

Effect of manufacturing defects for the automated production of fiber metal laminates (FML)

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Motivations and goals

Automated production of FML is required for competitive high volume production to become a real alternative to aluminium and carbon structures.



Deviation from the ideal situation

Crucial tasks to address for effective automated FML production, focus on:

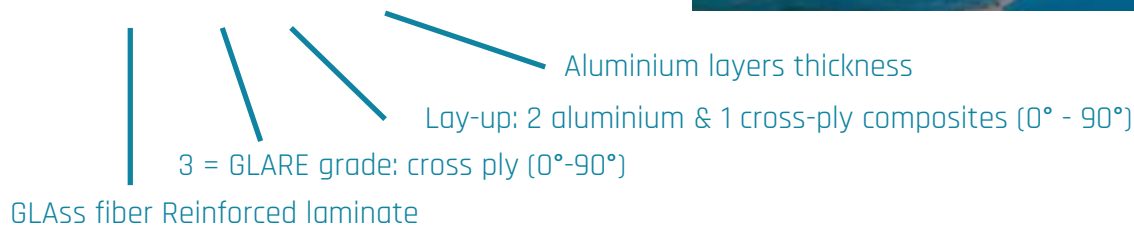
1. Which *flows* are likely to occur during the automated FML manufacturing?
2. Which kind of *defects* arise in the final FML?
3. How to discover and quantify these *defects*?
4. How do they influence the FML mechanical properties?

Deviation outside the agreed specification

Base material: GLARE

GLARE is a FML consisting of

- Alternating aluminium and composite layers
- Composite layers contains continuous glass fibers (S2) embedded in an epoxy resin (FM94)
- Fibre orientations are 0° , $\pm 45^\circ$ or 90° w.r.t. the rolling direction of the aluminium layers
- Code (e.g.): GLARE 3-2/1-0.4



Issues in automated GLARE manufacturing

Metal

Kinks

Abrupt band or deviation in a flat shape of thin (≤ 0.4 mm) aluminium sheets caused by localized bending during handling.



Composite

Gaps & Overlaps

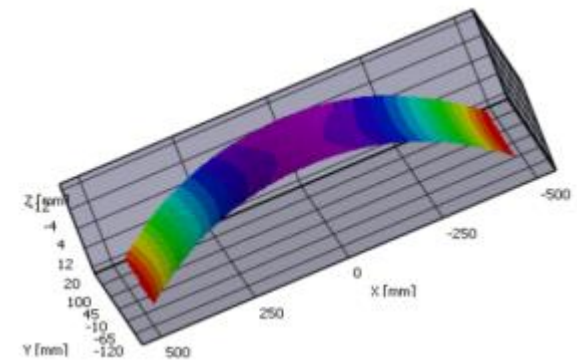
Situation of prepreg plies not being directly adjacent to each other, or overlapping each other, respectively.



