Conductivity improvement by using silver coated knitting yarn in NCF-reinforced laminates

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Abstract
The conductivity of NCF-reinforced laminates is improved by using electrically conductive knitting yarn. A test textile containing four different silver coated yarns has been produced to assess the effect on laminate conductivities. Depending on the yarn count and degree of silver coating the conductivity in thickness direction increases by up to two orders of magnitude. The highest value achieved is 540 S/m. There is also a substantial improvement of in-plane conductivity.

1. Introduction

The poor electrical conductivity of carbon fibre composites causes additional weight and cost in modern CFRP airframes as additional features need to be installed to ensure sufficient electrical conductivity. Especially the conductivity in thickness direction is several orders of magnitude lower than that of metals (see Figure 1).

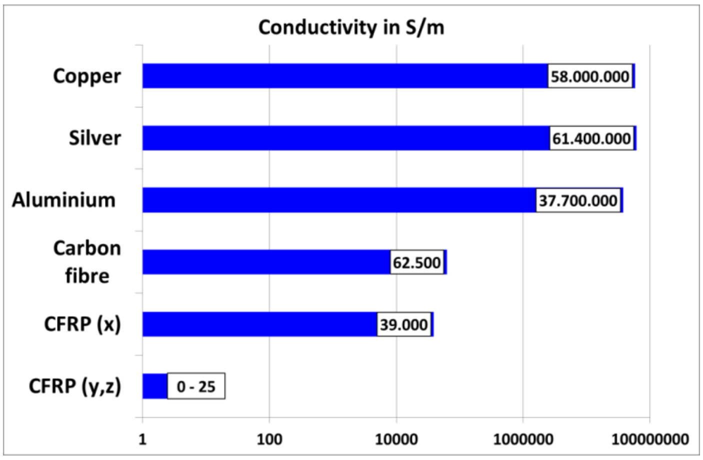

Figure 1: Electrical conductivity of different materials [1]

2. NCF with conductive knitting yarn

NCFs (Non-Crimp-Fabrics) are widely used as reinforcement textiles for parts produced in infusion technologies. They consist of stacked, unidirectional layers of reinforcement fibres, which are held together by knitting yarns. Those knitting yarns allow an uninterrupted path through the thickness of a textile ply. Therefore metal coated knitting yarns effectively increase the conductivity of laminates in

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z-direction. The potential of this technology has been demonstrated previously. NCF textiles were produced on lab scale by sewing unidirectional woven fabrics together with conductive yarns [1].

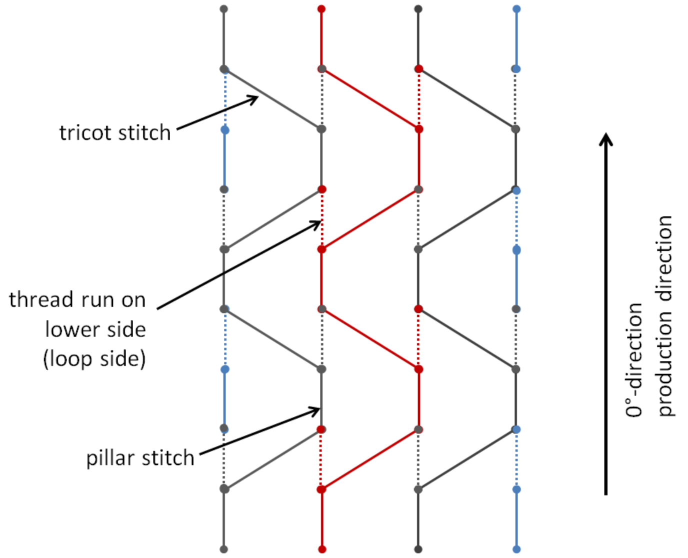

Figure 2: Stitching pattern of the NCF

Based on these promising results an NCF with silver coated knitting yarns has been produced. The carbon fibre layup is +/-45° with 194 g/m² per ply. Figure 2 shows the stitching pattern. Pillar and tricot-stitch are alternating after every stitch. For the pillar stitch each knitting yarn is always processed by the same needle. For the tricot stitch the yarn changes between two adjacent needles. This creates a zig-zag line on the upper surface of the textile. On the lower side of the textile the knitting yarn runs in a straight line, regardless which stitching pattern is one the upper side. On the lower side the knitting yarn forms a loop. Therefore this side is often referred to as loop side. An NCF with a combination of pillar and tricot stitch has a better drapeability than one with pure pillar stitch.

To assess the effect of different yarn conductivities, the textile is split widthwise in four sections for four knitting yarns. The yarns vary in yarn count and degree of silver coating (see Table1).

