Renewable Materials for Automotive Applications

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1. INTRODUCTION

After having been almost completely replaced by their synthetic counterparts in the sixties and seventies, natural materials are regaining ground in automotive applications. The use of renewable materials has gathered much momentum throughout the nineties. One of the major reasons for this renewed growth is an increased awareness for our environment, reflected in phrases such as ‘protection of resources’, ‘reduction of CO_2 emissions’, and ‘recycling’.

Beside the use of renewable resources as alternative fuels (bioalcohols such as methanol and ethanol in Brazil, or the so-called bio-diesel, a rape oil methylester, in European countries) and oils for hydraulics and lubrication, the use of plant fibers as insulating or damping materials or as fillers or reinforcement in polymeric materials plays an important role.

2. CURRENT APPLICATIONS OF PLANT FIBER COMPOSITES

Plant fibers are currently only used in the interior of passenger cars and truck cabins. Besides their use in trim parts such as door panels or cabin linings, plant fibers are used extensively for thermo-acoustic insulation. Such insulating materials, mainly based on cotton fibers recycled from textiles, have relatively high fiber contents of more than 80% by weight. Trim parts in Brazilian trucks, made of a mixture of jute coffee bag wastes and polypropylene bags, show that recycling sometimes can lead to advanced applications. Another well established field of application is the use of coconut fibers bonded with natural latex for seat cushions. For this application the ability of plant fibers to absorb large amounts of humidity leads to an increased comfort that cannot be reached with synthetic materials. Aside from this kind of developments, fundamentally new applications have not been realized in recent years.

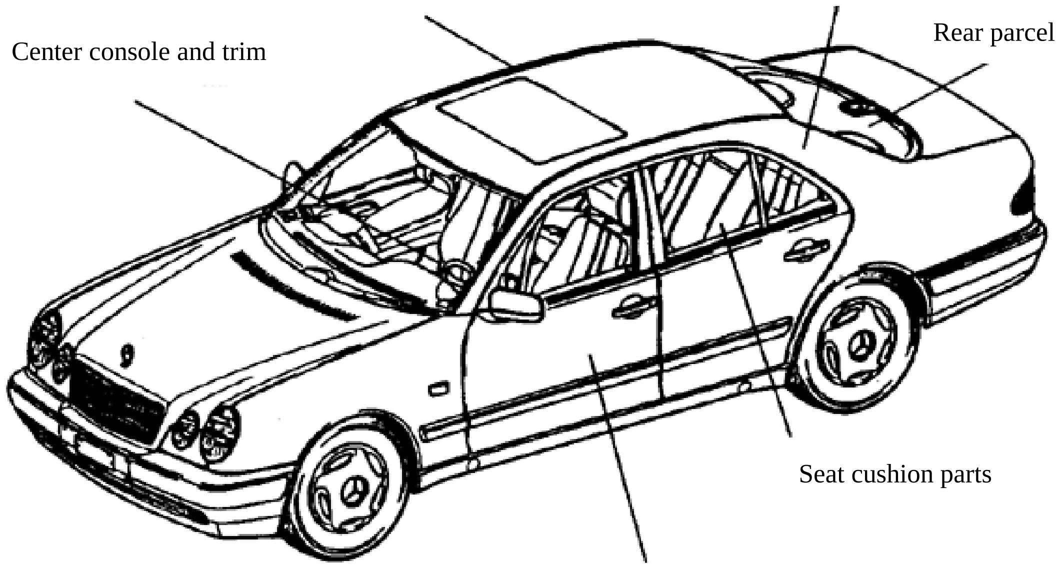

Fig. 1: Plant fiber applications in the current Mercedes-Benz E-Class.

An important step towards higher performance applications was achieved with the door panels of the Mercedes-Benz E-Class. The wood fiber materials previously used for the door panels was replaced by a plant fiber-reinforced material consisting of a flax/sisal fiber mat embedded in an epoxy resin matrix. A remarkable weight reduction of about 20% was achieved, and the mechanical properties, important for passenger protection in the event of an accident, were improved. Furthermore, the flax/sisal material can be molded in complicated 3-dimensional shapes, thus making it more suitable for door trim panels than the previously used materials.

