Chapter 3
Material Efficiency and 3R Objectives for Sustainable Industry Applications

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3.1 Introduction

The European Union Directive is strictly given, until the year 2030, waste that is suitable for reuse/recycling should not be accepted at a landfill, except for waste where landfilling provides the best environmental result. By the year 2035, we should reduce the amount of waste deposited to 10%, or less, of the total amount of municipal waste generated [1]. If we announce a postponement of the deadline and prepare an action plan that the Commission accepts, the period of 10% will be extended, but we must take measures to reduce the amount of waste deposited to 25% by 2035, however, limiting landfilling to 25% by 2035 is ambitious [1, 2]. And this is our primary goal of the proposed manuscript, reduce, recover, and recycle of windscreen foil. PVB foil is one of the essential parts in the interlayer of car glass or safety glass. Laminated glass, commonly used in the architecture and automotive industries, contains a protective interlayer, usually PVB, which forms a kind of fuse between two glass panes. From a study presented on Transparency market research [3], it is known that land transport was the largest for the end user of the PVB film segment on the market, representing more than 45% use as in 2014 [2, 4]. Figure 3.1 shows in detail the deposition of polyvinyl butyral film in the windshield of a car. It is the PVB foil that ensures that the glass does not break; it just shatters and sticks

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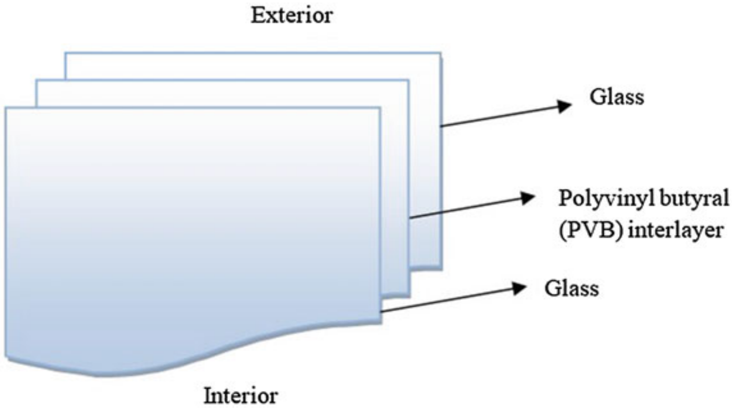

Fig. 3.1 Polyvinyl butyral foil as interlayer into windscreen (authors own processing)

together [5, 6]. The material that holds the layers of glass together is just polyvinyl butyral foil. Recycled polyvinyl butyral was contaminated (dust, glass fragments), so it was necessary to wash and dry the material before starting laboratory work thoroughly.

As part of the work, PVB in the form of flakes was used for research. Figure 3.2 shows the types of recycled PVB in different embodiments. Polyvinyl butyral is a thermoplastic material that is soluble in ethanol, butanol, ethyl acetate, butyl acetate, in mixtures of chlorinated hydrocarbons, and insoluble in aliphatic hydrocarbons (in gasoline) [5]. The density of the polyvinyl butyral used in the research was 1.07 g cm^{-3}, and the selling price of the recycled material is 0.25€ to 0.50€ per kg.

When using 3R objectives [6], specifically in the material recycling of plastic waste, either technologies used in the processing of "pure" plastics are used, which require pretreatment of plastic waste (crushing, grinding, washing, etc.) or modified technologies taking into account specific requirements in processing mixed plastic [7, 8]. If conventional plastics processing technologies are used in the material recycling of plastic waste, they allow the production of products with parameters comparable to products made of pure materials [8, 9]. The disadvantage of this approach is the requirement for a high degree of separation, that is, to be the input plastic waste is identifiable, and it was possible to classify it at least in the appropriate group of polymers [6]. Another problem is the requirement for high purity of the material, which means that this plastic waste must be not only mechanically treated (crushing, grinding, etc.) but also be freed of impurities before processing [4]. All these requirements must be met to ensure the quality requirements for products produced in this way from recycled plastic and to ensure the stability of the production process [3].

