*Research Article*

# Improving In-Vehicle Air Quality with Bio-Additive ABS Composites

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## Abstract

*In recent years, significant research efforts have focused on improving indoor air quality in vehicles and reducing volatile organic compound (VOC) emissions. Interior trim components release harmful gases, particularly under elevated temperature conditions, due to the degradation of organic structures, posing health risks to passengers. This risk is especially critical for children and animals who are exposed to prolonged travel periods in service vehicles. In this study, bio-based additives were incorporated into recycled acrylonitrile butadiene styrene (ABS) matrices used in interior trim sheet production to reduce environmental impacts and improve thermal performance. A mixture obtained from marine-origin algae and terrestrial plant powders (nettle, oak, and poplar leaves) was added to recycled ABS at 2 wt%. Total Organic Carbon (TOC) measurements were conducted under ambient conditions. Results showed that carbon emissions from bio-additive plates were 87.7% lower than those from non-additive plates. These findings demonstrate that natural additives exhibit gas adsorption capabilities within ABS matrices and offer an effective and sustainable alternative for improving in-vehicle air quality. In this context,* *the present work provides an important contribution both to recycling-based polymer utilization and to the development of eco-friendly, bio-composite automotive materials.*

**Keywords:** Interior trim, Bio-composite, Recycled ABS, TOC, Sustainable materials, VOC emission

## 1. Introduction

In recent years, the automotive industry has increasingly prioritized environmentally benign manufacturing strategies and the integration of sustainable material systems. A particular research emphasis has been placed on improving in-vehicle air quality, driven by expanding environmental regulations and public health considerations [1,2]. Given that individuals spend approximately 5.5% of their lifetime inside vehicles [3–5], volatile organic compounds (VOCs) and odor emissions originating from interior components have emerged as critical factors influencing both environmental safety and human well-being. Daily commuting times vary substantially depending on urban infrastructure, transport planning, and traffic density. Extended occupancy durations have reinforced the conceptualization of vehicle interiors as semi-permanent living spaces rather than transient transportation cabins. Consequently, consumer expectations related to interior comfort and air quality have intensified, particularly in regions characterized by high ambient temperatures, where thermal loading further exacerbates VOC release phenomena. Interior trim components exposed to prolonged thermal stress and ultraviolet radiation are known to accelerate the volatilization of organic constituents embedded within the polymeric matrix, thereby posing non-negligible risks to human health [6,7]. From a material utilization standpoint, German-manufactured vehicles exhibit the highest incorporation of polymeric composites, ranging between 300–365 kg per vehicle, corresponding to approximately 22.5% of the total vehicle mass. In comparison, this value averages 210–260 kg/vehicle (16%) in European and American fleets, 126–150 kg/vehicle (10%) in Japanese fleets, and 90–110 kg/vehicle (~8%) in Chinese vehicles [8]. VOC emissions originating from seats, carpets, adhesives, and polymeric trim panels are widely recognized contributors to interior odor intensity and air quality degradation [9]. Prolonged exposure to VOC-laden environments has been associated with neurological discomfort, respiratory complications, and chronic systemic impacts, with heightened vulnerability observed in children and domestic animals [10]. Recent investigative reports indicate that although the implementation of recycled polymers in automotive interiors substantially reduces environmental burdens, VOC emission control remains a persistent technical challenge requiring further mitigation strategies [11,12].

In this context, bio-derived fillers and lignocellulosic additives have garnered significant attention due to their dual functionality in improving mechanical/thermal performance and attenuating VOC release [13]. Numerous studies have demonstrated that high filler loadings—including calcite, wood flour, and metallic particulates—directly influence the microstructural homogeneity and physicochemical stability of composite matrices [14–20]. Specifically, biomass systems rich in cellulose, lignin, and tannin have been reported to enhance gas adsorption phenomena within polymer matrices, thereby reducing emission intensity [12].

Aligned with this emerging sustainability paradigm, the present study aims to investigate the environmental implications and emission-modulating capacity of bio-derived natural additives incorporated into recycled acrylonitrile butadiene styrene (ABS) matrices employed in commercial vehicle and urban minibus interior trim panel manufacturing. The objective of overarching is to assess the extent to which bio-reinforcement can simultaneously enhance recycled material performance, mitigate emission behavior, and improve in-vehicle air quality.

## 2. Materials and Methods

### 2.1. Sheet Production

Acrylonitrile Butadiene Styrene (ABS) material was used for the production of the panels. As the reinforcement material, bio-based additives were utilized, derived either from marine algae and similar sea plants, or from terrestrial plants such as nettles, oak leaves, and poplar leaves, obtained in the form of extracts from leaves and similar organic fibers. For plastic panel manufacturing, recycled ABS granules without any additives were fed into the extruder machine and processed at approximately 180–200 °C. The same procedure was also performed using recycled ABS combined with a 2% bio-based reinforcement mixture.

### 2.2. Measurement Procedure

The produced 2% bio-reinforced panels were tested for oxygen ($O_2$) concentration using the Kitagawa / AP-20 device in accordance with the ASTM D4490-23 standard for the determination of toxic gas or vapor concentrations. Following the production of reinforced and non-reinforced panels at OTM Plastik, on-site measurements were performed by laboratory personnel. The workplace measurements were carried out using a handheld pump and a short-term detector tube operating on the color-change principle, enabling instantaneous gas detection directly in the field. The measurement parameters are presented in Table 1. The expanded uncertainty value affecting each measurement result is indicated as "± value" in the corresponding result tables. In the calculation of expanded measurement uncertainty, the coverage factor was taken ABS Sheet 2, providing an approximate 95% confidence interval.

