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COMPOSITES

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CARS FROM RENEWABLE MATERIALS

Biofiber and biopolymer based composites are enjoying a renaissance for a variety of reasons and they have developed significantly over the past few years especially due to their renewable nature. The increased fuel efficiency in automotive and a growing awareness in environmental preservation are leading to further developments. Biobased fibers exhibit decent price stability, being less dependent on the price of oil than other materials and their use should be highly encouraged from an economical point of view. Biocomposites are becoming attractive alternatives to glass fibre reinforced polymer composites in automotive industries due to significant weight and cost savings. Many automotive components (interior and exterior) are now made from biofibre reinforced composites materials which are mainly based on polypropylene with reinforcing biofibres jute, flax, hemp, kenaf and wood. However, further research is still required to overcome obstacles such as moisture absorption and increased long-term stability for use as exterior components. This paper has been arranged in a way to illustrate the development of biocomposites use in automotive sector with further opportunities.

Keywords: **cars, biofibre, bio-based plastics, automotive interior component, automotive exterior component**

SAMOCHODY Z SUROWCÓW ODNAWIALNYCH

Kompozyty o osnowie polimerowej wzmocnione włóknem pochodzenia naturalnego („biokompozyty”) są coraz częściej stosowane również jako materiały konstrukcyjne. Ich główne zalety to odnawialność surowca oraz właściwości materiałowe zbliżone lub polepszone w stosunku do kompozytów konwencjonalnych, otrzymywanych na bazie polimerów syntetycznych wzmocnionych włóknem szklanym. Wyrobami z zastosowaniem surowców odnawialnych zainteresowane są różne gałęzie przemysłu, np. artykuły i sprzęt AGD, przemysł meblowy i samochodowy. Ze względu na znacznie mniejszy ciężar właściwy i wysokie parametry wytrzymałościowe kompozyty te są często stosowane na elementy i części wyposażenia wnętrza pojazdów. Dodatkową zaletą tych materiałów i wyrobów jest znacznie niższy koszt w przeliczeniu na jednostkę wagi oraz fakt, że cena włókien naturalnych jest w dużej mierze niezależna od wahań cen ropy naftowej. Części z biokompozytów są obecnie nieodłącznym elementem wyposażenia każdego nowego pojazdu. Dotychczas najczęściej stosowane są kompozyty na bazie PP wzmocnione włóknami lnu, juty, konopi, bananowca lub napełnione mączką drzewną. Obecne prace rozwojowe dotyczą poprawy wybranych charakterystyk materiałowych, jak chłonność wilgoci lub właściwości długotrwałe kompozytu (np. pełzanie). Nowym trendem jest również zastosowanie polimerów na bazie surowców odnawialnych („biopolimery”).

Słowa kluczowe: **samochody, włókna naturalne, biopolimery, części wyposażenia pojazdów**

INTRODUCTION

The field of biofibre research has experienced an explosion of interest, particularly with regard to its comparable properties to glass fibres within composites materials since 1990s. The main area of increasing usage of these composites materials is the automotive industry, predominantly in interior applications, because the need is the greatest here [1]. The growth outlook for bio-fibres in automotive components is expected to increase by 54 percent per annum [2]. The increase of biocomposites use in automotive applications is due to the legislation forcing to automotive manufacturers to reuse and recycle materials.

Biofibre reinforced polymer composites have been embraced by European car makers for door panels, seat backs, headliners, package trays, dashboards, and trunk liners and nowadays biofibre composites gain widespread acceptance in North American automotive industry [3, 4] also. More than 1.5 million vehicles substrate in the USA are the choice of bio-fibres such as kenaf, jute, flax, hemp and sisal and thermoplastic polymers such as polypropylene and polyester [3]. Bio-fibres have benefited from the perception that they are "green" or eco-friendly. What is proving more important is their ability to provide stiffness enhancement and sound damping at lower cost and density than glass fibres and mineral fillers.

The automotive industries throughout the world are continuously optimizing cost versus quality in order to remain competitive in the market. Moreover, increased importance of renewable resources for raw materials and recyclability or biodegradability of the product at the end of its useful life is demanding a shift from petroleum-based synthetics to agro based bio-fibres and biopolymer in automotive applications. To accelerate this process of switching to recyclable and biodegradable constituents, the legislations in USA & Europe have issued a specific directive on the end-of-life vehicles [5]. The directive, which came into effect at the turn of this century, predetermines the deposition fraction of a vehicle to 15% for the year 2005, and then gradually reduced to 5% for the year 2015. Furthermore, these fibre-based composites can contribute greatly to the automotive manufacturer's final goal by constituting a 30% weight reduction and a cost reduction by 20% [6].