If the goal is to produce products with high-quality parameters, only a limited amount of recycled waste can be used. In this fall, the recycled plastic can be used in the volume up to 20%.

Fig. 3.2 Types of recycled polyvinyl butyral (PVB) (authors own processing)

3.2 Material Characterization and Problem Definition

The general definitions of composite materials say that the composite materials are composed of at least two or more chemically different components. Where one of the components is referred to as a matrix (it is continuous) [9, 10]. The second component—filler, is dispersed in the matrix [11]. Table 3.1 provides general information on the suitability of the choice of matrix in the manufacture of a composite material. When choosing the type of matrix and filler in the composite material, it is important to know and define the basic factors [12] from which the method of preparation and subsequent application of the material is derived.

Recycled polyvinyl butyral [1, 13, 14], used in the research, has the following parameters (Table 3.2).

Table 3.1 The differences of matrix types [13] (authors own processing)

Material properties	Thermoset	Thermoplast (PVB)
Viscosity	Less	High
Elongation modulus	Less	High
Material strength	Less	High
Storage stability	Limited	No–limited
Efficiency (manufacturing efficiency)	Less	High
Recyclability	Bad	Good

Table 3.2 Material characterization of recycled polyvinyl butyral [13] (authors own processing)

PVB-polyvinyl butyral, recycled	
Form	Flakes
Color	Colorless
Size	20–30 mm
Purity	More than 97%
Impurity content	Less than 3%
Residual humidity	ca. 2%
Portion of glass particles	Less than 2%

Table 3.3 Results after tensile test for recycled PVB and resin PVB [14] (authors own processing)

Material	E-module (MPa)	σ_{max} (MPa)	ε_{max} (%)
PVB resin[a]	7.50	13.7	49.50
PVB recycled	5.000	17.5	145.96

[a]PVB resin—as a reference from Du Pont company [1, 2]

3.2.1 Mechanical Characteristics of Composites Smart Materials

The composite material, which is created by homogenization of recycled polyvinyl butyral and reinforced by high-strength fibers, is called “Composite material with long unidirectional fibers” [5, 15, 16]. The tensile test was used to evaluate the tensile strength of the material according to DIN EN ISO 527-1. Table 3.3 contains a comparison of tensile test results for commercial polyvinyl butyral and recycled polyvinyl butyral [17]. E-modulus and tensile stress are comparable, at relative elongation ε_{max} the values were different, due to the effect of internal forces and the method of homogenization.

3.3 Results and Discussion

By our research we used the fibers that were unidirectional oriented. Their important feature is the dependence of the physical properties of substances on the direction of the force [18]. It is known from the definitions that the strength of composite materials in the direction of fiber orientation, for example, longitudinal, is substantially higher than in the direction perpendicular to the fiber axis [19, 20]. The following figure (Fig. 3.3) shows an overview of the mechanical properties of selected fibers (Table 3.4), as reinforcement, in a composite material.

Polymer composite materials [21] have advantages over metal and ceramic composites, mainly in terms of high specific strength, available processing technologies, corrosion resistance, better dynamic and damping properties, and high dimensional stability [22]. An important factor is the possibility to produce complex parts in one go or the possibility of assembling them [23]. At present, 3D printing of plastic products also plays an important role, which represents a huge potential for usability [24]. Among the key reasons for the applicability of reinforced plastics (Table 3.5) is their high specific strength [25, 26]. Table 3.5 is compiled on the basis of processed

