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Innovative process technology LFT-D-NF offers new possibilities for emission reduced Long-Natural fiber-Reinforced Thermoplastic Components

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Abstract

Automotive components manufactured by using long-fiber reinforced thermoplastics have been firmly established for years for the purpose of large-scale production of semi-structural automotive components. In particular, the LFT direct processing method using glass reinforcements has increasingly achieved its objectives due to its cost saving potential and excellent material characteristics and it is the base of operation for the processing of natural fibers.

As a manufacturer of LFT and GMT processing plants Dieffenbacher GmbH & Co. meets the high requirements regarding material quality in order to guarantee a process for safe part production including an acquisition and evaluation system (SPC) of process data. The North America Division Dieffenbacher DNA offers this solution to the American market.

The process modifications as well as some material properties will be introduced and discussed in this paper.

Introduction

There is a need for establishing new direct processes in order to meet the demands of the automotive industry with regard to cost reduction and improvement in environmental protection. Dieffenbacher developed the LFT-D-ILC Process approximately three years ago [1] and introduces now the LFT-D-NF Process to the market.

Natural fiber reinforced thermoplastics are used in interior applications such as door panel covers, hatracks and rear luggage covers because of their low weight and their failure characteristics.

State of the art is the processing of natural fiber mats being impregnated in the mold with thermosets such as polyurethanes. An alternative that has been developed and introduced by Quadrant are the so-called hybrid mats. Extrusion compression molded or injection molded automotive components are still not existing due to thermal degradation of the fibers and therefore increased emissions. New long fiber granules are under development.

The Fraunhofer ICT, Dieffenbacher and TITK approach is to use the most cost attractive way of fiber incorporation into the melt [2]. Due to the nature of natural fibers being not continuous, a semi-finished natural fiber mat has to be produced which can be fed to the process continuously. The avoidance of an additional heating of f. ex. long fiber pellets increases mechanical properties and reduces energy costs.

The major difference of the Dieffenbacher LFT-D process is the separation of the matrix compounding step from the incorporation of the fiber mats in a second twin-screw-device. Usually plain thermoplastic polymers do not fulfill the requirements of a technical application and therefore need to be stabilized and modified. The separation of two compounding devices allows an optimized compounding of the matrix polymer with simultaneously increased output rate of the compounding unit. High shear strength has to be introduced into the molten mixture of polymer and additives to optimize the compounding. This can be realized by an ordinarily compounding unit. To reduce the contact time of the natural fibers with the polymer melt to avoid degradation the mat is added in a second twin-screw device. This integrated process prevents the granulation step of the matrix and with it polymer degradation.

The natural fibers which were investigated are flax, hemp and sisal. On the one hand these fibers are common in the automotive industry on the other hand side they show suitable mechanical properties e.g. stiffness and strength. Although the weight specific properties of natural fibers are outstanding one has to recognize that just the stiffness is in the region of glass fibers but not the strength, see *figure 1*. It is difficult to replace glass fiber reinforced components by natural fiber reinforced composites (NFC). It is rather better to identify components with requirements that can be fulfilled by NFC.

The In-Line Compounding LFT-D Process

In-Line compounding systems are integrated with the molding process to deliver homogeneous and reproducible long fiber reinforced compound in complete synchronization with the demand established by a cycle time of less than 30 s. In-Line compounding systems

currently in use are capable of providing five hundred kilogram per hour at a screw speed of about 500 1/min.

Figure 2 shows a schematic drawing of the in-line compounding system. Matrix granulates and additives are delivered to a combination of gravimetric dosing units, which guarantee a suitable mixing in respect of the mechanical requirements of the component. Usually colorants, antioxidants, heat stabilizers and coupling agents enable a suitable recipe for automotive applications. The molten compound exits the twin screw extruder through a film die right into the opening of the twin-screw-device. This is the location where the natural fiber mat is added.

Twin Screw Extruder Leistritz ZSE 60/GL

The compounder is a co-rotating, closely intermeshing and self-cleaning Leistritz ZSE 60/GL unit with a L/D ratio of 32. The degassing takes place at 26 D, vacuum assisted or at atmospheric pressure. The underfed partly filled cylinder guarantees a large surface and with it a sufficient venting of the plasticised matrix. Depending on the chosen Polymer the possibility of adding special additives is given by a side feeding unit at 14 D. The melt pressure at the die is about 40-60 bar depending on the MFI of the polymer.