The main drivers for use of biofibre based composites in automotive applications are demand for lightweight parts, which leads to a lowering in fuel consumption and also good recycling possibilities of the composites to reduce the waste disposal problem. The other promoting factors of biofibre composites applications in automotive sector are reduction of greenhouse emissions, competitive pricing, technical advantages, social benefits and also growth opportunities for agriculture [7]. Biofibre composites application in automobiles is currently limited to car interiors and exterior applications are occasional and limited.

BIOFIBRE

Resources

The use of bio-fibre composites for automotive components is a phenomenon that has appeared and developed. The principal fibres now being used for this purpose belong to flax and hemp, grown in the temperate climates of Western Europe, and the sub-tropical fibres, jute and kenaf, mainly imported from Bangladesh and India, banana fibre from the Philippines, sisal from the USA (Florida), South Africa and Brazil and wood fibre from all over the world. Table 1 shows the commercially important fibre sources of agricultural bio-fibres that could be utilized for composites [8]. The traditional source of agro-based composites has been wood and for many countries, this will continue to be the major source.

TABLE 1. **Commercially important fibre sources [8]**
TABELA 1. **Komercyjnie dostępne włókna naturalne [8]**

Fibre	World Production (10^3 t)
Wood	1750000
Bamboo	30000
Jute	2861
Kenaf	970
Flax	830
Sisal	378
Hemp	214
Coir	931
Ramie	249
Abaca	98
Sugar cane bagasse	75000

Properties

The bio-fibre world is full of examples where cells or groups of cells are 'designed' for strength and stiffness. A sparing use of resources has resulted in optimization of the cell functions. Cellulose is a natural polymer with high strength and stiffness per weight, and it is the building material of long fibrous cells. The principal differences between the individual fibres are on their fibre qualities, lignin content and crystallinity etc. In between fibre qualities, the cellulose content and spiral angle is differed from fibre to fibre and also in a single fibre design. Natural and wood fibre is a composite of the three polymers cellulose, hemicelluloses and lignin, in which the unidirectional cellulose microfibrils constitute the reinforcing elements in the matrix blend of hemicellulose and lignin. The structure of such a fibre was built as multi-ply construction with layers P, S1, S2 and S3 of cellulose microfibrils at different angles to the fibre axis (Fig. 1).

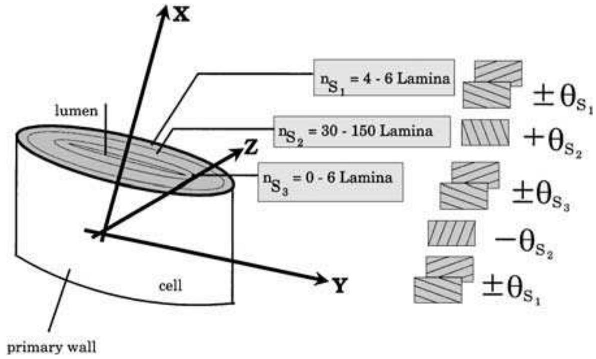

Fig. 1. Illustration of one single fibre cell [9]
Rys. 1. Schemat budowy pojedynczego włókna naturalnego [9]

According to single fibre cell layer, the different spiral angle of those layers will have a pronounced influence on the properties of the fibre. The elastic modulus dependency on the spiral angle of the fibre is determined (Fig. 2) with assuming that the fibres were lignin-free with a cellulose content of 65 wt. % typical for natural fibres. The relative thickness of the different layers were chosen to P = 8%, $S1$ = 8%, $S2$ = 76%, and $S3$ = 8%. It is seen that the elastic modulus decreases with increasing spiral angle.

