# Evaluation of the impact of recycled automotive waste in particleboard on water quality

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## *Abstract*

*This article assesses the environmental impacts of three-layer wood-based composites containing automotive industry waste (incorporated into the core layer) on aquatic environments. Water leachates from the composite samples were evaluated using ecotoxicological biotests with the test organisms Lemna minor, Sinapis alba, and Daphnia magna. Physicochemical parameters, specifically pH and chemical oxygen demand (COD), were determined to represent the total amount of organic substances leached into the water. A particleboard without automotive waste served as the control sample. The results indicate that incorporating automotive waste into wood-based materials is a viable recycling method, and the use of bioassays proves to be an effective tool for evaluating their environmental safety. The findings suggest the need to optimize the quantity of waste in production to minimize inhibitory effects on test organisms in aquatic environments while maintaining the required physical and mechanical properties of the composites.*

***Keywords**: waste, plastic, water leachate, automotive industry, chipboard, ecotoxicity*

## Introduction

The automotive industry is one of the most resource-intensive sectors of the economy in every developed nation. Coupled with its rapid advancement, a challenge arises regarding the constant increase in waste materials from both production and the disposal of end-of-life vehicles[1]. The average weight of a car is approximately 1.2 tons, representing 102.5 million tons of processed materials—including scrap iron, tires, non-ferrous metals, glass, polyurethane foam, car batteries, electronic waste, textiles, insulating materials, and, significantly, a vast number of plastic components[2].

Secondary raw materials that undergo further recycling include used tires and rubber parts, plastic components, waste glass, ferrous and non-ferrous metal waste, liquids, electrical equipment, and waste from oil filters[3,4]. The recycling of automotive plastics is crucial for achieving overall sustainability targets. Their primary environmental benefit lies in reducing the volume of plastic and wood waste, which helps preserve natural resources and decrease landfill utilization[5].

One method of recycling plastic waste and rubber is their incorporation into particleboards (PB), which are molded wood-based panels produced by hot-pressing wood particles with an added adhesive. Their quality is determined by physical and mechanical property values, which are influenced by the input raw materials and technical factors[6]. Non-wood materials, such as automotive industry waste, are also added to particleboards to utilize this waste, reduce raw wood consumption, and achieve new material properties. To maintain the appearance of the particleboards, the composition of the surface layers is always kept unchanged[7,8]. This approach reduces landfill waste and resource extraction. Compared to traditional alternatives, wood-plastic panels offer significant environmental advantages due to the use of recycled materials, the reduction of harmful emissions, and a lower overall carbon footprint. In the present article, we assess the environmental impacts on the aquatic environment of three-layer particleboards—where the core layer is manufactured from automotive plastic waste—using ecotoxicological testing. Bioassays are significant ecotoxicological indicators of environmental pollution and can play a vital role in enhancing environmental monitoring and determining the hazardous nature of substances.

## *EXPERIMENTAL*

### Materials and methods

The experiment focused on evaluating the impacts of particleboards manufactured with various automotive plastic and rubber waste contents on the aquatic environment. The procedure involved the preparation of water leachates, in which the following parameters were determined: pH, $COD_{Cr}$ (chemical oxygen demand using potassium dichromate), and ecotoxicological bioassays.

Three-layer wood-based composite materials were produced by incorporating polymers from automotive waste into the particleboards. The boards were manufactured using wood particles derived from spruce logs processed at Kronospan s. r. o. in Zvolen, Slovakia. The wood particles used in the core layer ranged from 0.25 mm to 4.0 mm in size, while the particles used in the surface layers were finer, between 0.25 mm and 1.0 mm. Automotive plastic waste was supplied by ALUEX s. r. o. in Zvolen, Slovakia. This plastic waste was cut into smaller pieces, cleaned, and subsequently processed into granules using plastic crushing equipment at the Technical University in Zvolen. Granulation was performed using a DP 11–240/350 plastic crusher (Profing, Slovakia) and an ABS 1080 dust extractor (Holzmann Maschinen, Austria). The granules (1 mm to 4 mm in size) were sieved using an AS 200 digit cA analytical sieve shaker (Retsch, Germany) to ensure uniform particle size. The size of the resulting granulates ranged from 1.0 to 4.0 mm. A urea-formaldehyde (UF) resin (Kronores CB 1100 F) was used as a binder, containing 67.1% solids, with a viscosity of 460 mPa·s, a gel time of 55 seconds, and a pH of 8.6. To facilitate the curing process, ammonium nitrate ($NH_4NO_3$, 47% concentration) was used as a hardener, along with a 30% paraffin emulsion to enhance the water resistance and durability of the final product. The manufacturing process followed standard particleboard production technology. The entire production methodology adhered to the procedures specified in Utility Models No. 10248 and No. 10249[9, 10]. The particleboards used in the experimental section (Figure 1) had dimensions of 350 x 350 x 18 mm, and the granulate content in the samples was 10% (Table 1). Testing higher concentrations of the incorporated waste in PB production led to a degradation of mechanical, physical, and fire-retardant properties; consequently, a 10% substitution of wood mass with plastic waste was established. The fabrication of single-layer PBs with varying volume percentages (10%, 15%, and 20%) of the aforementioned plastics serves as a preliminary step toward optimizing the production of three-layer PBs. Research findings concerning single-layer PBs indicated that a 10% polymer particle content is optimal. For this reason, subsequent research focused exclusively on the production of three-layer PBs with a 10% plastic fraction.

