DOI 10.5162/SMSI2023/E5.4

Material-integrated Temperature Sensors for Wireless Monitoring of Infusion and Curing in Composite Production

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This work was supported by the German Federal Ministry for Economic Affairs and Climate Action based on a resolution of the German Bundestag, (Nr. 20941 N).

Summary:

This paper presents a novel sensor node for wireless monitoring of local laminate temperature for production of fibre reinforced plastic (FRP) composites. The sensor is realized as a battery-less, flexible RFID tag for material integration and therefore usable throughout the whole composite life cycle. Measurement results are reported for a case study of an eight-layer glass fiber composite production, allowing for flow front monitoring during infusion, and giving information about curing progress.

Keywords: wireless, temperature, sensor, composite, infusion, curing

Introduction

Rising production volumes and number of use cases for FRP components demand for increasingly efficient production processes. A major part of production time and cost is polymer curing, which is strongly dependent on temperature [1]. This is why local matrix temperature data contains information about reaction rates of the material and therefore about curing progress [2]. Also, temperature influences resin viscosity and therefore flow, distribution and impregnation throughout the fibre lay-up during infusion [2].

Consequently, measurement of local temperature is one of the basic ways to get information about both infusion and curing processes. To precisely estimate cure state, surface measurements are often too indirect, especially for thicker layer structures. To circumvent this, temperature sensors can be integrated into the laminate structure prior to infusion. Conventionally, wired sensors are used, creating several problems in turn. Apart from significantly complicating FRP production by impeding build-up of the vacuum foils and seals, protruding wires are prone to breakage during component application.

This paper presents results of integration tests for wirelessly monitoring matrix temperature. The sensor measures local temperature inside the laminate, both during production and later usage of the composite part.

State of the Art

Resin flow monitoring during FRP production has been subject of several publications. [3] successfully integrated wired pressure sensors for flow front and impregnation monitoring. Similarly, [4] used wired pressure sensors in wind turbine blade manufacturing. [5] and [6] integrated off-the-shelf RFID transponders to monitor production, thereby showing that embedding wireless sensors into FRP is generally feasible. Both [7] and [8] have presented work on wireless temperature and pressure monitoring for flow front observation and prevention of local voids. The sensors worked well during infusion but dropped out as temperature increased during cure. In order to monitor cure, [9] successfully used material-integrated temperature sensors and showed that outside measurement was not able to give the same information.

Sensor Design

The sensor [10] used for the presented experiments is realized as flexible printed circuit board. It operates fully passively, harvesting all power from the reader-supplied electromagnetic field via its spiral antenna and RFID chip [11]. For temperature sensing, a *TMP117* [12] is utilized, as it is a small, pre-calibrated, high precision sensor with very low power consumption.

Experiments and Setup

For validation of the process monitoring functionality, two FRP boards were fabricated, containing three sensor tags each. This was done with a vacuum assisted resin infusion setup on a heated table surface (see Fig. 1). To fix the tags in position on the textile and ensure good adhesion, they were cleaned, degreased, and attached with special glue [13].

Prior to infusion, table temperature (T_R) was set to 40 °C and the resin reservoir was heated to 30 °C. The experiment was started by opening the infusion valves. As the vacuum foils etc. were transparent, process stages could be recorded visually for later-on correlation (see Fig. 2). After 17 minutes, the whole mould was visibly filled. To ensure complete fill-up, the resin inlet valve was closed three minutes later. At 22 minutes, the whole setup was covered with an insulating fleece to reduce heat dissipation at the surface and thereby accomplish a more homogeneous temperature distribution.

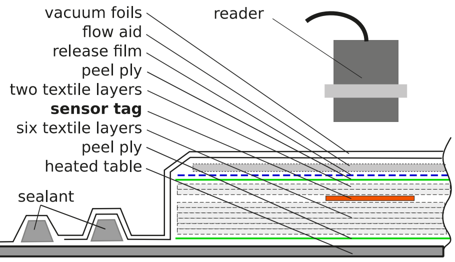

Figure 1: Schematic cross-section of layer stack-up

For curing, T_R was increased in three stages. First, it was set to 55 °C to initiate the curing reaction. After 2:12 h, T_R was set to 65 °C, and again increased to 75 °C at 2:42 h The sensors were read out continuously with three readers mounted above each tag, respectively.

