Technologies for Lightweight Structures 5(1) (2021), pp. 123-130
Special issue: 5th International MERGE Technologies Conference (IMTC), 1st–2nd December 2021, Chemnitz

Technologies for Lightweight Structures

Radar sensor integration and quality testing of sheet moulding compound parts in the automotive frequency range

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Keywords

Gigahertz (GHz) Range, Quality Analysis, Radar Sensor Integration, Relative Permittivity, Sheet Moulding Compound

Abstract

Sheet moulding compounds (SMC), a type of fiber-reinforced polymers with discontinuous fibers, are a highly used lightweight material due to their cost efficiency and processability. Since the use of radar sensors behind structural skin body parts for advanced drivers assistant systems in the automobile industry is increasing, the usability of this kind of material as a radar cover is examined. Additionally, a method for the analysis of SMC parts with radar measurement methods in the Gigahertz area is introduced. The hereby considered parameters are the fiber orientation, fiber volume content, and quality failures like welding lines as they are crucial for the mechanical properties of the material. The methods presented are already in use in the automotive industry for quality assurance of radar covers and show potential as a fast and non-destructive method to analyse those important material parameters of SMC components.

1 Introduction and motivation

In order to meet the increasingly demanding CO2 emissions reduction for vehicles, lightweight components are a decisive contribution to this task [1]. Long-fiber reinforced polymers such as sheet moulding compounds (SMC) are considered a promising lightweight candidate for mass production of automotive components, due to their cost efficiency and processability with good mass-specific material properties at the same time [2]. Therefore, discontinuous fiber reinforced composites are well established to replace structural metallic components in the automotive sector. In the field of this type of composite SMC's take a very large share among the most manufactured thermoset glass fiber reinforced materials in Europe in 2019 [3]. Another advantage of SMC's, which consists of a thermoset resin and embedded chopped fibers, is the high design freedom to manufacture parts with complex geometries [4]. The mechanical properties of SMC strongly depends on the fiber orientation and the fiber volume content [5]. During the molding of the part the material flow leads to local differences in the orientation and concentration of the fibers. To predict the mechanical properties the knowledge of these local differences is highly desirable [6]. The non-destructive Computed Tomography (CT) Scan method is used to fully analyse SMC parts in high resolution, which provides precise information, but is extremely time consuming and expensive. In addition, due to the size of the measurement devices, the dimension of the components to be examined is also limited.

Another substantial key technology in the automotive sector are frequency modulated continuous wave (FMCW) radar sensors to scan the car's environment for current and future advanced driver assistance systems (ADAS). Within the automotive sector their frequency range of operation is fixed in the area of 75 to 81 GHz by legal requirements [7, 8]. Most components in the sensor's direct environment are of similar dimensions to the sensor's electromagnetic wavelength of approx. 3.5 mm, which may lead to

Digital Object Identifier: http://dx.doi.org/10.21935/tls.v5i1.167
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resonating behavior. In the case of polymers, the type, thickness, geometry and orientation to the sensor affect the complex interaction of reflection, transmission and absorption with high frequency electromagnetic waves passing through. Since SMC components are used to replace outer skin parts of vehicles it is crucial to investigate the radar feasibility of these materials to use them in front of a radar. Therefore this paper shows an analysis of SMC material regarding its radar feasibility.

Additionally the radar measurements show an advantage for the material analysis of the SMC fiber architecture. Since this radar technology is highly used in the car industry measurement methods to analyse the reflection and transmission behavior of radar covers to be used as an end-of-line measurement system have been developed and show a fast analysis of the parts. The spatially resolved image of the high-frequency reflection and the spectral measurement of reflection factor in automotive frequency band [9, 10] allow a fast contact-less and non-destructive analysis of the material. In this paper investigations on performed radar measurements of SMC's are shown, which provide a first approach to the estimation regarding the fiber orientation and the content. Additionally, locally-resolved measurements of the reflection to examine the quality of SMC components are presented to see failures of the components, like fiber accumulations, areas with no fibers and weld lines. This concept can be carried out more quickly and with less effort than the known methods.