An increase in wood fiber content from 20% to 30% resulted in a rise in flexural strength from 44.88 MPa to 59.06 MPa, attributed to efficient stress transfer and favorable interfacial interaction between the matrix and the reinforcement. Conversely, further increasing the fiber content to 40% caused a decline in strength, as the higher reinforcement concentration prevented adequate fiber encapsulation by the polymer, leading to impaired interphase adhesion. Three-layer particleboards with 10% plastic filler exhibited superior mechanical properties compared to single-layer boards with the same plastic content, confirming the positive influence of the layered structure on stress transfer and the overall mechanical integrity of the material[11,12].

***Table 1: Composition and designation of experimental samples***

| Sample designation | Composition of particleboards |
|---|---|
| **PB** | Pure particleboard |
| **P10** | PB containing granulate from waste tires |
| **TK10** | PB containing granulate from waste seals and carpets |
| **LN10** | PB containing granulate from waste painted bumpers |
| **NN10** | PB containing granulate from waste unpainted bumpers |
| **PN10** | PB containing granulate from waste fuel tanks |
| **KVN10** | PB containing granulate from waste non-flammable cables |
| **KSH10** | PB containing granulate from waste flammable cables |
| **P10G10** | PB containing granulate from waste tires and graphite |
| **TK10G10** | PB containing granulate from waste seals, carpets, and graphite |

***Figure 1: Three-layer particleboard with incorporated polymer*** *(Photo: V. Mancel)*

### *Preparation of water leachates*

The quantity of the leachant (demineralized water) was calculated while maintaining a sample surface area to leachant ratio of 1:5. The leaching period was 24 hours; following this duration, the leachates were filtered and the resulting extracts were used for testing (Figure 2)[13].

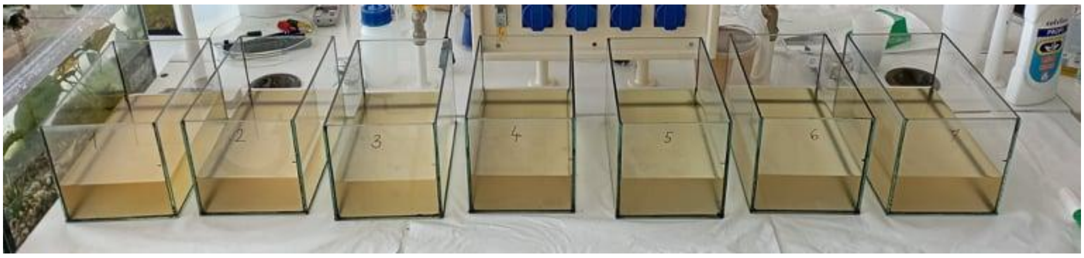

***Figure 2: Leachates prepared by 24-hour leaching (Photo: H. Hybská)***

### *pH determination*

Measured using an inoLab pH Level 1 pH meter (WTW, Germany) and a StirrOx G combination electrode[14].

### *Determination of chemical oxygen demand using potassium dichromate (COD$_{Cr}$)*

The oxygen demand determines the amount of oxidizing agent consumed for the oxidation of organic substances. Potassium dichromate was used as the oxidizing agent. The oxidation process took place in a strongly acidic sulfuric acid medium during a two-hour reflux (boiling). The amount of unconsumed potassium dichromate was determined titrimetrically. After adding the ferroin indicator, the solution is titrated with a standard solution of ferrous ammonium sulfate (FAS) until the first color change from blue-green to reddish-brown occurs[15].

