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strain gauge, CFRP, inkjet printing, machine tools

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INTEGRATED STRAIN GAUGE PRINTING IN A CFRP STRUCTURE

Our approach is to integrate printed strain gauges into a structure of laminated carbon fibre reinforced plastics (CFRP). This can provide minimizing disturbances caused by an additional sensor weight. Another point is to reduce the occurrence of pre-damage, as a printed structure is integrated directly into the CFRP. Due to the printing, no additional masses are applied to the CFRP by cables. To this end, the boundary conditions for the print are first explained. Subsequently, the strain gages were printed. For this purpose, studies were carried out regarding the orientation of the strain gage printing direction, the influence of repeated printing, the overlapping during printing and the subsequent lamination in CFRP plates. The sensors are to be used in the structure of the CFRP plate in a machine tool.

1. INTRODUCTION

Screen printing and offset printing were the first attempts to produce sensors. Here, however, the foil etching technique was still in use. First it was printed on the substrate, then powdered and then etched [1]. Today, interest in print usage has increased owing to the innovative technologies. This leads to cost reduction. [2, 3].

On the basis of the use of different substrates, the sensors can be used in a wide range of applications from aluminium sheet forming to medical parts [4–7]. Today, the aerosol process or the inkjet process are increasingly used [8–10]. The direct-writing approach is used in both methods [11, 12] Aerosol printing can be applied to three-dimensional, non-planar substrates in the millimetre range [12].

Studies on printed strain gauges were carried out with different structures. One was a direct printing on carbon fibre reinforced plastics, as well as on polyethylene-terephthalate flexible substrates [13, 14].

The Federal Ministry of Education and Research (BMBF) sponsors the project HYBRID[i] (“Intelligent lightweight structures for hybrid machine tools”, funding code

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02P14A114, http://www.hybridi.ovgu.de/hybridi/en/). The target from HYBRID[i] is the research of a generic intelligent lightweight component as an integral element of an exemplary machine tool. Because of its central function, a vertical Z sled was selected as a demonstrator component. Fibre compound and composite materials as a linkup with metallic structures find theirs usage within a hybrid system as material. At the same time the simple assembly to be realized and to be integrated sensor network is being explored. Therefore, it should be possible to monitor the structure and process properties. The concept for the sensor network is the use of printed strain gauges integrated into CFRP plates and structures (Fig. 1).

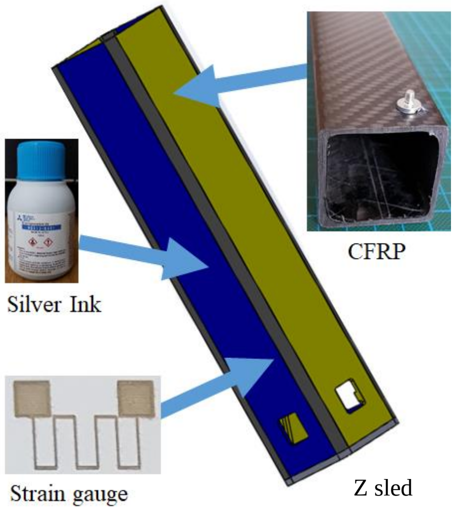

Fig. 1. Concept for the sensor network

Machine tools with lightweight construction offer possibilities for mass reduction and increased damping [15–18]. The use of CFRP raises new questions in crash screening. Previous investigations concerning the clamping of machine tools have shown intelligent parts [19, 20]. The project HYBRID[i] is therefore developing an intelligent Z sled that makes it possible to check the load on the Z sled to be checked at any time by means of integrated strain gauges.

2. BOUNDARY CONDITIONS

A DIMATIX Materials Printer DMP-2850 is used for the tests (Fig. 2). Two different print heads are included as standard. These tests are carried out with the 10 picolitre print head. The ink NBSIJ-MU01 (Silver Nano Particle Ink) from Mitsubishi Paper Mills Limited was applied. The physical properties are listed in Table 1 [14]. The substrate was used Geha's F02 inkjet film, which has a thickness of 135 micrometre. Another substrate is the EPSON Premium Glossy Photo Paper with a thickness of 250 micrometre.The strain gauge were examined under a Keyence VHX-5000 900F. A multimeter Fluke 115 true rms was applied to determine the output resistances. The print settings have been selected so that the voltage was 25 volts and the frequency was 23 kilohertz. Furthermore, another setting was created with the voltage of 20 volts and a frequency of 5 kilohertz [7]. The parameters can be found in Table 2.

