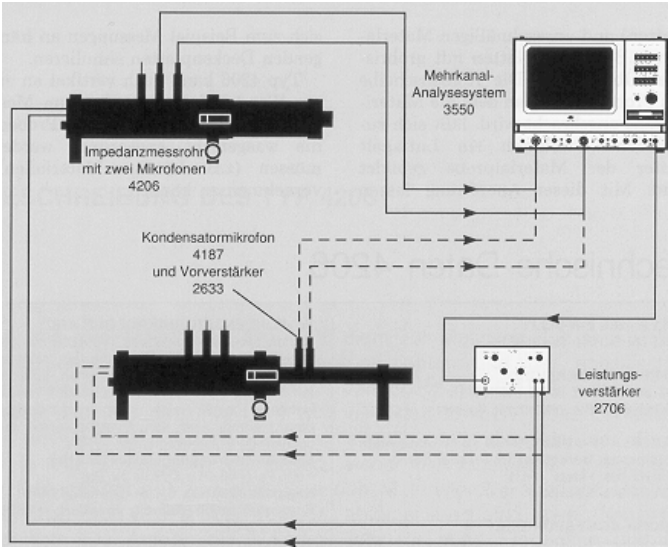


Figure 9. Principle of measurement with Impedance tubes.

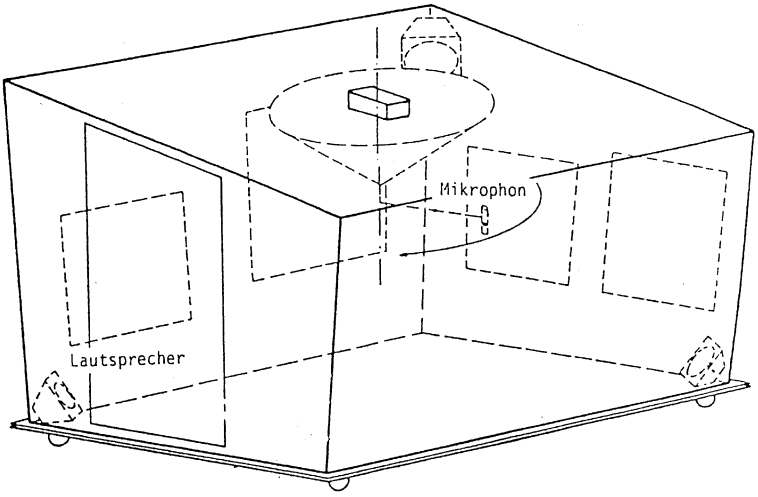


Figure 10. Schematic of an Alpha cabin.

Figure 11. Inside view of an Alpha cabin.

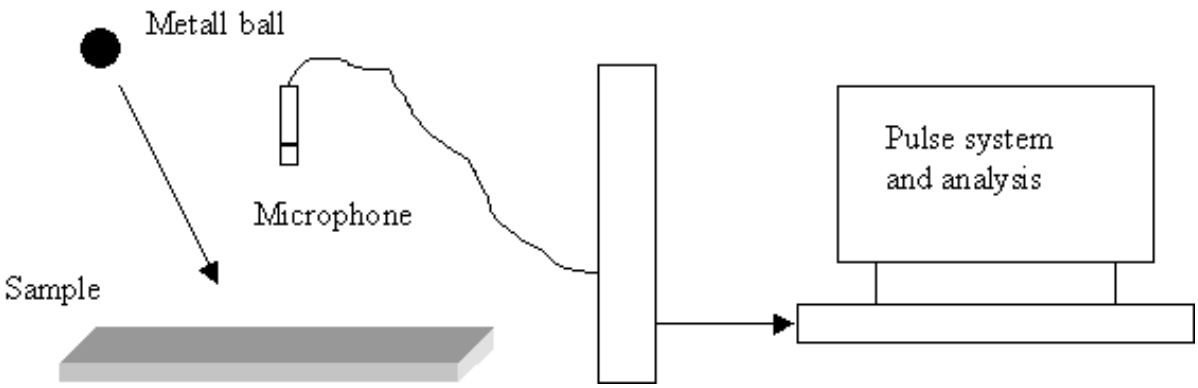


Figure 12. Principle of reflection measurements.