### Ecotoxicological testing of leachates

Preliminary tests were conducted with a minimum of six replicates. The following biotests were used:

***Growth inhibition (stimulation) test of common duckweed (Lemna minor) – producent***[16, 17] (Table 2).

***Table 2: Test conditions for the test organism Lemna minor***

| **Parameter** | *Lemna minor* |
|---|---|
| **Bioassay conditions** | 25°C ± 2°C, day/night simulation; continuous illumination with min. intensity of 6,500 lux |
| **Control sample** | Z-medium (nutrient solution from CCALA, Třeboň, Czech Republic) |
| **Reference substance** | 3,5-dichlorophenol, $EC_{50}$ = 3.1 mg/l (limit 2.2 – 3.8 mg/l) |
| **Sample volume** | 1 mL / 1 well |
| **Exposure duration** | 3 days |
| **Preliminary test** | 1 frond per 1 mL of sample under the same conditions |
| **Validity criteria** | Average number of fronds in the control at the end of the test > eight times the initial count; pH at the end of the test < 1.5 units difference compared to initial pH |
| **Monitored response** | Evaluated frond count; visual assessment – necrosis, chlorosis; growth rate μ and growth inhibition Iμ (%) compared to control |

From such obtained values of μ inhibition (stimulation) of growth $I_{\mu i}$ shall be calculated for every tested concentration

$$I\mu_i = \frac{(\mu_k - \mu_i).100}{\mu_k}$$

where $I_i$ = inhibition (stimulation, when $I_{\mu i}$) of growth in % determined on the basis of comparison of growth velocities,

$\mu_i$ = growth velocity for tested concentration,

$\mu_k$ = growth velocity in control.

**Acute toxicity test on daphnids (*Daphnia magna*) – consumer**[18, 19,20] (Table 3).

***Table 3: Test conditions for the test organism Daphnia magna***

| **Parameter** | *Daphnia magna* |
|---|---|
| **Test organism** | Daphnia magna Straus (Cladocera, Crustacea), neonate individuals from parthenogenetic culture |
| **Bioassay conditions** | 21°C ± 2°C; 7.8 ± 0.2 (pH); laboratory environment |
| **Control sample** | Dilution water prepared from analytical grade (p.a.) solutions of $CaCl_2.2H_2O$ (1), $MgSO_4.7H_2O$ (2), $NaHCO_3$ (3), KCl (4); by adding 10 ml of each solution (1)-(4) and filling with demineralized water to a volume of 1 liter |
| **Reference substance** | $K_2Cr_2O_7$, $EC_{50}$ = 0.85 mg/l (limit 0.3 – 1.5 mg/l) |
| **Sample volume** | Min. 5 ml per individual, maintaining a solution column height of min. 3 cm |
| **Exposure duration** | 48 hours |
| **Preliminary test** | 5 daphnids per undiluted sample, identical conditions for control |
| **Validity criteria** | Immobilization ≤ 10 %, change in dissolved $O_2$ concentration ≤ 2 mg/l |
| **Monitored response** | % immobilization and mortality of individuals, dissolved oxygen, $EC_{50}$ |

Determination of % immobilization

$$\text{Immobilization (\%)} = 100 - \left(\frac{A_v}{A_z} * 100\right), \text{ where:}$$

$A_v$ – number of individuals that are survivors at the end of testing,

$A_z$ – number of individuals that are survivors at the beginning of testing (number of daphnia used).

### Root growth inhibition test of a higher vascular plant (*Sinapis alba*) – producer[21] (Table 4)

***Table 4: Conditions of the preliminary test using Sinapis alba seeds***

| **Parameter** | *Sinapis alba* |
|---|---|
| **Test organism** | White mustard (*Sinapis alba*), variety – Mega, Pstruša; color: ochre-yellow, size: 1.5 – 2 mm, germination rate: 99% |
| **Temperature** | 20°C ± 1°C, TS 606 CZ/2-Var incubator (WTW, Germany) |
| **Control** | Dilution water |
| **Exposure duration** | 3 days |
| **Preliminary test** | 10 seeds per 20 mL of sample, with an identical setup applied to the control |
| **Validity criteria** | Individual $IC_{50}$ values must not differ by more than 30% |
| **Monitored response** | Root growth inhibition compared to control – IC (%) |

Inhibition (stimulation) $I_i$ of the growth of root of higher plants should be calculated using the equation:

$$I_i = \frac{L_k - L_v}{L_k}.100,$$

where $L_v$ is the average length of root in the tested concentration of aqueous leachate in cm,
$L_k$ is the average length of root in control in cm.

