Acta Tecnología - International Scientific Journal about Technologies
Volume: 6 2020 Issue: 2 Pages: 45-48 ISSN 2453-675X

doi:10.22306/atec.v6i2.79 *Received: 28 Apr. 2020; Revised: 02 June 2020; Accepted: 10 June 2020*

INCREASING THE ECONOMIC POTENTIAL OF RECYCLED POLYVINYL BUTYRAL BY REDUCING ITS ATMOSPHERIC DEGRADATION

Lucia Knapčíková
Technical University of Košice, Department of Industrial Engineering and Informatics, Bayerova 1, Prešov, Slovak Republic, EU, lucia.knapcikova@tuke.sk (corresponding author)
Marcel Behún
Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Institut of Institute of Earth Resources, Letná 9, Košice, Slovak Republic, EU, marcel.behun@tuke.sk
Annamária Behúnová
Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Institut of Institute of Earth Resources, Letná 9, Košice, Slovak Republic, EU, annamaria.behunova@tuke.sk

Keywords: circular economy, waste, windscreen, PVB, atmospheric humidity
Abstract: The global market for polyvinyl butyral is segmented based on the end-user industry into the fields of construction, transport and electrical engineering. The application possibilities of recycled polyvinyl butyral (PVB) depend on its thorough preparation for use. This paper aims to analyse PVB in terms of its atmospheric degradation, to which it is susceptible, like most thermoplastics. By correctly determining the gravimetric water content, we can more precisely set the test conditions and thus increase its application possibilities to various areas of industry. Precisely because of fundamental properties such as excellent durability, stability and superior mechanical strength, it makes PVB a more advantageous choice for automobile manufacturers. Also, this product protects against infrared radiation and UV, noise reduction. With the growing number of automobiles, together with the change in consumer preference for safety, we expect demand to increase in the polyvinyl butyral market in the following years.

1 Introduction

According to the European Commission statistics reports, it is currently estimated that between 8 and 9 million automobiles are scrapped each year in Europe [1]. In Slovakia, this amount reaches 30,000 automobiles per year. [1] One important aspect directly related to car glass recycling is that laminated glass represents up to 3% of the total material in an automobile at the end of its life.
In Europe, this laminated glass means approximately 480 000 tonnes per year, which come exclusively from end-of-life automobiles [1]. However, there will come a time when each product ends its life and eventually ends up as waste [1,2].

The European Union's priority is to re-use this waste in the production process (Fig. 1). The essence is the application of the circular economy to the production process itself, to the design. It is not that easy with automobile [2,3]. An old automobile contains several dangerous substances such as oil, acid, chemical compounds contained in liquids, such as brake fluid, coolant, airbag detonators, etc. Therefore, the old automobile is included in the category of "hazardous waste" [3]. Manipulation and disposal of an old automobile in Slovakia, according to the Waste Act No. 79/2015 Coll. may be performed only by an authorized processor of waste automobiles.

Figure 1 Circular economy application into automobile industry [2, Authors own processing]

From automobile laminated glass recycling, it is essential to focus on the use of new advanced technologies and thus achieve high purity polyvinyl butyral film. Economic gains are a necessary aspect for processors and customers (Fig. 2), as the production costs of cleaned

INCREASING THE ECONOMIC POTENTIAL OF RECYCLED POLYVINYL BUTYRAL BY REDUCING ITS ATMOSPHERIC DEGRADATION

Lucia Knapčíková; Marcel Behún; Annamária Behúnová

polyvinyl butyral are between 4 and 5 EUR per kg, while the current expenses for resin PVB are between 9 and 13 EUR per kg [3]. Another important aspect is that it obtains a recycled product with similar technical properties as a resin material that can be used for primary use, in laminated glass production, as opposed to what currently happens with polyvinyl butyral waste [4]. It is essential to use innovative laminated glass recycling technology that will improve the environment for all existing processes, bringing high industrial value and high economic efficiency [2,5].