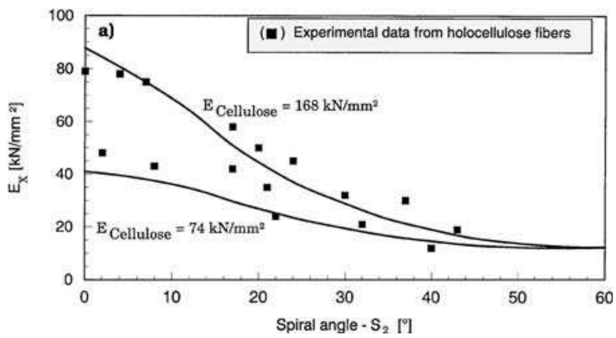

Fig. 2. Correlation between spiral angle and elastic modulus of a natural fibre [9]
Rys. 2. Korelacja pomiędzy modułem Younga a kątem nachylenia fibryl celulozy we włóknie naturalnym [9]

The combination of interesting mechanical and physical properties of different fibres is presented in Table 2.
The main reasons influencing the steady growth of natural fibres in this sector include: comparative weight reduction (10÷30%), better mechanical and manufacturing properties, easy processability, relatively good impact performance, with high stability, occupational health advantages in assembly and handling compared to glass fibre, no emissions of toxic fumes when subjected to heat, sustainable renewable raw material resource, environmental balance during material and energetic use, recycling possibilities by incineration with energy recovery or by regrinding and relative cost advantages compared to conventional constructions.

Constraining factors which are preventing the more widespread adoption of bio-fibre substrates include: concerns over the consistency of quality of the bast fibre supply and the long term availability of fibre, persistent technical problems, mostly connected with either fibre quality from batch to batch, or grouped as emission problems (fogging and odour).

BIOPOLYMER

Public concern about the environment, climate change and limited fossil fuel resources are important drivers to find alternatives to crude oil. Bio-based plastics may offer important contributions by reducing the dependence on fossil fuels and the related environmental impacts. Biopolymers have experienced a renaissance in the recent years. Many new polymers were developed from renewable resources. Such as starch, i.e. a naturally occurring polymer, were re-discovered as plastic material. Others are polylactic acid (PLA) that can be produced via lactic acid from fermentable sugar and polyhydroxyalkanoate (PHAs), which can be produced from vegetable oils next to other bio-based feed stocks.

The developments in emerging bio-based plastics are spectacular from a technological point of view. The market of emerging bio polymer has been experiencing rapid growth. The global average annual growth rate was 38% from 2003 to 2007. In the same period in Europe, the annual growth rate was as high as 48%. The worldwide capacity of bio-based plastics will increase from 0.36 million metric tonnes in 2007 to 2.33 million metric tonnes in 2013 and to 3.45 million metric tonnes in 2020. The most important production in terms of production volumes will be starch plastics, PLA and PHA [11].

Based on biotechnical development, as opposed to the conventional chemical conversion methods, high strength technical polymer polyamide (PA) produced based on 100% renewable resources and exhibits a particularly robust and technically relevant performance [12]. Bio-based PA (6.10 and 5.10) materials represent their weight saving of about 6%, low water absorption, better dimensional stability and improved flow characteristics compared with conventional fossil-based PA 6 compounds.

PROCESS

In principle, the production techniques for natural fibre composites can be similar to those for glass fibres. Exceptions to this are techniques used where continuous fibres are used like pultrusion or where fibres are chopped like in spray-up or SMC-prepreg preparation. Each manufacturing technology in the automotive industry has its own possibilities and restrictions. The cost of fabrication of a composites material part generally represents a major portion of the total cost. The time-tested manufacturing techniques for many applications are compression moulding, sheet moulding compound (SMC), pultrusion, reaction injection moulding (RIM), and vacuum-assisted resin transfer moulding (VARTM). Such as automotive door-in liners uses natural fibre mat which is just sprayed with resin, not moistened, and compressed into its final contour in a hot tool. The components can be covered easily by using the air permeability in a vacuum covering process (Fig. 3).
Table 3 represents an overview of the different processing possibilities in the automotive industry.

TABLE 2. **Properties of glass and natural fibres [10]**
TABELA 2. **Właściwości wybranych włókien naturalnych w odniesieniu do włókna szklanego [10]**

Property	Fibre						
	E-glass	flax	hemp	jute	sisal	abaca	cotton
Density, g/cm^3	2.55	1.4	1.48	1.46	1.33	1.5	1.51
Tensile strength*, 10^6 N/m^2	2400	800÷1500	550÷900	400÷800	600÷700	980	400
E-modulus, GPa	73	60÷80	70	10÷30	38	–	12
Specific, E/density	29	26÷46	47	7÷21	29	–	8
Elongation at failure, %	3	1.2÷1.6	1.6	1.8	2÷3	–	3÷10
Moisture absorption, %	-	7	8	12	11	–	8÷25
Price/kg, $, raw (mat/fabric)	1.3 (1.7/3.8)	- 1.5 (2/4)	0.6÷1.8 (2/4)	0.35 1.5/0.9÷2	0.6÷0.7	1.5÷2.5	1.5÷2.2

