

Development of biobased photocurable resin for LCD 3D printing of reprocessable catalyst-free vitrimer

Aukse Navaruckiene

Department of Polymer Chemistry and Technology, Kaunas University of Technology, Kaunas, Lithuania

Kastytis Pamakstys

Institute of Environmental Engineering, Kaunas University of Technology, Kaunas, Lithuania

Aysu Nasiribouyony and Vilde Sereikaite

Department of Polymer Chemistry and Technology, Kaunas University of Technology, Kaunas, Lithuania

Visvaldas Varzinskas

Institute of Environmental Engineering, Kaunas University of Technology, Kaunas, Lithuania, and

Jolita Ostrauskaite

Department of Polymer Chemistry and Technology, Kaunas University of Technology, Kaunas, Lithuania

Abstract

Purpose – This research aimed to develop a novel photocurable biobased resin for LCD 3D printing of reprocessable catalyst-free vitrimer.

Design/methodology/approach – A series of new photocurable biobased resins composed of dipentaerythritol pentaacrylate, 1,3-diglycerolate diacrylate, mixture of glycerol methacrylate isomers and resveratrol triglycidyl ether were designed without transesterification catalyst and their photocuring features were investigated to determine the most suitable for LCD 3D printing. The photocuring kinetics was investigated by real-time photorheometry. The thermal and mechanical properties, stress relaxation, self-welding, reprocessability and LCD 3D printability of the selected polymer were investigated.

Findings – The determined influence of different resin components is as follows: dipentaerythritol pentaacrylate and 1,3-diglycerolate diacrylate increase photocuring rate and rigidity of resulting polymers, mixture of glycerol methacrylate isomers reduces viscosity and resveratrol triglycidyl ether reduce shrinkage. The selected polymer exhibits vitrimeric properties and thermal stability higher by ca. 100°C than that of most biobased vitrimers reported in the literature and other polymers obtained from the commercial resins for optical 3D printing.

Originality/value – This study demonstrates the importance of resin design for successful application in optical 3D printing and reveals the main challenges in selecting the right components to obtain the targeted vitrimer properties. The exceptional thermal stability and LCD 3D printability of the developed vitrimer are important for manufacturing precise and complex products for various industries, while self-welding and reprocessing capabilities are crucial for the reuse of such products.

Keywords Biobased photopolymers, Vitrimers, Photocuring, LCD 3D printing

Paper type Research paper

1. Introduction

Plastic waste pollution is one of the most concerning environmental issue globally (Phelan *et al.*, 2022). In Europe, almost 40% of plastics are used as packages where they are single-use and end up in the environment (Ceballos-Santos *et al.*, 2024; Gündoğdu *et al.*, 2024). The high demand of plastics for packaging is due to their versatility, low cost, chemical resistance and lightweight (Phelan *et al.*, 2022). Increasing plastic waste pollution and limitations in recyclability are driving scientists to look for new and more

environmentally friendly materials (Gonzalez *et al.*, 2025; Willis *et al.*, 2025).

© Aukse Navaruckiene, Kastytis Pamakstys, Aysu Nasiribouyony, Vilde Sereikaite, Visvaldas Varzinskas and Jolita Ostrauskaite. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at <http://creativecommons.org/licenses/by/4.0/>

The current issue and full text archive of this journal is available on Emerald Insight at: <https://www.emerald.com/insight/1355-2546.htm>



Rapid Prototyping Journal
32/8 (2026) 1988–1998
Emerald Publishing Limited [ISSN 1355-2546]
[DOI 10.1108/RPJ-12-2025-0656]

Funding: This research was conducted as a part of the project “Mission-driven Implementation of Science and Innovation Programmes” (No. 02–002-P-0001) funded by the Economic Revitalization and Resilience Enhancement Plan “New Generation Lithuania”, Innovation Agency, Lithuania.

Received 15 December 2025

Revised 9 January 2026

Accepted 16 January 2026

Vitrimers are a relatively new class of polymeric materials that can help solve the worldwide plastic waste pollution problem (Zhang *et al.*, 2024). Vitrimers combine the mechanical properties of thermosets and the recyclability properties of thermoplastics (Zheng *et al.*, 2021). They are strong and rigid due to their crosslinked structure and can be easily recycled using dynamic covalent bonds that undergo exchange reactions (Zee and Nicolaÿ, 2020). There are several types of vitrimers bond exchange reactions: disulfide exchange, imine exchange, boronic ester exchange, transesterification, etc. (Denissen *et al.*, 2015). One of the most common and easiest types of bond exchange in vitrimers is the thermally activated transesterification reaction of the ester and hydroxyl groups (Zhou *et al.*, 2025; Liu *et al.*, 2020). The transesterification catalyst is usually crucial for stress relaxation and reprocessability of vitrimers, and the most widely used one is zinc acetylacetonate hydrate (Kumar *et al.*, 2025). However, most catalysts, including zinc acetylacetonate hydrate, are commonly expensive and toxic and can cause serious health damage (Tran *et al.*, 2024). Because of that catalyst-free vitrimers are of great interest to the scientific community (Cai *et al.*, 2025).

Catalyst-free vitrimers provide all the positive features of vitrimers and makes them environmentally friendly due to their low toxicity. Recently catalyst-free epoxy vitrimer with repairability properties was synthesized using thermal polymerization of trifunctional amine and was able to maintain flexural strength similar to the original sample after four healing cycles (Li *et al.*, 2025). Gallic acid was used for the thermal polymerization of epoxy-based catalyst-free vitrimer with a high glass transition temperature (109–122°C) (Yao *et al.*, 2024). Lately, a fully biobased, catalyst-free vitrimer was synthesized using tannic acid and showed promising scratch healing, shape memory and welding properties (Li *et al.*, 2024). However, most biobased catalyst-free vitrimers have low thermal stability which limit their areas of application (Sereikaite *et al.*, 2025). High thermal stability enables their application in high temperature environments such as automotive, aerospace or electronics and ensures that the vitrimers do not undergo thermal destruction during use (Abdelbary, 2014). That is highly important because it prevents the release of harmful organic compounds which might occur during thermal decomposition (Shanmugam *et al.*, 2024). Furthermore, most catalyst-free vitrimers, reported in the literature, are synthesized using thermal polymerization, which is a time and energy consuming process, and only a few of them are synthesized using a more environmentally friendly photopolymerization method (Shi *et al.*, 2017).

Photopolymerization allows a rapid production of vitrimers at room temperature with low production waste generation (Vilanova-Pérez *et al.*, 2024). Recently, a biobased catalyst-free vitrimer was synthesized by photopolymerization using glycerol derivative and showed promising self-welding properties and reprocessability, and was also successfully applied in optical 3D printing technology (Sereikaite *et al.*, 2025). This technology allows products to be printed very accurately and with a smooth surface finish, which is impossible to achieve using other 3D printing techniques (Sun *et al.*, 2005). Optical 3D printing generates only a small amount of production waste compared to other manufacturing techniques, most of which are defective models and supports of the printed models (Afridi *et al.*, 2024). However, due to the small amount of optical 3D printing

production waste, it is too expensive to recycle them, and they are mainly thrown away in landfills (Husna *et al.*, 2024). Reprocessability of vitrimers would allow the reuse of even small amounts of printing waste for the manufacturing of new products, thereby reducing plastic pollution (Toldy *et al.*, 2025).

The aim of this work was to develop a new photocured catalyst-free transesterification vitrimer with high thermal stability, suitable for optical 3D printing technology. A photocurable system was composed of epoxy monomer selected for the increase of rigidity and reduced shrinkage of resins (Pabricaite *et al.*, 2024) and acrylate monomers, which were selected to increase the photocuring rate of resins and control the viscosity. Three biobased acrylate monomers dipentaerythritol pentaacrylate (produced by chemical modification of vegetable oils (Sereikaite *et al.*, 2025), glycerol 1,3-diglycerolate diacrylate and mixture of glycerol methacrylate isomers (both can be produced from glycerol, obtained as a by-product of biodiesel production (Ngaosuwan, 2024). These acrylate monomers were selected due to their wide viscosity range and high amount of hydroxy and acrylic functional groups. Resveratrol triglycidyl ether (produced by chemical modification of resveratrol that is formed naturally by various plants such as grapes (Koushki *et al.*, 2018) was selected as epoxy monomer due to its rigid aromatic structure. Two photoinitiators, free-radical TPO and cationic CPI-410S, were selected for this study due to the high activity at 405 nm, which is necessary for LCD 3D printing. Elegoo Mars Pro LCD 3D printer was chosen for this study due to its high printing speed and cost-effectiveness (Chaughule and Dashaputra, 2021). Composed resins were investigated by real-time photorheometry to select the most promising one for LCD 3D printing.

