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"Green Carbon" from Algae for Automotive Applications

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Abstract: *Due to the continuous decrease in the level of oil resource, nowadays researchers from all fields are concerned with the creation of new bio plastics with special properties. The present work presents a series of such properties, which become achievable when reinforcing organic fibre materials obtained by reactive extrusion of thermoplastic Polyurethan (TPU) with Polylactid-Acid (PLA) in a twin-screw extruder and covalently linked into PLA-TPU-Blends, through the innovative "one-step process" technology, using the IMC Krauss Maffei injection moulding compounder, at the IKT University of Stuttgart. The elongation at break of PLA-TPU-Blends and the impact strength could be increased without significant reduction of strength and stiffness. A balanced relation between improved impact strength and reduced stiffness can be achieved by varying of the blend components. By using the partially biobased Polyurethane and natural fibres, a biobased content of more than 90% could be achieved. More and more advanced technologies allow the manufacture of components with reinforcements made of glass fibres, natural or carbon fibres obtained from polypropylene or Lignin. Due to their low specific weight compared to glass, carbon fibres are preferred for lightweight structures in the automotive or aeronautics industries. Green Carbon fibres, made in innovative ways from acrylonitrile resulting in the production of Bio-Diesel from algae, can successfully replace the conventional carbon fibres of Polypropylene, having identical properties. Fibre reinforcement aims to improve mechanical strength and impact resistance and increases the dimensional stability under heat of the composite. This feasibility study shows a method to realize fibre-reinforced materials using Green Carbon fibres with remarkable stability and rigidity similar or better than aluminum and steel for lightweight constructions.*

Keywords: *carbon fibres, green carbon, algae, natural fibres, fibres reinforcement, PLA-TPU-blends*

1. Introduction

Given the increasing demands on reducing the mass of automotive components, fibre reinforced plastics are an increasingly attractive alternative for the automotive industry. On the other hand, environmental concerns have resulted in a renewed interest in sustainable composites focusing on bio-based fibres [1]. Reducing the mass of vehicles is a solution that can reduce CO_2 emissions. According to an Audi company statistic, a reduction of mass by 100 kg leads to a reduction of CO_2 emission by 8-11 g/km [2]. At the same time, the car components are becoming more and more complex as they take on different new functions and, at the same time, they are components of the vehicle's structure of resistance.

Ever since the first cars built in 1950-1960 in East Germany (DDR), due to the reduced possibilities from that time, there were used car components made of thermosetting plastics, a glue based on Phenol, with reinforcement of cotton fibres or wood sawdust. This is why Trabant cars also bore the name "Plasticbomber". In West Germany, the Lloyd (Borgward-Group in Bremen) factories produced, in the early 1950s, the body of Lloyd P 300 and 400 models of "Plywood" (compressed wood sawdust) covered with artificial leather, which was nicknamed "Leukoplastbomber". Then, in the mid-1950s, at the Lloyd Company the compressed sawdust was replaced with steel, but the Trabant remained, until the last year of production (1990), the follower of the concept "Cotton-Phenol-Glue". Even today, some truck cabs are made from cotton fibres and Phenol-Glue [3].

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The decreased weight of the components produced from renewable resources makes them attractive in the automotive industry. This is highlighted by the statistics in the field. The components inside the vehicles, such as the interior of the doors or the luggage compartment, reinforced with fibres, are made, in most cases, from natural fibres (flax, hemp, jute, chenat, sisal, abaka, etc.) [3, 4]. For the exterior of the body, fibreglass reinforcements are preferred, with properties similar to those of steel and aluminum [3, 5, 6]. Fibres of flax, hemp, jute and chenat, due to their natural properties (they are located on the outside of the plant stem thus giving them stability in the wind), confer impact stability in case of accidents. They have been successfully tested even on racing cars, then moving on to the series production of road vehicles [3].

Reinforcement fibres are generally referred to as active reinforcing additives, increasing the stability and rigidity of the components. The efficiency of fibre reinforcement increases as interruptions between fibres, in the plastic mass, become increasingly rare [6]. Between the complexity of the achievable components and their mechanical properties there is a correlation depending on the fibre length [7, 8]. The most commonly used reinforcements are flax, hemp as well as jute, kenaf, sisal or abaka reinforcements [6].

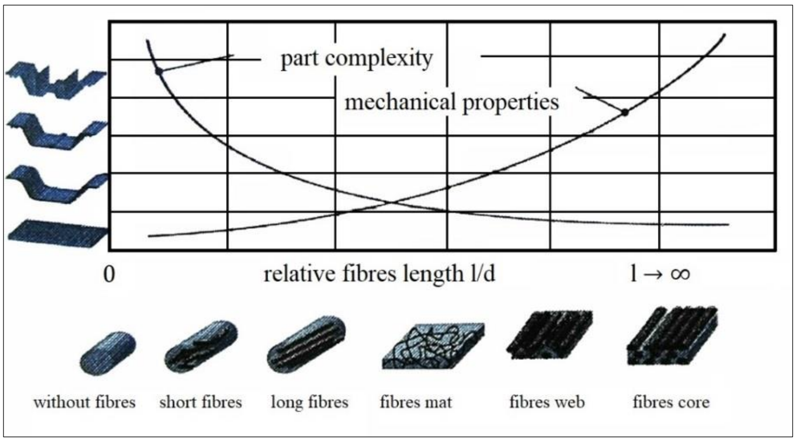


Figure 1. Correlation between the achievable complexity of the components and mechanical properties, depending on the length of the reinforcement fibers [8]

Carbon fibres have a higher stability than natural fibres and a lower mass. They are preferred for light parts in the aeronautics, automotive, wind power and sporting goods industries [5]. By manufacturing of lightweight components, fibres or carbon fibre braids are incorporated into a plastic matrix. The manufacturing technologies are specific to the production of long fibres reinforced plastics, such as pressing, filament winding, or hand lay-up [3, 9]. Carbon fibres made by PP carbonization, having a lower price than natural fibres or glass, were initially preferred by the aeronautics and racing cars industries. Subsequently, however, carbon fibres from Lignin were produced with a slightly lower stability than those produced from petroleum, but higher than glass fibres, thus making the first series of BMWi3 cars with carbon fibre components in 2013 [3]. In previous decades, researchers have also been concerned about breaking capacity of composite brake shoes for different types of vehicles [10].