*Table 1. Measurement parameters recorded from the sheets after production*

| | Measurement Duration (min) | Parameter Name | Detected Concentration (mg/m³) ± Uncertainty | Temperature (°C) | Pressure (kPa) | Humidity (% RH) |
|---|---|---|---|---|---|---|
| **ABS Sheet 1 – Bio-reinforced** | 1 | $O_2$ | 10,51 ± 0,65 | 19,8 | 102 | 62,3 |
| **ABS Sheet 2 – Non-reinforced** | 1 | $O_2$ | 9 ± 0,56 | 19,9 | 102 | 61,8 |

## 3. Results

Following the sheet production, the measured carbon emission values released into the air were expressed in ppm (parts per million). The measurement results obtained from the recycled ABS sheet were 79.2, 80.1, and 78.8 ppm, respectively. The recycled ABS sheet reinforced with 2% plant-based extract exhibited emission values of 9.2, 10.2, and 9.8 ppm, as presented in Figure 1. based on the results, while the recycled ABS sheet emitted an average of 79.37 ppm carbon into the air under the specified measurement conditions (19 °C), the 2% bio-reinforced recycled ABS sheet released 9.8 ppm carbon under the same conditions. These findings clearly demonstrate the significant effect of bio-based additives on reducing carbon emission values in ABS sheets.

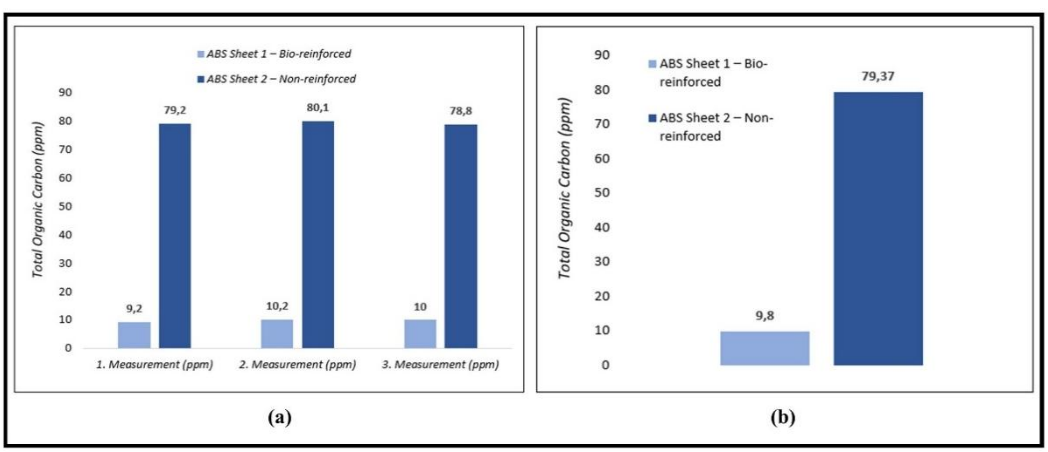


*Figure 1. (a) Total Organic Carbon (TOC) Measurements, (b) Average Total Organic Carbon (TOC) measurements of bio-reinforced an d non-reinforced*

## 4. Discussion and Conclusion

In the present investigation, the volatile emission characteristics of sheets manufactured from recycled ABS were systematically examined, and the impact of 2 wt.% bio-derived reinforcement on carbon-based gaseous release was quantitatively assessed. The experimental findings unequivocally reveal that the incorporation of plant-origin additives into the ABS matrix engenders a pronounced suppression of carbon emissions, analogous to VOC-related outgassing phenomena. This emission attenuation is distinctly demonstrated by the reduction of carbon release from an average concentration of 79.37 ppm in unmodified recycled ABS sheets to 9.8 ppm upon bio-reinforcement. The observed mitigation mechanism is plausibly attributed to the lignocellulosic moieties intrinsic to the plant extracts, which facilitate the development of a more coherent and interlocked interfacial morphology within the thermoplastic matrix. Such bio-structured constituents are reported to diminish the inter-segmental free volume and suppress polymer chain mobility, thereby generating a denser macromolecular network [20–22].

As a consequence, diffusion pathways for volatile species are significantly restricted, culminating in a marked decline in gas-phase release. Furthermore, the antioxidative components inherent to the bio-based additives may moderate thermally induced oxidative scission, thereby hindering the generation of low-molecular-weight volatile compounds, which constitutes a secondary yet complementary suppression mechanism. The elevated emission levels registered for unreinforced recycled ABS are ascribed to cumulative degradation phenomena, including chain scission events, oxidation-induced structural disorder, and the persistence of entrapped volatiles originating from prior processing cycles. The integration of bio-derived reinforcement demonstrably counteracts these degradation-induced liabilities and enhances the environmental compatibility of the recycled thermoplastic system.From a sustainability perspective, the inclusion of 2 wt.% natural reinforcement emerges as an efficacious strategy not only in diminishing the emission footprint of recycled ABS but also in advancing vehicle interior air quality requirements.

As an extension of this work, forthcoming research will encompass an in-depth mechanical interrogation of bio-modified recycled ABS sheets, including tensile, flexural and impact resistance profiling, with the aim of elucidating the correlation between microstructural tailoring and macroscopic durability performance.

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