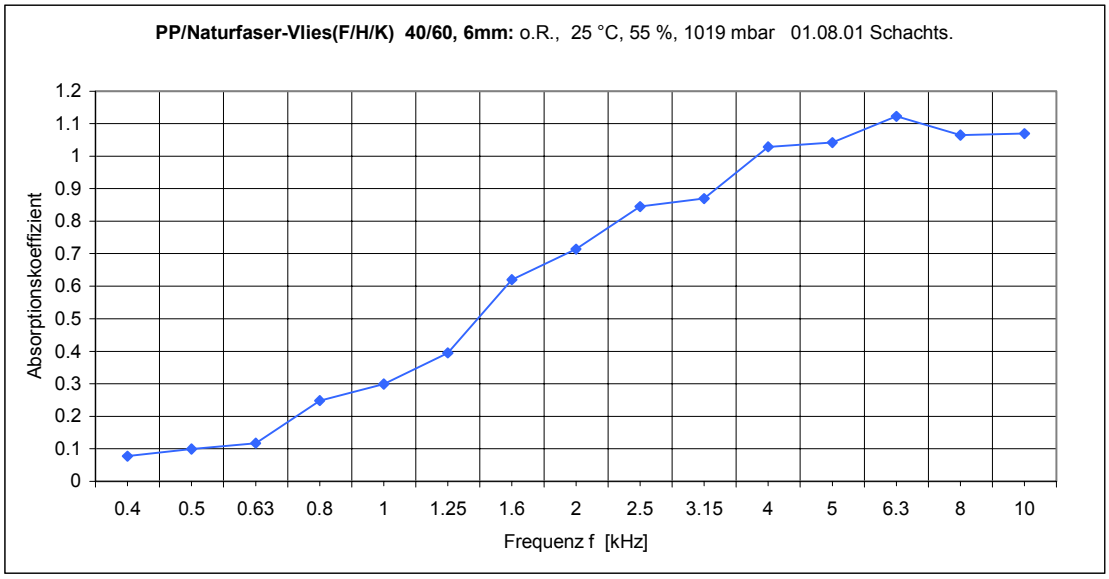


Figure 13. Absorption coefficient of a PP/NF fleece 40/60.

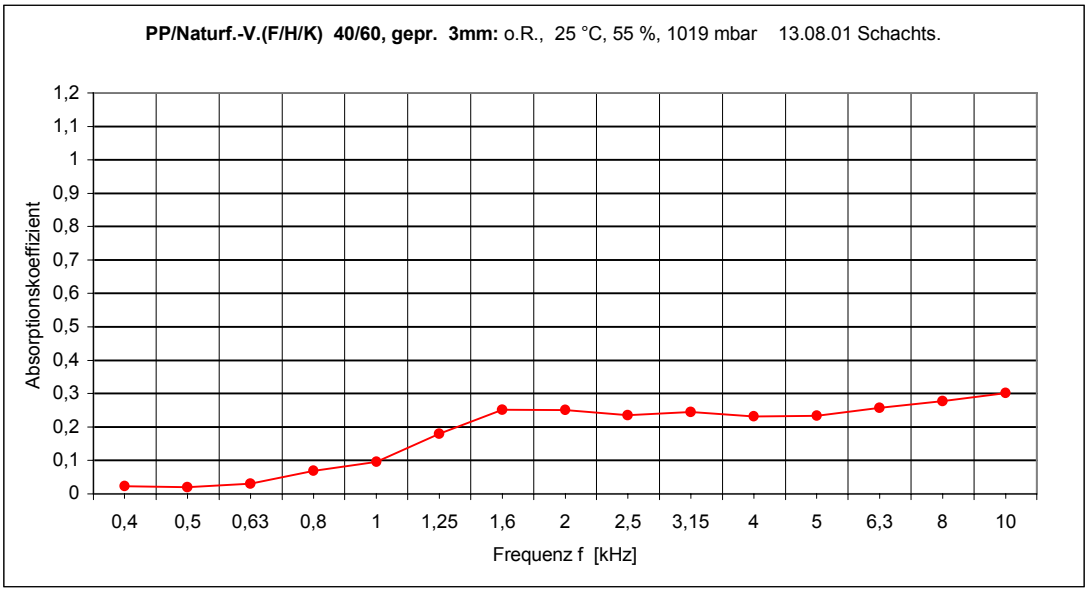


Figure 14. Absorption coefficient of a compressed PP/NF fleece 40/60.