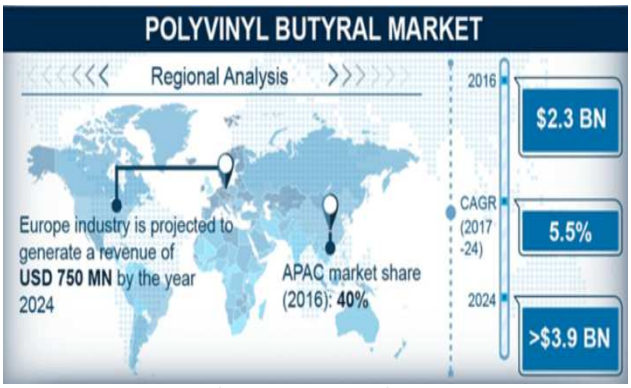

Figure 2 Global forecast analysis for polyvinyl butyral (2016-2024) [4]

The automotive market is a crucial factor in the growth of global polyvinyl butyral in the period 2016-2024 [1]. Polyvinyl butyral is used in the production of laminated glass of architectural and automotive applications. Automobile manufacturers use laminated glass to make roof windows, side and rear windows and windscreens [6]. These laminated glasses are produced by joining PVB (Fig. 3) between layers of two glass panels under extreme pressure and temperature conditions.

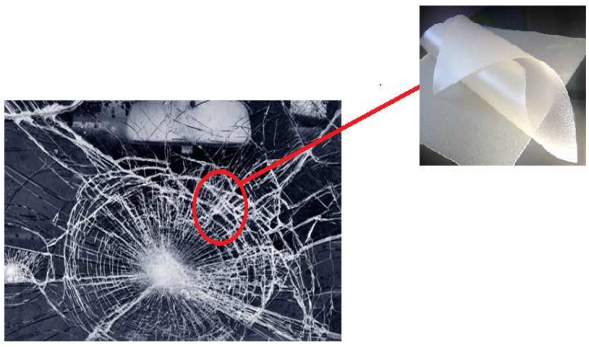

Figure 3 Recycled polyvinyl butyral as safety interlayer in the windscreens [14]

Laminate glass is used in the automobile for safety reasons, as it protects against head injuries in accidents [6-8]. PVB has key properties such as excellent durability, better edge stability and excellent mechanical strength, which makes them a more advantageous choice for car manufacturers. In addition, this product provides protection against infrared and UV radiation, noise reduction, and offers overall vehicle safety [8]. With increasing automobile production, together with a change in consumer preference for automobile safety, demand in the polyvinyl butyral market is likely to increase [9].

2 Research Methodology

The preparation of recycled polyvinyl butyral before use in laboratory and industrial applications is a crucial step [5,6]. Because polyvinyl butyral is loosely stored in "big bags" in the warehouse after recycling, the surrounding moisture is absorbed thereby the material itself. [8]. Recycled polyvinyl butyral contains impurities that were present after the recycling process, due to processing, packaging, storage. Therefore, it is necessary to get the material to the state that is most suitable from an economic and processing point of view before starting work [10]. PVB storage capacities are limited in many countries. Accordingly, some countries were already increasing storage costs and trying to make manufacturers and PVB processors re-use this type of waste and returned it to the production process [11,12].

Figure 4 Recycled polyvinyl butyral [13,14]

The polyvinyl butyral was prepared in the laboratory under the ambient temperature 21 °C and 60% humidity. Characteristics of the determination of the gravimetric water content in the sample of recycled polyvinyl butyral are presented in the Table 1.