2. Materials

Dipentaerythritol pentaacrylate (DPEPA, Merck), 1,3-diglycerolate diacrylate (GDGDA, Merck), mixture of glycerol methacrylate isomers (GLYFOMA, Evonik), resveratrol triglycidyl ether (RTE, Specific Polymers) diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide (TPO, Merck), sulfonium salt CPI-410S (CPI-410S, San Apro) and 2,5-bis(5-tert-butyl-2-benzoxazolyl) thiophene (UVB, Merck) were used as received (Scheme 1). The compositions of the resins are presented in Table 1.

2.2 Composition of photocurable resins

The primary mixtures containing 10 w.% of RTE, 30–90 w.% of GDGDA, 0–60 w.% of GLYFOMA, 0–30 w.% of DPEPA, 2.5 w.% of photoinitiator TPO, 2.0 w.% of photoinitiator CPI-410S and 0.08 w.% of UVB were mixed at 25°C for 10 min until they had a homogeneous consistency (Table 1).

2.3 Preparation of photopolymer samples

Polymer samples were prepared using LCD 3D printer Elegoo Mars Pro. Printed polymer specimens (70x10x1 mm) were then washed with isopropanol and post-cured for 5 min under a UV/Vis lamp with 310 mW/cm² intensity.

2.4 Methods

The methodology of the experiments and measurements performed in this study is described in detail in the

Scheme 1 Chemical structure of dipentaerythritol pentaacrylate (DPEPA), 1,3-diglycerolate diacrylate (GDGDA), mixture of glycerol methacrylate isomers (GLYFOMA), resveratrol triglycidyl ether (RTE) diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide (TPO), sulfonium salt CPI-410S (CPI-410S) and 2,5-bis(5-tert-butyl-2-benzoxazolyl) thiophene (UVB)

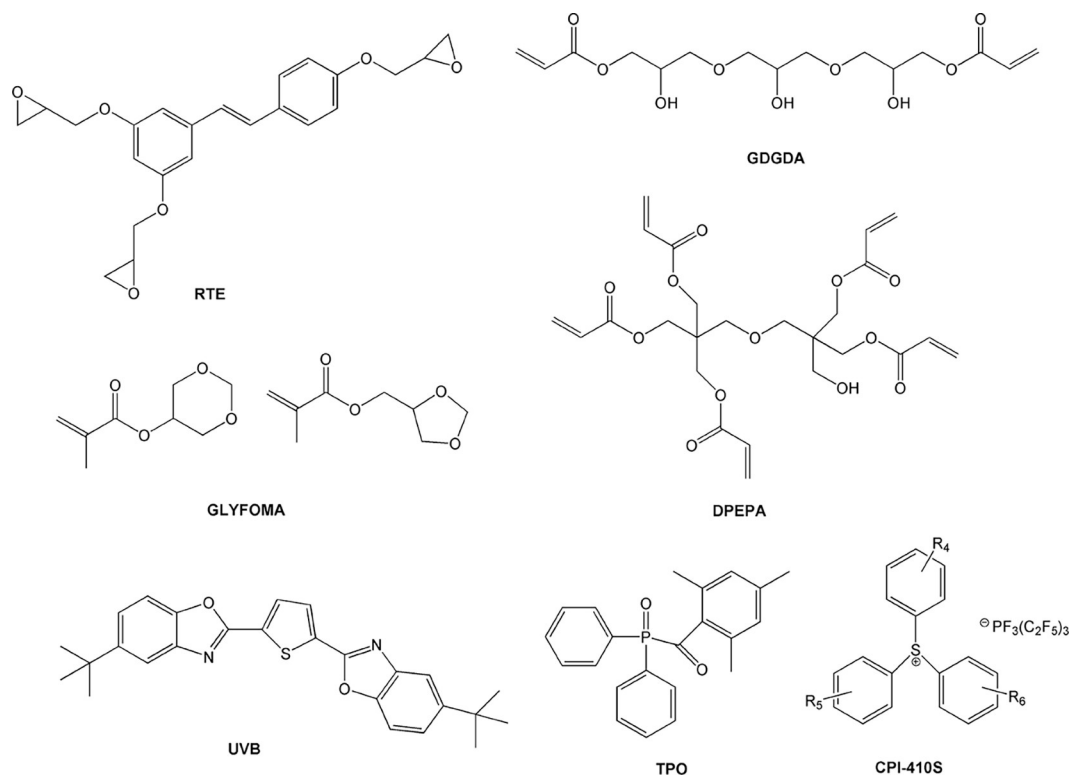


Table 1 Composition of resins N1–N5

Resin	Amount of RTE, w. %	Amount of GDGDA, w. %	Amount of GLYFOMA, w. %	Amount of DPEPA, w. %	Amount of TPO, w. %	Amount of CPI-410S, w. %	Amount of UVB, w. %
N1	30	70	–	–	2.5	2	0.08
N2	10	90	–	–	2.5	2	0.08
N3	10	30	60	–	2.5	2	0.08
N4	10	45	45	–	2.5	2	0.08
N5	10	30	30	30	2.5	2	0.08

Supplementary material file. Polymer structure was characterized by Fourier transformation infrared spectroscopy (FT-IR), Soxhlet extraction and swelling tests. The thermal properties of polymers were examined by dynamic mechanical thermal analysis (DMTA) using the shear mode and thermogravimetric analysis (TGA). The tensile test was performed to determine mechanical characteristics. Microsoft Excel program ANOVA was used to statistically analyze the results.

3. Results and discussion

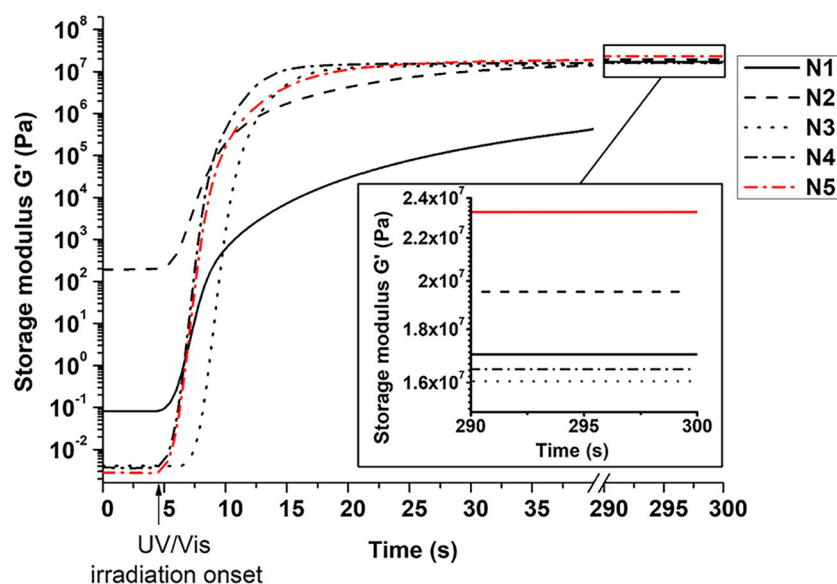
3.1 Photocuring kinetics

Real-time photorheometry was used to investigate rheological characteristics of photocurable resins and to select the most

promising resin for LCD 3D printing. The results are presented in [Table 2](#) and [Figure 1](#). Resin **N1** was composed of 70 w. % of acrylate monomer 1,3-diglycerolate diacrylate and 30 w. % of epoxy monomer resveratrol triglycidyl ether. GDGDA was selected because of its biobased origin and three hydroxy groups in its structure, which are crucial for successful transesterification reactions ([Hayashi and Ricarte, 2025](#)). RTE was selected because of the biobased origin and aromatic structure, as the rigid aromatic structure reduces shrinkage and increases mechanical strength and thermal stability of the resulting polymers ([Mohanty and Bae, 2015](#)). Sample **N1** had a very low shrinkage (4.5%), but the high viscosity of the resin **N1** (30703 mPa·s) made it unsuitable for 3D LCD printing. To reduce viscosity, the amount of highly viscous RTE was reduced from 30 to 10 w. % and the resin **N2** was composed.