## Results and discussion

### Physicochemical Characterization

The pH value serves as a fundamental indicator of the system's chemical equilibrium and exerts a significant influence on the progression of chemical and biological processes, including solute solubility, contaminant mobility, and microbial activity[20]. The pH and COD (Chemical Oxygen Demand) values determined in the leachates following a 24-hour leaching period are presented in Table 5.

***Table 5: pH and COD values***

| **Sample** | **PB** | **P10** | **TK10** | **LN10** | **NN10** | **PN10** | **KVN10** | **KSH10** | **P10G10** | **TK10G10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 6.07 | 6.31 | 7.29 | 6.05 | 6.20 | 5.54 | 5.96 | 5.86 | 5.57 | 5.56 |
| **COD mg/l** | 936.70 | 1133.90 | 1084.60 | 1281.80 | 345.10 | 493.00 | 542.30 | 591.60 | 443.70 | 443.80 |

**Notes:** PB – neat particleboard; PB containing: P10 – waste tire rubber granulate; TK10 – granulate from waste seals and carpets; LN10 – granulate from waste painted bumpers; NN10 – granulate from waste unpainted bumpers; PN10 – granulate from waste fuel tanks; KVN10 – granulate from waste flame-retardant cables; KSH10 – granulate from waste flammable cables; P10G10 – waste tire rubber granulate and graphite; TK10G10 – granulate from waste seals, carpets, and graphite.

## pH evaluation

The pH values presented in Table 5 range from 5.54 to 7.29, indicating a spectrum from weakly acidic to slightly alkaline. The lowest pH value was recorded for the leachate from the sample containing 10% fuel tank granulate (PN10). Conversely, the leachate from the particleboard (PB) containing 10% waste seal and carpet granulate (TK10) exhibited an alkaline pH of 7.29. No significant differences in pH were observed among the remaining leachates. In previous studies, authors[23, 24] reported a pH of 3.66 for single-layer neat PB, whereas the pH of three-layer neat PB was 6.07. In the present experiments, the pH of all single-layer PB samples containing 10% waste granulate (including unpainted and painted bumpers and fuel tank granulate) remained acidic. These findings are consistent with the results of[25], who also reported acidic pH values for all samples (containing seal granulate, tire rubber, and neat PB). Sackey et al.[26] determined the pH of leachates from various wood species and identified the influence of leaching duration on pH variations. They observed that alkalinity increased with leaching time, which is presumably attributable to the release of hydroxide ions into the solution due to oxidation. The pH values obtained after 24 hours of leaching were comparable to those of the spruce wood utilized in our experiments.

## Chemical Oxygen Demand Evaluation

Chemical Oxygen Demand (COD) represents the amount of oxygen required for the chemical oxidation of organic and inorganic reducing substances present in water using a strong oxidizing agent. This indicator serves as a critical parameter for assessing the degree of water pollution, where higher COD values signify a greater concentration of oxidizable substances and a potentially higher environmental burden on the aquatic ecosystem[27]. Primarily, COD reflects the extent of organic contamination, specifically compounds susceptible to chemical oxidation, such as various soluble organic compounds, polymer residues, plastic additives, and degradation products of lignocellulosic materials.

In the context of aqueous leachates from particleboards (PB) containing plastic waste, the COD value primarily reflects the quantity of released organic substances derived from the wood components (e.g., lignin, hemicelluloses, and extractives) as well as plastic-related additives (e.g., plasticizers, stabilizers, or low-molecular-weight degradation products). Consequently, elevated COD levels indicate a higher degree of organic contamination in the leachate and a potentially increased environmental impact upon contact with aquatic environments.

As indicated in Table 5, the COD of the neat particleboard (control sample) was 936.70 mg/L. The maximum COD value of 1281.80 mg/L was recorded in the leachate from PB containing 10% waste painted bumper granulate (LN10); in contrast, the value for the sample with 10% unpainted bumper granulate (NN10) was approximately four times lower. This disparity is presumably attributable to the leaching of organic compounds from the paint into the aqueous phase. In leachates from single-layer PB with 10% unpainted bumper granulate[24], the COD value was approximately 3.5 times higher than that observed in our experiments with three-layer PB. Similarly, for PB containing 10% fuel tank granulate, the literature value was 863.4 mg/L greater than our current results. Regarding PB with 10% painted bumper granulate, the COD for the single-layer variant[28] was approximately 200 mg/L higher than the three-layer sample with the same waste type and proportion. Comparable values were determined for leachates from PB containing 10% waste seals and 10% waste tire rubber[25]. Regarding the COD indicator, the difference between single-layer and three-layer PB containing seals and tire rubber is essentially negligible. For neat single-layer PB, COD values reported in[23, 25] were identical; however, the value for the three-layer neat PB used in our experiment was approximately 1310 mg/L lower (likely due to the greater amount of material utilized in its production). It should be noted that the relationship between COD values and the observed ecotoxicological effects is not necessarily direct. While COD represents the total amount of oxidizable organic substances present in the leachate, it does not provide information about the specific chemical composition or toxicity of individual compounds.