Table 1. Knitting yarns used in the NCF

Designation	Yarn count	Degree of silver coating
33PL	33 dtex	high
44PL	44 dtex	high
44HC	44 dtex	Medium
110PL	110 dtex	High

3 Conductivity measurements

The conductivity in thickness direction is measured on 6 samples per series. Resin rich layers on the surfaces are removed by grinding and sand blasting. After cleaning, the surfaces are metallised with conductive silver paint. The sample size is 40 mm x 40 mm.
The size of the samples for determining the conductivity in-plane is 20 mm x 100 mm. The short sides are coated with silver paint after cutting the samples with a wet saw. Further surface preparation such as grinding is not necessary.

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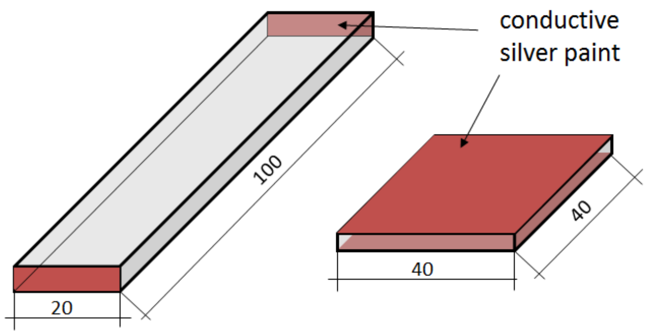

Figure 3: Test coupons for conductivity measurement; left: in-plane, right: in thickness direction

4. Results and discussion

4.1 Electrical conductivity in thickness direction

The main objective of using conductive knitting yarns is to improve conductivity in thickness direction. Table 2 lists the measurement results. Figure 4 shows them graphically.

Table 2. Conductivity in thickness direction, layup $[+45°/-45°]_{6S}$

Designation	Knitting yarn	Yarn orientation	Electrical conductivity	
			σ_z in S/m	coef. of var.
Z-33PL-X	33PL, 33 dtex, high degree of silver coating	intersecting	**174.6**	7.0 %
Z-33PL-P		parallel	**142.9**	7.0 %
Z-44PL-X	44PL, 44 dtex, high degree of silver coating	intersecting	**240.2**	9.4 %
Z-44PL-P		parallel	**150.8**	4.7 %
Z-44HC-X	44HC, 44 dtex, medium degree of silver coating	intersecting	**22.3**	4.8 %
Z-44HC-P		parallel	**11.1**	6.9 %
Z-110PL-X	110PL, 110 dtex, high degree of silver coating	intersecting	**541.3**	5.9 %
Z-110PL-P		parallel	**290.5**	18.9 %
Z-non-P	Reference, non-conductive yarn	parallel	**0.7**	7.5 %

For each conductive yarn there are two variants of laminates. The carbon fibre layup is $[+45°/-45°]_{6S}$ and identical for all laminates. However in the first configuration the production direction of every second textile is in 0°-direction of the laminate. The other half is oriented in 90°-direction. Thus the dominant directions of the knitting yarns of adjacent textiles are intersecting. The left half of Figure 5 shows the contact plane between two textiles.
In the second configuration all textiles are aligned parallel in one direction (see right half of Figure 5). Figure 4 illustrates that the conductivity of the configuration with intersecting yarns is a lot higher than the parallel version.

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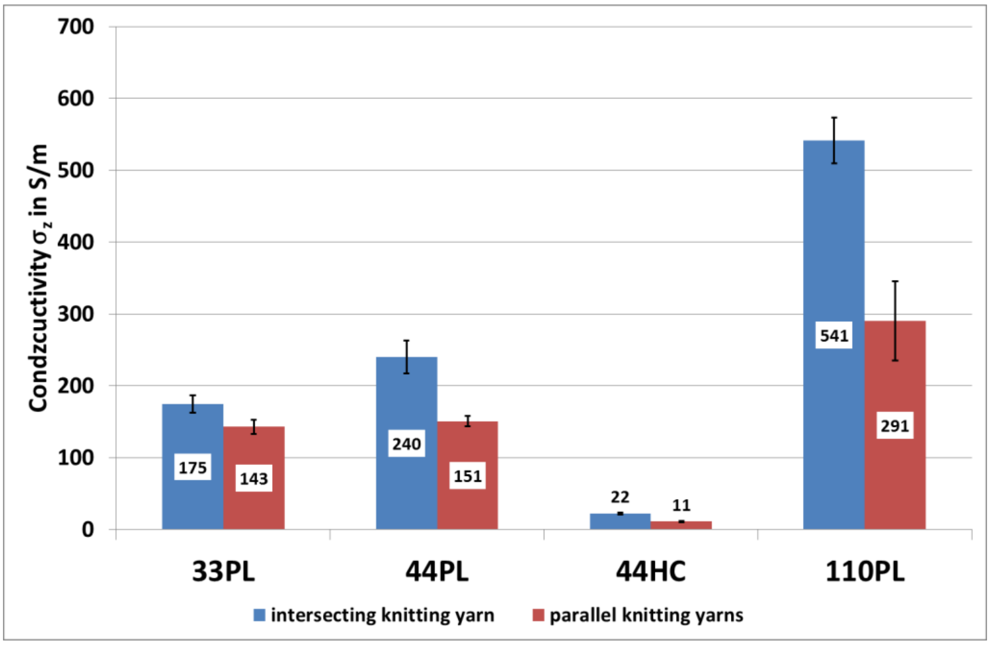