Table 2 Rheological characteristics of resins N1–N5

Resin	Storage modulus, MPa	T_{gel} , s	Induction period, s	Shrinkage, (%)	Viscosity, mPa·s
N1	17.35 ± 0.68	12.00 ± 0.5	0 ± 0	4.5 ± 0.1	30703 ± 216
N2	19.62 ± 0.76	1.75 ± 0.0	0 ± 0	9.0 ± 0.2	14081 ± 153
N3	16.09 ± 0.54	3.75 ± 0.1	2 ± 0	14.5 ± 0.6	47 ± 2
N4	16.50 ± 0.49	1.75 ± 0.0	0 ± 0	13.5 ± 0.5	176 ± 6
N5	22.96 ± 0.82	1.75 ± 0.0	0 ± 0	12.5 ± 0.3	381 ± 18

Figure 1 Dependence of G' values of resins N1–N5 on irradiation time

This change reduced the viscosity and increased the shrinkage value almost by double. However, the viscosity of **N2** was still too high. To further reduce viscosity, the amount of GDGDA was reduced to 30 w.% and 60 w.% of other acrylate monomer GLYFOMA was added to the composition (**N3**). The addition of GLYFOMA greatly reduced the viscosity to 47 mPa·s, but also increased the shrinkage and the value of the gel point (t_{gel}). Next, the amounts of both acrylate monomers were changed to 45 w.% to reduce the gel point and the resin **N4** was composed. The resulting resin had a lower gel point (1.75 s) and low viscosity (176 mPa·s), but the storage modulus was too low (16.50 MPa). To increase the rigidity and storage modulus of polymers, DPEPA was added to the composition and resin **N5** was prepared using 30 w.% of each acrylate monomer and 10 w.% of epoxy monomer. The resin **N5** had a low gel point (1.75 s), a suitable viscosity for LCD 3D printing (381 mPa·s) and the resulting polymer showed high rigidity of 22.96 MPa. After evaluating these results, resin **N5** was selected for further investigation as the most suitable for LCD 3D printing.

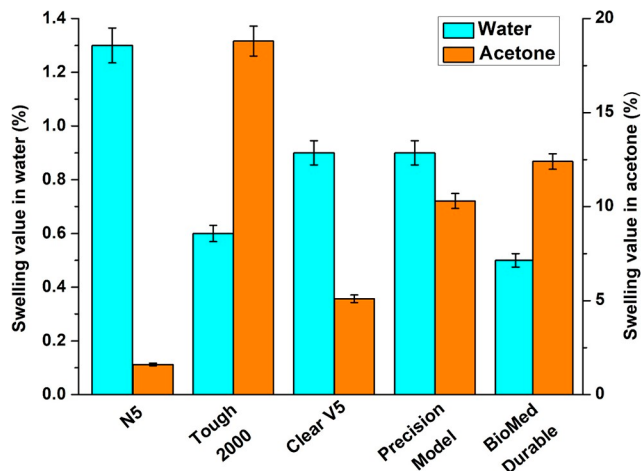
3.3 Characterization of polymer structure

The FT-IR results are described in Supplementary Material section **S2. Results** and **Figure S1** in Supplementary Material. Swelling tests (**Figure S2** in Supplementary Material) and soxhlet extraction were performed to confirm

the cross-linked structure of the vitrimer **N5**. The high value of the yield of insoluble fraction (93.0%) and the very low swelling values after 8 h of swelling in water (0.6%), acetone (0.9%) and toluene (0.0%) confirm that a rigid polymer network with short chains between crosslinking points was formed. These results show that the polymer structure is more similar to that of polar solvent acetone than that of nonpolar solvent toluene, allowing polar solvent molecules to penetrate the polymer more easily.

To further analyze the results of vitrimer swelling, the swelling value was measured after 24 h. Similarly to previous results, no swelling was indicated in toluene and the highest swelling value was indicated in acetone (1.6%) and water (1.3%). These results were compared to polymers synthesized from some common commercially available resins for optical 3D printing (**Figure 2**). **N5** had a slightly lower swelling value in acetone compared to Formlabs Clear V5 and a much lower value compared to Formlabs Tough 2000, Precision model and BioMed Durable. However, the swelling value in water was slightly higher compared to all polymers synthesized from commercially available resins for optical 3D printing (**Formlabs, 2025**). These results prove that vitrimer **N5** is suitable for optical 3D printing and is resistant to non-polar solvent toluene and only swells slightly in polar solvents, such as water and acetone.

Figure 2 Swelling values of vitrimer N5 and polymers synthesized from selected commercially available resins in water and acetone after 24 h



3.4 Thermal characteristics

Thermogravimetical analysis (TGA) and dynamical mechanical thermal analysis (DMTA) were selected to determine the thermal characteristics of vitrimer N5. DMTA and TGA curves are presented in **Figure S3** in Supplementary material. Vitrimer had a high glass transition temperature (T_g) – 68°C, which was almost twice higher than that of the polymer synthesized from commercially available BioMed Flex 80A resin ($T_g = 37^\circ\text{C}$) (Formlabs, 2025) (**Figure 3**). Vitrimer N5 showed promising

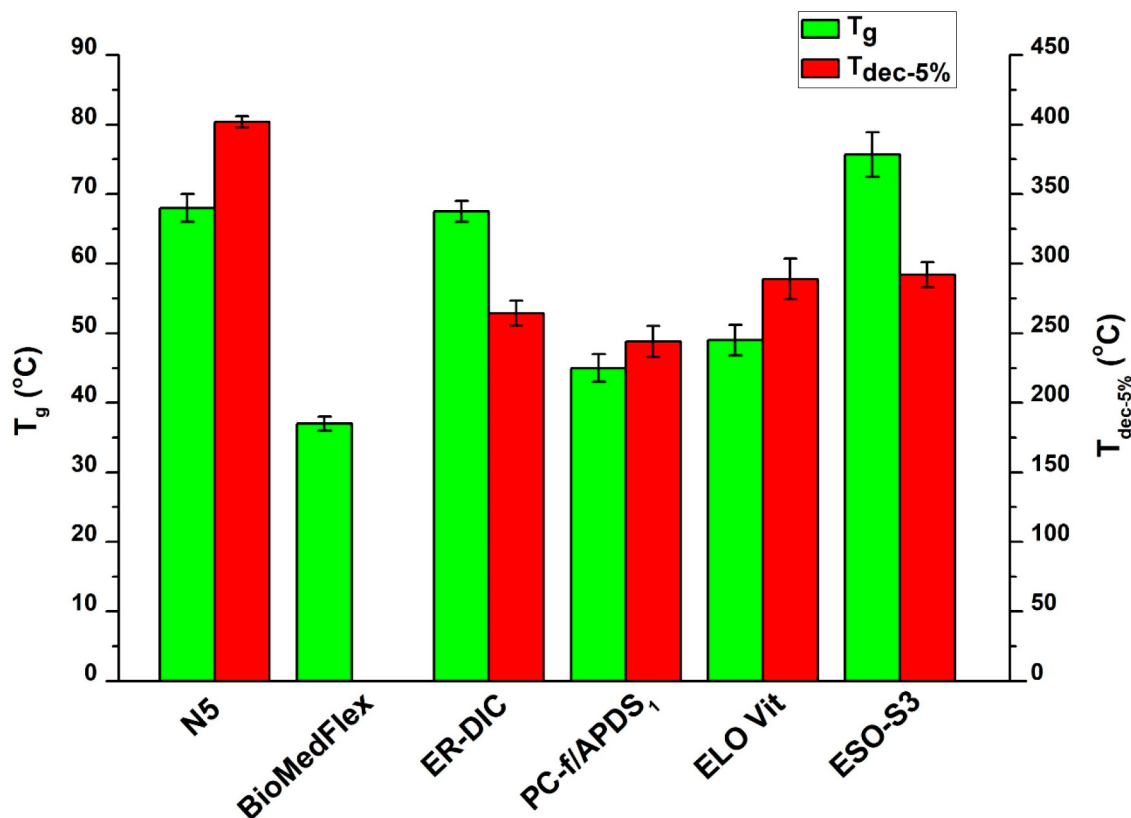
results compared to other biobased vitrimers prepared by thermal polymerization. It had a higher T_g than polybenzoxazine-based vitrimer PC-f/APDS₁ (Wang *et al.*, 2025a, 2025b) and epoxidized linseed oil-based vitrimer ELOVit (Sangaletti *et al.*, 2023). Compared to other vitrimers, the vitrimer N5 had T_g very similar or slightly lower than that of the vitrimer based on resorcinol diglyceryl ether ER-DIC (Zhan *et al.*, 2025) and catalyst-free epoxidized soybean oil-based vitrimer ESO-S3 (Li *et al.*, 2024). These results confirm that T_g of vitrimer N5 is similar or higher than that of other biobased vitrimers.