2 Materials and methods

SMC is composed of reinforcing fibers, a thermosetting matrix, application-specific additives and fillers, mostly calcium carbonate, and is industrially established and very widespread due to its low price, the wide range of possible applications and the good achievable mechanical properties.The used vinyl ester (VE) resin material is defined by a density of 1.31 g/cm³ and consists of 80 wt.% basic resin and 20 wt.% calcium carbonate filler. For the material characterisation of the VE resin, specimens are prepared with a width of 25 mm and a thickness of 4 mm. The characterization of the glass fiber reinforced SMC is based on the HUP 25/60 RN-9500/43529 type SMC material with a density of 1.86 g/cm³ made by Polynt GmbH,which is made from the same base resin but different fiber volume contents and containing E-glass fibers of 50 mm length. The SMC specimen are produced and extracted as described in Figure 1. In the left figure, the fibers will align along the flow direction due to the polymer flow. In the right figure, a weldline was provoked by the two flow fronts flowing towards each other.

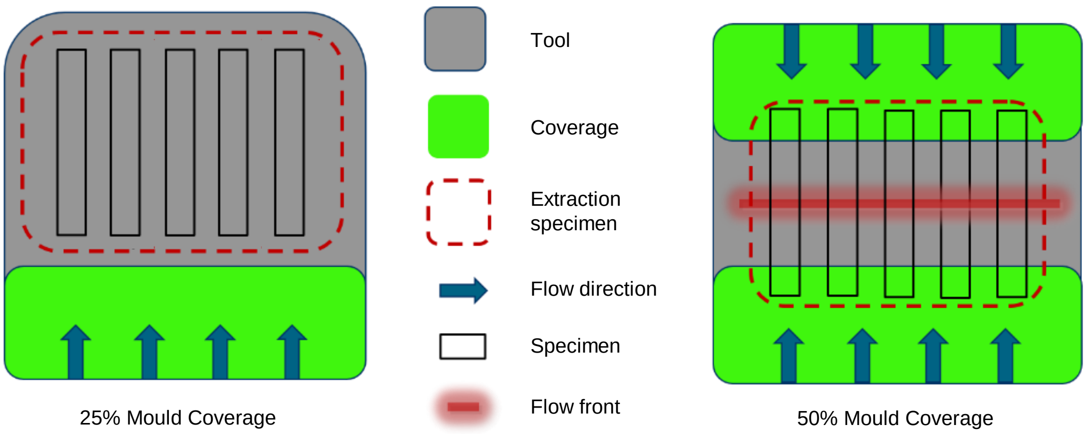

Figure 1: Illustration of specimen production process and extraction

The material property, which describes the interaction of a polymer with the electric field and can be used to analyse an SMC part, is the value relative permittivity [11]. For the estimation of the material parameter relative permittivity, an ultrawideband FMCW radar with a bandwidth of 24 GHz from 68 GHz to 92 GHz is used as a signal transceiver [10]. The setup is a free space reflection measurement, which shows high flexibility is contact-less and non-destructive (see Figure 2). Additionally, it has advantages regarding its low demands on sample size (diameter in centimeter region) with the only assumption is having one or more plane and parallel surfaces. To ensure precise measurements an empty room calibration measurement is carried out first, which is subtracted from the sample measurement to eliminate all system internal reflections and non-idealities. For the normalization of the reflection magnitude to one and a phase of 180°, an additional metallic reflection measurement is performed.