Provision of a natural fiber mat

The provision of natural fibers needs an additional manufacturing step: the production of a fiber mat, see *figure 3*. Because of handling and impregnation problems as well as additional costs, card slivers were not used.

To avoid deviation in the mass per unit area the compressed natural fiber bag has to be opened and the fibers have to be separated. To homogenize the properties of a NFC usually different types of fibers from different growing areas are mixed by combing. The advantage of natural fibers is their flexibility without breaking. Impact properties can be increased by adding synthetic fibers. The composition of the mat used for the following investigation was green flax (72 weight-%), Polyacrylnitril (PAN, 18 weight-%) and PP filaments (10 weight-%). The mats are fixed by needles plunging up to 13 mm in depth. The density of stitches is about 5 per cm². The mass per unit area is 400 g/m². This type of mat is the most cost effective way regarding the state-of-the-art technology. The mat is coiled up and is ready for being delivered to the processor of the final part.

The coil is fixed on a conveyer belt which moves forward with an adjustable constant speed, see *figure 4a*. Therefore a homogeneous dosing is guaranteed. By touching the polymer film exiting the compounder the mat is automatically pulled into the twin screw device, see *figure 4b*. The temperature of the molten PP should be lower compared to the PP of the glass reinforced LFTs to avoid thermal degradation.

Twin-Screw-Device (ZSG)

The interface to the twin-screw-extruder differs fundamentally compared to the feed-in zone of glass. To assure a homogenous and reproducible feed-in of the mat it has to be free of wrinkles. A special cylinder geometry takes care for the transportation of the long fibers into the cylinder to avoid congestion. A special screw design opens up the mat and is responsible for a good fiber wet out and impregnation. Because of its effective cylinder length of about 8 D, the dwell time of the natural fibers in the hot melt is limited to a necessary minimum.

The ZSG continuously provides the plasticized LFT/NF compound. A slot die vacates the bulk molding preform at molding temperature on a fully automated conveyer belt. To raise productivity and output it is possible that a two conveyer belt comes into operation. The conveyer belt is covered by a heat tunnel to prevent temperature decrease at the surface of the extrudate. When the extrudate is gripped by a handling robot, the heat tunnel opens. The ZSG length of 8 D combined with the design of the feed-in section avoids a separate degassing of the extrudate. The obtained extrudate shows a uniform geometry which is suitable for either manual or robotical handling. A breakthrough was achieved by a new slot die which is adjustable in thickness. With this possibility, tailored plastificate geometries can be realized which lead to a significant reduction of necessary clamping forces to fill the mold and therefore to lower investment cost. Very thin components can be realized. Because of the high volume content of natural fibers compared to glass fibers for the same weight content this fact plays an important role. Suitable mold filling analysis to optimize the tailoring can be performed at the Fraunhofer ICT.

Design of a Modern LFT-Press

In a high volume production depending on the part size, a modern hydraulic LFT-press with a clamping force in the range of 15.000 up to 30.000 kN is recommended. Usually a press table with 3.600 to 2.400 mm in dimension is used [2]. Speed of press closing movement can be raised up to 800 mm/s. The maximum forming speed is 80 mm/s. The characteristic value for pressure built-up time is 0,5 s. The described press is suitable for two-cavity molds in which two parts can be molded during a cycle time of just 25 s. This includes the closing of the press inclusive control of working stroke and pressure built-up (4-5 s), cooling time (approx. 8 s), opening of the press inclusive pressure reduction and the control of the opening movement (4-5 s) as well as the loading and unloading of the press (approx. 8 s). The consistent mold closing movement is supported by an active parallelism control.

LFT/NF-Material Properties

The degree of freedom regarding the use of new polymer blends and different types of fibers enables an individual matching of the compound according to the specific needs of the application.

The specific selection of additives, particularly coupling agents for the improvement of fiber matrix adhesion enables the adjustment of stiffness and energy absorption in just a certain range. Whereas the addition of synthetic fibers such as f. ex. PAN, PES, Lyocell, Viskose increases the energy absorbing properties up to 160%! [3], see [figure 5](#). Furthermore the synthetic fiber stabilizes the mat manufacturing process.