Furthermore, N5 showed high thermal stability with a temperature of 5% weight loss ($T_{\text{dec-5\%}}$) of 402°C. This value was higher than that of most biobased vitrimers reported in the literature (**Figure 4**). The high $T_{\text{dec-5\%}}$ and T_g expands the areas of application to aerospace, automotive, electronics and other industries.

3.5 Mechanical properties

The tensile test showed that catalyst-free vitrimer N5 is a rigid and stiff material with a high value of Young's modulus (767 MPa) and tensile strength (16 MPa) and minimal elongation at break (0.2%). The tensile stress-strain curve is presented in the Supplementary **Figure S4**. High stiffness and low elongation at break indicate that polymer is brittle. The brittleness is a critical factor limiting the use of polymers in structural components, however brittleness can also be used as advantage. Brittle polymers usually are hard and scratch resistant, therefore can be used as coatings (Gao *et al.*, 2025). N5 showed higher Young's modulus values and lower elongation at break than vitrimers

Figure 3 Glass transition temperature and temperature of 5% weight loss of polymers



produced by thermal polymerization ESO-S3 (Li *et al.*, 2024), ELOVit (Sangaletti *et al.*, 2023), Xyl0.6 (Li *et al.*, 2023) and castor oil-based vitrimer prepared by photopolymerization ECO_0.1CNT (Bergoglio *et al.*, 2024) (Figure 4). However, the tensile strength of vitrimer N5 was lower than that of the epoxidized soybean oil-based vitrimer ESO-S3 (Li *et al.*, 2024) and the epoxidized linseed oil-based vitrimer ELOVit (Sangaletti *et al.*, 2023), indicating that vitrimer N5 is more rigid compared to those vitrimers. The mechanical characteristics of the N5 vitrimer were compared to those of the polymers synthesized from commercially available resins for 3D printing and were similar to those of PR48 (Arkema, 3D Printing Development Center, 2025) and Phrozen Pro ABS-Like (Ultimate 3D printing, 2025) (Figure 4). Young's modulus, and elongation at break of vitrimer N5 were similar to Siraya ABS-Like (Siraya Tech, 2025), Weerg Classic (Weerg, 3D Printing Services, 2025) and PhotoCentric Firm (Photocentric Inc, 2025); however tensile strength was lower indicating its rigidity. The results show that the mechanical characteristics of the N5 vitrimer are comparable with

Figure 4 Mechanical characteristics of polymers

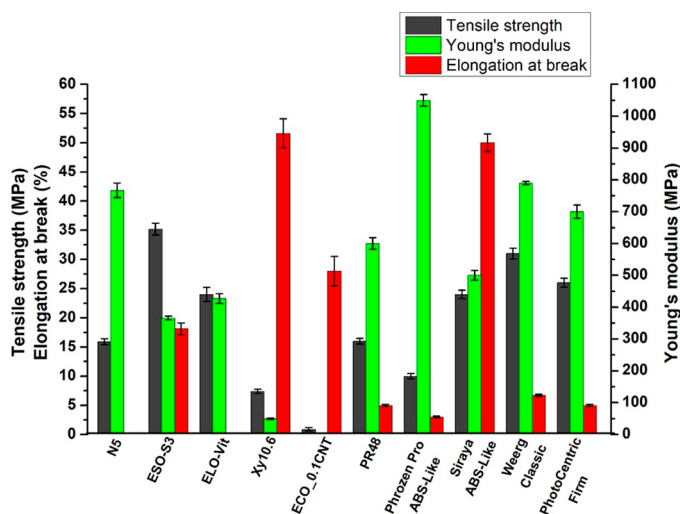
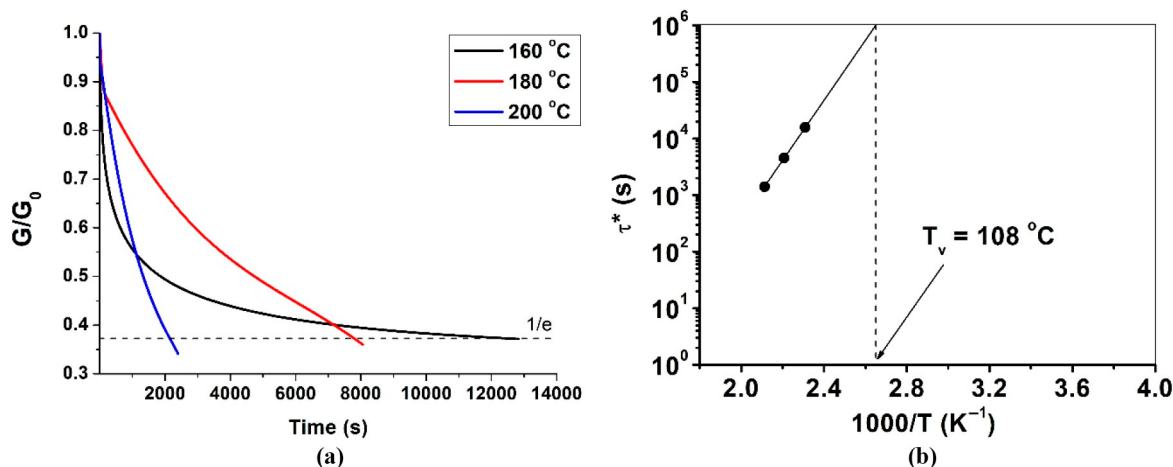


Figure 5 Stress relaxation curves versus time (a) and the Arrhenius plot of relaxation times of N5(b)



other biobased vitrimers and polymer samples prepared by optical 3D printing of commercial resins.

3.6 Stress relaxation of vitrimer

Vitrimers can rearrange their inner network and reduce the relaxation of inner stress by dynamic bond exchange (Liu *et al.*, 2020). Topology rearrangements were investigated by measuring the stress relaxation of polymer N5, and the topology freezing transition temperature (T_v) was determined from the Arrhenius curves for relaxation time of 10^6 s (Figure 5a–b). The T_v of the vitrimer N5 was 108 °C. Relatively low T_v allows vitrimer reprocessing at lower temperature compared to other vitrimers and thermosets and reduces the energy cost of reprocessability due to the low temperature required (Toldy *et al.*, 2025).

