Ultrasound Based Monitoring of Flow Front and Laminate Thickness without Contact to Part

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Keywords: *Ultrasonic; Flow front monitoring; Thickness monitoring; Cure monitoring; Experimental; Process Control*

Introduction

As liquid composite moulding processes are very sensitive to deviations in raw materials and process parameters, sensing systems providing information about the flow propagation inside the preform are highly demanded for process development or as input for process control.

Ultrasonic process monitoring of flow front propagation

For monitoring LCM processes ultrasonic sensors are particularly well suited, as they obtain all of the most crucial information about the process state. Furthermore they do not require direct contact to the part, thus the part surface and the mould vacuum integrity are not affected.

The DLR has developed small and low cost ultrasound sensors which allow the integration of a dense sensor network. These sensors require less effort in order to integrate them and provide broader information in comparison to conventional transducers. The sensors are applied on the outer side of the mould (Figure 1), from where the sound waves propagate through the wall and then interact with the part. [1, 2]

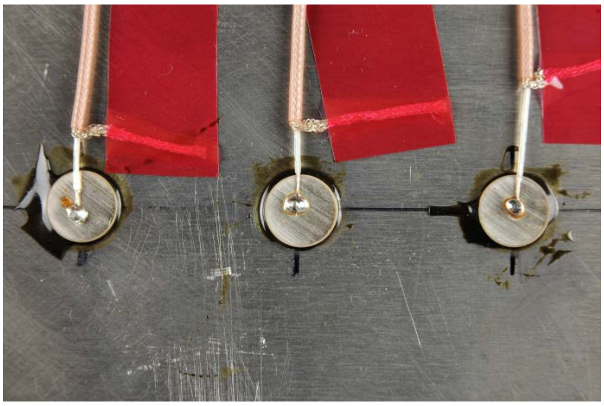

Figure 1: *Low cost ultrasound sensors mounted on outer mould side*

When the sound waves hit on the part surface, a large fraction is reflected back to the sender while the remaining sound waves pass through the part. Before the laminate is impregnated the sound waves are reflected completely. By analysing the reflection signal the arrival of the flow front can be obtained in a very robust way in almost all mould materials.

Furthermore, not only the arrival time, also the flow speed and even its direction can be derived by enhanced signal processing. These two additional parameters, which every single sensor can provide, help to reconstruct and even extrapolate the flow front evolution.

This technique was evaluated in a transparent mould, where the flow front position, speed and direction in reference to the sensor position was documented on video and then calculated by image processing. The comparison of the sensor and video results showed a very high agreement. The flow front speed can be measured with at least 3.5 % accuracy. The precision of the angle depends largely on the mould thickness, where at small thicknesses the precision is best.

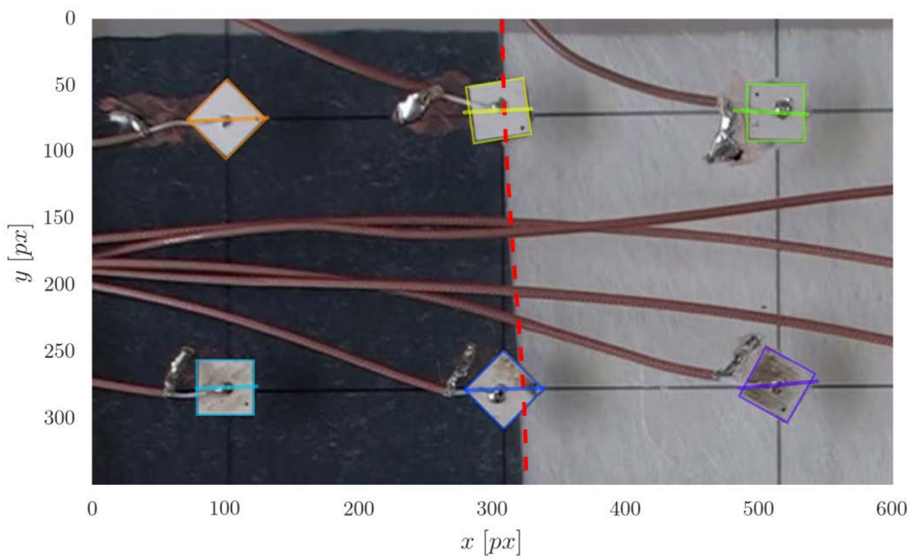

Figure 2: *Validation of monitoring flow front direction (transparent mould and coloured silicone oil)*

Ultrasonic process monitoring of laminate thickness and cure

Besides the flow front the laminate thickness can be derived from the sound propagation time through the part, which then can be used for thickness control by pressure and infusion time adaption. As the sound velocity is depending on the degree of cure, temperature and fibre volume content, this influence has to be compensated in order to calculate the exact thickness. This compensation can be achieved by a calibration measurement beforehand or with special sensor settings to measure the current and local sound velocity and calculate the laminate thickness.

Lastly the cure progress as well as gelation and vitrification can be monitored with the same sensors. Up to gelation, where the resin is still able to flow, the resin’s sound velocity increases only slightly. As the laminate thickness is set, the changes of sound propagation time are only linked to cure and temperature.

The system has already proven to work in near industrial manufacturing environment. In the EU project LOCOMACHS the sensors and measurement equipment was successfully used in an autoclave-based infusion to manufacture aeronautical wing ribs. The flow front, laminate thickness and cure monitoring was used to control the process parameters to achieve complete impregnation, the thickness tolerances and complete cure while aiming at short process duration.

The developed sensor system, a short theoretical overview, experimental validation and first near industrial applications including autoclave based infusion will be presented.

Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°314003.

References

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