After dilution with PP the investigated mat resulted in a natural fiber content of 24 weight-% green flax and 6 weight-% PAN fibers. For evaluation purposes the Mercedes A-class underbody cover was selected as a demonstrator, see [figure 6](#).

Glass fibers are fragile and sensitive to compounding. The fiber length contributes significantly to the energy absorbing properties. Natural fibers are very flexible and different in their built-up. In the performed investigations the influence of screw design on fiber length and mechanical properties had to be evaluated [4]. On the one hand a screw design with a conveyer screw and no shear elements was used and on the other hand a screw design with kneading discs and high shear exposure of the melt was selected. The results are shown in [figure 7](#).

Natural fiber reinforced thermoplastics are not shear sensitive like glass fiber reinforced LFTs. The material which was processed by the shear intensive screw was difficult in handling because of the shorter fiber. Nevertheless the shorter fiber did not show any reduction in the static mechanical properties. No difference in E-modulus, strength as well as flexural properties arises, whereas the energy absorption is increased by up to approx. 15-40%. Influences of the synthetic fiber concerning the compensation of the natural fiber degradation could not yet be identified. Additional trials without PAN have to be performed to exclude any influence. The increase of mechanical properties under high shear can be associated with the structure of a natural fiber. Under shear the flax fiber (15-100 μm) opens up and so-called elementary fibers (5-20 μm) with a larger surface are exposed to the matrix. These fibers generally show higher strength, because of their structural homogeneity. The number of fiber pull-out mechanisms increases significantly and therefore the energy absorption of the component. Comparative trials with green flax and different fiber diameters approve these results.

Second ambition of the investigation was focused on the influence of PAN fibers on the static mechanical properties. With just 6 weight -% of synthetic fibers the

energy absorption was doubled. PAN fibers show good tensile properties and very good energy absorption properties because of their elongation under load. While having a negligible impact on tensile and flexural properties, synthetic fibers increase energy absorption, see [figure 8](#). The combination of different types of natural fibers as well as synthetic fibers creates numerous possibilities in tailoring the materials to the specific requirements of the application. The results of many trials show that the addition of synthetic fibers is more efficient than the modification of the polymer and the provision of numerous elementary fibers.

The results show that the achieved mechanical properties are in the range of natural fiber reinforced components manufactured by alternative processes. Part quality is guaranteed by a suitable process control. The LFT-D/NF technology is an effective technology at a lower cost level.

Advantages of the LFT-D-ILC Process

The most compelling advantage consists in the cost savings by avoiding the step of manufacturing a semi-finished product like NF pellets or pre-impregnated mats. The economic advantage is derived from the efficiency of the process, its reliability and from the use of raw materials such as plastic pellets, natural fiber mats and additives. Maintaining inventories of multiple grades of pre-compounded pellets or LFT-NMT-plates are not necessary and save logistics cost. Thermoplastic natural fiber reinforced extrudate is just-in-time produced on demand.

Unlike pre-compounded pellets or plates, natural fibers as well as thermoplastic polymers entering the in-line-system have undergone a single heat history. The reduced exposure to thermal degradation leads to improved initial and long-term properties for molded composite components. A significant reduction of emissions could be achieved during manufacturing and is expected during life cycle. Final investigations regarding f. ex. CARB-tests still have to be performed.

The expenditure for total energy consumption to produce a composite component is significantly less compared to alternative processes. In the direct process energy which is spent transforming raw materials into LFT-pellets or NMT-plates, transporting the pellets or plates to the component manufacturer and subsequent reheating of the pellet or plate feedstock prior to compression or injection molding, are completely eliminated.

LFT-D-ILC is perfectly suited to match the material formulation to the requirements of the application. The selection of materials is not constricted by the efficiency of a semi-finished material supplier's production. The glass fiber content and the composition of the molding material can be adjusted like required. This is realized by

computer controlled gravimetric feeders and screw speed as well as by the confection of the natural fiber mat. This enables the possibility of individual color matching.

Compression molding offers several advantages compared to injection molding. Beside less warpage especially in large area parts, the avoidance of weld lines can easily be achieved without a cost intensive multi-cascade mold technology. A homogenous pressure in the mold and no pressure gradient as well as the short cycle time especially when the part has to be in-line decorated are other benefits of the compression molding process.