3. PLANT FIBER COMPOSITES

Fig. 2 shows the main categories of lignocellulosic fibers. With a good availability and a comparatively low price, flax, sisal, jute, and coconut play the most important role.

In Europe, the commercially most important plant fiber is still flax. Whereas mainly by-products of the textile industry were used in the past, mainly because of their low price, fibers are now increasingly obtained from plants cultivated specifically for industrial application fibers. New fiber decordigation techniques have been developed, in particular for the so-called green flax.

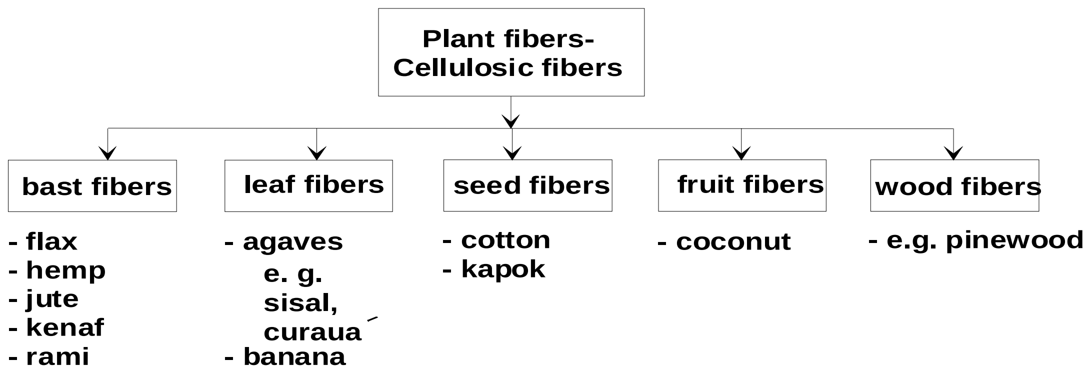

Fig. 2: Classification of plant fibers

The culture of hemp has been revitalized in Europe in recent years. Hemp provides higher yields and stronger fibers than flax. But because the processing of hemp fiber is not yet sufficiently sophisticated, flax seems to remain the preferred fiber.

Besides the fibers, the matrix has a strong influence on the properties of compound. Thermoset polymers such as PF (phenolic resin) are established binders for cotton or similar fibers in the production of inner trim parts and insulating or damping materials.

At the moment, materials with conventional thermoset binders such as epoxy (EP) or PF fulfill the requirements for higher performance applications. They provide sufficient mechanical properties, in particular stiffness and strength, at acceptably low price levels. Compared to compounds based on thermoplastic polymers such as polypropylene (PP), thermoset compounds have a superior thermal stability and lower water absorption . However, the demand for improved recycling concepts and alternative processing techniques are expected to result in a substitution of the thermoset polymers by thermoplastic polymers.

Considering the ecological aspects of materials selection, the substitution of synthetic fibers by plant fibers is only a first step. The pressure to curb the emission of greenhouse effect-causing gases such as CO_2 into the atmosphere and an increasing awareness of the finiteness of fossil energy resources are leading to the development of new materials that are entirely based on renewable resources. One example of an established polymer derived from renewable raw materials is polyamide 11 (PA11). This polymer, based on castor oil, has unique characteristics that make it especially suitable for flexible tubing in fuel or braking systems. But all materials developed until now (based for example on starch, cellulose, sugar) do not fulfill the requirements for automotive applications.

Apart from well-known methods such as *dumping*, *incineration,* and *recycling,* so called “bio-composites“ could offer a new way of disposing of industrial wastes: biological decomposition. Prototype materials, some of which are already established in other industries, are under investigation but not yet available at acceptable properties and prices for automotive applications.