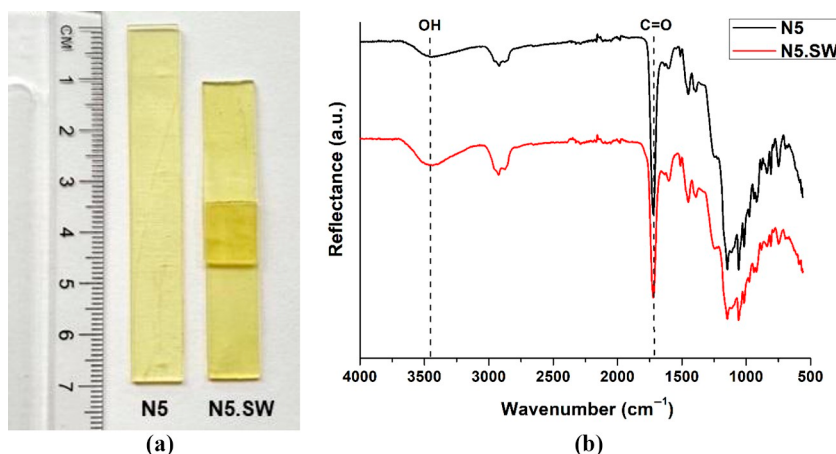
3.7 Self-welding behavior of vitrimer

The tensile test was performed to investigate mechanical characteristics of self-welded vitrimer N5.SW and to compare the results obtained with those of the original catalyst-free vitrimer N5 sample. Tensile stress-strain curves are presented in Figure S4 in Supplementary material. The pictures of the original (N5) and self-welded (N5.SW) samples are presented in Figure 6a. Young's modulus was slightly reduced from 767 to 643 MPa after self-welding compared to the original sample. Tensile strength was also reduced from 16 to 7 MPa indicating that after self-welding the vitrimer became more rigid. The elongation at break remained the same and was lower than 1%. FT-IR spectra of the original and self-welded sample were recorded to confirm that no chemical reaction occurred during self-welding (Figure 6b), and no visible changes between the N5 and N5.SW vitrimer spectra were observed.

3.8 Reprocessability of vitrimer

Reprocessability allows the production of new products using polymer waste. Three hot press reprocessing cycles were performed to catalyst-free vitrimer N5, and numbers 1, 2 or 3 were added to the vitrimer codes indicating the first (N5.1), second

Figure 6 Picture of original vitrimer N5 sample and sample after self-welding N5.SW (a), FTIR spectra of vitrimer N5 and N5.SW (b)



(N5.2) and third (N5.3) cycle. The pictures of the original (N5) and samples after each reprocessing cycle are presented in Figure 7a. The tensile test was performed to investigate mechanical characteristics of the vitrimer after each cycle of reprocessing. Tensile stress-strain curves are presented in Figure S4 in Supplementary material. The results are presented in Figure 7b. Young's modulus and tensile strength values gradually decreased after each reprocessing cycle. The reason for that might be microstructural damage or nonreversible bond breakage due to thermal destruction of vitrimer caused by repeated heating cycles, inappropriate process conditions such as too low or too high pressure or temperature and uneven distribution of vitrimer powder in the pressing frame forming air gaps in vitrimer specimen, which are common causes of reduced mechanical strength in vitrimers (Lorenz *et al.*, 2025; Toldy *et al.*, 2025). The elongation at break remained the same after all cycles of reprocessing and was less than 1%. FT-IR spectra of the original vitrimer N5 and reprocessed vitrimer samples N5.1, N5.2 and N5.3 were recorded to confirm that no chemical reaction occurred during reprocessability process (Figure 7c), and there were no visible changes between N5 vitrimer spectrum and spectra of its samples after reprocessing. These results show that vitrimer N5 is suitable for reprocessing and can be used for the production of new products by hot pressing.

3.9 Shape-memory properties of vitrimer

Vitrimer N5 showed thermoresponsive shape-memory properties and was able to maintain two temporary shapes determined by its T_g and T_v . The shape-memory behavior of vitrimer N5 is presented in Figure 8. The first temporary shape was obtained by reshaping the vitrimer sample at a temperature higher than its T_v and then fixing it by cooling it down to a temperature lower than T_v . The second shape is obtained by reshaping the vitrimer at temperature higher than its T_g , and then fixing it by cooling it down to a temperature lower than T_g . Vitrimer N5 was able to maintain its temporary shapes and return to its permanent shape according to temperature. Between the temperatures of T_g and T_v the mobility in vitrimer chains is increased making it more elastic, while dynamic covalent network still maintains fixed topology. As a result, vitrimer acts like a thermoset with some elasticity (Denissen *et al.*, 2015).

3.10 LCD 3D printing

The printability of N5 resin was tested using a Elegoo Mars Pro LCD 3D printer, and the packaging component of electronic devices such as solar panels, sensors or other microschemes (Figure 9) was successfully printed, showing that the selected resin is suitable for this technology (Hirankittiwong *et al.*, 2025). 3D printing was performed several times for the replicas of the same component and showed good reproducibility under selected parameters with identical product quality, e.g. smooth surface, transparency and precise shape. Optical 3D printing enables fast fabrication of precise complex shape products, which cannot be made using other technologies, and generates low amount of waste (Das *et al.*, 2025). It is an environmentally friendly process that helps reduce plastic pollution (Madineh *et al.*, 2025). Another advantage of optical 3D printing compared to other technologies (such as extrusion, cast molding, etc.), is the cheap and fast personalization of products (Wang *et al.*, 2025a, 2025b). The shape of the product can be easily adapted to personal needs by changing the model using only a computer program, and there is no need for expensive molds (Singh *et al.*, 2025). Furthermore, optical 3D printing enables printing of small quantities of products or several different products at the same time. This feature is very important not only for packaging production, but also in other areas such as medicine, optics, aerospace technology and others (Erdem *et al.*, 2023). The suitability of resin N5 for optical 3D printing expands its areas of application to various fields including medicine, aerospace, automotive, electronics and other (Khan, *et al.*, 2026).

4. Conclusions

In this study, new catalyst-free photosensitive resins composed of dipentaerythritol pentaacrylate, 1,3-diglycerolate diacrylate, mixture of glycerol methacrylate isomers and resveratrol triglycidyl ether were successfully designed and their photocuring features were investigated to determine their suitability for LCD 3D printing and investigate the properties of most suitable vitrimer. The main conclusions are as follows:

- Dipentaerythritol pentaacrylate and 1,3-diglycerolate diacrylate increase photocuring rate and rigidity of resulted polymers, mixture of glycerol methacrylate isomers reduces viscosity and resveratrol triglycidyl ether reduce shrinkage.

Figure 7 Picture of original vitrimer N5 sample and vitrimers samples after each cycle of reprocessing (a), mechanical characteristics (b) and FTIR spectra (c)