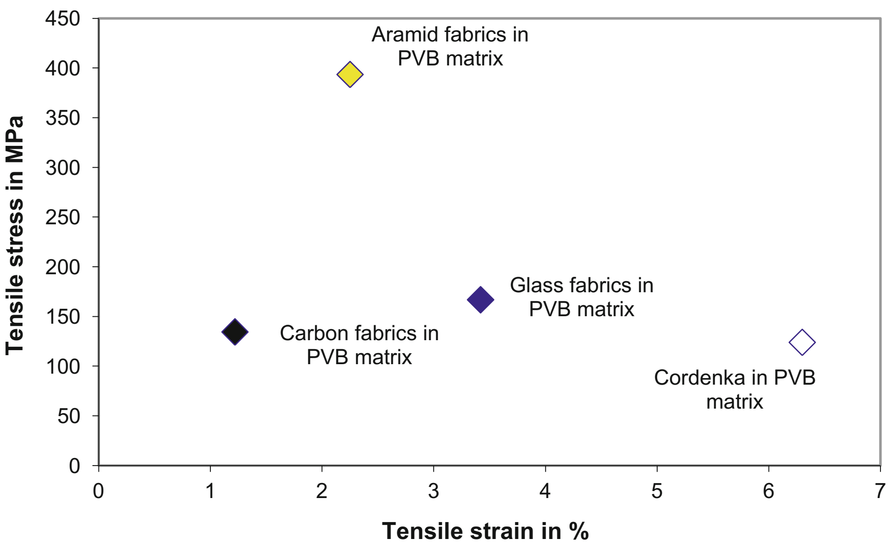

Fig. 3.3 Comparison of mechanical properties of composites materials (authors own processing)

Table 3.4 Results after tensile test for composite materials (matrix PVB and filler) (authors own processing)

Filler in the matrix	σ_{max} (MPa)	ε_{max} (%)
Aramid fibers	393.6	2.25
Carbon fibers	134.3	1.22
Glass fibers	166.8	3.42
CordEnka	124.0	6.30

Table 3.5 Compilation of key usability factors for materials from recycled polyvinyl butyral (authors own processing)

Material	Key factors				
	PVB without filler	Composite with aramid fibres	Composite with carbon fibres	Composite with glass fibres	Composite with cordenka
Material strength	–	+++	+++	++	++
Shape memory	+++	+++	+++	+++	+++
Elasticity of material	+++	++	++	++	+++
Dynamic and damping properties	+++	+++	++	+	++
Transparency	+++	–––	–––	–––	–––
Corrosion resistance	+++	+++	+++	+++	+++
UV stability	++	+++	+++	+++	+++
Possibilities of surface treatment	+++	++	++	++	++
Available technology process	+++	+++	+++	+++	+++
Low input cost	+++	+++	+++	+++	+++
Non-toxicity	+++	+++	+++	+++	+++
Recyclability	+++	+++	+++	+++	+++

Legend: – low, –– limited, ––– unacceptable (material properties) + good, ++ good (with the application possibilities), +++ excellent

mechanical properties and general properties of usability [27] of individual types of material with their direct application in practice.

The fact that the following years will revolutionize the use of composite materials plays an important role in the selection of factors.

3.4 Conclusions

The new product, which in this case is a composite material of recycled polyvinyl butyral, generally has several stages of development. Only by constantly increasing the professional knowledge and practical experience of employees and, last but not least, by constantly improving the processes of innovation and development, the company leads to the development of new products, with their application possibilities. Application of traditional material like wood, or plastics without filler, with a comparison of our new composite brings a possibility to respond to customized customer's requirements. The coloration, using color pigments, is extremely resistant to weather conditions, and therefore, the appearance of the material does not change fundamentally even after years.

The use of composites material in the exterior conditions has advantages in the followed areas:

- Does not rot
- Does not corrode
- Does not absorb moisture

Advantages over of the sustainable composites materials:

- Newly created material
- Cheaper inputs
- Mechanical properties are common with other similar material
- Harmless

By using a composite material made of recycled polyvinyl butyral and reinforced with glass, carbon, aramid, and Cordenka fibers, it also prevents the penetration of soil moisture into the fencing. The advantage of 3R objectives by windscreens, especially by polyvinyl butyral foil we see in a material lifetime, vibration absorption, and fire resistance. Definitely, this composite material we can consider to be a future material.

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