4 MANUFACTURING PROCESSES

Fig. 3 shows the main manufacturing processes presently used for the production of plant fiber composites.

- **Compression Molding** of
  - resinated plant fiber mats
  - plant fiber/PP hybrid mats
  - NMT (Natural fiber Mat reinforced Thermoplastics) comparable to GMT (Glass fiber Mat reinforced Thermoplastics)
  - EXPRESS Process (extrusion-compression molding)
- **Structural Reaction Injection Molding (S-RIM)**
- **Injection Molding with short fiber reinforcement**

Fig. 3: Manufacturing processes

The most important technology is undoubtedly compression molding. Different variations of this process, with details depending on the company developing the technology, are suitable for the processing of plant fibers. In general, the differences lie in the way the fibers and the binding polymers are combined and brought into the mold. Some processes use a pre-melted polymer (e.g. the EXPRESS technology), some use a fibrous polymer that is combined with the plant fibers into hybrid mats before compression molding, others use polymer powder that is introduced into the fiber mats before compression molding.

As almost all processes use the fibers in the form of mats, decordigation of the fibers and the processing of the mats are key issues for the technology.

5 PROPERTIES

The properties of plant fiber composites depend strongly on the type of fiber, but also on the type of matrix, the fiber-matrix combination and the manufacturing process.

Fig. 4 shows stress-strain diagrams of different types of plant fiber materials in a bending test. The differences in the deformation behavior of the materials are significant. Some of the flax fiber compounds have a stiffness comparable to that of conventional glass fiber compounds.

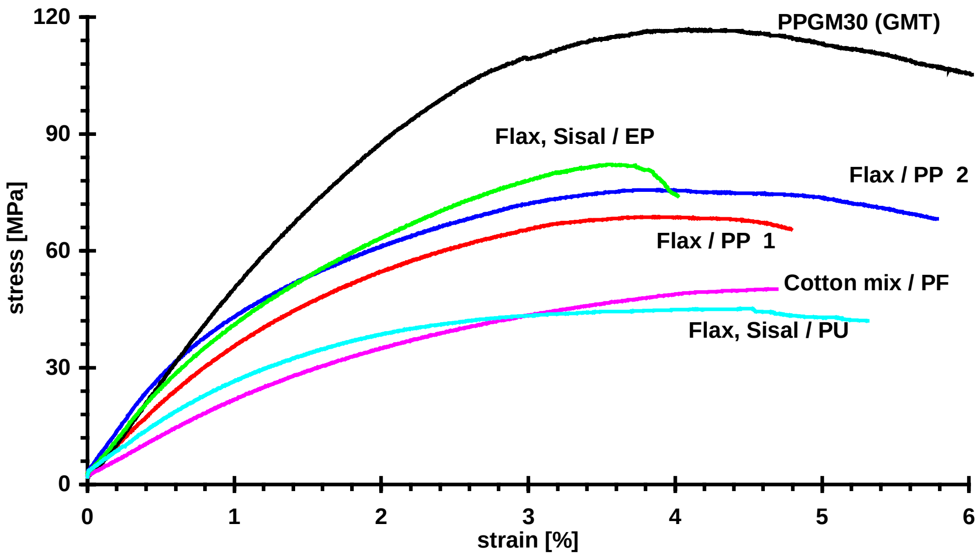

Fig. 4: Bending test according to DIN EN 63

The tensile strength versus impact resistance diagram in Fig. 5 affords a comparison of the behavior of a glass fiber composite with that of a flax fiber-reinforced polypropylene made in a GMT/NMT process over various stages of development.