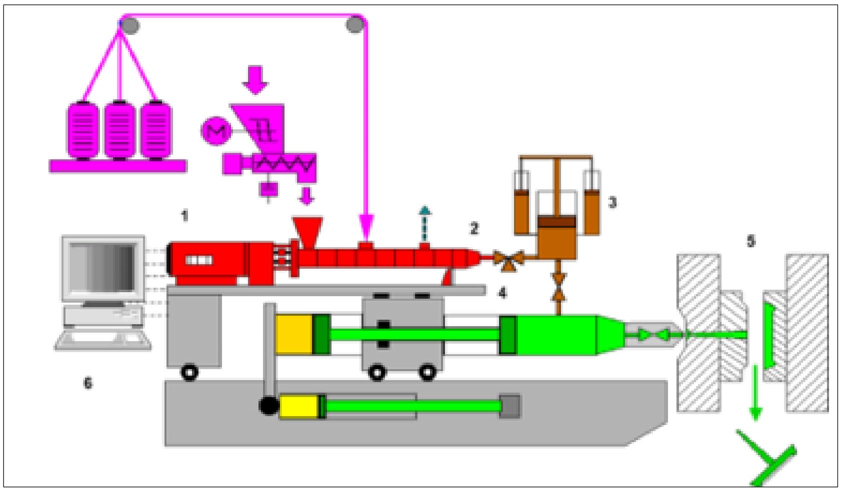
When designing the lightweight components of vehicles, three aspects are important: (a) construction, (b) design and (c) materials used [11]. The geometric complexity of the achievable components and the requirements regarding the mechanical properties determine the practicable manufacturing technology [8]. The potential of reinforcement is efficiently used by following of the property's dependence on orthotropy (fibre orientation) in the design concept and by using of appropriate technologies during the execution [5]. A recent overview regarding the influences of materials, process, design or management show the recent study of Luca & Pasare (2019) using the Ishikawa diagram - Model 4M + 5 M and deliver a new classification of causes which generate defects of injection molding products [12]. An efficient technology for reinforced automotive components is the IMC machine from Krauss Maffei.

This paper aims to analyze the reinforcement of PLA-TPU-Blends biomaterials, highlighting the properties and the quality, and describing the process of obtaining Green Carbon fibres from algae.

2. Materials and methods

2.1. Optimization of the processability using Krauss Maffei's Injection Molding Compounders (IMC) technology

This technology was realized by coupling a twin screw extruder, as a reactor for modifying plastics, with an injection moulding and close-/mould-system in a single machine and it was developed and optimized in collaboration with IKT University of Stuttgart. Advantages of this technology are observed particularly where it is important to achieve high throughputs, to manufacture products with high filler contents or to solve complex plastification and compounding problems. As a result, injection moulding compounders are venturing more and more into new application fields [13]. Convinced of the outstanding advantages of the IMC technology, the supplier for the auto industry Faurecia (Nanterre, Paris) successfully adopted the IMC Krauss Maffei technology immediately after its launch on the market. Faurecia specializes in the production of several car components (doors, cockpit, dashboards, seats, frontends and exhaust) and is the number 1 car components manufacturer in Europe and number 3 worldwide. According to its statistics, Faurecia delivers 26% for PSA-Gruppe (Peugeot, Citroen), 23% for VW, 16% for Renault-Nissan, 10% for Ford, 6% for General Motors and Daimler Chrysler and 4% for BMW. The main market is France (35%), followed by Germany (24%) and the rest of Europe (25%), with Faurecia being the main supplier on the frontend market [14].



Legend:
(1.) ZE 25 – L/D=56,
(2.) start-up valve,
(3.) melt storage system,
(4.) injection moulding system,
(5.) close-/mould-system,
(6.) Interface

Figure 2. Injection moulding compounder (IMC) from Krauss Maffei
[Source: IKT Uni Stuttgart]

The modular construction of the twin-screw extruder in the IMC machines allows the technological process to be adapted by choosing the appropriate elements in the twin screw configuration, and by adjusting the rotation speed of the screw, the optimal reaction time between the added components is also adjusted, resulting in a homogeneous compound, with constant properties. Coupling a continuous-operating twin screw extruder to the injection molding machine is done through a melt storage system. Fibres, reinforcing materials and additives can be effectively incorporated into the polymer matrix. The modular construction of the machine allows the addition of additives in different zones required by the production process. The one step process using injection moulding compounder (IMC) has particular advantages especially in reinforcing fibre materials: (1) reducing fibre shortening, by eliminating granulation of materials in the "two steps" process (compounding/extrusion and injection moulding), (2) reducing material overheating, the material being heated in the IMC only once, (3) increasing mechanical properties of products [15]. Thermoplastic materials with long fibre reinforcements are obtained by adding fibres directly from the rowing. The amount of added fibres is regulated by the number of filaments in the rowing and the speed of the twin screw. Shortening the fibres and dispersing them in the polymer matrix depends on the twin screw extruder elements used. For the proper dispersion of the fibres in composites, even special multi comb elements (germ. Multikaemmelemnte MKE) elements [16] have been designed at IKT University of Stuttgart.

2.2. Properties optimization by reinforcement of the bio materials PLA-TPU-Blends

Due to the decrease in the level of oil resources, bio-sourced materials have a growing demand on the market. The most commonly used organic plastics in components at the moment are made from sugar, starch, cellulose, Phenol or Lignin oils. The Agency of Renewable Materials Germany by her German name Fachagentur Nachwachsende Rohstoffe e. V. (FNR) 2015 statistics report a global production of 1.5% organic plastics.