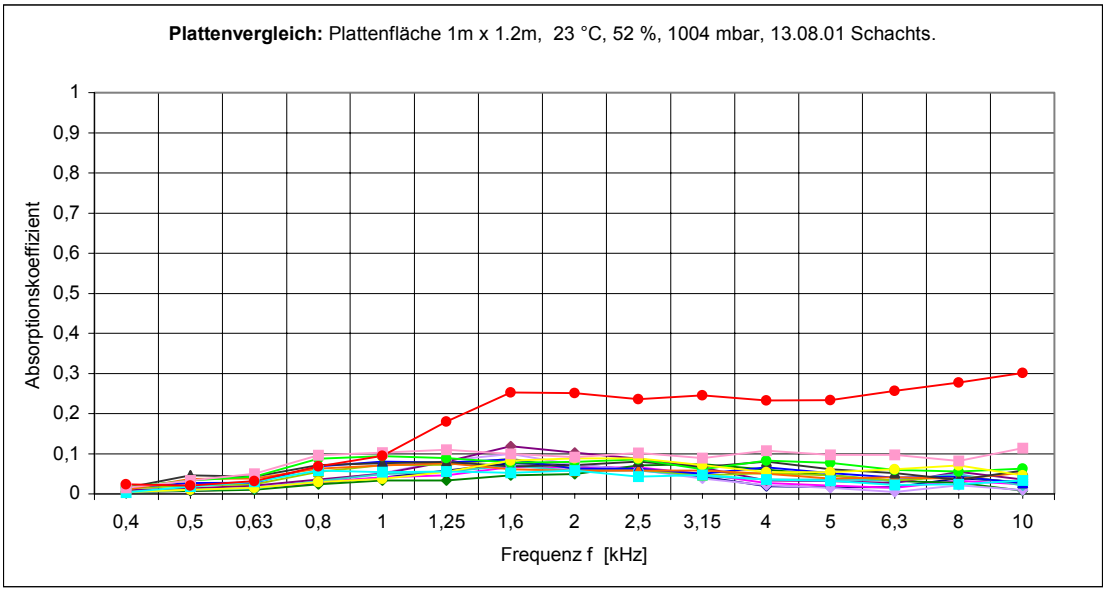


Figure. 15. Absorption coefficient of a PP/NF- plate compared to conventional materials.