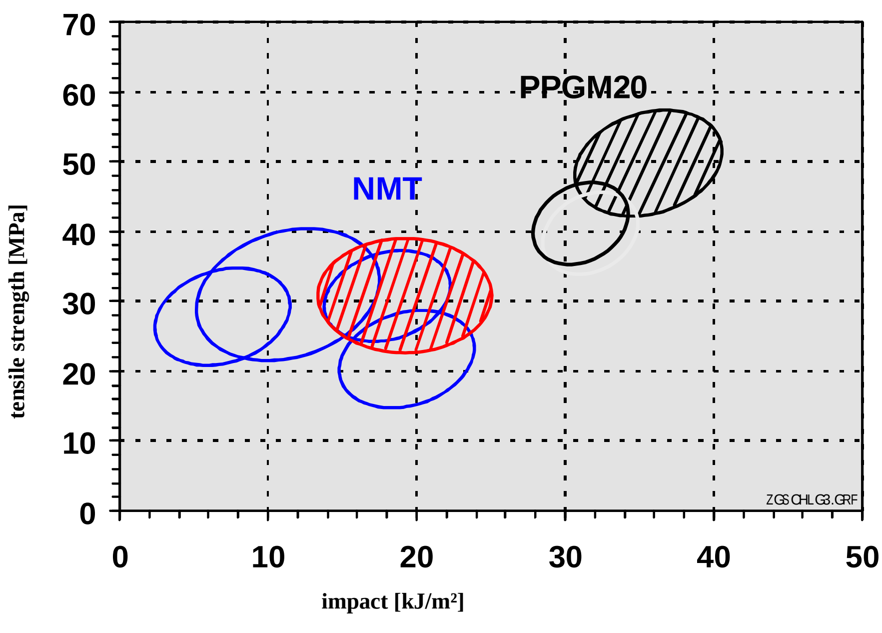

Figure 5: Tensile strength versus impact behavior

The NMT was improved during the development process and came close to the performance of the GMT. However, this material was developed under series production conditions and a significant difference remains, especially with respect to the impact behavior.

One characteristic of plant fibers is their ability to take up and store humidity. In seat cushions this characteristic is desired, but for other applications, water absorption must be prevented. This is the main reason why until now plant fiber applications have been limited to the interior of the vehicles.

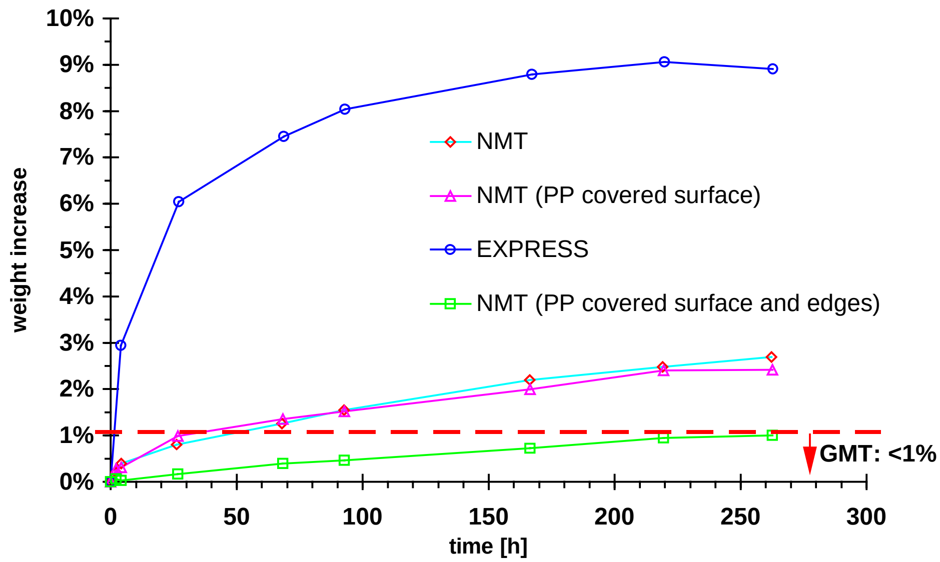

Figure 6: Water absorption of flax fiber reinforced polypropylene

Adjusting the compound materials and optimizing the processing makes it possible to reduce water absorption to a level similar to that of glass fiber compounds (Fig. 6). These results open up a whole spectrum of interesting new applications and would allow the substitution of glass fiber materials also in exterior components. For such applications, uncontrolled decomposition by fungi and bacteria has to be prevented. No evidence so far points to major problems for the future concerning long term resistance of plant fiber materials.