This paper presents, as example, the reinforcement of PLA-TPU-Blends biomaterials, made at IKT University of Stuttgart, with natural fibres and glass using the IMC machine, provided by the institute. PLA-TPU-Blends were made according to WO/2011/157691 [17].

PLA is a biomaterial made from sugar, beet or maize, produced by Nature Works and commercialized at favorable prices. In most used production processes, such as the Nature Works manufacturer, the lactic acid diester, the lactide, is first dimerised and purified. Then a synthesis of Polylactide by ring-opening polymerization takes place. The percentages and ordering of the three lactide stereoisomers in macromolecules influence the properties of the polymers, such as: molar mass, stiffness, elongation at break, and the crystallinity ratio, which can be influenced during the production process [18].

However, the PLA biomaterial has the disadvantage of a difficult processing due to the adhesion of injection molding or thermoforming tools, its rigidity and its less impact strength. Flexibility and increased impact resistance of polylactide (PLA) was successfully achieved at IKT University of Stuttgart using thermoplastic polyurethane (TPU) as impact modifier. For PLA flexibilization, both types of synthetic thermoplastic (TPU), made by BASF, and types of Bio-TPU, made from castor oil have been tested. If the biogenic ratio in the composites made with synthetic polyurethane is determined by the biomaterial PLA, the use of Bio-Polyurethane from castor oil raises the proportion of biogenic mass of the materials to over 95%. Using a type 4,4-Diphenylmethandiisocyanats (MDI) compatibilizer, both component compatibility and improved mechanical properties were achieved through partial cross-linking. PLA and TPU components react with MDI, forming new covalent bonds and a network, but the properties of the material remain thermoplastic. Thermoplastic polyurethane (TPU) consisting of soft and hard segments split into the basic components, resulting in shorter diols. These diols react with modified 4,4-Diphenylmethandiisocyanats (MDI) and with the (-OH) groups of polylactide (PLA) forming new covalent bonds. Through these reactions a Block-copolymer is generated at the border between the two phases, which prevents the separation of the two phases in the following processes. By reinforcing composites with glass or natural fibres, Isocyanate groups can react with (-OH) groups on the surface of the fibres, preventing the so-called pull-out effect of the fibres [17]. The mechanical properties achievable by creating blends from PLA and TPU have been presented detailed at scientific symposiums [19, 20], and the potential of using these PLA-TPU-Blends in the automotive industry has been studied by comparing the mechanical properties with those of the PA6, PA66, PP polymers [21]. In the numerous studies carried out at IKT University of Stuttgart, remarkable was a linear decrease in PLA rigidity, as well as an exponential increase in elasticity and impact resistance of PLA – TPU - Blends, proportional to the added TPU (Figure 3).

Studies carried out at IKT University of Stuttgart show a good correlation of mechanical properties with PLA-TPU-Blends morphologies and an influence of the proportion of MDI compatibilizer on mechanical properties. Moreover, the comparison of PLA-TPU-Blends properties with those of PP, PA6, PA66 synthetic materials (Figures 4 and 5) showed comparable and even better mechanical properties than those of the conventional materials used in the automotive industry. Thus, the types of PLA-TPU-Blends (70:30) have approximately the same E-Module as PE-HD (High-density polyethylene), PP-B (PP block copolymer), PP-R (PP random polymer), as it can be seen from Figure 4, but higher yield strength than of conventional PE and PP plastics. The PLA-TPU-Blends types (80:20) have a slightly higher E-Module than the PA6 conditioned (after the absorption of humidity) and similar yield strength. Remarkable is the comparison of the impact resistance of these PLA-TPU-Blends with different types of PP (Figure 5), in which the superiority of the bio PLA-TPU-Blends bio materials is clearly increased, beginning with approx. 20% TPU added [20].