In the present study, some samples with relatively lower COD values still exhibited high levels of biological inhibition. This may be explained by the presence of specific toxic substances, such as low-molecular-weight organic compounds, plastic additives, or degradation products, which can exert significant biological effects even at low concentrations.

Therefore, COD should be interpreted as a general indicator of organic load rather than a direct predictor of ecotoxicity. These findings underline the importance of combining chemical and biological assessment methods when evaluating the environmental impact of composite materials containing recycled waste.

Wood is a complex natural polymeric composite primarily composed of carbon, oxygen, hydrogen, and trace amounts of nitrogen. Its principal constituents include cellulose (approx. 40 – 50%), hemicelluloses (20 – 30%), and lignin (20 – 30%), supplemented by extractives and ash content. During the 24-hour leaching process, water-soluble extractives (such as tannins, pigments, and sugars) were released from the wood structure into the aqueous medium. Therefore, Chemical Oxygen Demand (COD) was employed as a parameter to quantify the amount of leached organic substances in the water.

## Ecotoxicological Characterization

### *Lemna minor* Growth Inhibition (Stimulation) Assay

The objective of this assay was to quantify the effects of the aqueous leachates on the vegetative growth of the plants throughout the experimental period. Table 6 summarizes the primary results concerning the growth rate inhibition (Iμ) of *Lemna minor* across the individual leachate samples, while the corresponding graphical representation is provided in Figure 3.

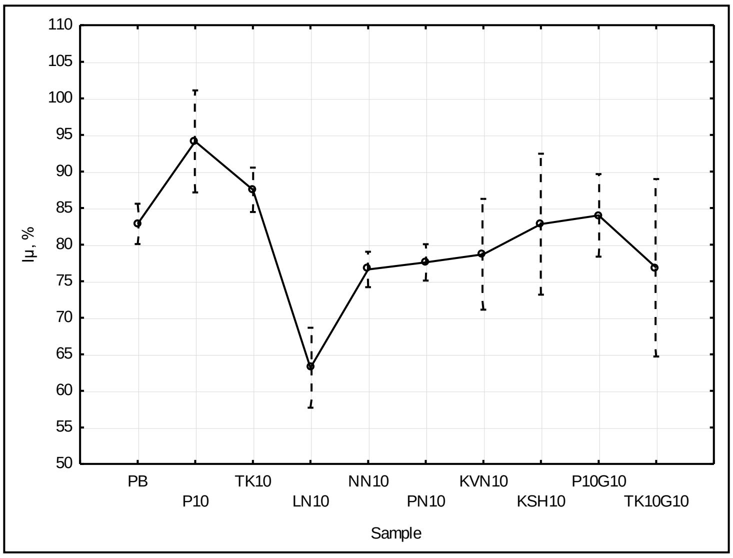

***Figure 3: Graphical representation of growth inhibition (Iμ, %) of Lemna minor in leachates from wood composite samples***

**Notes:** PB – neat particleboard; PB containing: P10 – waste tire rubber granulate; TK10 – granulate from waste seals and carpets; LN10 – granulate from waste painted bumpers; NN10 – granulate from waste unpainted bumpers; PN10 – granulate from waste fuel tanks; KVN10 – granulate from waste flame-retardant cables; KSH10 – granulate from waste flammable cables; P10G10 – waste tire rubber granulate and graphite; TK10G10 – granulate from waste seals, carpets, and graphite.

According to[16, 17], a preliminary test is classified as positive if the growth inhibition of the algal culture is ≥ 30% or if growth stimulation reaches ≥ 75% relative to the control. The obtained results indicate that all growth rate inhibition (Iμ) values in this assay were positive. The lowest Iμ percentage was recorded in the leachate from the sample containing 10% waste painted bumper granulate (LN10). Conversely, the highest inhibition was observed in the sample containing 10% waste tire granulate (P10). Authors in[24] reported Iμ values of 81.56% for samples with 10% painted bumper granulate, 70.08% for unpainted bumpers, and 83.40% for fuel tanks. The inhibitory effect of the leachates from three-layer boards on the *Lemna minor* test organisms was more pronounced than the results obtained from single-layer PB leachates[24]. According to[23], the inhibitory effect on *Lemna minor* growth for the control single-layer PB sample was comparable to the value determined for the three-layer neat PB leachate.