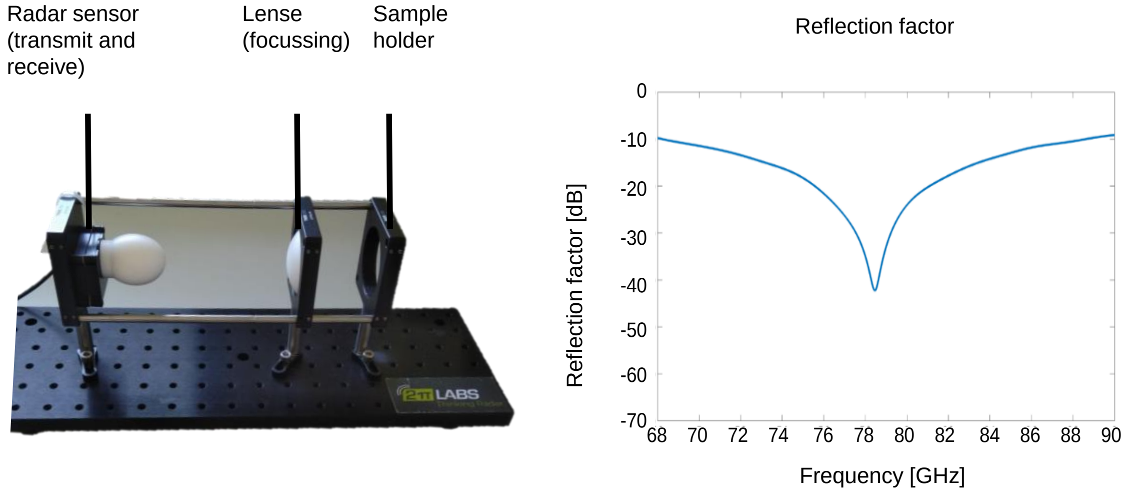

Figure 2: Measurement setup for estimation of relative permittivity

Another measurement result is carried out with the QAR tester (QAR Tester Rohde und Schwarz, see Figure 3, [9]). It shows the spatially resolved image of the high-frequency reflection. The bandwidth start at 74 GHz and ends at 79 GHz with an polarization angle of 45° and an image pixel size of 0,5 mm x 0,5 mm. The generated image allows wave adjustments and high reflective and thus dazzled regions to be found. The measurement can also be performed over the volume of the part, to show the reflection in different inner layers of the material.

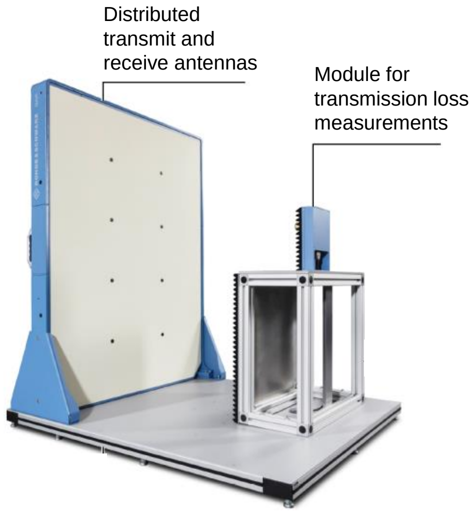

Figure 3: Measurement setup for the spatially resolved reflection image and the reflection volume [7]

3 Results and discussion

The reflection factor measurements, which lead to the estimation of the relative permittivity, were made in different orientations and positions of the specimen. The estimation results of the specimen with 25 % mould coverage and pure resin, manufacturer specification of 40 % and 60 % glass fiber content show, that the relative permittivity increases with the amount of fibers in the specimen (Figure 4). This is due to the fact that the relative permittivity of glass is higher than the resins permittivity, which is around 3.

The increase shows linear behavior, but the standard deviation of the measurement with included fibers indicates stronger variations of the measurement within a glass fiber sample compared to the pure resin. This suggests that the stronger deviations may also be due to fiber orientation and volume concentration. Due to this, the use of SMC parts for radar covers requires a critical evaluation if the process can be controlled in such a way that low local fiber orientation and volume content deviations occur and the components are thus suitable for the use in radar covers.

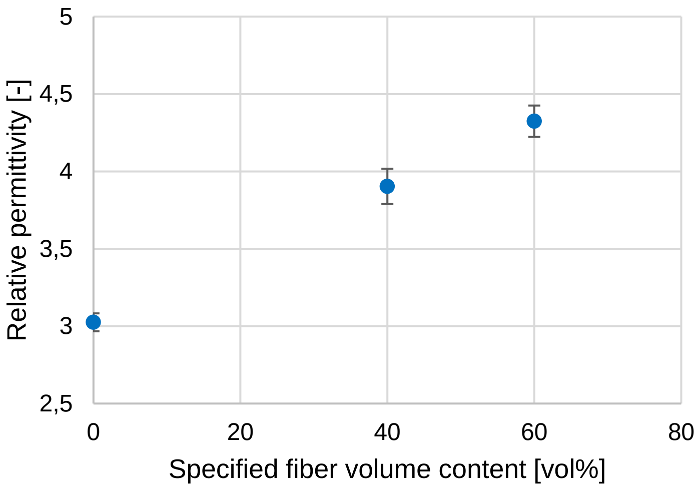

Figure 4: Relative permittivity over manufacturer specification of fiber volume content

However, the measurements, which lead to the results of the limited usability as a material for radar covers, could possibly help to find a fast and non-constructive analyses method for SMC components.