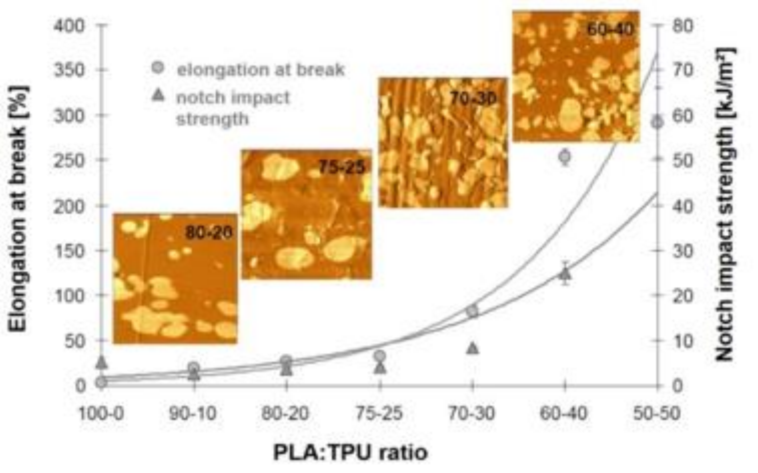


Figure 3. The influence of Bio-TPU on elasticity and impact strength

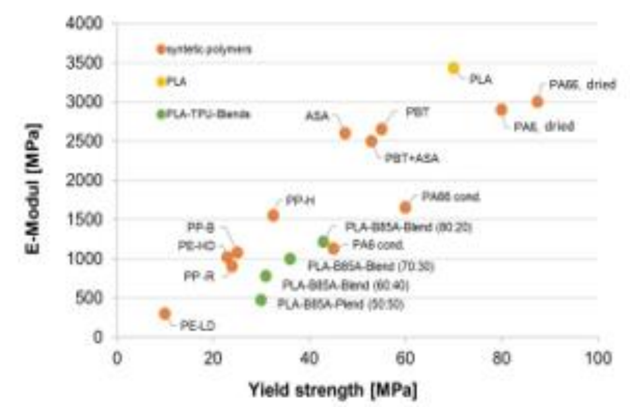


Figure 4. Comparison of common syntetic polymers with PLA-TPU-Blends

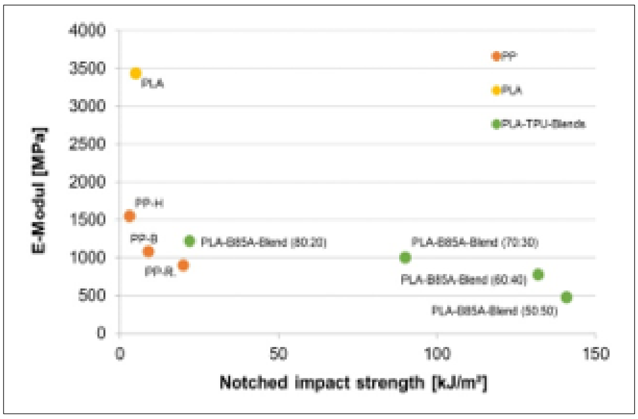


Figure 5. Comparison of PLA-TPU-Blends toughness with Polypropylen PP

The good workability of the modified PLA-TPU-Blends materials has been successfully tested in fold core materials for sandwich structures for aircraft industry (Figure 6).

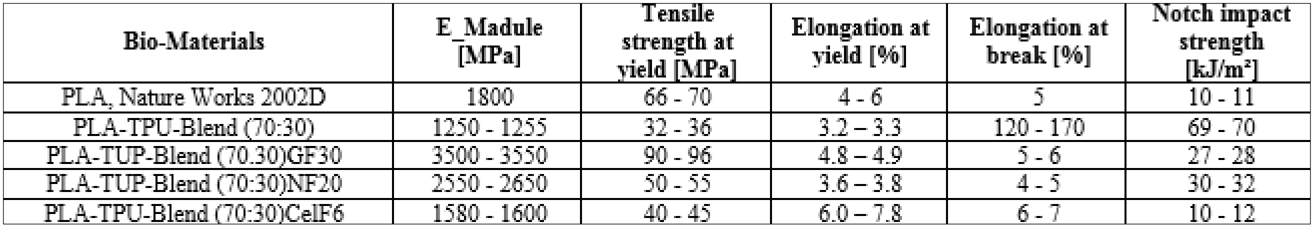
Figure 6. Core of foldcore materials, the basic elements of lightweight construction for aircraft industry

The fold core materials are the basic elements of lightweight construction with good stability and stiffness and they are composed of several layers. A possible variant consists of a core and two plates, which are bonded to the core. The core has the function of keeping the two cover plates at a distance, thus the cover plates can take over the load force, which would cause bending. The sheets made from PLA-TPU-Blends have a very good workability in the moulds for making fold core materials for sandwich structures with remarkable mechanical properties [22].

2.3. Optimization of the mechanical properties when reinforcing PLA-TPU-Blends with fibres

Previously, we specified that one of the necessary properties of the car components is the impact resistance in case of accidents. The increase of the impact resistance of the bio PLA material by the addition of TPU was highlighted. Increasing the impact resistance of composites can also be achieved by reinforcing them with natural fibres or glass, thus making reinforced composites with increasingly efficient properties. In the example of this work, the reinforcement of bio-polylactide material (PLA) with fibres was successfully performed in one-step process, when the PLA was modified with the more flexible thermoplastic polyurethane (TPU) material using the IMC machine provided by the IKT University of Stuttgart. Using the IMC machine, PLA-TPU-fibre reinforced blends were made according to WO/2011/157691 - Method for producing blends from Polylactide (PLA) and thermoplastic Polyurethane (TPU) - by adding glass and natural fibres directly from rowing in a one-step process [17]. The mechanical properties achieved when reinforcing PLA-TPU-Blends (70:30) with fibres are shown in Table 1. For experiments, a Nature Works 2002D type PLA with an 1800 MPa E-Module and a synthetic B85A type Polyurethane (BASF) were used. For reinforcement, StarRov® LFTPlus 490 (size prepared for PP) glass fibres from Johns Manvile, Denver, USA, cellulose rowings type Tencel® and jute fibre rowings were used. The amount of fibres in compound and the workability depends on the quality of the fibres, the machine dimensions, the twin-screw extruder configuration designed and the practicable compounding speeds. For this purpose, studies were carried out at IKT University of Stuttgart with different twin-screw-extruder configurations and subsequently the mechanical properties and the quality of the composites obtained were analyzed. PLA-TPU-Blends with approx. 30% glass fibre were carried out using the IMC machine provided by the institute. The jute and cellulose fibres used being lighter, the maximum amount of fibres in good working conditions was approx. 20-22% jute and approx. 6% cellulose.

Table 1. Mechanical properties of fiber reinforced bio materials



Bio-Materials	E_Madule [MPa]	Tensile strength at yield [MPa]	Elongation at yield [%]	Elongation at break [%]	Notch impact strength [kJ/m²]
PLA, Nature Works 2002D	1800	66 - 70	4 - 6	5	10 - 11
PLA-TPU-Blend (70:30)	1250 - 1255	32 - 36	3.2 – 3.3	120 - 170	69 - 70
PLA-TUP-Blend (70.30)GF30	3500 - 3550	90 - 96	4.8 – 4.9	5 - 6	27 - 28
PLA-TUP-Blend (70:30)NF20	2550 - 2650	50 - 55	3.6 – 3.8	4 - 5	30 - 32
PLA-TPU-Blend (70:30)CelF6	1580 - 1600	40 - 45	6.0 – 7.8	6 - 7	10 - 12

The mechanical properties shown in Figure 7 highlight the flexibility of bio PLA material in addition to TPU, when the E-Module is reduced from 1800 MPa to approx. 1250 MPa and the elasticity increases from 5% for PLA, to 120-170% for PLA-TPU-Blends (70:30). By fibre reinforcement of PLA-TPU-blends (70:30) it is noticed a relative percentage increase of the E-Module of approx. 181% at the addition of 30% glass fibres compared to the initial value of PLA-TPU-Blend (70:30), and for composites reinforced with approx. 20% jute fibres, a relative percentage increase of 108% E-Module, and in composites reinforced with approx. 6% cellulose fibres a relative percentage increase of only approx. 27%.