Laminate

Residual stresses

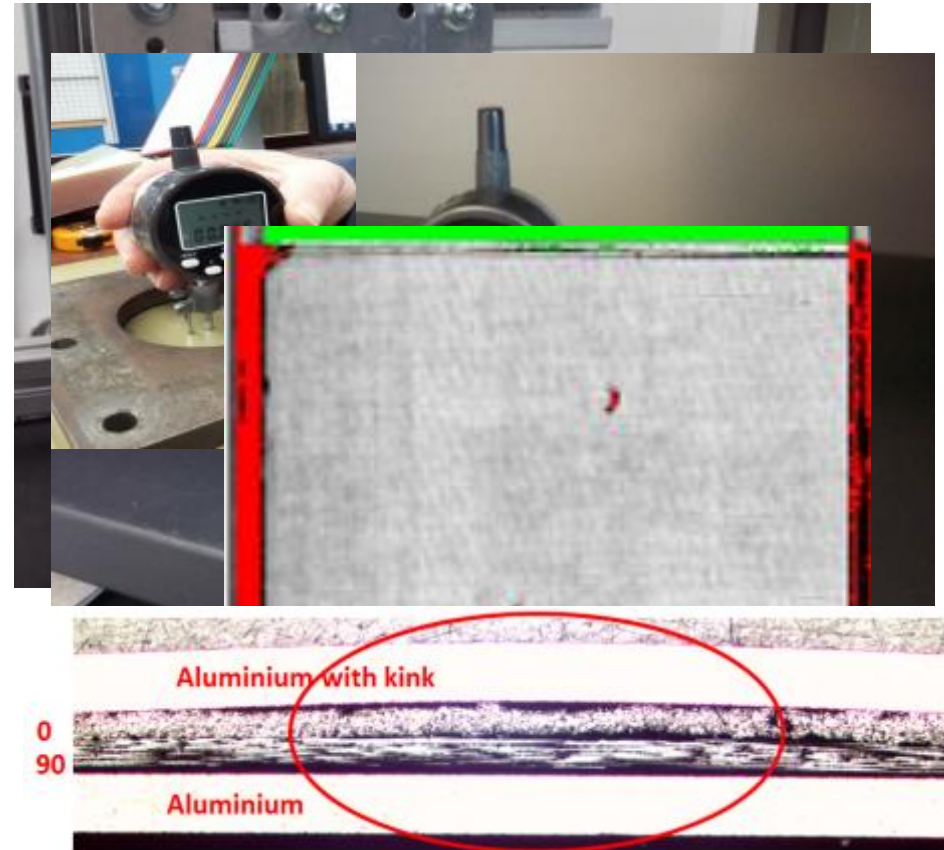
Undesired built-in stresses happening during manufacturing which can affect the lifetime of the component.



Detection, analysis and quantification of defects: approach and results

Kinks

- GLARE 3 - 2/1 - 0.3&0.4
- Development of a specific setup for kink manufacturing;
- Kink depth evaluation (*severity classification*) via an integrated ring tool;
- Kink detection in GLARE laminates via ultrasonic inspection;
- Optical evaluation of the effect of kinks: delamination/void onset.



Detection, analysis and quantification of defects: approach and results

➤ Critical parameters (*from flaws to defects*)

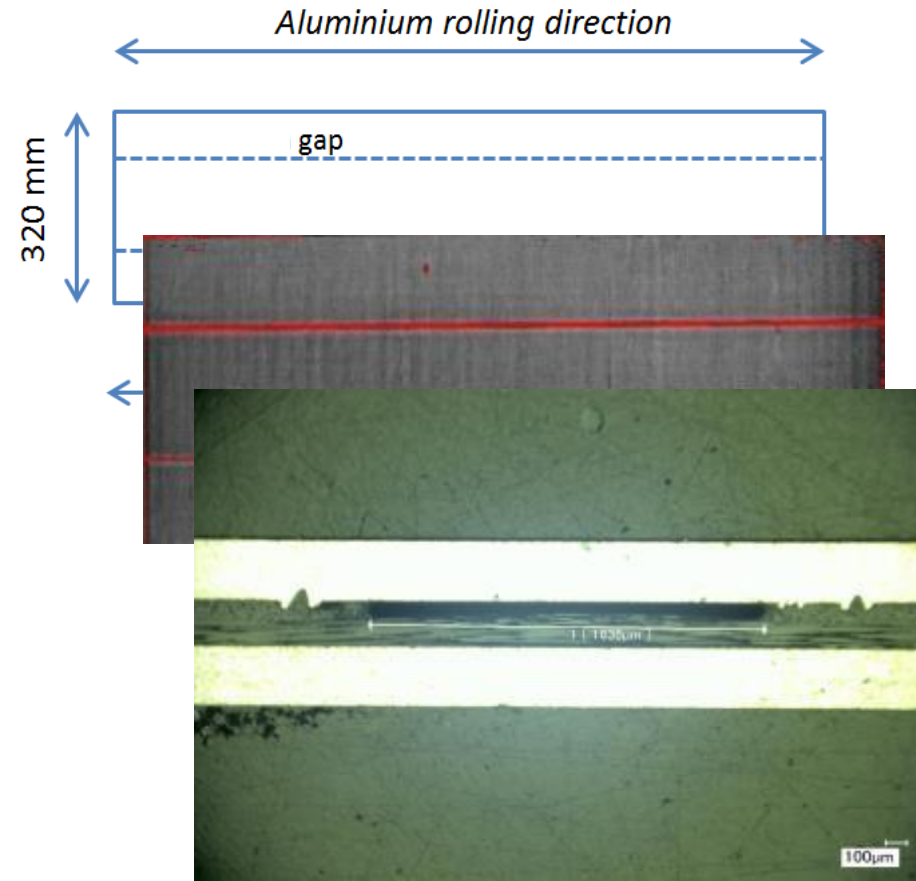
- Kink depth: if < 0.3 mm, no detection.
- Kink position w.r.t the mould: if the aluminium sheet with the kink was placed next to the mould, no detection (*and vice versa!*).
- Al sheet thickness t : if $t = 0.4$ (stiffer than $t = 0.3$), only kink with depth > 0.4 can be detected.