Table 1 Characteristics of the determination of the gravimetric water content in a sample of recycled polyvinyl butyral

Weight of the test sample before analysis	6 x 10 g
The temperature in the laboratory drying equipment	60 °C
Sample drying time	24 h
Standard	DIN ISO 11465

Reduction of atmospheric degradation of recycled PVB by gravimetry water content

Polymers materials (including natural polymers) are perhaps the most sensitive materials to changes in chemical structure due to external conditions and the resulting changes, especially in physicomechanical and chemical properties [13]. The most important factors that trigger the chain mechanism of chemical changes in the polymeric material are UV radiation, heat, the presence of oxygen and especially ozone [6]. Mechanical stress and possibly the presence of chemicals, especially organic solvents, usually also contribute to the acceleration of chemical degradation processes [7,9].

The events that take place in the polymer due to these factors are called the general term degradation (or ageing), with a gradual decrease in molecular weight after the initial phase of degradation and, in the presence of oxygen or ozone, the oxidation of polymer macromolecules.

These changes are, of course, undesirable because the polymer is usually degraded and polyvinyl butyral is no exception [11].

The water content of the sample was determined by gravimetric determination of the water content, which represents the amount of water contained in the test sample [7].

The water content was determined as follows, according to mathematical relations [14]:

$$w = (mw / md + mw) . 100\% \quad (1)$$

where individual quantities mean:

w- gravimetric water content [%]
m_w- the weight of sample before analysis, wet sample [g]
m_d - the weight of the sample after analysis, dry sample [g].

3 Results and discussion

The six randomly selected samples of recycled polyvinyl butyral were analysed. After the separation of PVB itself, the waste still contains glass particles, which reduces the scope of its use. External storage of PVB material is not recommended because moisture and ultraviolet radiation generally degrade the properties of PVB [3,12].

Also, the possibility of primary PVB pollution increases [8]. Due to the sticky and soft surface of the PVB waste film, it is assumed that if improper storage, a lot of impurities will easily stick to the surface and thus reduce the quality in the area of use of the recycled product [13]. PVB storage capacities are limited in many countries. Accordingly, some countries are already increasing storage costs and trying to make manufacturers, respectively [1,13].

The following Table 2 is a summary of the results before and after the measurement. The samples were weighed on laboratory scales of the mark Kern EW N, which work with a measurement sensitivity of 0.001 g.

Table 2 Results of gravimetric water content analysis in a sample of recycled polyvinyl butyral [14]

Sample	Weight before analysis m_w [g]	Weight after analysis m_d [g]	Gravimetric water content w [%]
1.	10.060	10.030	0.500
2.	10.036	10.002	0.500
3.	10.050	10.019	0.500
4.	10.080	10.033	0.501
5.	10.053	10.024	0.500
6.	10.082	10.042	0.500
Average value	10.060	10.025	0.500

From measurements, we observed that the water content of a sample of recycled polyvinyl butyral has an average value of 0.500%. The sample was dried in a laboratory drying equipment at 60 °C for 24 hours (Table 3). For this type of thermoplastic, the essential water content is max. up to 1.5%.

Table 3 Final material characteristics of recycled polyvinyl butyral [14]

PVB-polyvinyl butyral, recycled	
Form	flakes
Colour	colourless
Size	20-30 mm
Material purity	more than 97%
Impurity content	less than 3%
Residual humidity	ca. 1.5 %
The proportion of glass particle content	less than 2%

The test sample meets the prescribed requirements and is ready for further use, given the necessary analyses and processing capabilities of this type of thermoplastic.

4 Conclusions

Long since in 2012, the European Commission adopted strict government regulations on reducing emissions for automobiles. The manufacturers make them switch to the use of lightweight plastics as a substitute for metals. A high percentage of the use of plastic materials (or components)

is expected in the future due to the growing demand from consumers, where weight reduction, low consumption and, conversely, high vehicle performance play an important role. With recycled polyvinyl butyral, which we obtain after recycling car parts, we will increase the economic potential of using this commodity on the market. With the eco-design, the manufacturers solve the issue of circular economy in the design of the final product.

By determining the gravimetric water content in the sample of recycled polyvinyl butyral, we reached a value of 1,5%, which means excellent application and processing possibilities for this type of recycled material.

