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Comparison of different conductive fillers in silicone for the purpose of replacing metallic conductive structures in flexible implants

Brensing, A.[1], Hauck, S.[2], Ruff, R.[1], Poppendieck, W.[1], Hoffmann, K.-P.[1]

[1]Fraunhofer Institute for Biomedical Engineering IBMT, St. Ingbert, Germany
[2]Ilmenau University of Technology, Ilmenau, Germany

alexander.brensing@ibmt.fraunhofer.de

Abstract: *Graphite (G), Carbon Black (CB) and Carbon Nanotubes (CNT) are compared regarding their usability as conductive filling particles in medical silicone. Produced test structures were characterized mechanically and electrically. CNT turn out to produce the lowest electrical resistance at the lowest concentration. This and the small elongation dependency of the test structure resistance at lengthening up to 6 % cause CNT to be the ideal filler. Therefore CNT filled silicone is the best choice to replace metallic conductive structures in flexible implants.*

Keywords: *silicone, electrical functionalization, Carbon Black, Graphite, Carbon Nano Tubes*

Introduction

Many efforts were made to manufacture flexible implants [1]–[4]. Usually metallic conductive tracks are used because of their good conductivity. Meander conducting paths are used to achieve stretchable implants. However, due to the different mechanical properties of metal and the flexible substrate mechanical stress arises at the occurrence of tensile strain and thereby it is possible that the implant is damaged. One approach to overcome this problem is the use of *all polymer technology*, replacing the metals with conductive polymers [5], [6].
In this work we compare different conductive filling materials that can be used for electrical functionalization of Polydimethylsiloxane (PDMS).

Methods

For preparation of the conducting polymers, Nusil Med 6015 was used as polymeric host matrix. Using a speed mixer, conductive particles were intermixed. As filling materials we used 10, 20 and 30 wt% CB (LUH GmbH), 20, 36, 40 and 45 wt% G (LUH GmbH) and 2, 3.5 and 5 wt% multi walled CNT (Sigma Aldrich Chemie GmbH).
To compare the different materials, the electrical and mechanical properties are of interest. Experiments were done with test structures that were designed based on the German standard DIN 53504:2009 (ICS 83.060) [7] (length 75 mm, width 4 mm, thickness 2 mm) as shown in Figure 1.

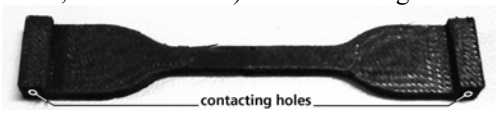

Figure 1: Tensile test structure with contacting holes for electrical and mechanical characterization of filled polymers

Both electrical resistance and the lengthening of the test structure were measured simultaneously. Measurements were repeated at least 15 times for each test structure. For this purpose a special test site was constructed and evaluated, which can automatically measure the specific electric resistance as a function of the mechanical tension. The decrease of the cross-sectional area can be calculated via optical measurement of the sample relief at elongation.
With a 3D printer (Stratasys Dimension Elite), special clamps were built to hold the test structures and contact them for the measurement of different resistance values. The contact to the current supply was applied with two single metallic plugs that are put in the intended hole in the test structure.

Results

Figure 2 shows a comparison between G, CB and CNT, each at the highest concentration possible to produce test structures. The viscosity of polymers with higher particle concentrations was too high to produce test structures without large air bubbles. The resistance was measured over the entire test structure.

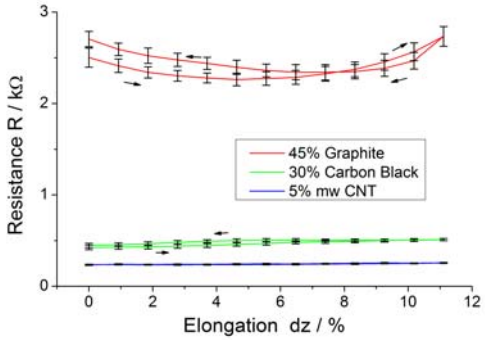

Figure 2: Resistance as function of the test structure elongation. Comparison of different conducting fillers each at the highest concentration.

