Rapid Control of Machined Glass Fiber Reinforced Plastics by Single Shot Terahertz Time Domain Spectroscopy

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***Abstract*— We apply single shot THz Time Domain Spectroscopy to control glass fiber reinforced plastics that were machined during their production. The THz imaging reveals that the mechanical processing as hole punching introduced significant modifications to the composite structures, also beyond the directly impacted region. These changes can be precisely localized and further characterized in order to classify the types of defect. The results show that the time of flight information is particularly sensitive to changes in the complex fiber and polymer matrix network. They can be visualized and quantified with B- and C-scans. Thanks to the ultrashort duration and high repetition rate of acquisition, the single shot technology is suited for the control of composites within cycle time of industrial production.**

I. INTRODUCTION

POLYMER composites are increasingly used in industrial applications, e. g. in the automotive and aerospace sectors. They should combine low weight with specific mechanical properties and high resistance to static or cyclic stresses. For their structural functionality and integration into assemblies, they are often machined during or after production [1]. This can lead to significant modifications of the composite structure and to failure in service.

The potential of THz Time Domain Spectroscopy (THz-TDS) for the control of composite materials, particularly of glass fiber reinforced plastics and their properties, has been shown by several groups. Fiber orientation and filling degree, moisture content, stress induced modifications, and defects can be revealed [2-4]. Here we apply single shot (SS-)THz-TDS based on supercontinuum encoding in balanced detection to precisely reveal and characterize defects inside machined industrial glass fiber reinforced polyamide 6 (GFRP). This ultrafast approach is particularly suited for application on production control or on-site inspection.

II. RESULTS

The concept and reliability of the SS-THz-TDS are described in reference 5, and the configuration and performance used here in reference 6. The samples were studied in transmission, positioned in the intermediate focal plane of the spectrometer. Imaging was performed by raster scanning under a 0 degree angle of incidence relative to the main plane of the samples. The presented data comprises the results of one spatial scan without averaging. It was recorded during horizontal translation of the sample at a maximal speed of 0.25 m s^{-1} and a spectrometer acquisition rate of 1 kHz defining the maximum step width of 0.25 mm. The overall acquisition time for 50 cm^2 was ~1 minute.

Figure 1 shows a photo of the composite under investigation and two images based on part of the data from the time domain, two dimensional representations of amplitude and time of flight (TOF) of the principal THz pulse. The GFRP laminate with 1.8 mm wall thickness is formed to a three dimensional structure and machined during fabrication. The sample exhibits three curved regions: at the right boarder, at the left linking two levels with a depth difference of ~20 mm (vertical line around X = 27 mm) and around the hole (diameter of ~15 mm, depth of ~10 mm). The latter region was formed directly by hole punching. The curved regions exhibit higher amplitude losses and time of flight due to the enhanced effective thickness of the woven fabric composite.

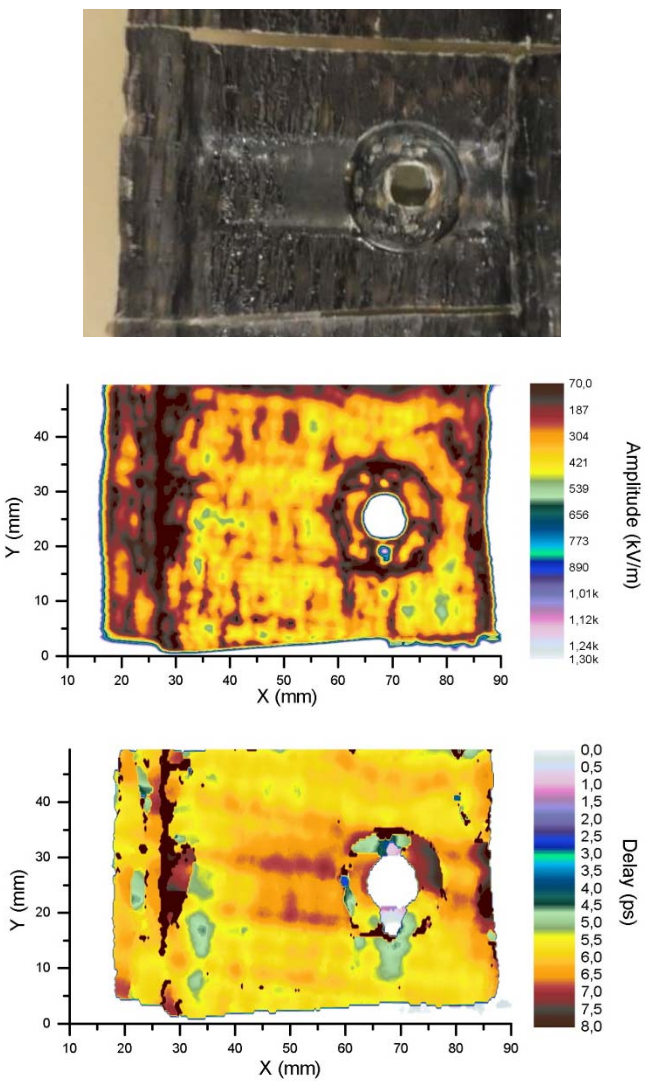

Fig. 1. From top to bottom: photo of the GFRP sample revealing the punched hole and the adjacent mechanically impacted region, corresponding THz images based on amplitude and time of flight of the main transmitted pulse.

Both amplitude and TOF images, with transversal resolution on the scale of few 100 micrometers, reveal two punctiform modifications in the top and the bottom of the hole. A significant destruction of the composite network is also disclosed in the mechanically impacted region around the hole indicating a shift of cracked composite material from white to red zones in the TOF image. Increased scattering and diffraction reduce the THz pulse amplitude. The TOF reveals a further defected zone outside the directly impacted region (Y = 5-15 mm, around X= 70 mm).

