NDT&E International 62 (2014) 29–39

Contents lists available at ScienceDirect

NDT&E International

journal homepage: www.elsevier.com/locate/ndteint

Characterization of surface defects on composite sandwich materials based on deflectrometry

E.R. Fotsing*, A. Ross, Edu Ruiz

CCHP, Department of Mechanical Engineering, École Polytechnique de Montréal, PO Box 6079, Station Centre-ville, Montréal, QC, Canada H3C 3A7

ARTICLE INFO

Article history:
Received 18 June 2013
Received in revised form
12 November 2013
Accepted 16 November 2013
Available online 23 November 2013

Keywords:
Glass fibres
CFRP
Surface defects
Deflectometry
NDT

ABSTRACT

This paper presents a new characterization technique to measure and quantify surface defects in composites. During manufacturing of composite sandwich parts, imperfections appear on the skins due to molding parameters such as temperature, pressure and humidity. Recurring imperfections observed on the surface of composites include surface porosities, resin shrinkage and gloss variation. Although several methods to characterize such defects were developed in the past, visual inspection remains widely used in the industry. In this paper, two different types of surface defects often encountered in the composite industry are measured: surface porosities and resin shrinkage. The proposed measurement method uses an optical system based on deflectometry. Unlike other methods, this technique provides real-time mapping of reflected light intensity. It also provides surface curvature variation which is the most relevant criterion for surface appearance analysis. The results further suggest that setting a threshold on a given parameter (e.g. total surface area of porosities per unit area of sample) and using a fully automated procedure would make this approach very efficient for quality control operations of composite parts.

1. Introduction

In a variety of engineering fields, composite materials are rapidly replacing the so-called conventional materials. The specific properties and design flexibility of composites are among the most attractive advantages of these materials. Besides mechanical properties, surface finish of composite parts is among the most important criteria for quality control. Good surface finish improves not only the esthetics of the final structure but also the quality of the part assembly after manufacturing. While several NDT&E techniques [1–4] are available for the detection of damage in highly stressed and fatigue-loaded zones, applications to surface finish characterization of composite materials are limited. Industries such as business airplanes and luxury cars have very high standards regarding surface quality control. However, the perception of surface appearance and quality is highly subjective, and the pass-or-fail decision depends on the techniques and standards used. Industry experts repeatedly debate what standards should be adopted and what levels of defects should be accepted. Subjectivity is also highly dependent on human factors. For these reasons, quality control can fluctuate greatly not only from one industry to the next, but also on the same production. In order to reduce the impact of human factor on quality control, new techniques should produce quantitative data from procedural measurements. Ultimately, surface characterization standards should be implemented. In the composite industry terminology, class A surface corresponds to high quality surface finish. However, no clear and generally accepted definition of class A surface can be found. In the literature, some authors referred to class A surface as a surface with an optical appearance similar to steel panel [5].

Traditionally, surface finish is defined by the degree of waviness and roughness. By passing a stylus tip or a laser over the surface, roughness can be measured and evaluated in terms of the arithmetic average Ra [6–9]. This parameter is broadly used to quantify the quality of machining techniques such as grinding and polishing that are used to improve surface appearance. Waviness is a surface characteristic associated with highly polished or high gloss surfaces. It is usually defined as periodic irregularities with spacing greater than roughness. The wavelength of the waviness is usually ranged between 1 and 10 mm and can be clearly seen by human eyes at a distance between 50 cm and 3 m [10]. Several systems used to evaluate waviness are available. The Daimler Benz surface analyzer mechanically scans the surface to determine the profile. The standard deviation of the measurement with respect to the surface centerline gives the waviness [11]. ALSA (Advanced Laser Surface Analyzer), which is the recent development of the LORIA (Laser Optical Reflected Image Analyzer), uses optical scanning to measure surface quality. Laser lines are directed onto the surface of the sample at high incident angle to form a trace across the surface. The laser reflects on the surface at low angle

* Corresponding author. Tel.: +1 514 340 4711x3140.
E-mail address: edith-roland.fotsing@polymtl.ca (E.R. Fotsing).

0963-8695/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ndteint.2013.11.004