* Tensile strength strongly depends on type of fibre, being a bundle or a single filament

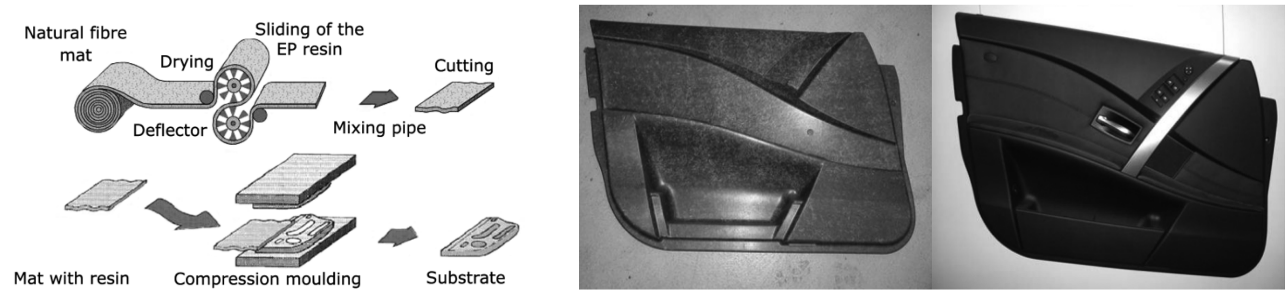

Fig. 3. Mat compression process and ready component part; raw and covered by all functional and decorative details [13]

Rys. 3. Schemat przetwórstwa metodą prasowania włókien; elementy nośne drzwi bocznych z biokompozytów [13]

TABLE 3. **Different processing techniques for automotive components**
TABELA 3. **Główne technologie przetwórcze biokompozytów stosowanych w przemyśle samochodowym**

Process	Polymer, %	Fibres, %
Casting, Hot press	Thermoset: Acrylate or Melamine resin (5)	Wood/cellulose fibre (partly synthetic fibre) (85÷90)
Fibre mat with resin, Hot press	Thermoset: Acrylate or Phenol resin (10÷15)	Wood fibre (partly synthetic fibre) (70÷80)
Fibre mat, Gluing, Hot press	Thermoset: Epoxy resin Polyurethane (35÷50)	Flax, Jute, Sisal, Hemp, Kenaf (50÷65)
Fibre mat, Gluing, Hot press, Profile (Extrudate Glued)	Thermoset: Phenol or polyester resin (50÷60)	Flax, Jute, Sisal, Hemp, Kenaf (40÷50)
Hot press	Latex (50)	Coir fibre (50)
Fibre mat, heating, cold pressing	Thermoplast; PP (Co-PES) - synthetic fibre, natural resin, cellulose acetate, lactate (45÷55)	Flax, Hemp, Kenaf (45÷55)
Extrudate profile, heating, cold pressing	Thermoplast, PP or Co-PES (65÷75)	Wood fibre (25÷35)
Long-Fibre-Injection-Moulding	Thermosets (60÷75)	Sisal fibre, Carden band (20÷40)
Long-Fibre-Injection-Moulding or mat foaming	Polyurethane (2K) resin	Sisal mat (20÷40)
Granules, Injection moulding, Extrusion	Thermoplast, PP or Co-PES, natural resin, cellulose acetate, Poly Lactic acid (60÷80)	Flax, Hemp, Kenaf (20÷40)

Johnson controls automotive presented an overview of the state of the art of the use of plastic-natural fibre composite materials for interior car parts and the technologies to produce such parts (injection moulding, low pressure injection moulding and co-injection moulding), with emphasis on the research lines performed on several kinds of natural and wood fibres (jute, flax, kenaf, eucalyptus) to be applied to semi-fished products: granules (short natural fibre) for injection moulding processes and they are: (a) FIBRIT process, (b) Lignotock process, (c) Polywood process, (d) natural fibre/PP (LoPreFin, Fibroflax) process, (e) Fibropur process, and (f) COIXIL process [14].