A major disadvantage associated with the use of natural plant fibers is the variation in fiber quality. Important parameters are the type of ground on which the plant grows, the amount of water the plant receives during growth, the year of the harvest, and most importantly the kind of processing and production route. An approach to solving this problem is mixing batches of fibers from different harvests.

For applications inside the car or truck cabin, unpleasant smell and fogging must be prevented. The use of plant fiber materials in standard production has shown that these materials do not present a problem in this respect. The best results were achieved with plant fibers of high quality embedded in conventional thermoset binders. In terms of fogging these materials are often better than conventional synthetic materials.

Natural fibers can normally only be processed at temperatures below 230°C. This excludes some polymers and manufacturing processes requiring higher temperatures. With regard to a substitution of glass fibers this is the principal disadvantage.

4. ARGUMENTS FOR PLANT FIBER COMPOSITES

In the past the main reason for using plant fiber reinforced components (insulation and linings made of cotton wastes, trim parts made of wood fibers) was the extremely low price of these products.

Improved technical properties justify the use of high-grade materials of a higher price level.

The light weight design possibilities with plant fibers have already been proven, for example with the door panels of the E-Class. But also for safety reasons it was important to realize a superior impact behavior using long flax fibers instead of short wood fibers.

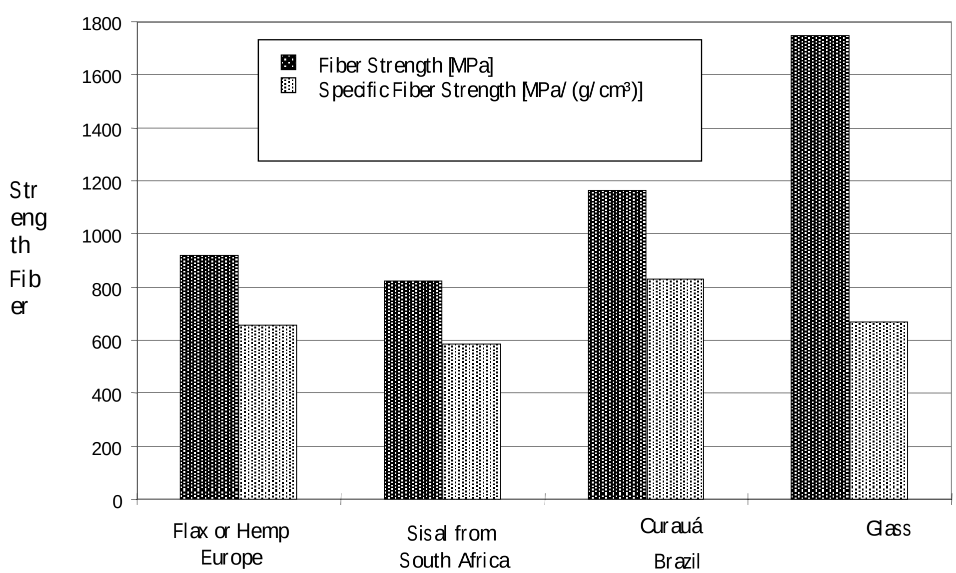

Fig. 6: Specific strength of plant fibers compared to glass

Figure 6 shows the strength of different plant fibers compared to glass. Considering the specific properties, a weight saving potential of about 15% compared to glass fiber-reinforced materials is not unrealistic. At the moment this is one of the most relevant technical driving forces for further developments.

In assembly and production areas of the factory where glass fiber components are trimmed or mounted, workers increasingly complain about skin irritations and respiratory diseases caused by the inhalation of fiber dust. The use of plant fibers may solve those problems.

Fig. 7 shows the industrial and natural life cycles of a product made from renewable resources. Because the CO_2 emission produced by EMBEDincineration at the end of the technical cycle is compensated through photosynthesis during growth, the total CO_2 balance is zero and the emissions thus do not contribute to the greenhouse effect.