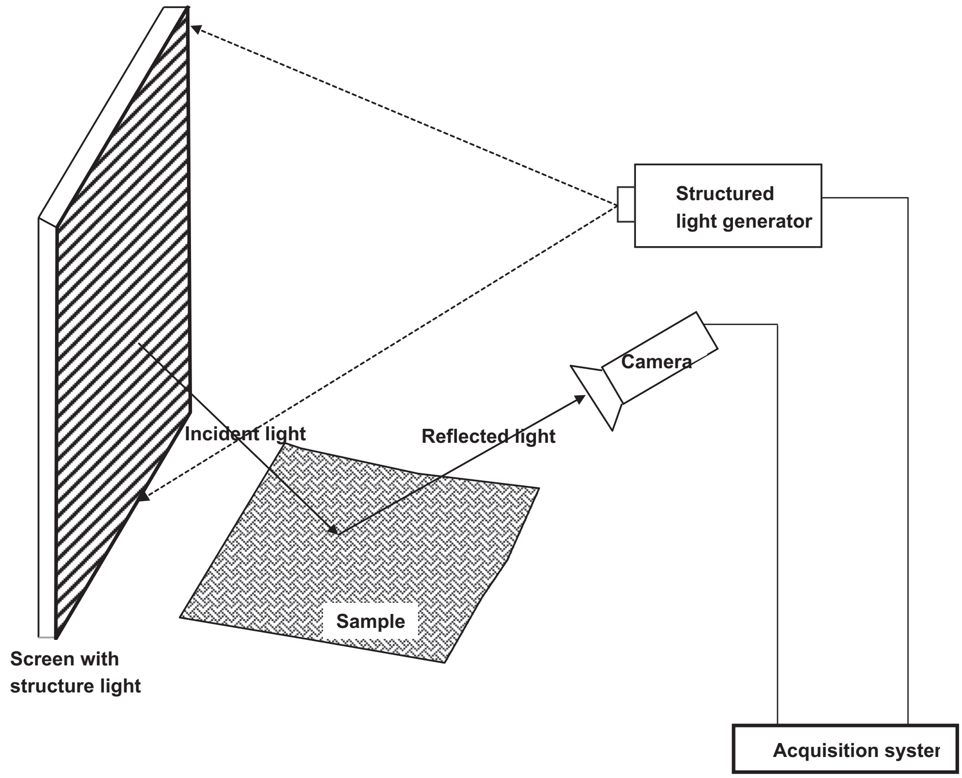

Fig. 1. Schematic view of the Ondulo set-up [27].

and forms an image of the trace on a detection screen. The image is recorded using a high definition camera. Short-range waviness (wavelength less than 3 mm) causes the laser line to become wider, whereas long-range waviness (wavelength greater than 10 mm) leads to a curving of the laser line [11]. The Wavescan-plus from Byk-Gardner works under the same principle as the ALSA. The Diffracto D-Sight [12] is also based on an optical method where a white light projected on the sample is reflected onto a mirror opposite to the light source and reflected back on the sample. The obtained image is recorded with a digital camera and compared with a reference in order to evaluate the shape irregularities [13]. Recently a new system called Ondulo was developed by Visuol Technologies. This system is based on the deflectometry principle in which a structured black and white light is used to measure the local slopes of a deformed structure.

Resin shrinkage [14,15], resin starvation areas [16], porosities [17] and gloss variation are common manufacturing induced surface defects. Such defects in composite materials highly depend on manufacturing parameters including temperature, consolidation pressure and resin viscosity. Due to the presence of fibers, surface finish of composite parts cannot be improved by polishing or grinding, and it depends therefore on the surface finish of the mold. This is valid for Resin Transfer Molding (RTM), Sheet Molding Compound (SMC), hand lay-up, prepreg curing and many other processes. Regardless of the manufacturing method, surface defects must be quantified in an objective manner in order to find optimal manufacturing parameters leading to minimal defects. Optical systems such as ALSA, Wavescan-Plus and Diffracto D-Sight are used to characterize the surface finish of composite materials with a certain degree of success. However, one aspect only of the surface appearance can be characterized using each of these techniques. In addition, the techniques still rely on comparison with a reference sample which does not eliminate the subjectivity of human perception. On the other hand, arithmetic roughness (Ra) measured with a surface profilometer [18,19] drastically increases when the stylus encounters porosity even though the surface surrounding the defect is similar to the reference sample. Moreover, several profiles are needed in order to assess the overall surface topology with this technique. In the case of composites with randomly distributed surface porosities, the density of porosities rather than the Ra is best suited to represent the surface finish of the composite part. The density of porosity is defined as the ratio of the total surface area of porosities in a sample with respect to the total surface of the sample. A means of quickly obtaining the density of surface porosities and local surface deformation is the use of deflectometry [20–22]. In this case, a structured light pattern of periodic white and black fringes is projected on a screen and directed onto the surface of the sample. A high-resolution digital camera is used to record the structured light pattern reflection from the surface. The captured light is phase shifted and a series of images is captured, allowing quantification of the sample's local curvature variation, which is the most relevant criterion for surface appearance analysis. This data can be used afterward to determine whether discontinuities on the surface should be considered as unacceptable defects.

The main purpose of the present study is to provide an objective characterization method for different surface defects encountered in the composite materials industry. The paper deals especially with composite sandwiches used in the aeronautic industry. Two types of surface defects are investigated, namely, resin starvation areas (surface porosities) and local surface deformation due to resin shrinkage. A qualitative analysis using deflectometry based equipment [23] is proposed to define an acceptability threshold for this type of material. Furthermore, quantitative methods to detect and quantify these surface defects are also proposed and discussed.

2. Deflectometry

According to the deflectometry principle, a structured light (black and white fringes) with an initial phase is projected from a