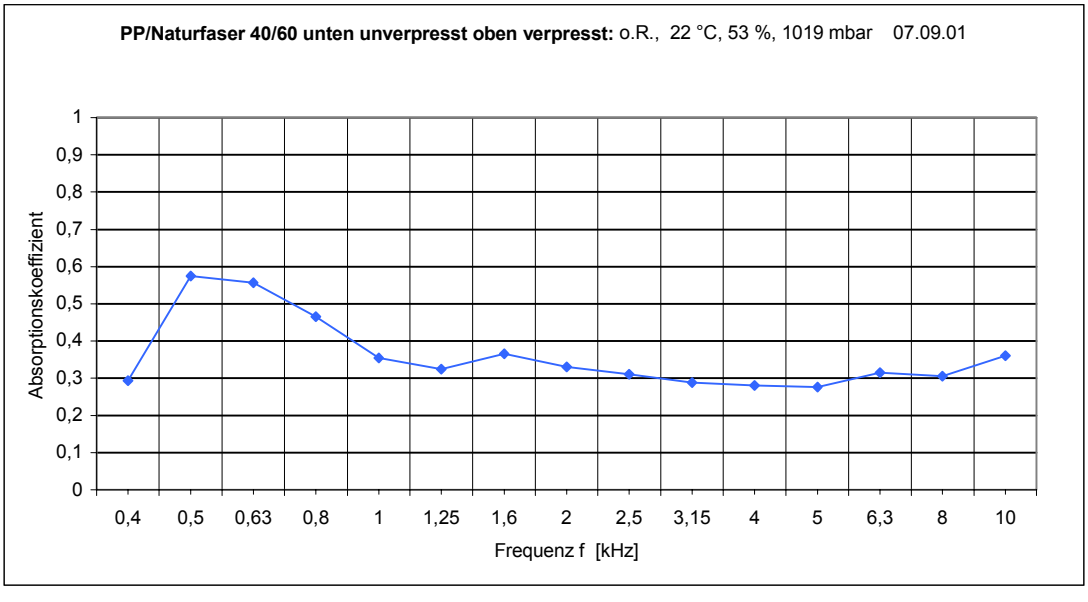


Figure 16. Absorption coefficient of a layered composite (top layer compressed fleece, bottom layer uncompressed fleece).

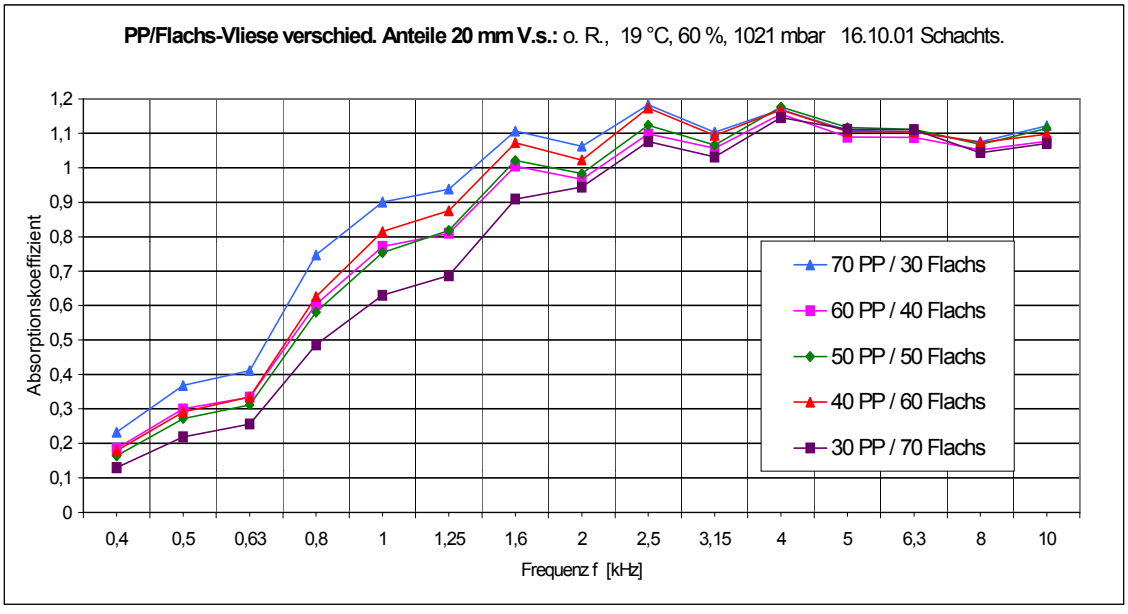


Figure 17. Comparison of absorption coefficients of hybrid fleeces with different PP/NF portions.