Detection, analysis and quantification of defects: approach and results

Gaps

- GLARE 3 - 2/1 - 0,3&0,4;
- Manufacturing of gaps in a single ply with different widths: 2, 3, 4, 5 mm;
- Gap detection in GLARE laminates via ultrasonic inspection;
- Optical evaluation of the effect of the gap: *fibres missing*.



Detection, analysis and quantification of defects: approach and results

Gaps

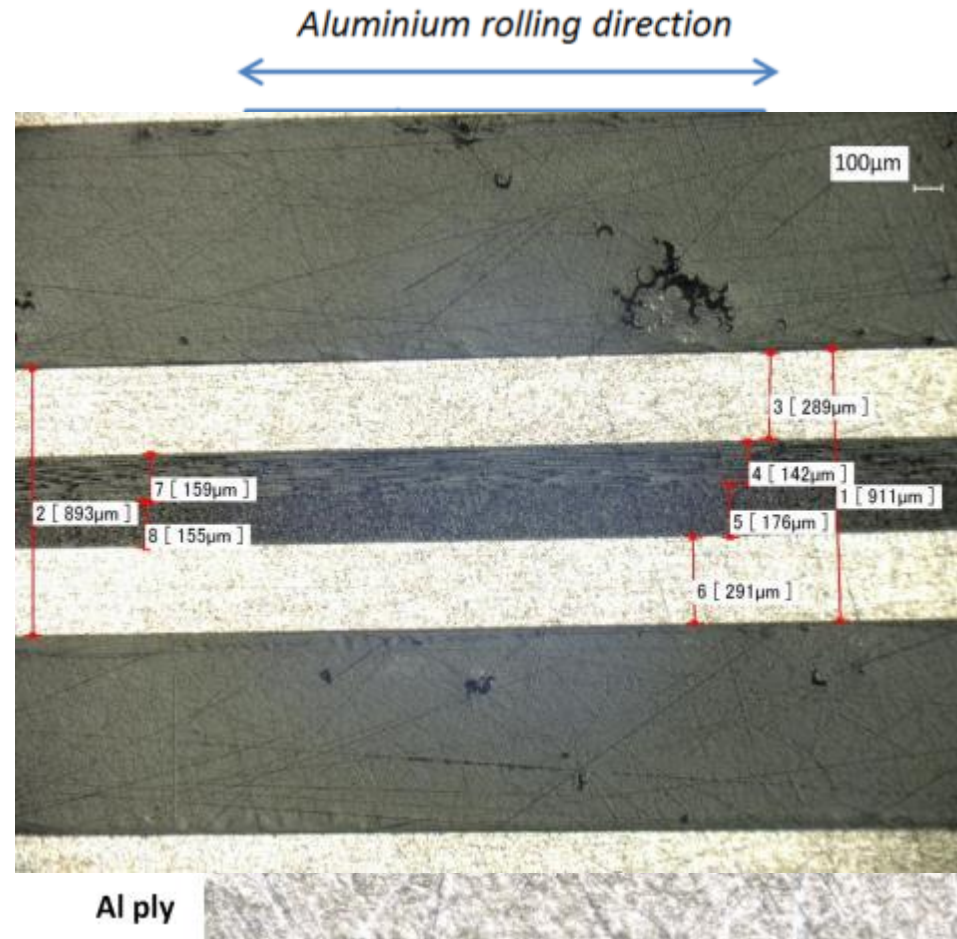
- Gaps do not keep a constant width along the length of the laminate.
- The fibers next to the gap roll towards the void left by the gap leading to a reduction of the initial gap width.
- The gap width reduction, on average, is greater when a stiffer laminate is used (aluminium $t = 0.4$ mm).