***Table 6: Basic statistical characteristics for Lemna minor***

| **Sample** | **Iμ, %** | | | | **Repetitions** |
|---|---|---|---|---|---|
| | **Average** | **STDEV** | **Confidence interval** | | |
| | | | **-95.00%** | **95.00%** | |
| **PB** | 82.84 | 0.64 | 80.08 | 85.59 | 4 |
| **P10** | 94.11 | 1.62 | 87.13 | 101.09 | 4 |
| **TK10** | 87.50 | 0.71 | 84.46 | 90.54 | 4 |
| **LN10** | 63.16 | 1.27 | 57.69 | 68.64 | 4 |
| **NN10** | 76.60 | 0.56 | 74.18 | 79.02 | 4 |
| **PN10** | 77.58 | 0.58 | 75.09 | 80.06 | 4 |
| **KVN10** | 78.68 | 1.76 | 71.10 | 86.25 | 4 |
| **KSH10** | 82.80 | 2.24 | 73.16 | 92.44 | 4 |
| **P10G10** | 84.00 | 1.31 | 78.35 | 89.65 | 4 |
| **TK10G10** | 76.84 | 2.82 | 64.71 | 88.98 | 4 |

**Notes:** PB – neat particleboard; PB containing: P10 – waste tire rubber granulate; TK10 – granulate from waste seals and carpets; LN10 – granulate from waste painted bumpers; NN10 – granulate from waste unpainted bumpers; PN10 – granulate from waste fuel tanks; KVN10 – granulate from waste flame-retardant cables; KSH10 – granulate from waste flammable cables; P10G10 – waste tire rubber granulate and graphite; TK10G10 – granulate from waste seals, carpets, and graphite.

### *Sinapis alba* Root Growth Inhibition Assay of a Higher Vascular Plant

The primary advantages of these bioassays include their inherent simplicity, versatility, and low material and economic requirements. Table 7 presents the root growth inhibition percentages (IC %) for the higher plant species—white mustard (*Sinapis alba*)—following exposure to the 24-hour leachates of the individual samples, while the corresponding graphical comparison is illustrated in Figure 4.

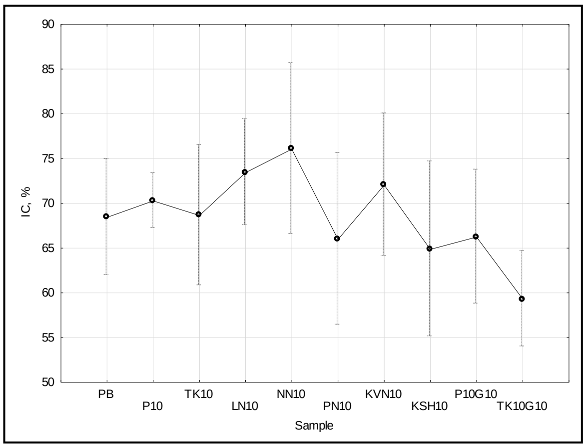

**Figure 4: Graphical representation of root growth inhibition (Iμ, %) of Sinapis alba in leachates from wood composite samples**

**Notes:** PB – neat particleboard; PB containing: P10 – waste tire rubber granulate; TK10 – granulate from waste seals and carpets; LN10 – granulate from waste painted bumpers; NN10 – granulate from waste unpainted bumpers; PN10 – granulate from waste fuel tanks; KVN10 – granulate from waste flame-retardant cables; KSH10 – granulate from waste flammable cables; P10G10 – waste tire rubber granulate and graphite; TK10G10 – granulate from waste seals, carpets, and graphite.