Fig. 2. First test printing strain gauges on photo paper

Table 1. Physical properties silver ink [14, 21]

Ink	Result
Viscosity [mPa×s]	2.30 +/- 0.50
Silver Concentration [%]	15
Density [kg/m^3]	1.200 +/- 0.0200
Temperature for printing [°C]	20
Humidity [%rh]	40

Table 2. Print properties

Print properties	Voltage [V]	Frequency [kHz]
1	25	23
2	20	5

3. PRINTING TESTS

3.1. ORIENTATION OF THE STRAIN GAUGES

The next step was to check the alignment when printing the strain gauges. A strain gauge (No. 1) with the dimensions 15.88 × 10.00 mm was used (Fig. 3).

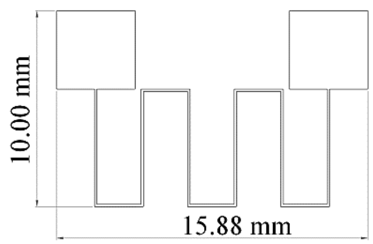

Fig. 3. Strain gauge test structure number 1

The connection points were arranged once on the left side (Fig. 4: Orientation 1) and in another variant on the right side (Orientation 2). The print direction is from left to right and from top to bottom. Furthermore, the connection point was arranged at the top or bottom. Printing on photo paper resulted in a 14 percent higher resistance to horizontal and right printing of the strain gauges (Fig. 4). If the size of the strain gauge allows a print with the arrangement 3 to be selected (Fig. 4), the resistance is 6 percent higher.

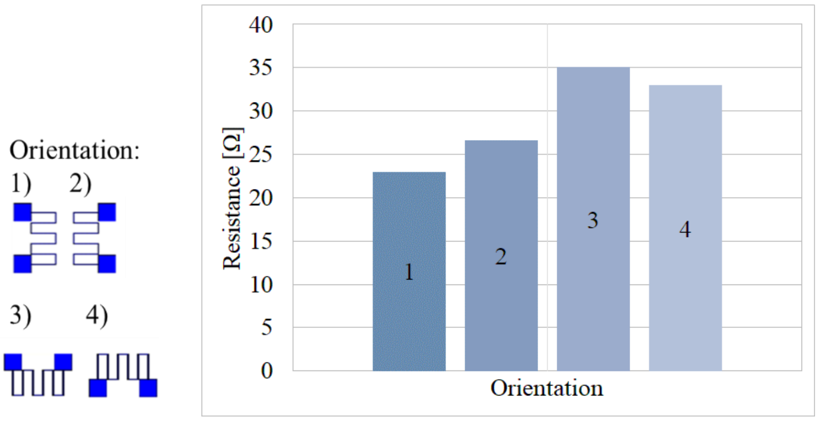

Fig. 4. Different orientation of the strain gauges on photo paper

3.2. REPEATED PRINTING

To increase the resistance and to exclude gaps during printing, the same structure was printed several times. The test structure (No. 1, Fig. 3) for strain gauges was used again and the number of prints amounted to 5. However, there was a negative influence of repeated printing (Figs. 5, 6). There was a deterioration in resistance of about 77 percent with five repetitions compared to one-time printing. The double print led to a deterioration of around 68 percent. Fig 6. shows a comparison one-time printing and five-time printing.