Its most notable features include:

- Toughness;
- Flexibility;
- Neutral colour (possibility to add colour pigments);
- Non-conductibility;
- BAT (Best Available Technology).

Recycled polyvinyl butyral can be used as:

- Binder for materials (metal, inorganic, organic, magnetic);
- Binder for fabrics;
- Matrix for composite materials coatings;
- Adhesives.

By using polyvinyl butyral in various areas of industry, we are thus meeting the EU's goals, where sustainability plays an important role.

Our next research priority is to increase the share of the use of recycled PVB in new products, where we will work following the principles of circular economy and the products will be customized according to customer´s demand.

References

[1] Eurostat statistics, [Online], Available: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselv&lang=en [06 Apr. 2020], 2020.
[2] Re-cycle, Re-use, Re-nault, [Online], Available: http://projects.mcrit.com/esponfutures/index.php/home/24 -re-cycle-re-use-re-nault, [06 Apr. 2020], 2020.
[3] Recycled PVB, [Online], Available: http://www.recycled-pvb.eu/descripcion_en.php, [10 Apr. 2020], 2020.
[4] Polyvinyl butyral market, [Online], Available: https://www.gminsights.com/industry-analysis/polyvinyl-butyral-pvb-market [14 Apr. 2020], 2020.
[5] Polyvinyl butyral [Online], Available:https://www.ihs.com/products/polyvinyl-butyral-chemical-economics-handbook.html [10 March 2019], 2020.
[6] Maveba s.r.o., [Online], www.maveba.eu [09 Sep. 2019], 2020.
[7] DHALIWAL, A. K., HAY, J. N.: The characterization of polyvinyl butyral by thermal analysis, *Thermochimica Acta*, Vol. 391, No. 1-2, pp. 245-255, 2002. doi:10.1016/s0040-6031(02)00187-9
[8] BARRY, C.M.F., ORROTH, S.A.: *Processing of thermoplastics*, Harper, CH.A., Modern Plastics Handbook, USA, 2000.
[9] LIPTÁKOVÁ, T., ALEXY, P., GONDÁR, E., KHUNOVÁ, V.: Polymérne konštrukčné materiály, [Online], Available: http://kmi2.uniza.sk/wp-content/uploads/2009/10/POLYMERY-Po-RECENZII.pdf [09 Apr. 2020], 2012. (Original in Slovak)
[10] DEL LINZ, P., WANG, Y., HOOPER, P. A., ARORA, H., SMITH, D., PASCOE, L., CORMIE, D., BLACKMAN B. R. K., DEAR, J. P.: Determining Material Response for Polyvinyl Butyral (PVB) in Blast Loading Situations, *Experimental Mechanics*, Vol. 56, No. 9, pp. 1501-1517, 2016, doi:10.1007/s11340-016-0179-5
[11] ZHANG, H.J, HEALY, N., SHEN, L., HUANG, Ch. Ch., ASPIOTIS, N., HEWAK, D., W., PEACOCK, A. C.: Graphene-Based Fiber Polarizer With PVB-Enhanced Light Interaction, *Journal of Lightwate technology*, Vol. 34, No. 15, pp. 3563-3567, 2016. doi:10.1109/JLT.2016.2581315
[12] FARZANA, R., RAJARAO, R., SAHAJWALLA, V.: Characteristics of waste automotive glasses as silica resource in ferrosilicon synthesis, *Waste management and research*, Vol. 34, No. 2, pp. 113-121, 2015. doi:10.1177/0734242X15617010
[13] KNAPČÍKOVÁ, L.: *Optimizing of technological processes by plastics recovery*, Dissertation Thesis, FVT TUKE, 2011.
[14] KNAPČÍKOVÁ, L.: *Investigation of materials on the base of recycled polyvinyl butyral*, Habilitation Thesis, FVT TUKE, 2016.

Review process
Single-blind peer review process.