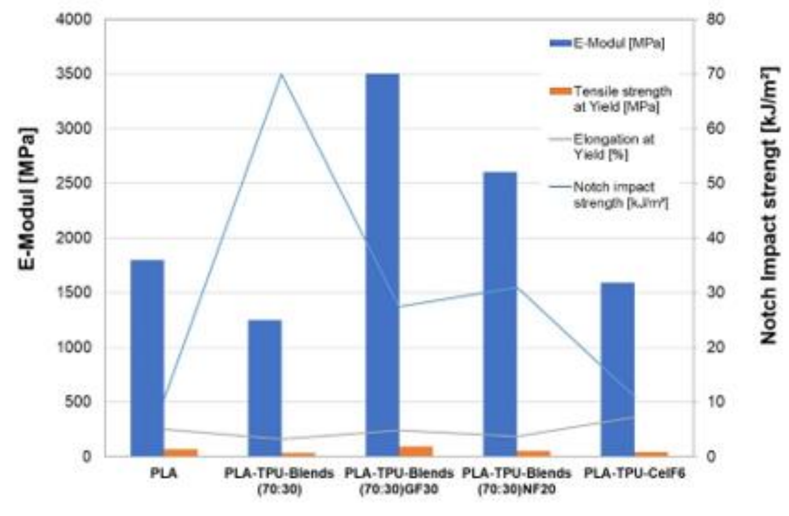


Figure 7. The mechanical properties of PLA-TPU-Blends by reinforcement with fibres

Figure 7 also shows a remarkable variation of impact strength. At TPU ratio of approx. 30% substantially increases the flexibility of the material (from 5% to 120-170%), and its brittle properties improve with approx. 600%, notch impact strength increasing significantly in this case from approx. 10 [kJ/m²] approx. 70 [kJ/m²]. By fibre reinforcement, in general, there is a decrease of notch impact strength compared to that of the basic material PLA-TPU-Blend (70:30), for all the types of fibres used, the relative percentage decrease being dependent on the type of fibres used (Table 1), however, the brittle properties remain better than the bio PLA material. By glass fibre reinforcements, notch impact strength compared to PLA-TPU-Blends (70:30) has a relative percentage decrease of approx. 61%. The notched impact strength of PLA-TPU-Blends (70:30) reinforced with 20% jute fibres decreases with approx. 55%, and by using of 6% cellulose result a relative percentage decrease of notch impact strength of approx. 84%.

Compared to PLA, fibre reinforcement and the flexibilization using a TPU ratio of approx. 30% result in a relative percentage increase of the notched impact strength of approx. 162% for glass fibre reinforcements, approx. 195% for samples armed with approx. 20% jute and a relative percentage increase of only approx. 5% on reinforcement with 6% cellulose.

Of course, other types of natural fibres can be also successful used for reinforcement: flax, hemp, kenaf, ramie, abaka, nettle, having densities close to approx. 1.2-1.6 g/cm^3. The sisal fibres have a lower density. The finesse, stability, flexural modulus and elongation are different. The quality of the fibres depends on the preparation method [3].

2.4. Quality analysis of fibre reinforced composites

Fibre dispersion, the adhesion to blended components and the fibre length were subsequently analyzed with the microscopic equipment provided by IKT University of Stuttgart. Figure 8 shows the good adhesion of PLA-TPU-Blends matrix fibres.

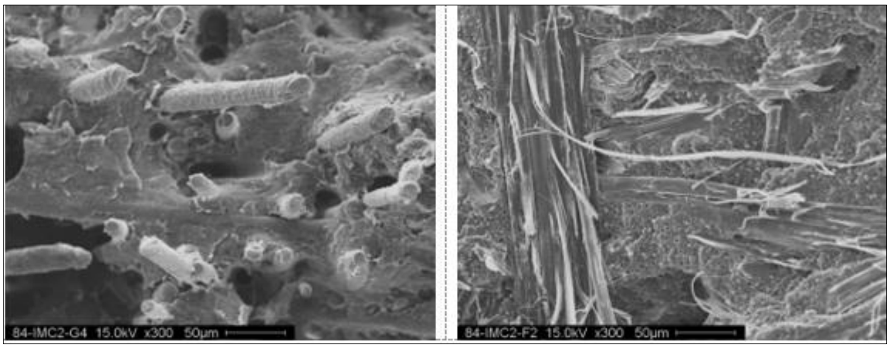


Figure 8. Examples of PLA-TPU-Blends with glass reinforcement (left) and jute reinforcement (right) (Source: IKT Uni Stuttgart)

When reinforcing PLA-TPU-Blends with fibres (glass and natural), the components also react with the groups (-OH) on the fibre surface, thus making a good connection between fibres and blends, which prevents the so-called pull-out-effect. PLA-TPU-Blends reinforced with natural fibres can be used to make the interior body elements of vehicles [17, 19-21].

2.5 Thermal stability of reinforced PLA-TPU-Blends

One of the important properties of the automotive components is the thermal stability. This components heat up either during operation, at the circulation of hot fluids through them, or under the influence of the solar radiation. Technical problems like this can be hardly or sometimes impossibly to be solved using of common materials. The reinforcement with fibres increases the dimensional stability under heat of the composites. For example, when reinforcing PA6 with glass fibres in a proportion of 30%, the dimensional stability under heat of composite PA6GF30 increases to 190-215°C, compared to 50-80°C, for PA6. In PA66 reinforcement with 30% glass fibres, the thermal stability is modified up to 235-250°C for PA66GF30, compared to 70-100°C for PA66 [6, 21]. A high heat-aging resistance up to 220°C, excellent weld line strength and burst pressure performance need automotive components like air intake manifold. The steady heat transfer of the engine polyamide intake manifold was studied at the Politehnica University of Timisoara (UPT). Experimental data is used to generate the numerical model of airflow simulation through the intake manifold [23-25]. Heat-resistance Polyamide (PA) type Ultramid®Endure D3G7 reinforced with glass fibres with a very good processability and its high heat-aging resistance up to 220°C was developed 2017 at BASF Company for air intake manifold with integrated charge air cooler by Magneti Marelli, a business of Fiat Chrysler Automobiles (FCA) for the Alfa Romeo Giulia [26].