In the following experiments the fiber content was 60 % and the relative permittivity was measured at different positions of the specimen. On these specimen positions the fiber content has been evaluated with a thermogravimetric analysis (Pyrolysis method). The results were deviated in horizontal (perpendicular to the flow direction) and vertical orientation (in flow direction) of the fibers. In the horizontal fiber orientation the deviation to linear behavior are higher compared to the vertical orientation, see Figure 5. Here, the vertical polarization of the test rig could have an influence. The measurement with the lowest fiber volume content indicates is quite similar for the horizontal and vertical orientation, which indicates a random distribution of the fibers at this position.

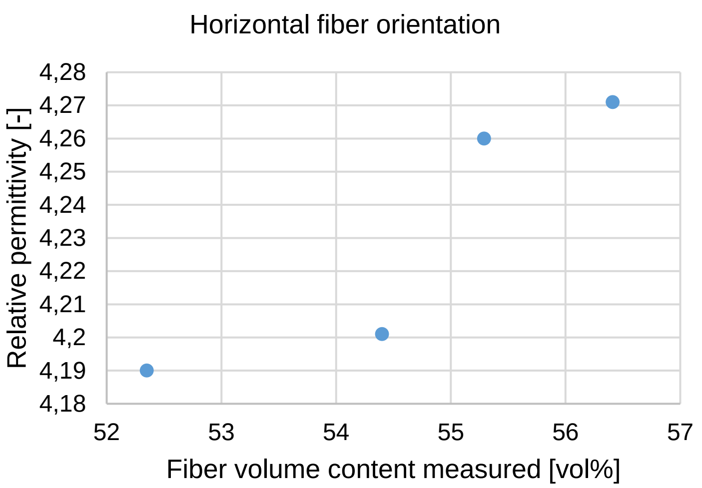

Figure 5: Relative permittivity over of fiber volume content in horizontal fiber orientation

The vertical orientation shows linear behavior, by increasing of the fiber volume content the relative permittivity rises (Figure 6). In general all measurements show that the vertical orientation shows higher permittivities than the horizontal orientation.

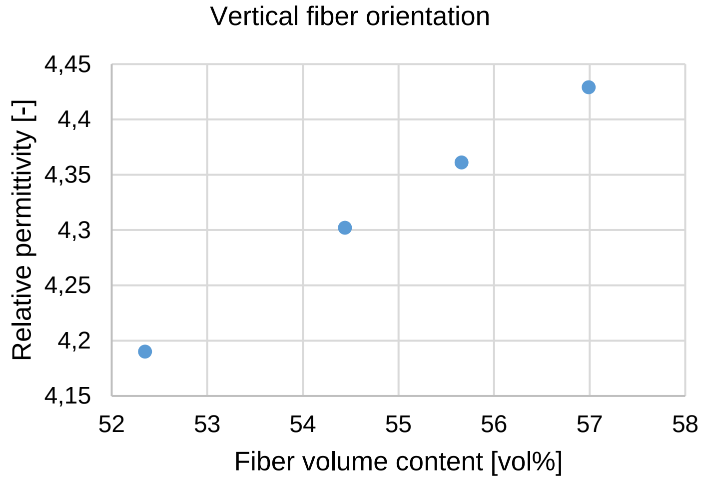

Figure 6: Relative permittivity over of fiber volume content in vertical fiber orientation

For very homogeneous fiber distribution there is no significant difference in permittivity detectable. To increase the comparability of the fiber volume content and the relative permittivity the measurement spot has to be exactly and only on the spot to be examined with the thermogravimetric analysis.

These first results show, that there is a difference between the two orientations of the fibers detectable and the permittivity correlates with the fiber volume content in different parts of the sample. Further experimental analysis has to be performed to elaborate this correlation in more detail.