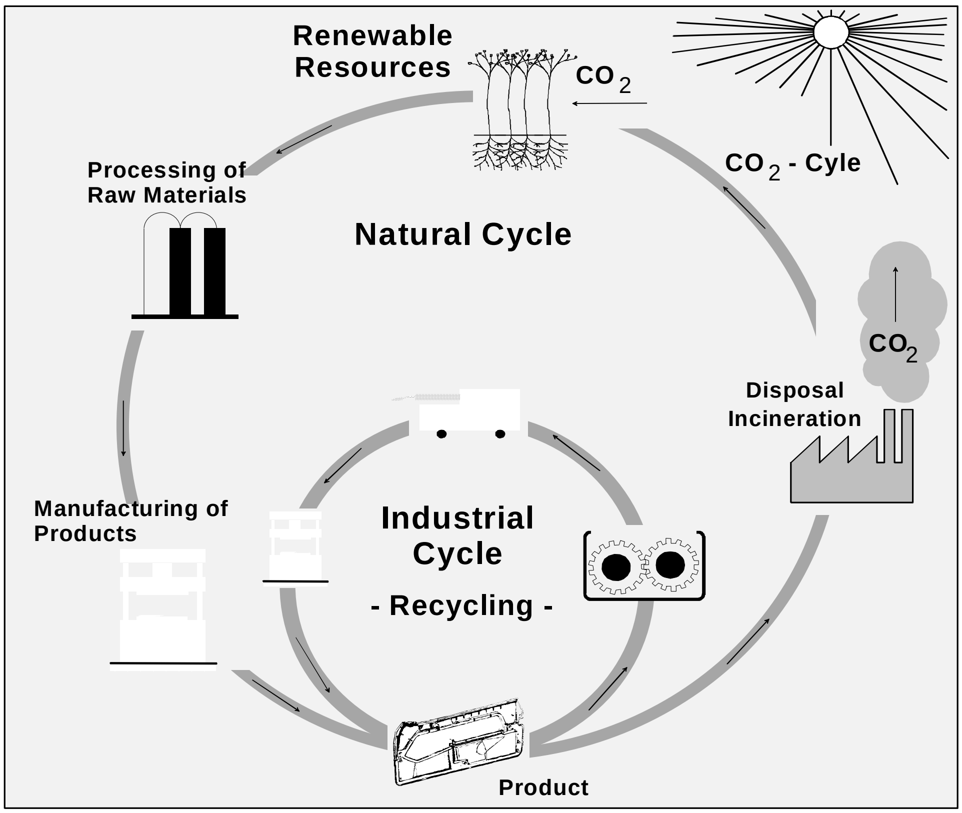

Fig. 7: Interaction between natural and industrial cycles

Life cycle analysis on flax fiber-reinforced polypropylene proved these advantages compared to an equivalent glass fiber-reinforced material. The development of compounds based entirely on renewable resources will further enhance this benefit. This is the main ecological argument besides saving limited non-renewable resources such as crude oil.

Finally, plant fibers are more flexible than glass fibers. The implication is less fiber shortening during recycling processes and consequently superior properties of the recycled materials.

5. OUTLOOK

Development of plant fiber composites has only just begun. Although the ecological aspects of using natural fibers were the initial reason for their being considered for industrial products, future work will emphasize the specific technological properties and advantages of plant fibers.

The trend is towards increasing performance and the gap to synthetic products has become very small. Cultivation of fibers especially for technical purposes, continued development of fiber preparation methods, and new processing methods will further improve the properties. The high performance will enable the substitution of glass fibers on the level of GMT materials over a wide range of applications. The possibility to realize external components in the near future will thereby become a new impulse.

To fully realize the ecological advantages it is absolutely necessary to develop matrix materials based on renewable resources.

Furthermore the design principles of nature will play an increasingly important role alongside the technical uses of natural products and bionics will gain in importance .

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