2.6. “Green Carbon” in composite for automotive

The basic component of lightweight construction is lightweight material [5]. The advantage of glass fibres is the low price and they are currently available. Carbon fibres, though more expensive, are much lighter and have even better mechanical properties than glass fibres. Natural hemp fibres also have interesting properties at a low price. Tensile strength and processing temperature are limited by natural fibres [6]. However, given the specific weight, carbon fibres have the most remarkable properties regarding stability and rigidity [5].

2.6.1 The production of Green Carbon fibres from algae

The production of lignin carbon fibres is more economically advantageous. Nowadays innovative “Green Carbon” fibres were carried out from acrylonitrile (AN) obtained from the production of Bio-Diesel from algae. Figure 9 shows a flow chart of the Bio-Diesel production from algae [27]. Theoretical calculations show that the algae used to make carbon fibres consume more CO_2 from the atmosphere than it is released due to the decomposition of the composites made with these fibres, the ecological balance being in this case negative [27–29]. The technological process for the manufacture of "Green Carbon Fibres" from algae and their mechanical properties have been studied in detail by researchers at the Technical University of Munich (TUM), and subsequently found a number of application areas. Thomas Brueck (TUM) attests to the quality of carbon fibre from algae: they are absolutely identical to those of carbon fibres of petroleum origin, already widely used in industry. Current research projects aim to use, on a wider scale, these fibres of biological origin in the aeronautical and automotive industries. In an innovative project of TUM, the applicability of carbon fibres produced from algae has already been studied, in combination with hard granite stones, developing new construction materials, with a negative CO_2 balance, lighter than aluminum or steel [29].

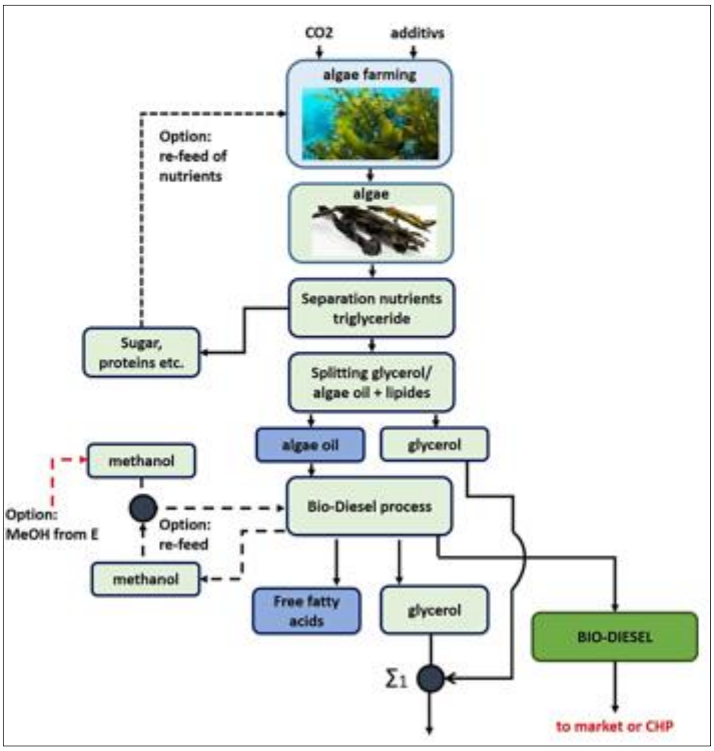


Figure 9. Flow Chart: Bio-Diesel production from algae [27]

In algae production, CO_2 is incorporated by algae as a bio-mass in the form of sugar or algae oil. This algae oil is extracted and is the raw material for other industrial processes, such as obtaining Bio-diesel (Figure 9) at the AlgaeTec Center of University of Technology in Munich. Microorganisms, such as yeasts, convert sugar from algae, through an enzymatic process, into glycerin and fatty acids, which are the basic raw material for other products, such as anti-friction fats or additives [27].

Conventional carbon fibres have been obtained since 1950 through the classic "SOHIO" process for the conversion of acrylonitrile (AN) obtained from Polypropylene (PP) into polyacrylnitril (PAN). For “Green Carbon fibres production”, several processes have been studied at TUM [27-29]. For the manufacture of polyacylnitril (PAN) from algae oil resulting from the production of Bio-diesel, advantageous results were obtained using the "DRALON" technology. Green Carbon from algae is obtained by carbonizing PAN fibres, in a process similar to the conventional one used to produce carbon fibres (CF) from PAN produced from Polypropylene (PP) of oil origin [27]. In order to increase the stability of the fibres, a so-called "graphitization" of the fibres can be carried out at temperatures higher 1800°C, after which a crystalline carbon structure is formed [6, 27].

2.6.2 Feasibility study regarding “Green Carbon” fibres adhesion by reinforcement

Therefore, carbon fibre reinforcements can be made with both carbon fibres of petrochemical origin (PP) and biological fibres, from lignin or algae. The good adhesion of the fibres of the polymer matrix determines the quality of the product. In the case of natural fibres, the (-OH) groups on the fibre surface can react with the MDI additive used in the manufacture of PLA-TPU-Blends. In the case of carbon fibres, the -NCOO groups of the polyurethane molecules and the additives (MDI or HDI) can react with polyacrylnitril (PAN) leading to a good adhesion of the carbon fibres in the composites made. Analyzes with the Fourier transform infrared spectroscopy (FTIR), carried out by Panda & De (2015) revealed new links between the groups (–NH–CO–O–) and PAN. The intermolecular hydrogen bonding between the hard crystalline and amorphous parts with the carbamate (–NH–CO–O–) network offers resistance to pH and temperature conditions [30]. Also, the -COO groups of polylactide (PLA) can react with MDI. As a result of these compatibilization reactions, a network is formed between the components of the polymer matrix and the fibres, which leads to the increased stability of the composites with fibre reinforcements [17].