Recycling

The LFT-D-NF process offers a further economical and environmental advantage referring to the direct reprocessing of recycled LFT/NF materials. It still has to be investigated whether NFC with a single heat history can be recycled. A gentle heating of the NFC after being shredded looks promising. Regarding emissions and remained mechanical properties, further investigations have to be carried out.

Usually production waste comes into operation. Components after life cycle can be utilized as well. After the shredding metal parts or particles have to be removed. Single screw shredders with a sieve aperture diameter of maximum 50 mm are most suitable to generate a particle size suitable to be added to the virgin material.

Future Technologies

The LFT-D process is an extraordinary versatile process. Material use, defined by the requirements of the

molded part, can be molded directly from raw material blends defined in-line prior to compression molding.

Different material combinations have to be evaluated in future trials. This includes different fillers like for example talc, calcium carbonate or chalk to influence cost and flow properties.

The combination of impregnated textile reinforcements like woven fabrics with long fiber reinforced material increases the mechanical properties - especially impact and stiffness properties - significantly. These tailored thermoplastic composite structures combine high mechanical properties of continuous fiber reinforcement with the possibility of achieving a complex shape by compression molding of long fiber reinforced material. Tailored automotive body structures can be molded economically attractive. The Fraunhofer ICT together with Dieffenbacher and other industrial partners won the European innovation JEC Award 2001 for the Direct-Forming-Process as well as the JEC award 2002 for the LFT-D-ILC process and tailored material structures, the so-called Tailored-LFTs [5].

Keywords:

Direct Process
 Long Fiber Reinforced Thermoplastics LFT
 Natural Fiber Reinforced Thermoplastics
 PC Production-Line Control
 LFT-D-ILC Technology
 In-Line-Compounding
 Thermoplastic Composites
 Tailored LFT
 Tailored LFT-D