***Table 7: Basic statistical characteristics for Sinapis alba***

| **Sample** | **IC, %** | | | | **Repetitions** |
|---|---|---|---|---|---|
| | **Average** | **STDEV** | **Confidence interval** | | |
| | | | **-95.00%** | **95.00%** | |
| **PB** | 68.43 | 2.04 | 61.93 | 74.93 | 4 |
| **P10** | 70.27 | 0.97 | 67.17 | 73.37 | 4 |
| **TK10** | 68.63 | 2.47 | 60.77 | 76.49 | 4 |
| **LN10** | 73.43 | 1.86 | 67.51 | 79.35 | 4 |
| **NN10** | 76.05 | 3.00 | 66.50 | 85.61 | 4 |
| **PN10** | 65.98 | 3.01 | 56.39 | 75.57 | 4 |
| **KVN10** | 72.04 | 2.50 | 64.09 | 79.98 | 4 |
| **KSH10** | 64.85 | 3.07 | 55.07 | 74.63 | 4 |
| **P10G10** | 66.23 | 2.35 | 58.74 | 73.72 | 4 |
| **TK10G10** | 59.29 | 1.68 | 53.95 | 64.63 | 4 |

**Notes:** PB – neat particleboard; PB containing: P10 – waste tire rubber granulate; TK10 – granulate from waste seals and carpets; LN10 – granulate from waste painted bumpers; NN10 – granulate from waste unpainted bumpers; PN10 – granulate from waste fuel tanks; KVN10 – granulate from waste flame-retardant cables; KSH10 – granulate from waste flammable cables; P10G10 – waste tire rubber granulate and graphite; TK10G10 – granulate from waste seals, carpets, and graphite.

According to[21], the results of the preliminary assay are considered positive if the root growth inhibition is ≥ 30 %. The determined values indicate that all leachates from the tested samples yielded positive results. The maximum root growth inhibition for white mustard was recorded in the leachate from the sample containing 10% unpainted waste bumper granulate (NN10). In contrast, the lowest value was observed for the sample containing 20% waste seal, carpet, and graphite granulate (TK10G10). As shown in Table 7, the leachates prepared from the experimental samples exhibited a potent inhibitory effect on root growth. Previous findings by[24] indicated lower IC values for single-layer PB compared to the values obtained from the three-layer PB leachates in the present study. Regarding samples containing painted and unpainted bumpers, the assay was negative according to[25], which contrasts with the results obtained for the three-layer PB. For samples containing fuel tank granulate, the test was positive, a finding that was also confirmed for the three-layer PB leachates. Authors in[23] reported IC values of 46.26% for single-layer PB samples with 10% waste seal granulate and 51.21% for those with waste tire rubber; however, the three-layer PB leachates in this study demonstrated a more pronounced inhibitory effect on *Sinapis alba* root growth relative to the control. In the control sample investigated by Hybská et al.[23], the IC was determined to be 58.77%, whereas the value recorded in the three-layer board experiment was 10% higher.

### *Daphnia magna* Acute Toxicity Assay

The *Daphnia magna* toxicity assay is based on monitoring the behavior and survival of the organisms, specifically targeting immobilization—defined as the macroscopically observable inability to move independently within the water column. *Daphnia magna* exhibit high sensitivity to a broad spectrum of pollutants, making them an ideal model for ecotoxicological assessment. The immobilization percentage was calculated from the number of immobilized individuals; the resulting values after 24 and 48 hours of exposure are summarized in Table 8.

According to[18, 19, 20], the preliminary assay is classified as:

- **Positive** if mortality or immobilization reaches ≥ 50 % relative to the control during the exposure period. In such cases, the EC50 must be determined through range-finding and definitive tests.
- **Negative** if mortality or immobilization is < 50 % relative to the control, necessitating a limit test for verification.

The observed survival rates allowed the assay to proceed for an additional 24 hours (Table 8). Except for samples PN10 and TK10G10, the results were negative. All experimental conditions were strictly maintained, and the dissolved oxygen levels in the leachates met the established validity criteria for the assay.

***Table 8: Percentage immobilization of Daphnia magna after 24 and 48 hours of exposure***

| **Exposure Period** | **Observed Response** | **Sample** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **PB** | **PK10** | **TK10** | **LN10** | **NN10** | **PN10** | **KVN10** | **KSH10** | **P10G10** | **TK10G10** |
| **After 24 hours** | **Immobilization (%)** | 25 | 25 | 40 | 50 | 20 | 65 | 15 | 20 | 20 | 80 |
| **After 48 hours** | | 25 | 40 | 65 | 75 | 20 | 85 | 20 | 25 | 50 | 90 |

**Notes:** PB – neat particleboard; PB containing: P10 – waste tire rubber granulate; TK10 – granulate from waste seals and carpets; LN10 – granulate from waste painted bumpers; NN10 – granulate from waste unpainted bumpers; PN10 – granulate from waste fuel tanks; KVN10 – granulate from waste flame-retardant cables; KSH10 – granulate from waste flammable cables; P10G10 – waste tire rubber granulate and graphite; TK10G10 – granulate from waste seals, carpets, and graphite.