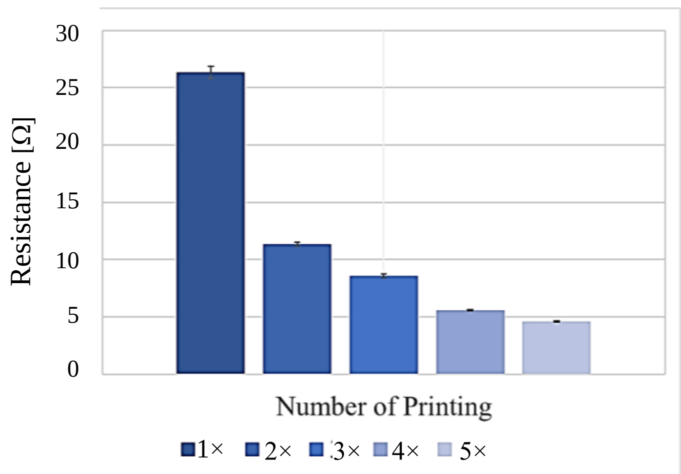

Fig. 5. Multiple printing on photo paper

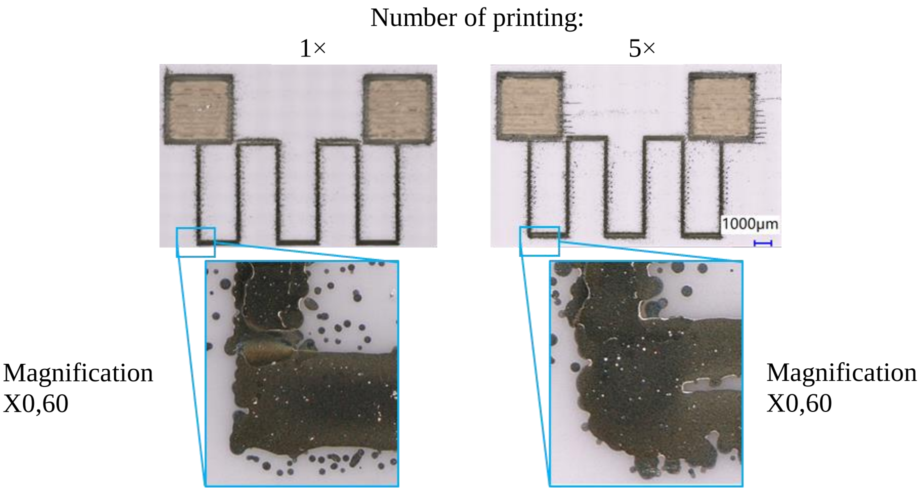

Fig. 6. Increase of the multiple printing strain gauges

3.3. DIFFERENT VARIANCE OF OVERLAP

In the next step, an overlap was constructed during the development process in order. The intention is to rule out the influence of overlapping on the windings, as this can lead to overlapping. In 3B it was shown that repeated printing has an influence on the resistance. The first variant was no overlap (Fig. 7), the second was a full overlap and the third variant had an overlap of 50 percent. Number of samples was five. The result is that the overlap of the traces has an influence on the strain gauges (Fig. 8). All three variants were planned for lamination.

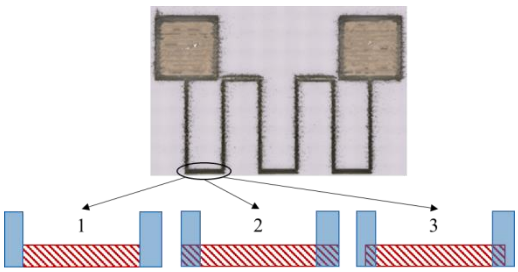

Fig. 7. Overlapping of the conductor path

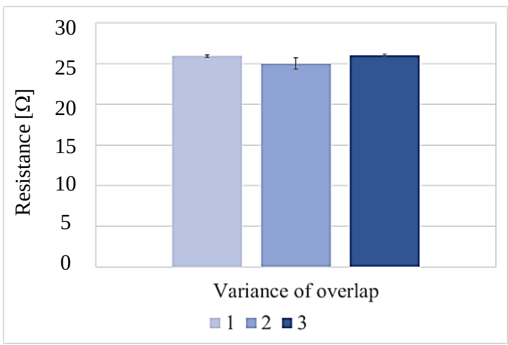

Fig. 8. Results of overlap printing

3.3. STRAIN GAUGE FOR LAMINATION

Then the strain gauges for lamination were printed. These are based on the dimensions of the test structure, but they are almost 91 percent longer in the overall structure (Fig. 9). The printing produced good results for the first and third variant. The second variant had interruptions in the printed image. The other two differ in resistance by around 4 percent. The printing with print parameters of Correia (Table 2) print properties 2 delivered only one result for the 3rd variant (Fig. 10).