The next paragraph focuses on the results of the spatially resolved image of the high-frequency reflection of the SMC specimen. In the weld line specimen the area of the weld line can be clearly detected in the reflection measurement, whereas on the surface of the SMC plate no visible defect can be seen (Figure 7). Weld line specimens made of SMC material show a large decrease in strength and therefore have to be detectable.

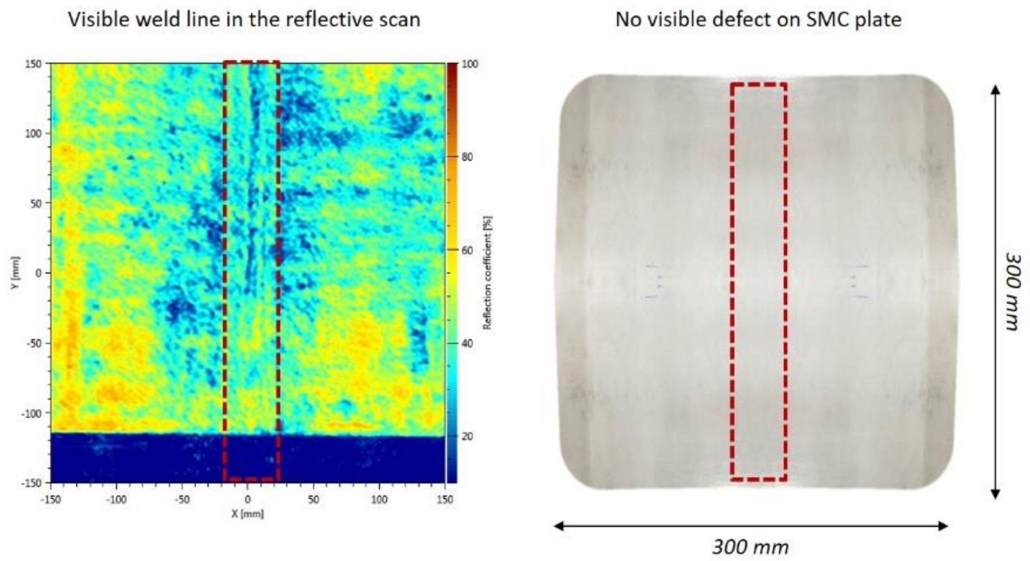

Figure 7: Illustration of the result reflection scan on an SMC plate with an externally not visible defect (weld line).

Another interesting phenomena, which can be seen in the reflection scan, is the accumulation of fibers at the beginning of the mould coverage area and at the end of the specimen, where the impact of the mould on the tool occurs, see Figure 8.

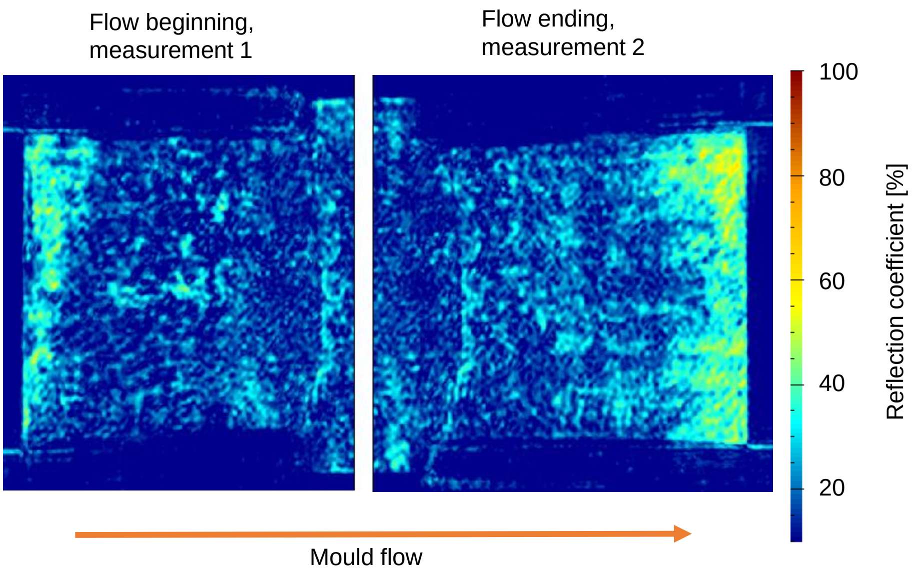

Figure 8: Spatially resolved reflection image of two measurements of a plate at the mould flow beginning and flow endling

The different fiber amount and orientation of an example plate can also be seen in the picture in Figure 9. The accumulation of the fibers occurs at the same position as in the measurement.