Detection, analysis and quantification of defects: approach and results

Overlaps

- GLARE 3 - 2/1 - 0,3&0,4;
- Manufacturing of overlaps in a single ply with different widths: 2, 3, 4, 5 mm;
- Overlap evaluation in GLARE laminates via ultrasonic inspection: no critical attenuation;
- Optical evaluation of the effect of the overlap: *fibres waviness*;
- Laminate thickness step: potential issue for back-up structures assembly..



Detection, analysis and quantification of defects: approach and results

Overlaps

- Overlaps do not lead to any visible defects in the final laminate.
- Fiber waviness represents an issue for the assembly of parts, especially if more overlaps occur along the same spot.
- Fiber waviness can represent an issue for the compression strength of the final laminate.

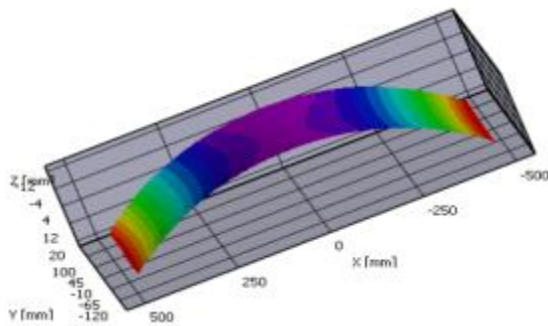


Detection, analysis and quantification of defects: approach and results

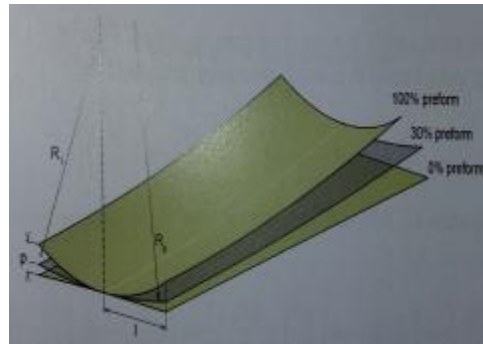
Residual stresses

$$\sigma_{Internal} = \cancel{\sigma_{sheet}} + \sigma_{cure\ cycle} + \sigma_{pre-forming} + \sigma_{tool-part}$$

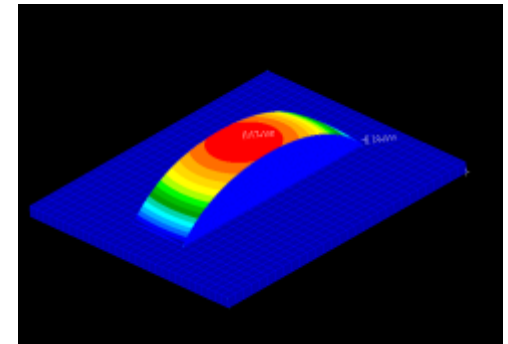
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Due to the anisotropic nature of GLARE.



Due to double curved panels manufacturing.



Due to shear interaction between the tooling and the curing part along their interface.

Conclusions and future outlooks

- A preliminary assessment of the presence of manufacturing flaws in GLARE laminates has been performed.
- Kinks, gaps, overlaps have considered since their presence can be likely affect the automated GLARE production.
- The investigation has addressed the detection (ultrasonic-based inspection), and the optical evaluation of the effect of such defects in the final GLARE laminate.

Conclusions and future outlooks

➤ Future investigation needs to address:

- A numerical-analytical-experimental-based joint approach for residual stresses evaluation,
- The influence of different GLARE grade and lay-ups,
- The relation with the mechanical properties degradation,
- The flaw thresholds for an effective manufacturing production.

Thank you