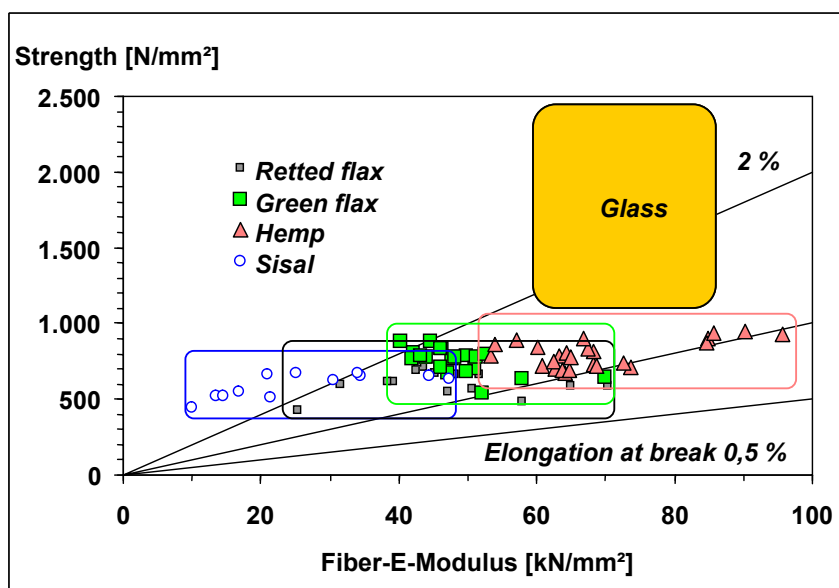


Figure 1: Mechanical properties of different natural fibers compared to glass

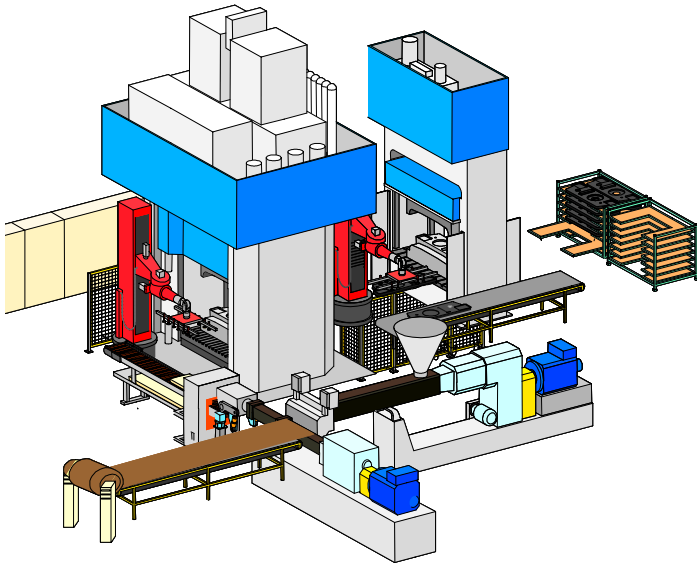


Figure 2: Schematic drawing of plant layout



Figure 3: Natural fiber mats



Figure 4b: Introduction of natural fiber mat in ZSG



Figure 4a: Dosing of natural fiber mat – conveyer-belt

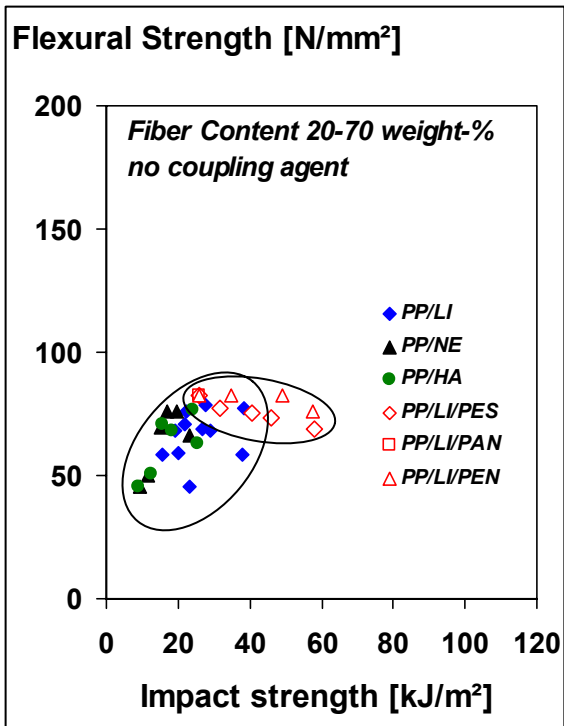


Figure 5: Influence of synthetic fibers



Figure 6: Underbody cover of Mercedes A-class

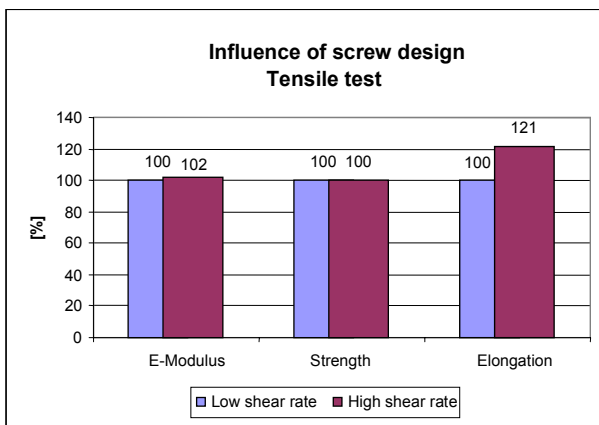
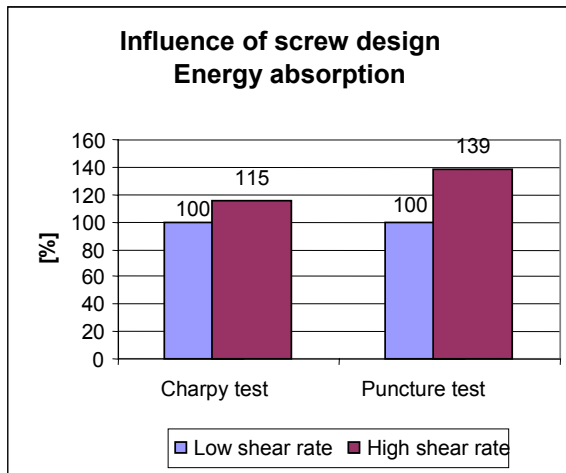
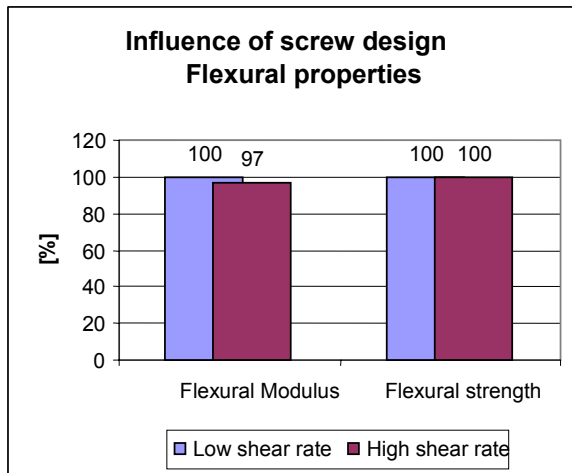