Figure 9: Picture of the fiber distribution of a plate with similar production process

Another feature of the spatially resolved reflection measurement is the possibility to record the volume of the reflection, which can be spilt into section of around 1 mm. The sample can therefore be analysed inside of the structure. The measurement from top to bottom, show both surfaces and three measurements in the middle of a weld line specimen, which include the weld line (Figure 10). The area with higher and lower amount of fibers can be seen, due to the different reflections in every slice. With this technology it is possible to see the inside of a probe with different layers within seconds.

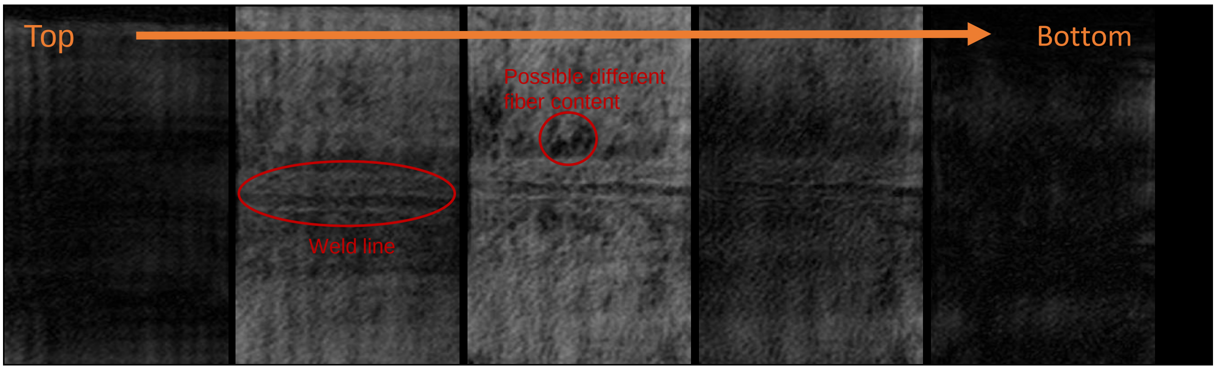

Figure 10: Volume measurement of the reflection from top (left) to the bottom (right) splitted up in layers

These first results show, that it is possible to detect quality issues of the SMC specimen with the spatially resolved reflection measurement. Further experimental analysis has to be performed to elaborate the fiber concentration in correlation to the reflection in more detail. Especially the wall thickness has to be taken into account, since the reflection is highly dependent on this parameter of the specimen.

4 Conclusion

The measurements of the relative permittivity of SMC parts show, that the fiber volume content is linear dependent on the value. Deviations due to the measurement orientation and position indicate that a closer look at the different positions could help to analyse SMC parts regarding their fiber orientation and volume concentration. The first results on this topic show, that there is a difference between the two orientations of the fibers detectable, with in the case of vertical polarization higher relative permittivity of vertical fiber orientation. The relative permittivity also correlates with the fiber volume content, if the results are viewed splitted for the two different orientations. Further experimental analysis has to be performed to elaborate this correlation in more detail and therefore be able to analyse the fiber content and orientation with the non-destructive method of the reflection measurement.

The first results on the spatially resolved reflection measurement show, that it is possible to detect quality issues of an SMC part with such a device. Especially the welding line can be spotted, but also areas with higher or lower fiber content. Further experimental analysis has to be performed to elaborate the fiber concentration in correlation to the reflection of the different layers and the reflection image in more detail. Especially the wall thickness has to be taken into account, since the reflection and other radar parameters are strongly dependent on this parameter of the specimen. It is also possible to look inside different layers of the sample.

These two measurement methods combined could lead to an easy-to-use and fast inline-measurement system, which is in principle already available on the market.

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