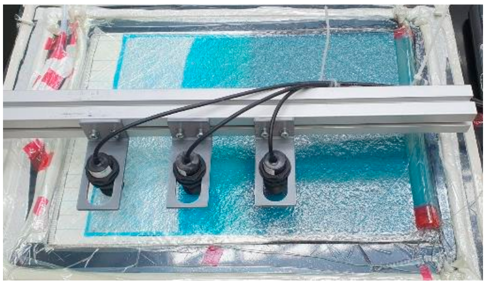

Figure 2: Experiment setup (top view)

Results

Measurement data for infusion and curing is displayed in Fig. 3 and 4. All sensors stayed functional until and after the end of the experiment. Results show a maximum deviation between sensor temperatures of approximately 1.9 °C for board one and 2.1 °C for board two, respectively. For both boards, maximum deviation was observable for the two tags positioned at greatest relative distance, supporting the conclusion that deviations were mostly due to inhomogeneous heating via the table surface. This could later be confirmed by thermal imaging.

During infusion, advancement of the flow front through the lay-up was reflected in the sensor values. In Fig. 3, a close correlation between visual arrival times of the resin at the tag positions is visible. This is indicated by a distinct drop in temperature, caused by the cooler resin, and a distinct rise in temperature briefly after. The latter can be attributed to increased heat flow from the table surface to the tags by better thermal conductivity of the fluid resin.

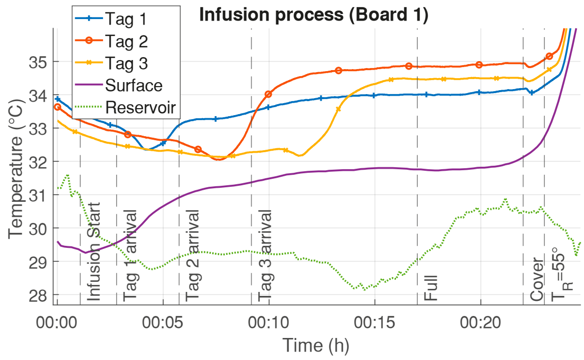

Figure 3:Sensor measurements during infusion, visual arrival times at sensors tags indicated (dashed lines)

During the first phase of heating, the exothermic nature of the curing reaction is visibly reflected in the measured values: Even though surface temperature stays nearly constant (ca. 2 °C drift), temperature inside the material shows a distinct local maximum, marking the exothermic peak of the curing reaction (see Fig. 4).

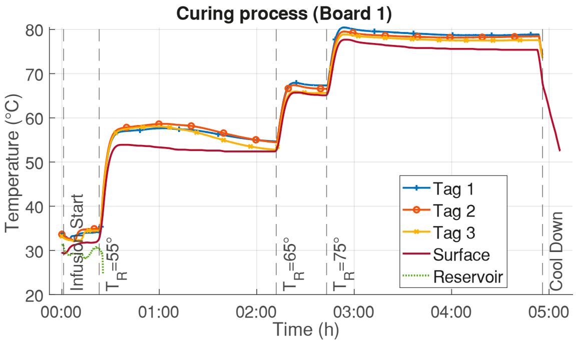

Figure 4: Overview of the production process for board 1. Change of heating targets indicated (T_R)

Apart from this, sensor tag data closely follows the values of the reference sensor located at the surface of the top vacuum foil, with the temperature inside the laminate being slightly higher, probably due to heat dissipation. During the second and third heating phase, inside temperatures follow surface temperature much more closely, indicating reduced heat generation of the curing reaction, thereby reflecting further progression of cure.

Conclusions and Outlook

This paper shows that wireless, material-integrated monitoring of the infusion process and flow front advancement is possible with the presented approach for temperature measurement. Also, progression of the curing reaction was deducible from the measured values. As for the impact of the sensor tags on structural integrity of the resulting FRP material, mechanical tests have yet to be conducted, the results of which will be subject of a future publication.