APPLICATIONS

The automotive industry requires composite materials that meet performance criteria as determined in a wide range of tests. Typical market specification includes the following criteria: ultimate breaking force and elongation, flexural and impact properties, fogging, odour and acoustic properties, suitability for processing: temperature and dwell time, dimensional stability, water absorption and crash behavior.

Interior components

Most of the composites currently used by the industry are designed with long-term durability in mind. Current applications, together with typical weights of used natural fibres are: such as front door-liners (1.2÷1.8 kg), rear door-liners (0.8÷1.5 kg), and seat backs (1.6÷2.0 kg), boot-liners (1.5÷2.5 kg), headrests (~2.5 kg) etc. The automotive components with biofibre reinforced composites can be expected to increase steadily with increased model penetration. All major vehicle manufacturers around the world now use natural fibre composites in various applications such as those listed in Table 4.

The automotive company Ford (Germany) is using kenaf fibres imported from Bangladesh in their model ”Ford Mondeo” and the door panels of the Ford Mondeo are manufactured by kenaf reinforced PP composites. The BMW Group incorporates a considerable amount of renewable raw materials into its vehicles. Package trays and door panel inserts for Saturn L200s and European-market Opel Vectras are made from mixture of kenaf and flax fibre.

Toyota Auto Body has developed body parts including the hood, pillers and roof using bio-plastic derived from plants [15]. The spare tire cover made from bio-

TABLE 4. **Automotive models, manufacturers and components using bio-fibres**
TABELA 4. **Zestawienie części i elementów samochodów różnych producentów wzmocnionych włóknem naturalnym**

Model	Manufacturer	Components
A2, A3, A4, A4 Avant, A6, A8, Roadstar, Coupe	Audi	Seat back, side and back door panel, boot lining, hat rack, spare tire lining
C5	Citroen	Interior door panelling
3, 5, 7 series	BMW	Door panels, headliner panel, boot-lining, seat back, noise insulation panels, moulded foot well linings
Eco Elise	Lotus	Body panels, spoiler, seats, interior carpets
Punto, Brava, Marea, Alfa Romeo 146, 156	Fiat	Door panel
Astra, Vectra, Zafira	Opel	Instrumental panel, headliner panel, door panels, pillar cover panel
406	Peugeot	Front and rear door panels
2000 and others	Rover	Insulation, rear storage shelf/panel
Raum, Brevis, Harrier, Celsior	Toyota	Door panels, seat backs, floor mats, spare tire cover
Golf A4, Passat Variant, Bora	Volkswagen	Door panel, seat back, boot-lid finish panel, boot-liner
Space star, Colt	Mitsubishi	Cargo area floor, door panels, instrumental panels
Clio, Twingo	Renault	Rear parcel shelf
Mercedes A, C, E, S class, Trucks, EvoBus (exterior)	Daimler-Benz	Door panels, windshield/dashboard, business table, piller cover panel, glove box, instrumental panel support, insulation, moulding rod/apertures, seat backrest panel, trunk panel, seat surface/backrest, internal engine cover, engine insulation, sun visor, bumper, wheel box, roof cover
Pilot	Honda	Cargo area
C70, V70	Volvo	Seat padding, natural foams, cargo floor tray
Cadillac Deville, Chevrolet TrailBlazer	General Motors	Seat backs, cargo area floor
L3000	Saturn	Package trays and door panel
Mondeo CD 162, Focus, freestar	Ford	Floor trays, door panels, B-piller, boot liner

plastic poly lactic acid (PLA) reinforced with kenaf fibre was employed in Toyota RAUM (Fig. 4). Toyota Motor Corp plans to replace 20% (in mass) of plastics used for its automobiles with bioplastics by 2015 [15]. The new Prius model that Toyota debuted, however, makes much more extensive use of eco-plastics, employing a PLA-PP alloy in seven components, including the front- and rear--door scuff plates, the cowl side-trim board, and the rear-deck trim cover.

Fig. 4. Spare tire cover made from kenaf fibre reinforced PLA composites for TOYOTA RAUM [16]

Rys. 4. Pokrywa muldy koła zapasowego z biokompozytu PLA z włókna kenaf (Toyota Raum) [16]

In the automotive industry another development announced in 2008 related to the Mazda 5 car. Bioplastic (namely PLA) is used in the interior consoles along with kenaf and PLA in the seat covers [17]. In the last few years, Volvo has started to use bioplastic soya based fillings in their seats along with natural fibres [18].