As indicated in Table 8, the number of immobilized individuals for the neat PB and NN10 samples remained constant at the 48-hour mark, with no additional immobilization observed. Conversely, an increase in immobilization was recorded for all other samples after 48 hours of exposure. The highest immobilization rate occurred in the leachate derived from the particleboard containing waste seal, carpet, and graphite granulate (TK10G10). Following the 48-hour exposure period, the assay yielded positive results for samples TK10, LN10, PN10, P10G10, and TK10G10. Authors in[24] reported immobilization rates of 63% and 65% after 48 hours for leachates containing 10% painted and 10% unpainted bumper granulate, respectively. In their study, only the leachate containing 10% fuel tank waste yielded a negative result (41%). It has been noted[23] that the preliminary assay for aqueous leachates from shredded tires was negative, whereas granulated tire samples yielded positive results (80% immobilization); this suggests a significant influence of particle size on the resulting leachate toxicity. Sackey et al.[26] conducted 48-hour assays with *Daphnia magna* for leachates from various wood species, observing immobilization across all samples. Furthermore, a team of researchers[28] evaluated 12 different tire types, concluding that all were toxic to *Daphnia magna* and consistently exhibited increased toxicity after 48 hours of exposure.

## Conclusion

The release of substances from automotive waste into the environment can be mitigated through minimization, reuse, recovery, and recycling, pursuant to the Waste Act No. 79/2015 Coll. One viable recycling pathway involves utilizing these wastes as wood substitutes in the production of particleboards (PB).

Experimental findings indicate that the manufacture of three-layer PB containing automotive waste is a technologically feasible recycling method. However, environmental impact assessments conducted via ecotoxicological assays highlight the necessity of optimizing the specific types and proportions of wood replacement. This optimization is essential to maintain the physical and mechanical properties of the PB while minimizing adverse effects on environmental components.

Based on these results, it can be concluded that the most significant difference between single-layer and three-layer PB was observed in the *Daphnia magna* immobilization assay. The leachate from the three-layer PB exhibited significantly lower toxicity toward *Daphnia magna* compared to single-layer PB[21, 22]. This is a positive outcome, as *Daphnia magna* is recognized as one of the most sensitive bioindicators, a fact corroborated by numerous studies[29, 30, 31, 32].

Furthermore, the results suggest a need to re-evaluate the 10% waste loading in particleboard production to further reduce inhibitory effects on aquatic test organisms. Aligning with COD values—representing the total organic content—the highest inhibitory effects were observed in leachates from PB containing painted bumper granulate (LN10), waste tires (P10), and waste seals and carpets (TK10).

Ultimately, the application of ecotoxicological assays across multiple trophic levels serves as an effective tool for assessing the environmental impacts of materials on the aquatic ecosystem.

Unlike conventional WPC materials, particleboards containing polymer waste represent a separate category of materials combining bonded lignocellulosic particles and heterogeneous polymer fractions, for which ecotoxicological data are still insufficiently investigated.

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# Hodnotenie vplyvu recyklovaného automobilového odpadu použitých v drevotrieskových doskách na kvalitu vody

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## *Súhrn*

*Článok sa zaoberá hodnotením environmentálnych vplyvov trojvrstvových drevných kompozitov (DTD) vyrobených s použitím odpadu z automobilového priemyslu v jeho strednej vrstve na akvatické prostredie. V rámci experimentálnej časti sa pripravili zo vzoriek DTD vodné výluhy, ktoré sa testovali pomocou ekotoxikologických testov s využitím testovacích organizmov Lemna minor, Sinapis alba a Daphnia magna. Boli stanovené vybrané ukazovatele hodnoty pH a CHSK (ako suma organických látok vylúhovaných do vody). Ako kontrolná vzorka bola použitá drevotriesková doska bez obsahu odpadu. Na základe získaných výsledkov môžeme konštatovať, že použitie odpadov z automobilového priemyslu je jedným zo spôsobov recyklácie odpadov do nových výrobkov a využitie biotestov vhodným nástrojom na posúdenie vplyvov na životné prostredie. Z výsledkov získaných pri posudzovaní environmentálnych vplyvov vyplýva potreba prehodnotiť množstvo použitých odpadov pri výrobe DTD tak, aby sa znížil inhibičný účinok na testovacie organizmy v akvatickom prostredí a pritom boli zachované fyzikálne a mechanické vlastnosti vyrobených DTD.*

***Kľúčové slová**: plast, vodný výluh, automobilový priemysel, odpady, drevotrieskové dosky, ekotoxicita*