References

[1] M. J. Lodeiro and D. R. Mulligan, ‘Cure Monitoring Techniques for Polymer Composites, Adhesives and Coatings’. National Physical Laboratory Teddington, Middlesex, United Kingdom, TW11 0LW, 2005. [Online]. Available: https://www.npl.co.uk/special-pages/guides/mgpg75.aspx?ext=.pdf

[2] S. Konstantopoulos, E. Fauster, and R. Schledjewski, ‘Monitoring the production of FRP composites: A review of in-line sensing methods’, *Express Polym. Lett.*, vol. 8, no. 11, pp. 823–840, 2014, doi: 10.3144/expresspolymlett.2014.84.

[3] M. K. Moghaddam, A. Breede, C. Brauner, and W. Lang, ‘Embedding Piezoresistive Pressure Sensors to Obtain Online Pressure Profiles Inside Fiber Composite Laminates’, *Sensors*, vol. 15, no. 4, Art. no. 4, Apr. 2015, doi: 10.3390/s150407499.

[4] A. Dimassi, M. G. Vargas Gleason, M. Hübner, A. S. Herrmann, and W. Lang, ‘Using piezoresistive pressure sensors for resin flow monitoring in wind turbine blades’, *Materials Today: Proceedings*, p. S2214785320305988, Feb. 2020, doi: 10.1016/j.matpr.2020.01.493.

[5] M. Veigt, E. Hardi, M. Koerdt, A. S. Herrmann, and M. Freitag, ‘Curing Transponder – Integrating RFID transponder into glass fiber-reinforced composites to monitor the curing of the component’, *Procedia Manufacturing*, vol. 24, pp. 94–99, 2018, doi: 10.1016/j.promfg.2018.06.014.

[6] E. Hardi, M. Veigt, M. Koerdt, A. S. Herrmann, and M. Freitag, ‘Monitoring of the vacuum infusion process by integrated RFID transponder’, *Procedia Manufacturing*, vol. 52, pp. 20–25, 2020, doi: 10.1016/j.promfg.2020.11.005.

[7] M. G. Vargas Gleason, R. Jedermann, A. Dimassi, and W. Lang, ‘Embedded Wireless Sensor Systems for Resin Flow Monitoring in Glass and Carbon Fiber Composites’, *IEEE Sensors J.*, vol. 19, no. 22, pp. 10654–10661, Nov. 2019, doi: 10.1109/JSEN.2019.2928635.

[8] M. G. V. Gleason, R. Jedermann, A. Dimassi, and W. Lang, ‘Wireless Piezoresistive Pressure Sensors Used for Quality Control in Glass Fiber Composite Laminates’, in *2018 IEEE SENSORS*, Oct. 2018, pp. 1–4. doi: 10.1109/ICSENS.2018.8589933.

[9] M. Hübner and W. Lang, ‘Online Monitoring of Composites with a Miniaturized Flexible Combined Dielectric and Temperature Sensor’, in *Proceedings of Eurosensors 2017, Paris, France, 3–6 September 2017*, Aug. 2017, p. 627. doi: 10.3390/proceedings1040627.

[10] L. Bertram, M. Brink, K.-D. Thoben, and W. Lang, ‘A Passive, Wireless Sensor Node for Material-Integrated Strain and Temperature Measurements in Glass Fiber Reinforced Composites’, 2022, pp. 182–193. doi: 10.1007/978-3-031-16281-7_18.

[11] ‘NHS 3152 - Therapy adherence resistive monitor’. NXP Semiconductors B.V., 2021. [Online]. Available: https://www.nxp.com/docs/en/data-sheet/NHS3152.pdf

[12] ‘TMP117 High-Accuracy, Low-Power, Digital Temperature Sensor With SMBus™- and I2C-Compatible Interface’. Texas Instruments Inc., Apr. 2021. [Online]. Available: https://www.ti.com/lit/ds/symlink/tmp117.pdf

[13] SAERTEX GmbH, ‘SAERfix®EP // SAERfix®UP KLEBEMATERIALIEN - Produktflyer’. 2022. [Online]. Available: https://www.saertex.com/de/service/downloads/saerfix/file/3a01f3af1d97f092dedccf5256905b94/0143-14-066_SAERTEX_Produktflyer_SAERfix_DEU.pdf