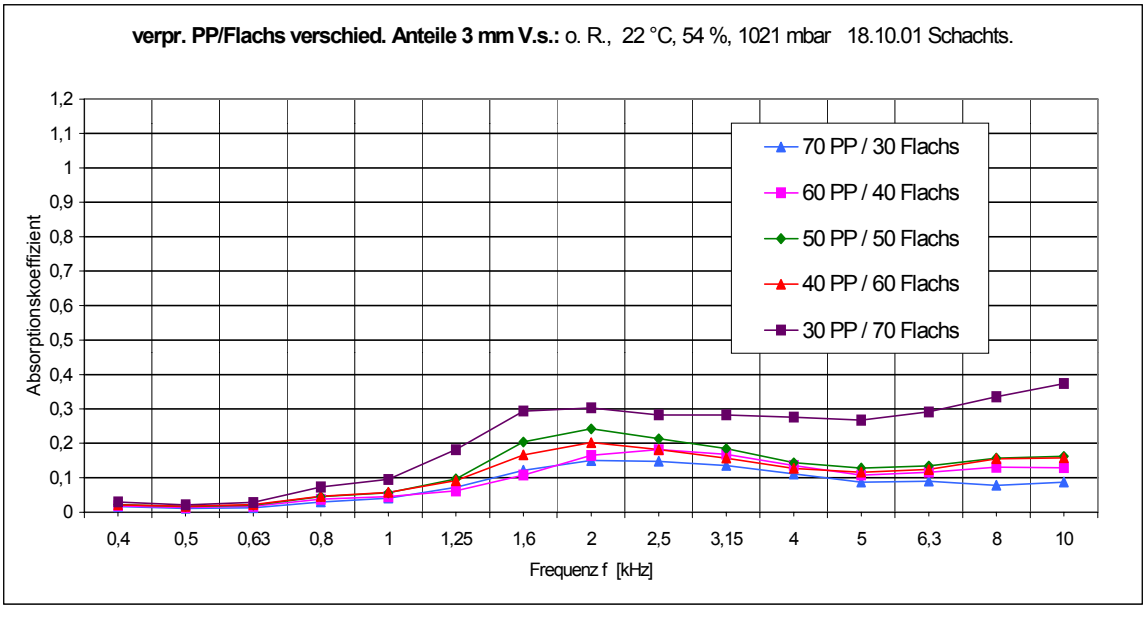


Figure 18. Comparison of the influence of the PP/NF portions in molded parts.

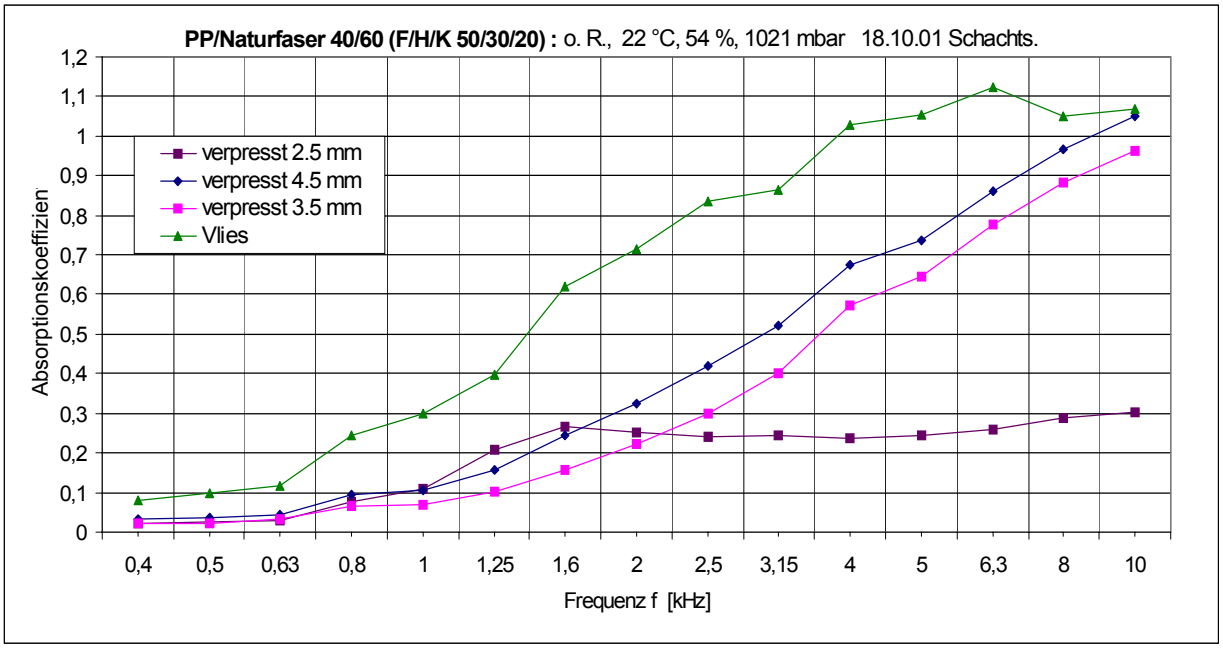


Figure 19. Influence of different molding.