Figure 4. Conductivity in thickness direction of the NCF with silver coated knitting yarn

The reason is the relevant yarn length in the contact plane between two textiles. This yarn length is an important part of the conductive path created by the silver coated yarns. Figure 5 shows a schematic drawing of the contact plane for both laminate configurations. The yarn on the upper surface of the lower textile is drawn in blue, the yarn on the lower surface of the upper textile in red. The dots indicate the points where the yarn pierces the NCF in thickness direction. The connection from a blue to the closest red dot contributes to the length of the conductive path in thickness direction. On average this length is longer and there are fewer contacts per area in the parallel configuration shown in the right half of Figure 5. This results in a lower laminate conductivity in thickness direction.

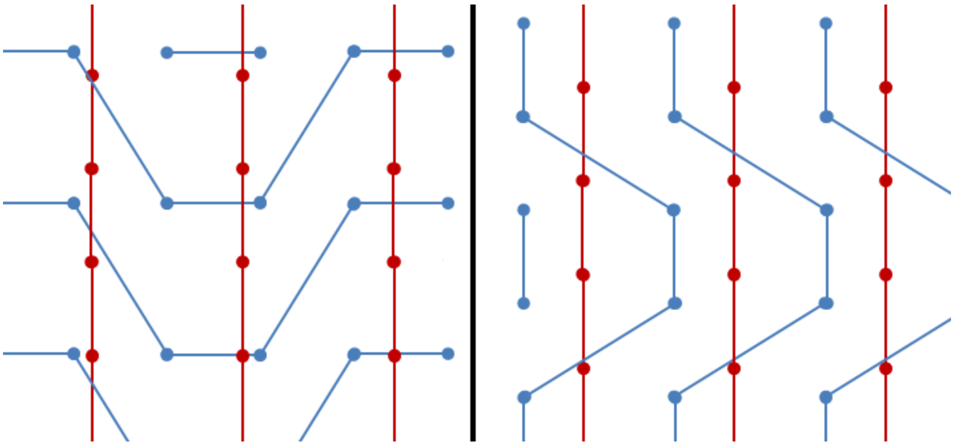

Figure 5. Contact plane between two NCF-textiles (blue: lower textile, red: upper textile)
left: intersecting production directions, right: parallel production directions

4.2 Electrical conductivity in-plane

The previous paragraph describes a strong increase of conductivity in thickness direction caused by the conductive knitting yarns. However as large parts of the yarns run in plane, there is also a significant increase of in-plane conductivity. Table 3 and Figure 6 show the results of these measurements. The coupons are cut from the same laminates as the specimens for measuring the z-conductivity.

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Table 3. Conductivity in-plane, layup [+45°/-45°]$_{6S}$

Designation	Knitting yarn	Yarn orientation	Measurement direction	Electrical conductivity	
				σ_{xy} in S/m	coef. of var.
XY-33PL-X	33PL, 33 dtex, high degree of silver coating	intersecting	0°	**11853**	2.9 %
XY-33PL-p-iP		parallel (0°)	0°	**16386**	1.9 %
XY-33PL-p-sP			90°	**7581**	1.8 %
XY-44PL-X	44PL, 44 dtex, high degree of silver coating	intersecting	0°	**14247**	3.5 %
XY-44PL-p-iP		parallel (0°)	0°	**20331**	2.9 %
XY-44PL-p-sP			90°	**8388**	1.6 %
XY-44HC-X	44HC, 44 dtex, medium degree of silver coating	intersecting	0°	**3390**	2.5 %
XY-44HC-p-iP		parallel (0°)	0°	**3730**	17.6 %
XY-44HC-p-sP			90°	**2692**	2.4 %
XY-110PL-X	110PL, 110 dtex, high degree of silver coating	intersecting	0°	**24173**	2.5 %
XY-110PL-p-iP		parallel (0°)	0°	**36207**	3.4 %
XY-110PL-p-sP			90°	**12223**	2.8 %
XY-non-X	Reference, non-conductive yarn	intersecting	0°	**2834**	5.1 %
XY-non-p-iP		parallel (0°)	0°	**3099**	4.4 %
XY-non-p-sP			90°	**2707**	2.1 %