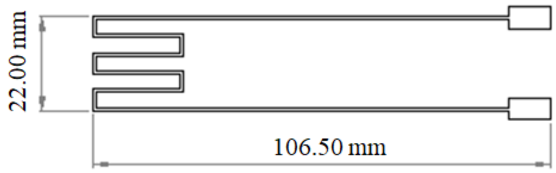

Fig. 9. Lamination test structure

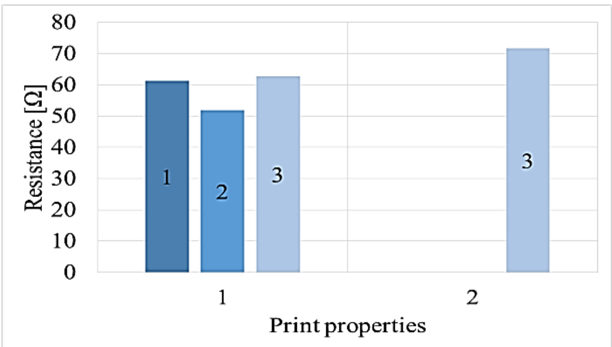

Fig. 10. Comparison of strain gauges

4. LAMINATION AND NEXT STEPS

The following step is the cutting-out the strain gauge with a laser cutter at the project partner Teon GmbH. The strain gauges are laminated into a 200 × 200 mm plate. The sheet thickness is approx. 1.8 mm. A quasi-isotropic plate structure is used and manual lamination. A spray is used for insulation. Fig. 11 shows a view of the test structure.

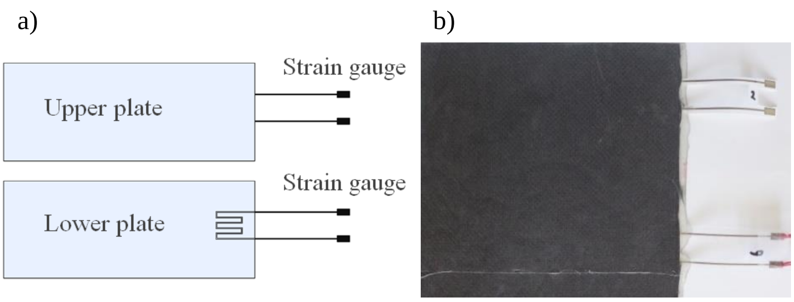

Fig. 11. a) Structure of the lamination, b) Test structure with integrated strain gauge

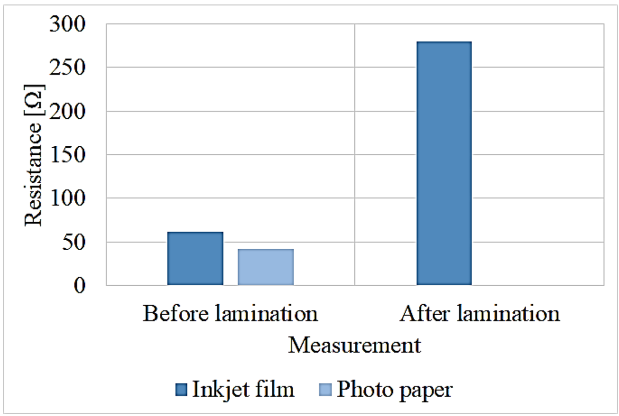

Fig. 12. Comparison of strain gauges before and after lamination

After hand lay up (Figs. 9, 11), plates are subjected to measurements. The lamination showed that no resistance was measurable with photo paper (Fig. 12). The resistances had increased almost fivefold with inkjet film.

5. CONCLUSIONS

The investigations have shown that the orientation of the strain gauges has an influence on the resistance to be measured. Here, the alignment of the connection points at the right side for long strain gauge, as well as at the top for small strain gauge is recommended. Repeated printing of the strain gauges is not recommended. A reduction of the resistance could be detected by repeated printing. The overlap showed slight differences in resistance. After lamination the print on photo paper does not provide any values. The print on inkjet film shows a significant increase in resistance. The work is now focused on improving the integration of the inkjet film into the CFRP plates.

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REFERENCES

[1] SEIDEL G., BLESS M., WESSER H., 1959, *Gedruckte Schaltungen – Technologie und Technik*, Verlag Technik Berlin.

[2] KO S.H., PAN H., GRIGOROPOULOS C.P., LUSCOMBE C.K., FRÉCHET J.M.J., POULIKAKOS D., 2007, *All-inkjet-printed flexible electronics fabrication on a polymer substrate by low-temperature high-resolution selective laser sintering of metal nanoparticles*, Nanotechnology, 18, 345202.