Middendorf emphasized in his paper presented at the 23rd Plastic Materials Colloquium (2013) of IKT University of Stuttgart the high potential of using lightweight carbon fibre reinforced components in the aeronautical, energy, automotive and sports goods industry. Fibre-reinforced materials, especially those with carbon fibres, have, because of their orthotropy (orientation dependence) as well as their remarkable stability and rigidity (Figure 10), an excellent potential for lightweight constructions. However, this potential can be used efficiently when taking into account the mechanical properties dependent on the orientation of the fibres and using appropriate manufacturing technologies [5].

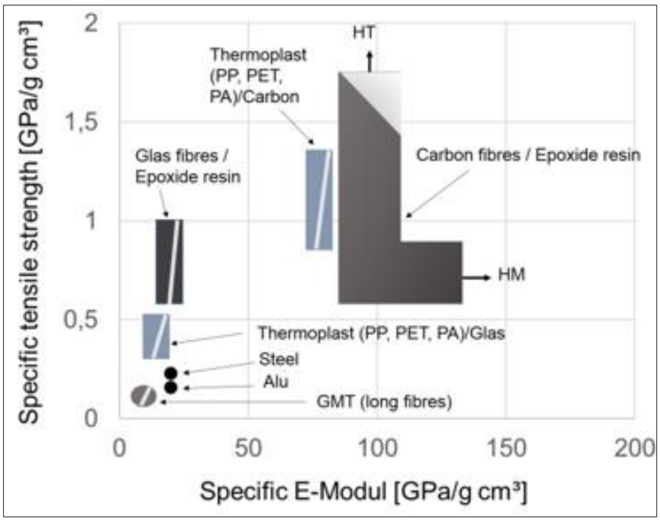


Figure 10. Comparison of mechanical properties related to the specific mass of lightweight construction materials [5]

Compared to steel, the use of fibre reinforcements can reduce the weight of the components by 60%, and compared to aluminum by 25%, an aspect demonstrated in many applications. Other notable advantages include fatigue properties of fibre reinforced composites, the variety of geometries achievable in accordance with a high degree of integration and high corrosion resistance [5]. From the mechanical properties shown in Figure 10, we notice E-Modules of fibre composites comparable to thermoplastics (PP, PET, PA). It is notable the E-Module of PLA-TPU-Blends (70:30) GF30 approx. 3500 - 3550 MPa (Table 1), close to that of PP, PA, PET and Epoxide resin with fibreglass reinforcement.

3. Results and discussions

Starting from the current situation of declining oil resources, researchers are focusing more and more on materials from organic sources. New materials with remarkable properties are being developed in more and more innovative projects. Given that researchers at the University of Munich have succeeded in creating new carbon fibres, generated from algae and called "Green Carbon", the idea of this feasibility study was born in which the possibilities of making composites with reinforcement from Green Carbon for automotive, aircraft or sports industries are described. Feasibilty study is the basic tool in engineering and describes a way to make a product or a project. In the present study, the proper definition of "feasibility study" was taken into account, which according to von Kennon & Drury's "Guide to mergers and acquisitions" [31] and in general according to project management [32] refers to an analysis of the possibilities of successfully carrying out a project taking into account all relevant factors: economic, technical, legal and other conditions imposed by the implementation plan. The novelty of this project is the use in lightweight car components of Green Carbon fibres as new materials of organic origin with a negative energy balance, these being lighter than fibre carbon of petroleum origin, also having mechanical properties equivalent to those of conventional carbon fibres made so far from Polypropylene (PP). The use of PLA-TPU-Blends with reinforcements for automotive and aircraft components has been successfully verified, blends having a very good adhesion to fibreglass and natural fibres or decorative foils used in the manufacture of dashboard elements. Figure 6 shows an example of the use of PLA-TPU-Blends materials in fold core for aeronautics components.

According to the requirements of a feasibility study, the possibilities and advantages of making reinforced components using the IMC technology (Figure 2), of great attractiveness on the current automotive market, with the special advantages of preparing the material in one-step by coupling a twin-strew extruder machines and an injection machine, thus avoiding material damage caused by overheating and a shortening of the fibres in the reinforcement. At the same time, the choice of technology was taken into account by the fact that nowadays the plastic preparation is realized more and more using reactive extrusion by functionalization, blending or cross linking of basic polymers. Using the IMC technology, the properties of materials made by extrusion reagents can be determined "online", "just in time" or "just in process" with an online-rheometer and sensors incorporated in the machine, the correction of production parameters can be performed immediately thus improving the technological process from an economical perspective.

Since the introduction, the importance of aspects (a) construction, (b) design and (c) material used has been shown. Using IMC technology increases the complexity of the components and the achievable mechanical properties. It is also shown in Figure 1, that there is a relationship between complexity and fibre length. A very good analysis of all influences related to material, process, design or management is done with Ishikawa diagram. To exemplify and better understand the mechanical properties achievable in Green Carbon fibre reinforcement, the process for preparing fibreglass and natural reinforcements was presented as an additional part of the study conducted at IKT University of Stuttgart and the conditions imposed by the legislation for the realization of the project for which this feasibility study was carried out, exposed in detail in WO/2011/157691 - Method for producing blends from Polylactides (PLA) and thermoplastic Polyurethane (TPU) were studied as well. When choosing a suitable material for a product, the engineer focuses on the existing data in the field and the attractiveness of the project on the market. For this reason, subchapter 2.1 of this paper presents a small marketing study, showing the attractiveness and capacity of components used on the market by car manufacturers such as Peugeot, Citroen, Daimler, BMW, VW, Ford, Renault and other examples in this study. Mechanical properties achievable in glass fibre and natural reinforcement of PLA-TPU-Blends were shown as an example in Figure 7. Besides the increased resistance to impact compared to Polylactid (PLA), PLA-TPU-Blends bio materials are more flexible, the properties being adaptable to the requirements of the finished product by varying the proportion of Polyurethane (TPU). When using a bio-TPU from castor oil the total biogenic mass of PLA-TPU-Blend reaches over 90%.