As is the case with the z-conductivity there is a clear difference between the two laminate configurations. For the parallel orientation most of the yarn runs in 0°-direction (see Figure 5). In 90° direction only the tricot stitch contributes to an increased conductivity. Since this is only a minor part of the yarn the conductivity in 90°-direction is lower than in production direction.
The laminate with intersecting knitting yarns is a mixture of these two cases. For 50 % of the reinforcement textiles the production direction is in 0°- direction, the other half is in 90°-direction. Therefore the in-plane conductivity of the laminate is the same in both directions. The value is approximately the mean value of the two measurements on the laminate with parallel knitting yarns.

All specimens listed in Table 3 have a +/-45° layup. There are no carbon fibres in measurement direction. For many applications a quasiisotropic layup such as [0°/45°/90°/-45°]$_{3S}$ is more representative. Changing to such a layup would increase the conductivity of all laminates. The reference would reach app. 12 000 S/m. This would reduce the relative improvement by the conductive yarns, but there would still be a significant increase.

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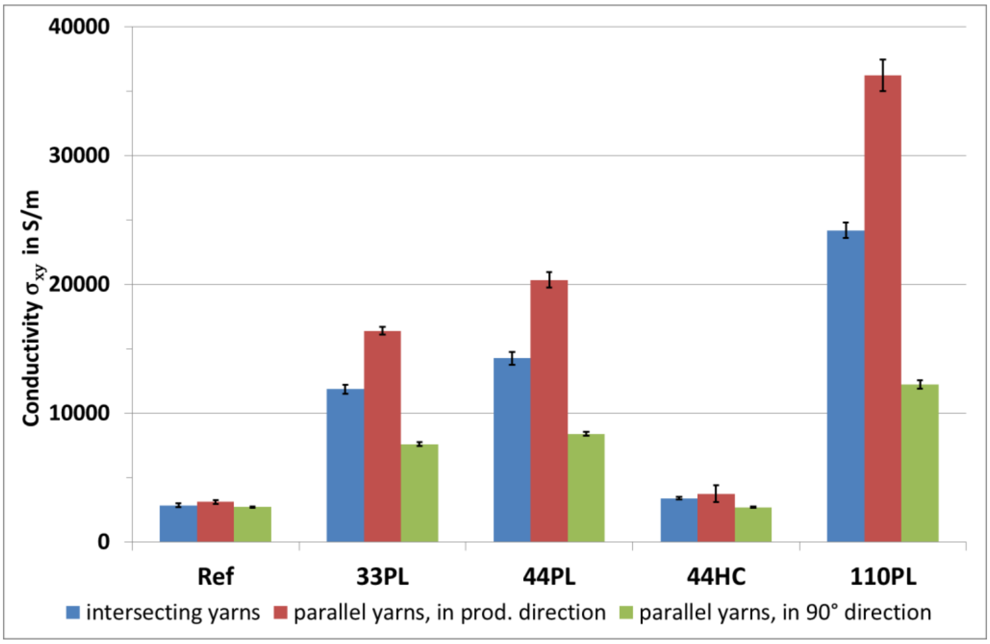

Figure 6. In-plane conductivity of the NCF with silver coated knitting yarn

5. Conclusion

Conductive knitting yarns in NCFs are an effective way to increase the conductivity in thickness direction. Depending on the type of yarn the conductivity increases by up to two orders of magnitude. The orientation of production directions strongly influences the electrical conductivities. For a high conductivity in thickness direction the production directions of adjacent textiles should be intersecting. In long thin parts this may not be preferable to avoid butt joints within the fibre plies. In this case the stitching pattern with alternating tricot and pillar stitch used in this paper is beneficial. A textile with pure pillar stitch would lead to a much lower conductivity since there would be few to no direct contacts between the parallel lines of conductive yarns in adjacent textiles.
The relative improvement of in-plane conductivity is smaller than in thickness direction but still significant. For laminates with a +/-45° carbon fibre layup the in-plane conductivity increases by a factor of app. five.

References

[1] J. Rehbein, Improving and modelling the electrical conductivity of NCF-reinforced CFRP. *Proceedings of the 20th International Conference on Composite Materials ICCM-20, Copenhagen, Denmark*, July 19-24 2015.

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