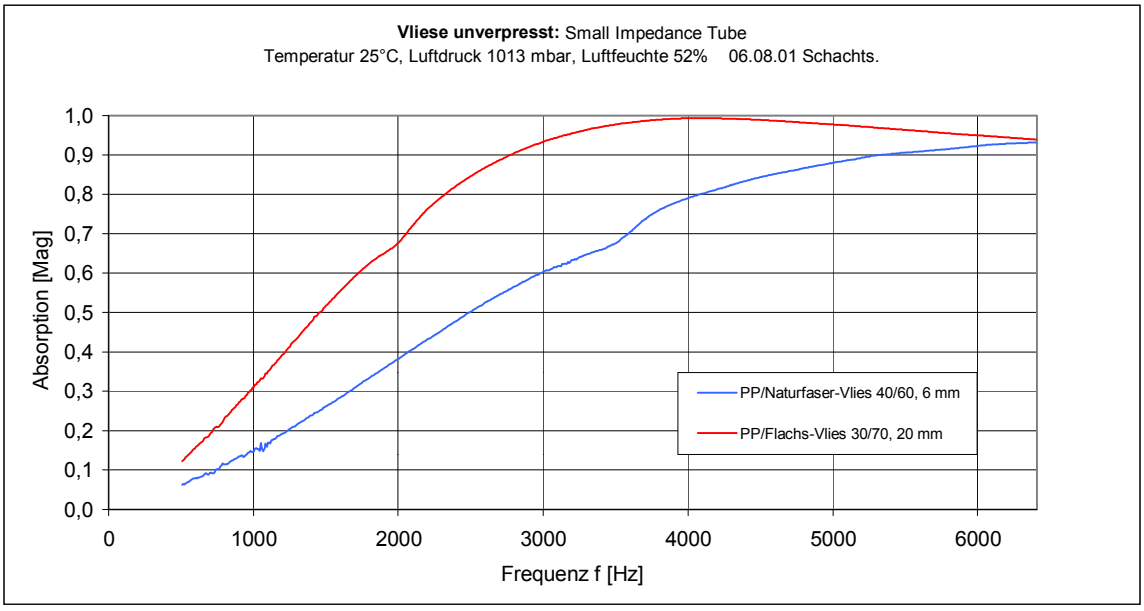


Figure 20. Perpendicular sound impact on different fleeces.