Figure 7: Influence of different screw designs on mechanical properties

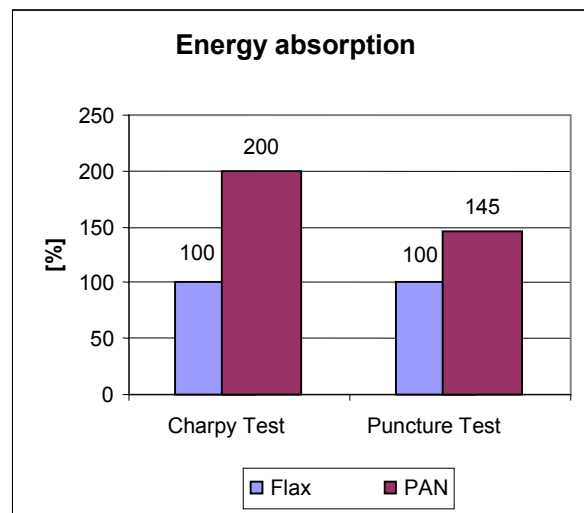
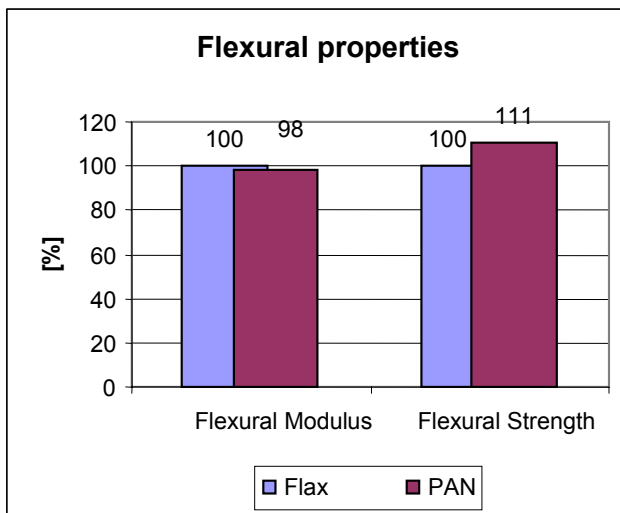
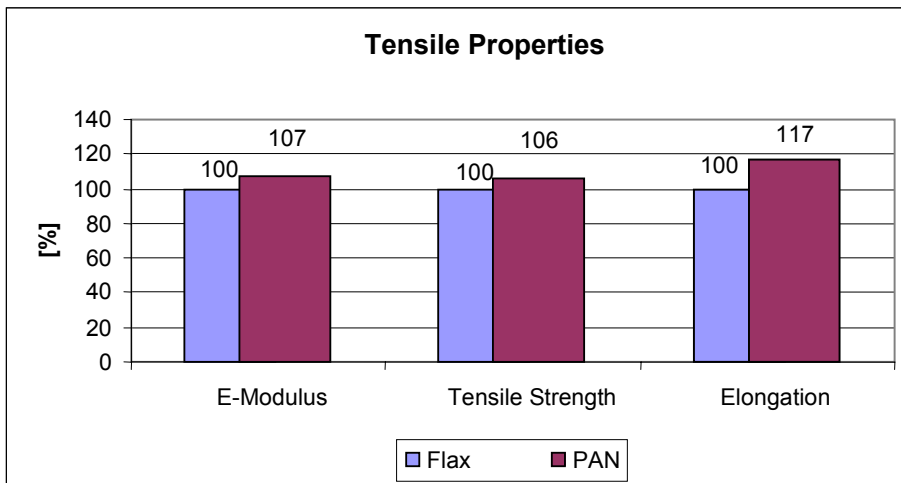


Figure 8: Influence of PAN fiber on mechanical properties

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