Remarkable is the different behavior of G and CB for different elongations. For visualization Figure 3 compares both at the same resistance, because CB filled test structures behaved similarly for different CB concentrations. While the CB filled test structure exhibited an almost constant increase of the resistance at elongation up to 11 %, the resistance of the G filled polymer decreased up to an elongation of 6 %. For further stretching up to 11 % the resistance reached its starting value. Both composites possessed a hysteresis behavior.

During lengthening, the resistance of the CB filled test structures was lower than during relaxation. The G filled structures behaved similarly up to an elongation of about 8 %. For higher elongations the resistance during lengthening was higher than during relaxation.

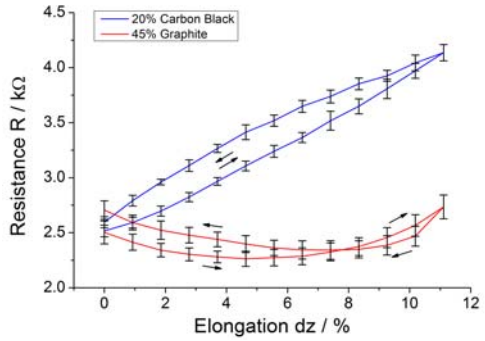

Figure 3: Comparison of the behavior of Graphite and Carbon Black as conducting fillers in PDMS as a function of the elongation.

For all tested CNT concentrations below 5 % elongation, the resistance of the test structures has a plateau (marked as red line in Figure 4). Within the accuracy of the measurement the resistance can be considered as independent from the elongation up to this value. This was not the case for the test structures filled with G that behaved similar to that shown in Figure 3 for all concentrations.

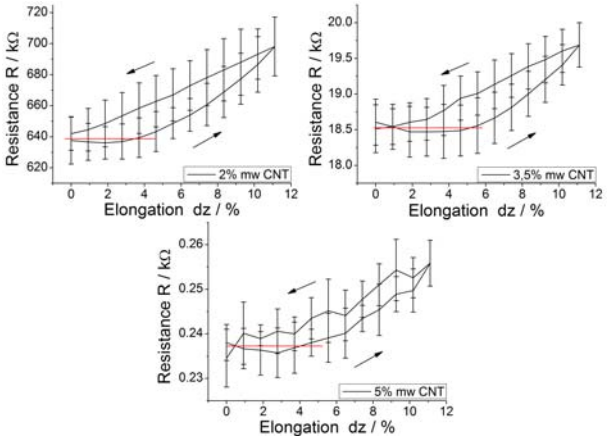

Figure 4: Resistance/elongation diagrams for different CNT concentrations. Plateaus are visualized as red lines.

Discussion

The different behavior of the G and CB test structures at elongation as seen in Figure 3 are probably a result of the different shapes of the filling particles. Conductive fillers with a flat structure (G) produce a percolation network much easier than spherical particles (CB) [8]. Lengthening of the test structures segregates spherical particles. By reorientation platy particles may be able to avoid the applied stress, coming from the tapering perpendicular to the elongation. Thereby the percolation network can optimize its structure and build up new connections resulting in a decreasing resistance. According to [8] the percolation threshold for G should be smaller than that of CB. The quality of filling materials we used may be the reason that we could not reproduce this. Furthermore no segregation with sonication or other methods was applied. Therefore the particles aggregated and higher concentrations were needed for formation of percolation networks. Due to the structure of the CNT they form the best percolation network within the polymer. The addition of already 5 wt% CNT produced a conductivity twice and ten times as good as the highest possible concentration of CB and G, respectively. Due to the elongation independency of the resistance below 6 %, CNT are the best choice for replacement of metallic conducting paths in flexible implants.

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