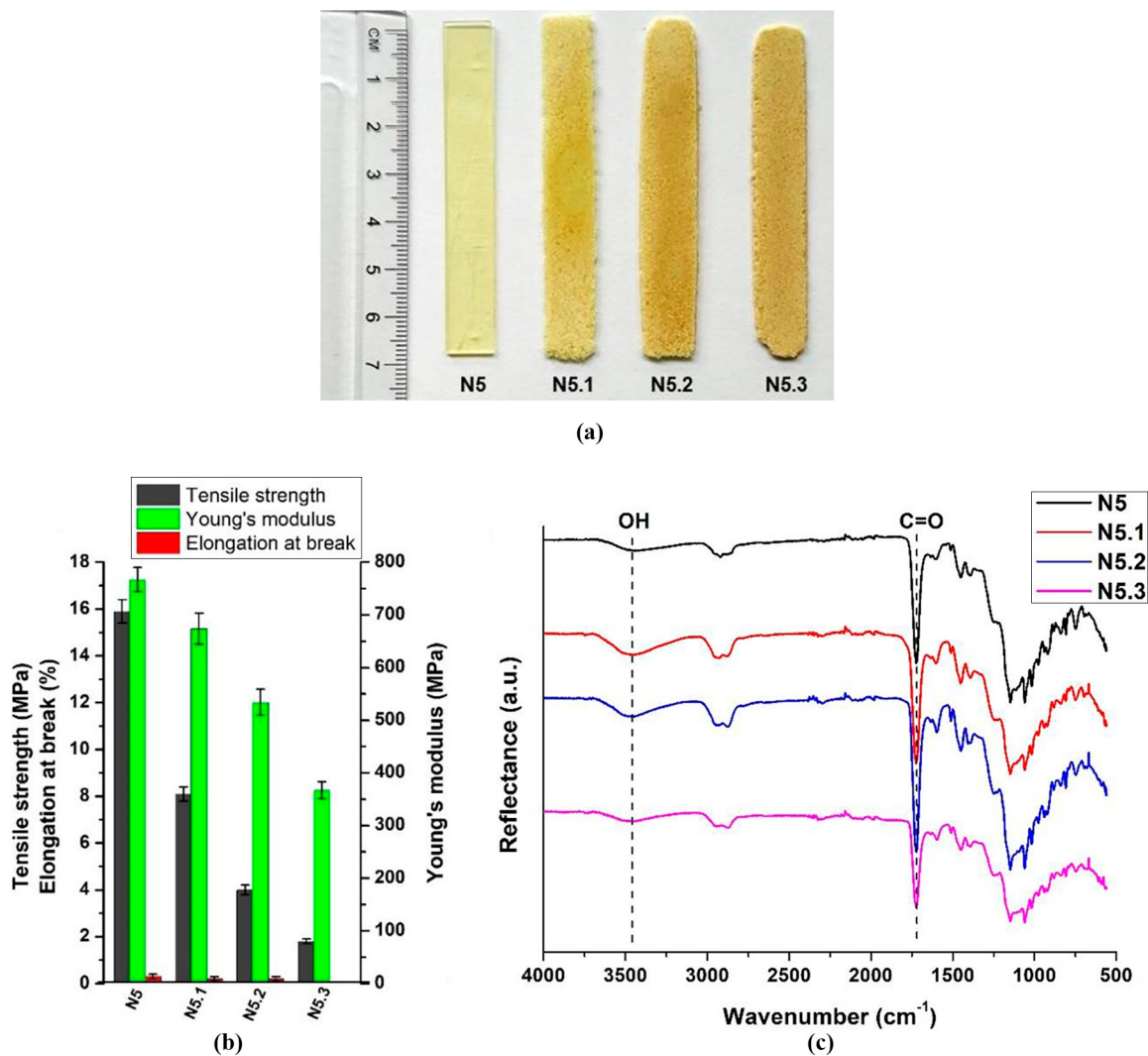


Figure 8 Shape-memory behavior of N5 vitrimer sample

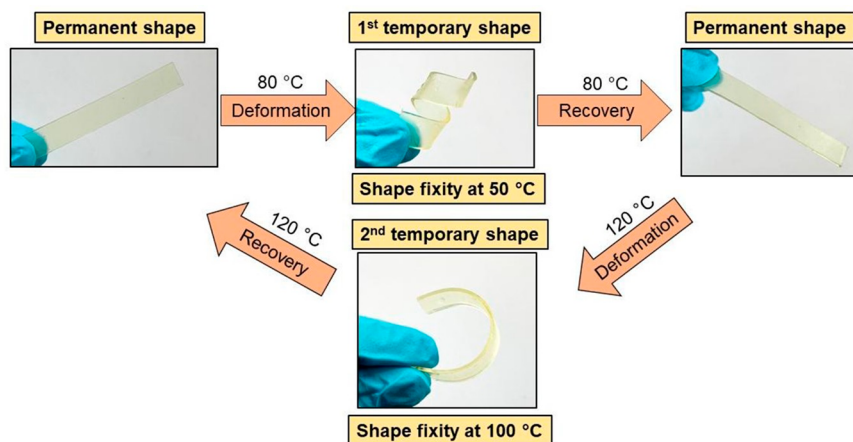
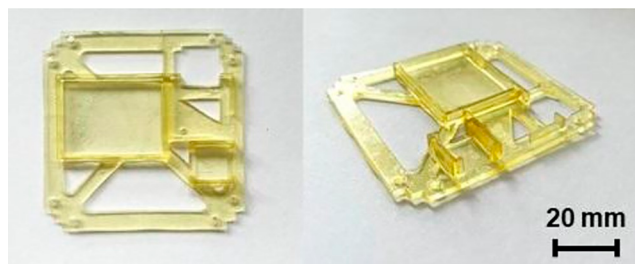


Figure 9 LCD 3D printed packaging component from N5 resin

Resin composed of 30 w.% of dipentaerythritol pentaacrylate, 30 w.% of 1,3-diglycerolate diacrylate, 30 w.% of mixture of glycerol methacrylate isomers and 10 w.% of resveratrol triglycidyl ether combined benefits of all monomers and was selected as the most promising for LCD 3D printing technology.

- Synthesized vitrimer had high yield of insoluble fraction (93.0%) and very low swelling values similar to polymers produced from commercial 3D printing resins. Vitrimer had high temperature of 5% weight loss (402°C), which was higher than those of most biobased vitrimers and its glass transition temperature was 68°C.
- Vitrimer demonstrated promising self-welding behavior and reprocessability. The Young's modulus was slightly reduced from 767–643 MPa after self-welding compared to original sample. The values of Young's modulus and tensile strength decrease after each cycle of reprocessing by 25% and 50%, respectively.
- The selected resin was applied in LCD 3D printing technology using Elegoo Mars Pro 3D printer and the packaging component of electronic devices was printed accurately with a smooth surface finish showing that selected resin is suitable for this technology.

This study presents new catalyst-free biobased transesterification vitrimer with high thermal stability, as well as self-welding behavior and reprocessability. This vitrimer has huge potential for the production of 3D printed packaging components with the ability to easily repair or reshape them after use.

References

- Abdelbary, A. (2014), *Wear of Polymers and Composites*, Woodhead Publishing, Cambridge UK.
- Afridi, A., Rashid, A.A. and Koç, M. (2024), "Recent advances in the development of stereolithography-based additive manufacturing processes: a review of applications and challenges", *Bioprinting*, Vol. 43 No. e00360, doi: [10.1016/j.bprint.2024.e00360](https://doi.org/10.1016/j.bprint.2024.e00360).
- Arkema. 3D Printing Development Center (2025), available at: <https://cpspolymers.com/PR48%20TDS.pdf> (accessed 11 November 2025).
- Bergoglio, M., Palazzo, G., Reisinger, D., Porcarello, M., Kortaberria, G., Schlögl, S. and Sangermano, M. (2024), "Cationic UV-curing of bio-based epoxidized castor oil vitrimers with electrically conductive properties", *Reactive and Functional Polymers*, Vol. 200 No. 105936, doi: [10.1016/j.reactfunctpolym.2024.105936](https://doi.org/10.1016/j.reactfunctpolym.2024.105936).
- Cai, J.Y., Liu, J.H., Wang, Y.L., Li, Z.M., Wang, Y.Z. and Wang, X.L. (2025), "Tri-functional diol-derived epoxy vitrimer: intrinsic flame retardancy, catalyst-free reprocessing, and high mechanical strength retention", *Polymer Degradation and Stability*, Vol. 241 No. 111528, doi: [10.1016/j.polymdegradstab.2025.111528](https://doi.org/10.1016/j.polymdegradstab.2025.111528).
- Ceballos-Santos, S., Sousa, D.B., García, P.G., Laso, J., Margallo, M. and Aldaco, R. (2024), "Exploring the environmental impacts of plastic packaging: a comprehensive life cycle analysis for seafood distribution crates", *Science of the Total Environment*, Vol. 951 No. 175452, doi: [10.1016/j.scitotenv.2024.175452](https://doi.org/10.1016/j.scitotenv.2024.175452).
- Chaugule, R.S. and Dashaputra, R. (2021), *Advances in Dental Implantology Using Nanomaterials and Allied Technology Applications*, Springer.
- Das, A., Sarmah, A., Luster, L.E., Green, M.J. and Bortner, M.J. (2025), "Additive manufacturing of vitrimers: interplay between polymer physics and processing approaches", *Chemical Engineering Journal*, Vol. 525 No. 170221, doi: [10.1016/j.cej.2025.170221](https://doi.org/10.1016/j.cej.2025.170221).
- Denissen, W., Winne, J.M. and Du Prez, F.E. (2015), "Vitrimer: permanent organic networks with Glass-Like fluidity", *Chemical Science*, Vol. 7 No. 1, pp. 30–38, doi: [10.1039/c5sc02223a](https://doi.org/10.1039/c5sc02223a).
- Erdem, A., Yildiz, E., Senturk, H. and Maral, M. (2023), "Implementation of 3D printing technologies to electrochemical and optical biosensors developed for biomedical and pharmaceutical analysis", *Journal of Pharmaceutical and Biomedical Analysis*, Vol. 230 No. 115385, doi: [10.1016/j.jpba.2023.115385](https://doi.org/10.1016/j.jpba.2023.115385).
- Formlabs (2025), available at: https://formlabs.com/eu/materials/?srsltid=5B0%5D=AfmBOorD82Ls_dIFu4uH4Nxq7yslRSZMv0j2Apk34rjAPnJfoaDD6ukf&print_technology%5B0%5D=SLA#materialproductlist (accessed 11 November 2025).
- Gao, Y., Jiang, Z., Zhang, J., Tan, H., Jin, J. and Jiang, W. (2025), "Models and theories regarding the brittle-ductile transition of rubber-toughened thermoplastics and their application in the design of High-Impact polymer composites with balanced toughness and rigidity", *Polymer Science & Technology*, Vol. 1 No. 4, pp. 314–329, doi: [10.1021/polymstech.5c00023](https://doi.org/10.1021/polymstech.5c00023).
- Gonzalez, C.S., Basdeo, A., Sanchez, F.A.C., Nouvel, C., Pearce, J.M. and Boudaoud, H. (2025), "Strategies for recycling multi-material polymer blends for additive manufacturing", *Sustainable Materials and Technologies*, Vol. 44 No. e01430, doi: [10.1016/j.susmat.2025.e01430](https://doi.org/10.1016/j.susmat.2025.e01430).
- Gündoğdu, S., Bour, A., Köşker, A.R., Walther, B.A., Napierska, D., Mihai, F.C., Syberg, K., Hansen, S.F. and Walker, T.R. (2024), "Review of microplastics and chemical risk posed by plastic packaging on the marine environment to inform the global plastics treaty", *Science of the Total Environment*, Vol. 946 No. 174000, doi: [10.1016/j.scitotenv.2024.174000](https://doi.org/10.1016/j.scitotenv.2024.174000).
- Hayashi, M. and Ricarte, R.G. (2025), "Towards the next development of vitrimers: recent key topics for the practical application and understanding of the fundamental physics", *Progress in Polymer Science*,