[3] KO S. H., CHUNG J., PAN H., GRIGOROPOULOSA C. P., POULIKAKOSC D., 2007, *Fabrication of multilayer passive and active electric components on polymer using inkjet printing and low temperature laser processing*, Sensors and Actuators A, Physical, 134, 161–168.

[4] ALLEN N.J., WOOD D., ROSAMOND M.C., SIMS-WILLIAMS D.B., 2009, *Fabrication of an in-plane SU-8 cantilever with integrated strain gauge for wall shear stress measurements in fluid flows*, Procedia Chemistry, 1, 923–926.

[5] RAUSCH J., SALUN L., GRIEHEIMER S., IBIS M., WERTHSCHÜTZKY R., 2011, *Printed Piezoresistive Strain Sensors for Monitoring of Light-Weight Structures*, Sensor+Test Conferences, B1 – Piezoresistive Sensors, 216–221.

[6] IBIS M., 2015, *Umformen von Aluminiumblechen mit aufgedruckter Elektronik am Beispiel von Dehnungsmess-streifen*, Aachen Shaker, 96.

[7] CORREIA V., CAPARROS C., CASELLAS C., FRANCESCH L., ROCHA J.G., LANCEROS-MENDEZ S., 2013, *Development of inkjet printed strain sensors*, Smart Materials and Structures, 22, 105058.

[8] MAIWALD M., 2010, *Untersuchungen zum Einfluss der Mikrostruktur auf die Eigenschaften aerosolgedruckter Sensorstrukturen*, VDI Verlag, 4–10.

[9] MAIWALD M., WERNER C., ZOELLMER V., BUSSE M., 2010, *INKtelligent printed strain gauges*, Sensors and Actuators A, Physical, 162/2, 198–210.

[10] POLZINGER B., KECK J., MATIC V., EBERHARDT W., KÜCK H., 2016, *Mit Inkjet und Aerosol Jet® gedruckte Sensoren auf 2D- und 3D-Substraten*, Technisches Messen, 83, 139–146.

[11] PIQUÉ A., CHRISEY D.B., 2002, *Direct-Write Technologies for Rapid Prototyping Applications: Sensors, Electronics, and Integrated Power Sources*, Academic Press, San Diego.

[12] SEIFERT T., SOWADE E., ROSCHER F., WIEMER M., GESSNER T., BAUMANN R.R., 2015, *Additive Manufacturing Technologies Compared*, Industrial & Engineering Chemistry Research, 54/2, 769–779.

[13] DUMSTORFF G., LANG W., 2016, *Strain gauge printed on carbon weave for sensing in carbon fiber reinforced plastics*, 2016 IEEE SENSORS, 1–3.

[14] ZHANG Y., ANDERSON N., BLAND S., NUTT St., JURSICH G., JOSHI S., 2017, *All-printed strain sensors: Building blocks of the aircraft structural health monitoring system*, Sensors and Actuators A: Physical, 253, 165–172.

[15] MÖHRING H.-C, 2017, *Composites in Production Machines*, Procedia CIRP, 66, 2–9.

[16] SUH, J.D., LEE, D.G., 2002, *Composite Machine Tool Structures for High Speed Milling Machines*, CIRP Annals – Manufacturing Technology, 51/1, 285–288.

[17] KROLL L., BLAU P., WABNER M., FRIESS U., EULITZ J., KLÄRNER M., 2011, *Lightweight components for energy-efficient machine tools*, CIRP Journal of Manufacturing Science and Technology, 4/2, 148–160.

[18] KULISEK V., JANOTA M., RUZICKA M., VRBA P., 2013 *Application of fibre composites in a spindle ram design*, Journal of Machine Engineering, 13/1, 7–23.

[19] MÖHRING H.-C., WIEDERKEHR P., LEOPOLD M, NGUYEN L.T., HENSE R., SIEBRECHT T., 2016, *Simulation aided design of intelligent machine tool components*, Journal of Machine Engineering, 16/3, 5–33.

[20] MÖHRING H.-C., WIEDERKEHR P., LEREZ C., SCHMITZ H., GOLDAU H., CZICHY C., 2016, *Sensor Integrated CFRP Structures for Intelligent Fixtures*, Procedia Technology, 26, 120–128.

[21] *Silver Nano Particle Ink*, 2012, *Mitsubishi Nano Benefit Series NBSIJ-MU01*, Mitsubishi Paper Mills Limited.