These 2-dimensional images based on the properties of the main THz pulse allow for the localization and preliminary characterization of defects, the further exploitation of the information rich data set of the THz-TDS raster scan can be used to quantify them. B-scans display the full temporal waveform for selected lines on the sample; examples are shown in figure 2. Among their various uses, B-scans can also be used to visualize TOF changes and to set them into reference with the proximity. In general, this representation of data is very sensitive to additional reflections that can be due to defects such as inclusion or delamination.

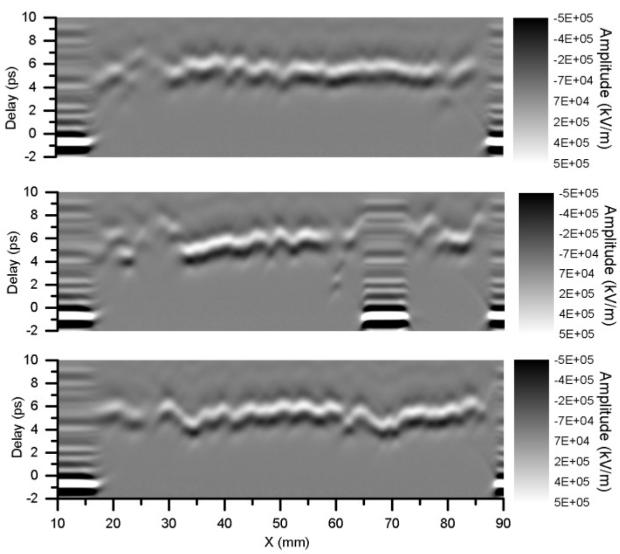

Fig. 2. B-scans, showing the THz electric field wave form in the time domain at selected horizontal lines. From top to bottom: at Y= 40, 25 and 13 mm (for spatial reference see figure 1). In areas without sample the THz main pulse peaks at -1 ps.

C-scans display the electric field amplitude in the time domain at a fixed selected delay (see figure 3). These temporal slices exhibit a particular high spatial resolution and are very sensitive to local thickness variations. For the two punctiform cavities in the top and the bottom of the punched hole, the remaining material can be calculated with the precise temporal information to be 360 and 250 µm thick. In the defected zone below the mechanically impacted region, the TOF is reduced by up to 0.9 ps (see B-scans) indicating internal porosity, corresponding to a loss of one laminate. These kinds of invisible defects significantly limit the functionality of the composite and can lead to failure during service.

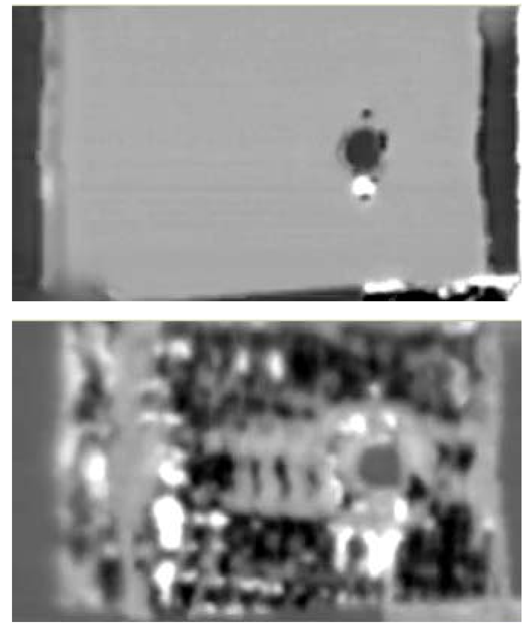

Fig. 3. C-scans, showing the images of the THz amplitude in the time domain at selected delays: at 0.5 ps at the top and 4.5 ps at the bottom (for temporal reference see figure 2).

III. SUMMARY

The present study illustrates that THz-TDS is a powerful and informative testing technique on composites such as GFRP. The applied single shot approach enables fast imaging with good spatial resolution. Consequently, manufacturing defects such as voids, delamination and internal destruction of the composite network in general can be localized and characterized. Acquisition speed can be further increased by adapting the laser repetition rate and the optical THz geometry to the specific industrial control objective.

ACKNOWLEDGEMENT

This work has been supported by “Investissements d’Avenir” of LabEx PALM (ANR-10-LabX-PALM-0039) and by “Ile de France” via “Aide à la Maturation” N° A 1412055Q.

REFERENCES

[1]. J. Ahmad, “Machining of Polymer Composites,” Springer Science & Business Media, 2009.

[2]. C. D. Stoik, M. J. Bohn, J. L. Blackshire, “Non-destructive evaluation of aircraft composites using transmissive terahertz time domain spectroscopy”, Optics Express, vol. 16, pp. 17039-17051, 2008.

[3]. C. Stoik, M. Bohn, J. Blackshire, “Nondestructive evaluation of aircraft composites using reflective terahertz time domain spectroscopy”, NDT&E International, vol. 43, pp. 106-115, 2010.

[4]. F. Ospald et al., “Aeronautics composite material inspection with a terahertz time-domain spectroscopy system,” Optical Engineering vol. 53, 031208 pp. 1-14, 2014.

[5]. U. Schmidhammer, V. De Waele, J.-R. Marques, N. Bourgeois and M. Mostafavi, “Single Shot Linear Detection of 0.01 - 10 THz Electromagnetic Fields,“ Applied Physics B, vol. 94, pp. 95-101, 2009.

[6]. P. Jeunesse and U. Schmidhammer, ““On-the-Fly” Monitoring With a Single-Shot Terahertz Time-Domain Spectrometer,” IEEE Sensors Journal, Special Issue on THz Sensing, vol. 13, pp. 44-49, 2013.