

Abstract

Humidity-Responsive Conductive Hydrogels: A Bio-Based Material for Flexible Electronics [†]

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[†] Presented at the 3rd International Online Conference on Polymer Science, 19–21 November 2025; Available online: <https://sciforum.net/event/IOCPS2025>.

Keywords: hydrogel composites; nanoparticles; conductive hydrogels; humidity sensors

1. Introduction

The increasing demand for biocompatible and flexible electronic materials has stimulated research into conductive hydrogels, particularly for biosensors and wearable device applications. Gelatin methacryloyl (GelMA), derived from cold-water fish skin, offers a renewable and biocompatible matrix. This study investigates the synthesis and characterization of GelMA hydrogels loaded with silver nanoparticles (AgNPs) to achieve conductivity, exploring the impact of formulation and environmental factors on material properties.

2. Methods

GelMA was synthesized (from gelatine derived from cold water fish skin, and methacrylic anhydride, Merck, Milan, Italy) and crosslinked using a visible light-activated photoinitiator (BAPO-PEG). AgNPs were incorporated via in situ reduction during crosslinking or by post-crosslinking immersion in silver nitrate solutions followed by a second irradiation. Hydrogel properties were assessed using Fourier-transform infrared spectroscopy (FTIR) with an ATR module (Nicolet Apex FTIR Spectrometer, Thermo Fischer Scientific, Waltham (MA), USA), photorheology on modular compact rheometer (MCR 702e MultiDrive, Anton Paar, Ganz, Austria), thermogravimetric analysis (TGA, Mettler Toledo, Columbus (OH), USA), swelling tests, and electrical conductivity measurements (LCR meter, BK precision 894, Sciospec Scientific Instruments GmbH, Bennewitz, Germany) under varying humidity conditions. Piezoresistive behavior was evaluated by measuring current changes under applied compressive strain using a universal testing machine (Z3-X500, Thumler GmbH, Numberg, Germany).

3. Results

FTIR confirmed successful GelMA synthesis. Photorheology allowed to optimize the BAPO-PEG concentration for rapid curing. TGA demonstrated the high thermal stability of the hydrogels up to 260–270 °C. High water absorption (300%) was observed. In situ AgNP formation delayed gelation, favoring the immersion method for AgNP incorporation. Electrical conductivity shown a high dependence on humidity, with dried samples exhibiting insulating behavior. Conductivity significantly increased with hydration, reaching 6.84 S/m for samples with the highest silver content (GelMA/Ag-50) at 100% relative



Academic Editor: Alessandro Pegoretti

Published: 14 November 2025

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humidity. Compressive strain enhanced conductivity, indicating piezoresistive properties suitable for sensing applications.

4. Conclusions

This study demonstrates the successful synthesis of conductive bio-based hydrogels by incorporating AgNPs into a GelMA matrix derived from fish skin gelatin. The resulting materials exhibit tunable electrical properties responsive to humidity and mechanical strain, making them promising candidates for biosensors, humidity sensors, and flexible electronic devices. Further research will focus on optimizing AgNP dispersion and long-term stability for real-world application.

Author Contributions: Conceptualization, C.N., A.C. and M.M.; methodology, validation, investigation: C.N., C.D.B. and A.C.; resources, M.M.; data curation, writing—original draft preparation: C.N. and A.C.; supervision, M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

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