Ford is also working with a biodegradable plastic (PLA) which is completely derived from the sugars in corn, sugarbeets, sugarcane, switch grass and other plants. Corn-based PLA polymer materials are used in the interior roof fabric and floor matting; soy based foam for seating, while soy and corn-derived resins replace carbon black in the tires. More immediate possibilities include using PLA for nondurable auto applications such as protective wrappings used during vehicle manufacturing and transit [4].

Mitsubishi Motor Corp. announced (February 2006) the formulation of interior automotive components from plant-based polybutylene succinate (PBS) incorporating bamboo fibres [19]. The racing car body panels of the Ford Mustang (Fig. 6) are produced with natural fibre reinforced bio resin by RTM process.

Fig. 5. Bioconcept Ford Mustang car body panels made from natural fibre reinforced bio resin [20]

Rys. 5. Karoseria samochodu wyścigowego ”Bioconcept Ford Mustang” wykonana z biokompozytów [20]

The new automobile cooler water boxes made of bio-based polyamide (PA 610) by Japanese motor vehicle supplier DENSO with Dupont (Germany) are the first technical part in the engine compartment, which is durable to long time high temperatures and aggressive chemicals [21].

Nowadays, 27 components of a car are manufactured from bio-fibre reinforced composites with a total weight of 43 kg (73% more than the previous weight) for the newest Mercedes S class [22] presented in Figure 6.

Fig. 6. Mercedes S class automotive components made from different bio fibre reinforced composites [21]

Rys. 6. Elementy wykonane z biokompozytów, Mercedes S [21]

Exterior Components

The automotive industries have been using biofibres for interior components for several years. But the new invention is that nowadays biofibre composites are used also in the exterior components of an automotive. However, the high moisture absorption behavior of these composites has restricted their use as exterior components.

Daimler's innovative application of abaca fibre in exterior under floor protection trim (Fig. 7) on the Mercedes A-class, which are extremely elastic and impressive tensile strength has been recognized [23, 24]. Mercedes-Benz Travego travel coach is equipped with flax fibre reinforced engine and transmission covers. Daimler considerably invested in research and development in flax fibre reinforced polyester composite for exterior or semi-exterior applications in recent years. A flax fibre based truck with exterior skirting panels is now in production. Other exterior parts (front bumper, under floor trim of bus) from flax fibre reinforced composites should be available shortly [25].

CONCLUSIONS

Biofibre reinforced composites has developed and employed significantly in automotive applications over the past few years. However, interfacial adhesion with a synthetic or bio matrix should be improved with suitable surface treatment. Owing to significant weight and cost savings, renewable materials are becoming attractive alternatives to glass and carbon fibre reinforced petroleum-based polymer composites. However, further research is still required to overcome obstacles such as moisture absorption and increased long-term stability for use as exterior components. Advances in construction of very large panels, structural design, and cost-effective manufacturing processes are still required. New materials from renewable resources, stronger, cheaper and eco-friendly, should be achieved. Renewable material based products for the automotive industry are the subject of increasing attention.

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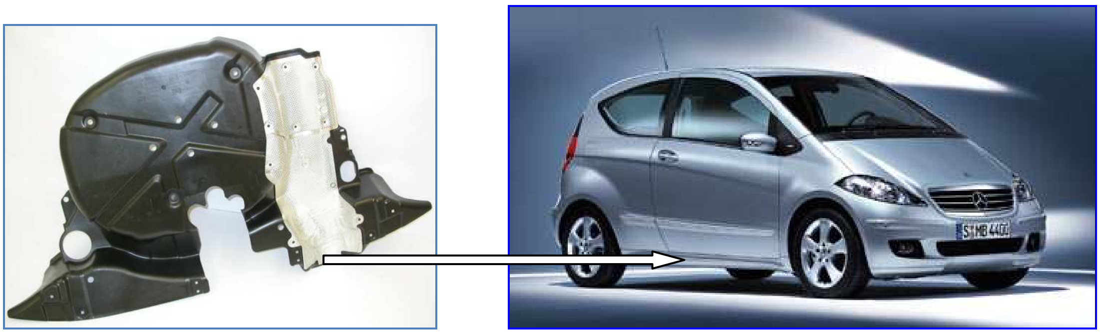

Fig. 7. Under floor protection trim of Mercedes A class made from banana fibre reinforced composites

Rys. 7. Ochrona podwozia (mulda koła zapasowego) na bazie PP/włókno bananowca, Mercedes A

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