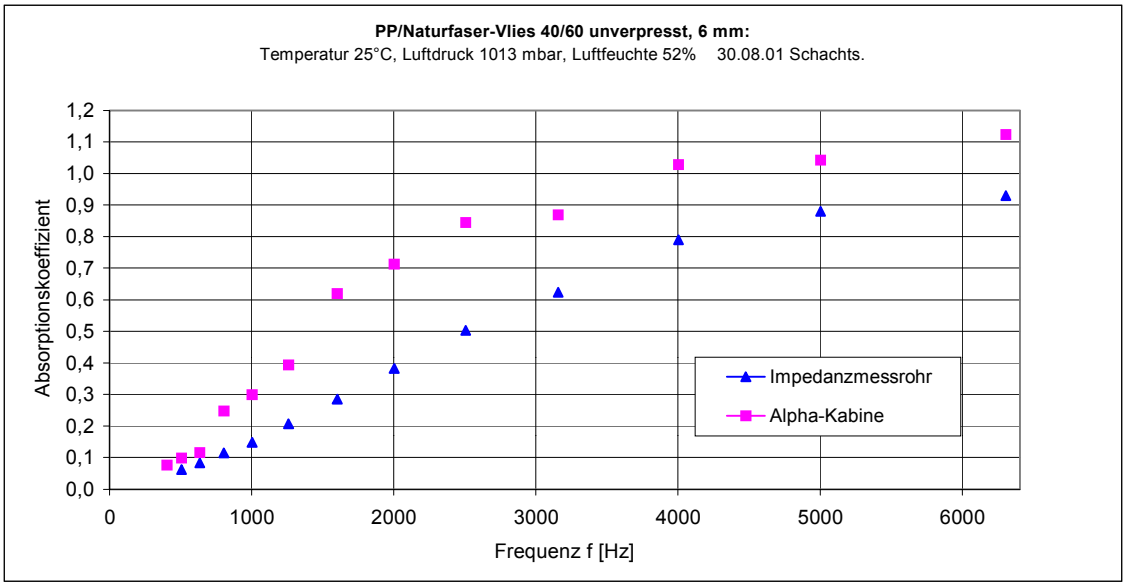


Figure 21. Comparison of two different measurement principles.

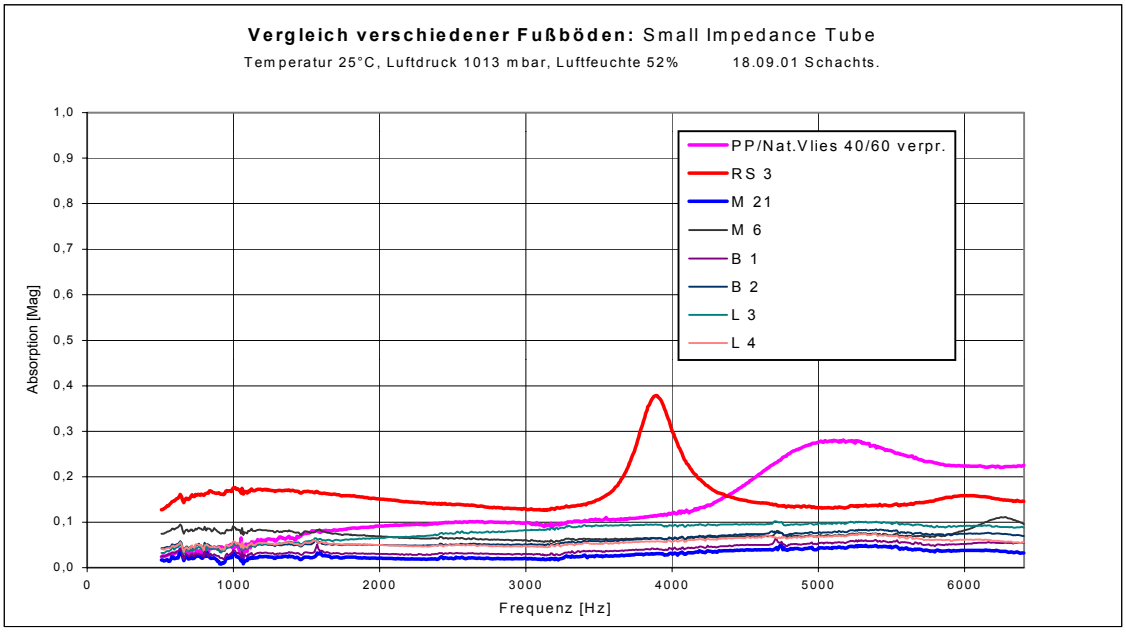


Figure 22. Absorption coefficient of different floor coverings.