- Vol. 170 No. 102026, doi: [10.1016/j.progpolymsci.2025.102026](https://doi.org/10.1016/j.progpolymsci.2025.102026).
- Hirankittiwong, P., Chomchok, T., Chakraborty, S., Prajongtat, P., Singh, D.P., Hongkarnjanakul, N., Channumsin, S., Ghosh, S. and Chattham, N. (2025), “Advanced engineered nanostructures for aerospace technology: a review”, *Results in Engineering*, Vol. 26 No. 105381, doi: [10.1016/j.rineng.2025.105381](https://doi.org/10.1016/j.rineng.2025.105381).
- Husna, A., Ashrafi, S., Tomal, A.N.M.A., Tuli, N.T. and Rashid, A.B. (2024), “Recent advancements in stereolithography (SLA) and their optimization of process parameters for sustainable manufacturing”, *Hybrid Advances*, Vol. 7 No. 100307, doi: [10.1016/j.hybadv.2024.100307](https://doi.org/10.1016/j.hybadv.2024.100307).
- Khan, K., Hussain, M.A., Tareen, A.K., Asghar, A., Hamza, M. and Chen, Z. (2026), “Advances in vat photopolymerization 3D printing: multifunctional materials, process innovations, and emerging applications”, *Materials Science and Engineering: R: Reports*, Vol. 167 No. 101120, doi: [10.1016/j.msere.2025.101120](https://doi.org/10.1016/j.msere.2025.101120).
- Koushki, M., Amiri-Dashatan, N., Ahmadi, N., Abbaszadeh, H.A. and Rezaei-Tavirani, M. (2018), “Resveratrol: a miraculous natural compound for diseases treatment”, *Food Science & Nutrition*, Vol. 6 No. 8, pp. 2473–2490, doi: [10.1002/fsn3.855](https://doi.org/10.1002/fsn3.855).
- Kumar, B.S., Robert, T.M., Roshith, K.R., Mathew, D. and Kumar, K.S.S. (2025), “Epoxy-anhydride vitrimers: reprocessability via facile transesterification”, *Next Materials*, Vol. 8 No. 100690, doi: [10.1016/j.nxmate.2025.100690](https://doi.org/10.1016/j.nxmate.2025.100690).
- Li, J., Ju, B. and Zhang, S. (2023), “Catalyst-free, sustainable epoxy vitrimers from epoxidized soybean oil and natural sugar alcohols”, *Industrial Crops and Products*, Vol. 205 No. 117466, doi: [10.1016/j.indcrop.2023.117466](https://doi.org/10.1016/j.indcrop.2023.117466).
- Li, J., Ju, B. and Zhang, S. (2024), “Fully biobased, catalyst-free vitrimers from tannic acid: a facile combination of mechanical robustness, recyclability and sustainability”, *Green Chemistry*, Vol. 26 No. 12, pp. 7113–7122, doi: [10.1039/d4gc00259h](https://doi.org/10.1039/d4gc00259h).
- Li, Y., Chen, Y., Hu, B., Tian, P., Zhang, C., Xing, X. and Jing, X. (2025), “Catalyst-free, environmental stable epoxy vitrimer based on a trifunctional amine with adjustable reactivity and its repairable composites”, *Polymer*, Vol. 329 No. 128509, doi: [10.1016/j.polymer.2025.128509](https://doi.org/10.1016/j.polymer.2025.128509).
- Liu, T., Zhao, B. and Zhang, J. (2020), “Recent development of repairable, malleable and recyclable thermosetting polymers through dynamic transesterification”, *Polymer*, Vol. 194 No. 122392, doi: [10.1016/j.polymer.2020.122392](https://doi.org/10.1016/j.polymer.2020.122392).
- Lorenz, N., Dyer, W.E. and Kumru, B. (2025), “High-Performance vitrimer entailing renewable plasticizer engineered for processability and reactivity toward composite applications”, *ACS Applied Polymer Materials*, Vol. 7 No. 3, pp. 1934–1946, doi: [10.1021/acsapm.4c03731](https://doi.org/10.1021/acsapm.4c03731).
- Madineh, H., Hosseinzadeh, Z., Adibhosseini, M.S., Ramesh, V., Saeb, M., Zarrintaj, P. and Kate, K. (2025), “Revolutionizing 3D printing: unleashing the power of conductive polymers for next-gen biomedical applications”, *Journal of Manufacturing Processes*, Vol. 155, pp. 1243–1269, doi: [10.1016/j.jmapro.2025.09.062](https://doi.org/10.1016/j.jmapro.2025.09.062).
- Mohanty, A.D. and Bae, C. (2015), *Advances in Organometallic Chemistry*, Academic Press, Oxford UK.
- Ngaosuwan, K. (2024), “Valorization of glycerol to Mono- and di-glycerides: feedstocks, intensified reactors, challenges and perspectives”, *Chemical Engineering and Processing - Process Intensification*, Vol. 205 No. 109978, doi: [10.1016/j.cep.2024.109978](https://doi.org/10.1016/j.cep.2024.109978).
- Pabricaite, A., Sereikaite, V., Navaruckiene, A., Raudonienė, V., Bridziuvienė, D. and Ostrauskaite, J. (2024), “Phloroglucinol-Based antimicrobial shape-memory photopolymers for microimprint lithography”, *ACS Omega*, Vol. 9 No. 51, pp. 50526–50536, doi: [10.1021/acsomega.4c08277](https://doi.org/10.1021/acsomega.4c08277).
- Phelan, A., Meissner, K., Humphrey, J. and Ross, H. (2022), “Plastic pollution and packaging: corporate commitments and actions from the food and beverage sector”, *Journal of Cleaner Production*, Vol. 331 No. 129827, doi: [10.1016/j.jclepro.2021.129827](https://doi.org/10.1016/j.jclepro.2021.129827).
- Photocentric Inc (2025), available at: <https://photocentricgroup.com/product/uv-dlp-firm-resin-3d-resin/> (accessed 11 November 2025).
- Sangaletti, D., Ceseracciu, L., Marini, L., Athanassiou, A. and Zych, A. (2023), “Biobased boronic ester vitrimer resin from epoxidized linseed oil for recyclable carbon fiber composites”, *Resources, Conservation and Recycling*, Vol. 198, p. 107205, doi: [10.1016/j.resconrec.2023.107205](https://doi.org/10.1016/j.resconrec.2023.107205).
- Sereikaite, V., Navaruckiene, A., Raudonienė, V., Bridziuvienė, B., Cerkaszkas, P., Lileikis, S., Pamakstys, K., Rainosalas, E., Schuller, A.S., Delaite, C. and Ostrauskaite, J. (2025), “Antimicrobial vitrimers synthesized from dipentaerythritol pentaacrylate and 2-hydroxy-3-phenoxypropyl acrylate for LCD 3D printing”, *Biomacromolecules*, Vol. 26 No. 7, pp. 4584–4594, doi: [10.1021/acs.biomac.5c00577](https://doi.org/10.1021/acs.biomac.5c00577).
- Shanmugam, V., Babu, K., Kannan, G., Mensah, R.A., Samantaray, S.K. and Das, O. (2024), “The thermal properties of FDM printed polymeric materials: a review”, *Polymer Degradation and Stability*, Vol. 228 No. 110902, doi: [10.1016/j.polymdegradstab.2024.110902](https://doi.org/10.1016/j.polymdegradstab.2024.110902).
- Shi, S., Croutxé-Barghorn, C. and Allonas, X. (2017), “Photoinitiating systems for cationic photopolymerization: ongoing push toward long wavelengths and low light intensities”, *Progress in Polymer Science*, Vol. 65, pp. 1–41, doi: [10.1016/j.progpolymsci.2016.09.007](https://doi.org/10.1016/j.progpolymsci.2016.09.007).
- Singh, N., Sinha, P., Sinha, D.M. and Banerjee, S. (2025), “Smart polymers for 3D printing applications: current status and future outlook”, *Polymer Chemistry*, Vol. 16 No. 41, pp. 4479–4523, doi: [10.1039/D5PY00741K](https://doi.org/10.1039/D5PY00741K).
- Siraya Tech (2025), available at, available at: <https://siraya.tech/products/fastbsike> (accessed 11 November 2025).
- Sun, C., Fang, N., Wu, D.M. and Zhang, X. (2005), “Projection micro-stereolithography using digital micro-mirror dynamic mask”, *Sensors and Actuators A: Physical*, Vol. 121 No. 1, pp. 113–120, doi: [10.1016/j.sna.2004.12.011](https://doi.org/10.1016/j.sna.2004.12.011).
- Toldy, A., Poór, D.I., Geier, N. and Pomázi, Á. (2025), “Recent advances and challenges in the mechanical and chemical recycling of vitrimers and fibre-reinforced vitrimer composites: a review”, *Composites Part B: Engineering*,