Natural fibres have been used as reinforcement since the post-war period due to the limited possibilities of that time. Composite materials have evolved more and more and fibreglass composites have gradually replaced automotive components. Composites with carbon fibre reinforcement are lighter than glass reinforcement and have, as can be seen from the Middendorf diagram in Figure 10, even better properties than steel and aluminum. Researchers in the field have highlighted a dependence between fibre length and the complexity of the finished product, which can be seen in Figure 1 of this feasibility study and which must be taken into account having an important role in choosing the technological process, especially the configuration and speed of twin-screw extruder and process temperature.

For easy guidance of the engineer who wants to replace currently used automotive components with bio materials such as PLA-TPU-Blends, mechanical properties of PLA-TPU-Blends materials were compared in the previous feasibility study "The potential of using bio plastic materials in automotive applications" [21] with conventional plastics such as Polypropylene (PP), Polyamide (PA), Polyethylene (PE), as well as Polybutylenterephthalate (PBT), a Styrol-Copolymer (ASA) and PBT/ASA- Blends, commonly used in the automotive industry. The comparison can be seen in figures 4 and 5 of this study. The properties of PLA-TPU-Blends with fibre reinforcement are similar to conventional plastics and can be successfully used in the manufacture of reinforced components in the automotive and aeronautical industries. Also in the previous feasibility study were presented in detail the achievable properties in the production of PLA-TPU-Blends and how the proportion of Polyurethane and the type of synthetic or bio Polyurethane influences the mechanical properties. The analyzes performed at IKT University of Stuttgart showed a good correlation of the morphological structure (Figures 3 and 8) with the mechanical properties.

A necessity of the feasibility study is the verification of other influences on the finished product that must be taken into account both when designing injection molding tools and when choosing the entire production process to achieve remarkable properties for fibre reinforcement. We have previously discussed a number of influences on fibre size. Middendorf clearly shows that there is an orientation of the fibres to the injection, which also requires the choice of an appropriate production process, the properties of the product depending on the orientation of the fibres and their size. The potential of carbon fibre reinforcements can be effectively utilized by choosing an appropriate design by following of the property’s dependence on orthotropy (fibre orientation) in the design concept of the carbon fibre light reinforcement materials and the corresponding manufacturing technologies, such as IMC technology. In addition to the twin-screw configuration, the process temperature and the rotation speed of the twin-screw, additives added to the chemical process will determine at the same time both the properties and the morphology of PLA-TPU-Blends materials. For this reason, in chapter 2.2 “Properties optimization by reinforcement of bio materials PLA-TPU-Blends” there were described the reactions between the components of bio materials, which constitute the matrix in which the fibres are incorporated, for a better understanding of the need to discuss the reactions that develops between the fibres of Green Carbon from algae, described at the end of this feasibility study. The reactive additives must be compatible with both the components in the blends and the added fibres, thus eliminating the pull-out effect of detaching the fibres from the matrix. During this time, the surface of the glass fibres must be pre-processed to react during reinforcement with the polymer matrix. Due to their nature, the natural fibres have -OH groups on the surface, which react with additives such as MDI and Polyurethane used in blends. The research of the literature found that they present groups, which react with MDI and Polyurethan, respectively, which by its nature contains MDI. The reactions between PAN and the (-N-CO-O) groups were demonstrated by FTIR analysis performed by Panda & De. This highlighted the reactions that will take place between Green Carbon fibres and the components of the mixture, meaning between Poyurethan (TPU) and Polyacrylnitrile (PAN) - the basic component of carbon fibres – to reactive extrusion, offering resistance to *p*H and temperature conditions of the reinforced material.

Subchapter 2.5 of this feasibility study also showed the increasing stability of the reinforced materials under heat and gave as an example the heat-resistance Polyamide (PA) type Ultarmid®Endure D3G7 for intake manifold, made by BASF. Preliminary studies for the intake manifold of reinforced polyamide were made at the Faculty of Engineering from Hunedoara, Politehnica University of Timișoara.

Another important advantage taken into account in the feasibility study is that, using Green Carbon fibres from algae in reinforcements and bio plastics such as PLA-TPU-Blends, especially in blends with polyurethane from castor oil, the total biogenic content of the material grows to over 90%, the carbon fibres in algae are lighter than those in synthetic carbon and lignin and have a negative CO_2 balance. The lignin carbon fibres are more economically advantageous and have already been used in the mass production of BMWi3 vehicles. "Green carbon" from algae with CO_2 negative balance reduces both the weight and the CO_2 balance of the final product.

From the examples presented, we notice the high potential of using fibre reinforced composites in lightweight construction for the automotive, aeronautical, energy and sporting goods industries.

This feasibility study provided a complex perspective on the field of green composites for automotive components, more specifically on PLA-TPU-Blends reinforced with Green Carbon fibres. The properties of these materials were tested and analyzed, then compared to those of synthetic polymers.

4. Conclusions

Based on the experimental data presented in this paper, it can be concluded that the chosen examples clearly show that nowadays the preparation of plastics has an intermediate position between that of engineering and natural science, as well as between material science and computer science, which is developing more and more. Engineers working in the field of plastics must master both manufacturing technology and chemical processes, machines and finished products with their properties, basic knowledge of polymer chemistry and fluid flow (rheology) absolutely necessary for tools design. Due to environmental changes, technological processes are increasingly innovative. Complex ceramic composites made of carbon fibres are currently made mainly by polymer technology, because they are sometimes impossible to achieve by conventional processes in the field of ceramics. Technologies in the field of natural science allow the realization of innovative ceramic fibres for super light components in cars and aircraft, reducing total CO_2 consumption through their negative energy balance.

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