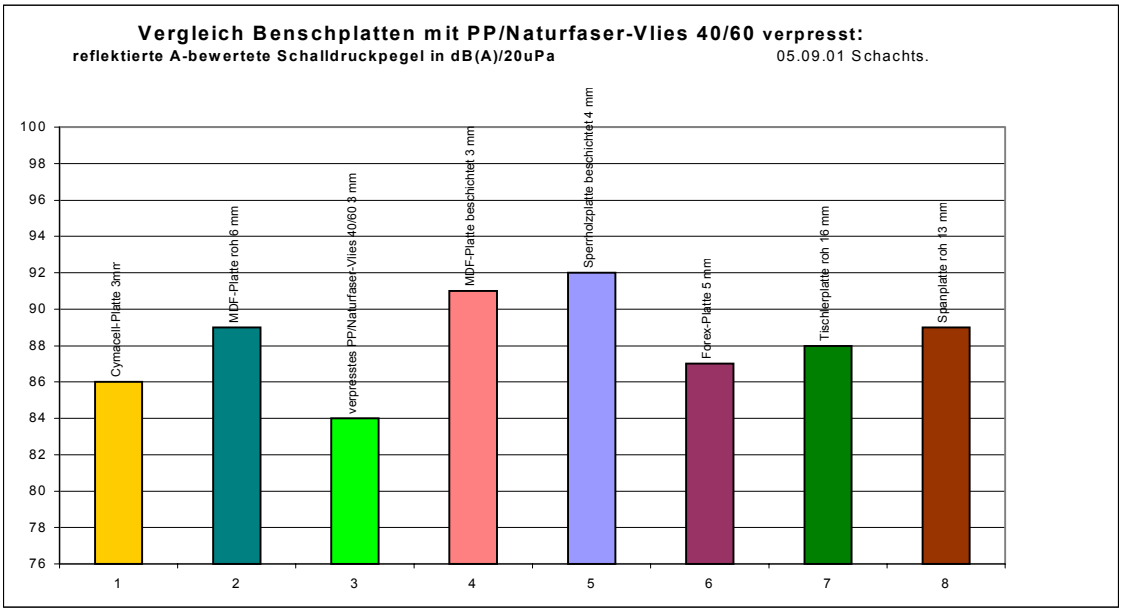


Figure 23. A-weighted sound pressure level of PP/NF- plates compared to standard materials.

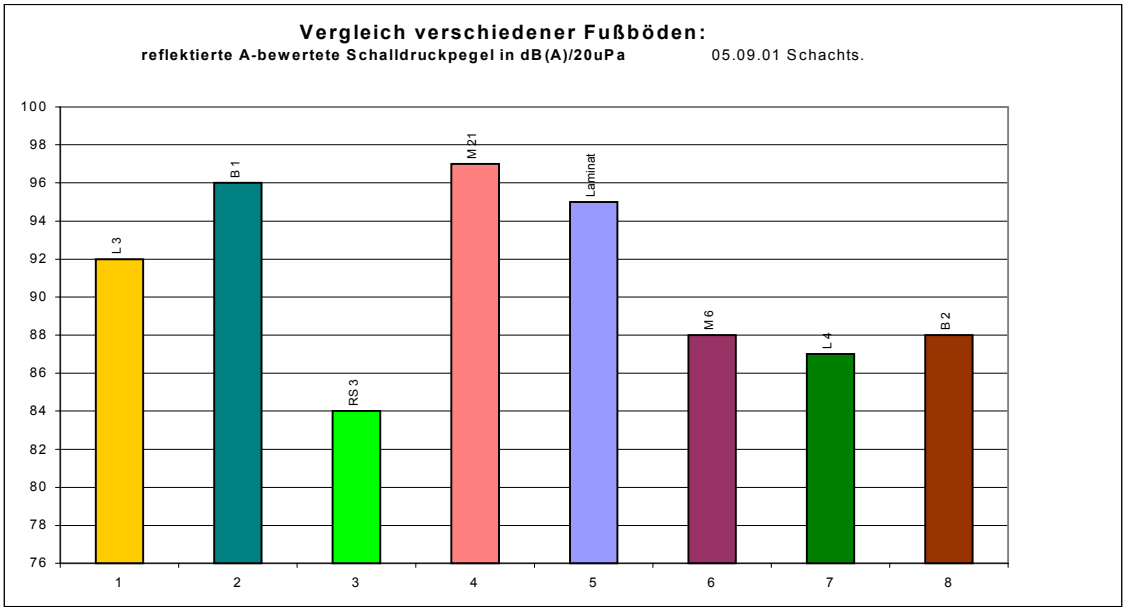


Figure 24. A-weighted sound pressure level of floor coverings.