- Vol. 306 No. 112760, doi: [10.1016/j.compositesb.2025.112760](https://doi.org/10.1016/j.compositesb.2025.112760).
- Tran, H.T.T., Radjef, R., Nikzad, M., Bjekovic, R. and Fox, B. (2024), “A vanillin-based vitrimer matrix for recyclable and sustainable carbon fibre-reinforced composites”, *Journal of Cleaner Production*, Vol. 483, p. 144289, doi: [10.1016/j.jclepro.2024.144289](https://doi.org/10.1016/j.jclepro.2024.144289).
- Ultimate 3D printing (2025), available at, available at: <https://ultimate3dprintingstore.com/collections/3d-printer-resin/products/phrozen-pro-series-abs-like-resin-matte-gray-1kg> (accessed 11 November 2025).
- Vilanova-Pérez, A., De la Flor, S., Fernández-Francos, X., Serra, À. and Roig, A. (2024), “Biobased imine vitrimers obtained by photo and thermal curing procedures—promising materials for 3D printing”, *ACS Applied Polymer Materials*, Vol. 6 No. 6, pp. 3364–3372, doi: [10.1021/acsapm.3c03234](https://doi.org/10.1021/acsapm.3c03234).
- Wang, F., Lu, X. and Xin, Z. (2025a), “Self-healing biobased polybenzoxazine vitrimers for anticorrosion application”, *Progress in Organic Coatings*, Vol. 203 No. 109168, doi: [10.1016/j.porgcoat.2025.109168](https://doi.org/10.1016/j.porgcoat.2025.109168).
- Wang, Z., Zhang, Z. and Kuang, X. (2025b), “Recent advances in polymer 4D printing: 3D printing techniques, smart material design, and healthcare applications”, *Smart Materials in Medicine*, Vol. 6 No. 3, pp. 305–333, doi: [10.1016/j.smaim.2025.09.001](https://doi.org/10.1016/j.smaim.2025.09.001).
- Weerg. 3D Printing Services (2025), available at: www.weerg.com/3d-printing-materialsresinbest-price-classic-resin (accessed 11 November 2025).
- Willis, K.A., Richards, M. and Hardesty, B.D. (2025), “Focusing plastic solutions up the waste hierarchy: pathways for a more circular economy”, *iScience*, Vol. 28 No. 9, doi: [10.1016/j.isci.2025.113217](https://doi.org/10.1016/j.isci.2025.113217).
- Yao, Y., Cao, Z., Huang, N., Yu, M., Tan, J. and Zhu, X. (2024), “Catalyst-free gallic acid-based epoxy vitrimers with reprocessability and high glass transition temperature”, *Polymer*, Vol. 311 No. 127462, doi: [10.1016/j.polymer.2024.127462](https://doi.org/10.1016/j.polymer.2024.127462).
- Zee, N.J.V. and Nicolaÿ, R. (2020), “Vitrimer: permanently crosslinked polymers with dynamic network topology”, *Progress in Polymer Science*, Vol. 104 No. 101233, doi: [10.1016/j.progpolymsci.2020.101233](https://doi.org/10.1016/j.progpolymsci.2020.101233).
- Zhan, L.Y., Li, P., Li, Y.D., Ran, Y. and Zeng, J.B. (2025), “Fully biobased epoxy vitrimer from resorcinol diglyceryl ether, vanillin, and 1,10-diaminodecane”, *European Polymer Journal*, Vol. 227 No. 113749, doi: [10.1016/j.eurpolymj.2025.113749](https://doi.org/10.1016/j.eurpolymj.2025.113749).
- Zhang, X., Lin, L., Zhou, H., Zhou, G. and Wang, X. (2024), “All-natural chitosan-based polyimine vitrimer with multiple advantages: a novel strategy to solve nondegradable plastic waste pollution”, *Journal of Hazardous Materials*, Vol. 465 No. 133030, doi: [10.1016/j.jhazmat.2023.133030](https://doi.org/10.1016/j.jhazmat.2023.133030).
- Zheng, J., Png, Z.M., Ng, S.H., Tham, G.X., Ye, E., Goh, S.S., Loh, X.J. and Li, Z. (2021), “Vitrimer: current research trends and their emerging applications”, *Materials Today*, Vol. 51, pp. 586–625, doi: [10.1016/j.mattod.2021.07.003](https://doi.org/10.1016/j.mattod.2021.07.003).
- Zhou, S., Qi, N., Zhang, Z., Jiang, P., Li, A., Lu, Y. and Su, X. (2025), “Recent progress in intrinsic self-healing polymer materials: mechanisms, challenges and potential applications in oil and gas development”, *Chemical Engineering Journal*, Vol. 511 No. 161906, doi: [10.1016/j.ccej.2025.161906](https://doi.org/10.1016/j.ccej.2025.161906).

Supplementary material

The supplementary material for this article can be found online.

Corresponding author

Jolita Ostrauskaite can be contacted at: jolita.ostrauskaite@ktu.lt