

Aerosol-jet printed carbon for stretchable sensors

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Summary:

This ongoing research investigates aerosol-jet printed carbon dogbones, which can be used in the future as stretchable deformation sensors. A pneumatic atomizer was used to print the ink, and the process conditions were optimized for stable deposition on rubber. Resistance of the printed dogbones remains stable with time, with the change below 0.01 % over 60 h. The dogbones can be stretched to at least 20 %, with gauge factors between 3.5 and 5.2. This validates a robust additive manufacturing route for durable strain sensors that can be integrated into tire systems.

Keywords: Aerosol jet printing, strain sensors, carbon ink, smart tires, additive manufacturing

Background, Motivation and Objective

Following deformation in tires has large benefit for their performance optimization. Conventional accelerometers function well between 40–140 km h⁻¹, [1] but they exhibit low signal-to-noise ratios outside this range. Integrated strain sensors are required to monitor tire conditions mechanical strains up to 15% [3]. Additive manufacturing via aerosol jet printing allows for seamless sensor integration directly. While silver-based inks are common, they react with sulfur in the rubber, leading to rapid degradation of the sensor material [4]. This research focuses on utilizing carbon-based inks (EXP 2619-44, CMI) to ensure chemical stability and mechanical robustness. Our objective is to optimize the pneumatic atomization process to fabricate stretchable sensors with high sensitivity.

Experimental and Process Optimization

The strain sensors were fabricated using an aerosol jet printing process on rubber substrates. We used stretchable carbon-based ink (EXP 2619-44, CMI), which was diluted to a 40% concentration with Carbitol Acetate to ensure stable printing. The printing was performed with a pneumatic atomizer using a 300 μm nozzle. For characterization of the samples, a profilometer was used to measure the profile. Resistance of samples were also measured, with a fixing platform for static tests and a stretching for strain/resistance tests. A Keithley 2470 SMU was used for resistance measurement in these tests.

To improve quality of the printing, we optimized the printing parameters by adjusting gas flows. This optimization prevented ink drops from forming at the nozzle tip and resulted in clearer print borders (see Fig. 1). After printing, the samples were annealed at 180 °C for 10 min.

This optimized printing route represents practical advancement, as the carbon-based material remains chemically stable and avoids the sulfur-induced degradation which is common for silver-based materials on rubber.

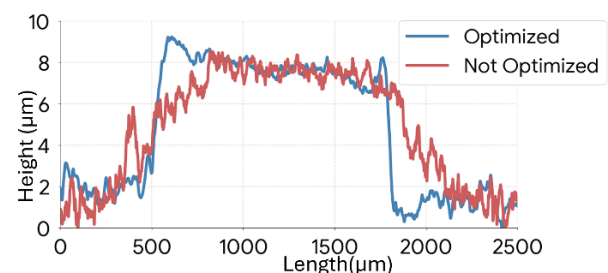


Fig. 1. Profilometry of the prints printed before and after optimization.

Results

Example of a dogbone printed with optimized conditions is shown in Fig.2. Resistivity was 1.86 $\Omega \cdot \text{cm}$, which is close to the material specifications from data sheet of the ink.



Fig. 2. Optical appearance of a printed dogbone.

The electrical performance of the printed sensors was evaluated through static and dynamic measurements. Static tests confirmed that the resistance of the carbon prints remained stable with time, with the change below 0.01% over 60 h.

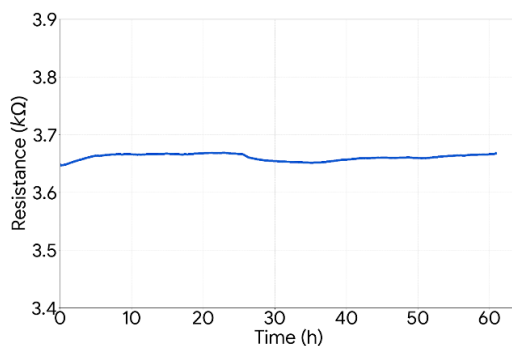


Fig. 3. Resistance of a printed dogbone as a function of time.

Mechanical measurements were also performed. Initial tests at low strain levels revealed a drop in resistance with increasing strain. As reported in literature for similar composite materials [5], this behavior was stabilized by applying a pre-stretch cycle to the samples. After this pre-stretch, the dogbone response became repeatable and stable. The samples were tested up to 20 % strain (see Fig. 4).

The sensitivity of the strain sensors was quantified by calculating Gauge Factor (GF). The measured GF values ranged between 3.5 and 5.2. This is higher than typical GF of commercial gauges, which is usually 2.1. These results demonstrate that this aerosol jet printed carbon sensors provide both the good sensitivity and the wide sensing range necessary for monitoring deformations in tires.

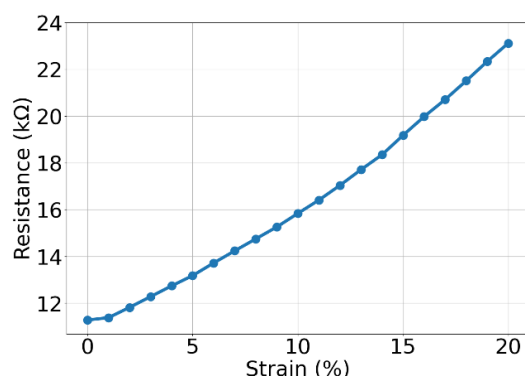


Fig. 4. Resistance as a function of strain.

Conclusion

In this work, we successfully developed a robust carbon-based aerosol-jet printed structure for potential applications in tires. The deposits are stable with time and under large mechanical strain. With gauge factors reaching 5.2 and stable performance at 20% strain, these prints are promising for sensors with high sensitivity and strain-range requirements in tires.

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