Engineering Fracture Mechanics 108 (2013) 195–208

Contents lists available at SciVerse ScienceDirect

Engineering Fracture Mechanics

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

How to reveal subsurface defects in Kevlar® composite materials after an impact loading using infrared vision and optical NDT techniques?

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A R T I C L E I N F O

Keywords:
Composites
Debonding
Infrared vision
Optical testing
Defects

A B S T R A C T

An integrated system between infrared vision and optical non-destructive testing techniques can be considered a viable, robust and reliable approach for both aerospace manufacturing and in-service inspections. In this paper, infrared vision is applied in different spectral bands on two impacted panels made of aramid–phenolic composite by applying two different methods, respectively: (1) near and short-wave infrared reflectography and transmittography, and (2) mid-wave active infrared thermography. Furthermore, optical methods, namely digital speckle photography and holographic interferometry, are used as well to highlight the damages due to the impacts on the samples. Some techniques provide more straightforward detection capabilities than others for different defect types.

1. Introduction

In the life of a structure, impacts by foreign objects can be expected to occur during manufacturing, service, and maintenance operations. In composite structures, impacts create internal damage that often cannot be detected by visual inspection. This internal damage can cause severe reductions in strength and can grow under load. Therefore, proper measures should be taken in the design process to account for these expected events. Concerns about the effect of impacts on the performance of composite structures have been a limiting factor in the wide spread use of composite materials. For this reasons, the problem of impact has received considerable attention in the literature [1].

Non-destructive testing (NDT) techniques are currently used to verify integrity of structural components in case of special events, and to assess and monitoring quality and effectiveness of repairs.

Infrared vision is an interesting approach that has the advantages of being non-contact, fast, and relatively inexpensive [2]. After the mid-wave infrared (MWIR) thermography (IRT) acquisitions by pulse thermography (PT) configuration, advanced signal processing techniques such as principal component thermography (PCT), pulse phase thermography (PPT), and high order statistics thermography (HOST) can be used in order to improve surface and subsurface damage detection [3].

In the NDT field, near-infrared (NIR) and Short-Wave (SWIR) reflectography and transmittography techniques can be considered a new line of research when applied on semi-transparent composite materials. Relevant publications can be found in

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0013-7944/$ - see front matter
http://dx.doi.org/10.1016/j.engfracmech.2013.02.030

Nomenclature

Acronyms

CCD	charge-coupled device
CMOS	complementary metal–oxide semiconductor
DE	double-exposure
DSP	digital speckle photography
EM	electromagnetic
EOF	empirical orthogonal function
ESP	electronic speckle photography
FFTs	fast Fourier transforms
FPN	fixed pattern noise
HI	holographic interferometry
HOST	high order statistics thermography
IRT	infrared thermography
LED	light emitter diode
MWIR	mid-wave infrared
NDT	non-destructive testing
NETD	noise equivalent temperature difference
NIR	near-infrared
PCA	principal component analysis
PCT	principal component thermography
PIV	particle image velocimetry
PPT	pulse phase thermography
PPTA	poly-*p*-paraphenylene terephthalamite
PT	pulsed thermography
ROI	region of interest
SNR	signal-to-noise ratio
SVD	singular value decomposition
SWIR	short-wave infrared thermography
VLWIR	very long wavelength infrared

Greek letters

λ	wavelength
μ	expectation or mean
σ^2	second central moment of a distribution
ϕ	phase delay
$\Delta\phi$	phase change
Δl	path variation
Δt	sampling interval
A	modulus or amplitude
$E[X]$	expected value
$\boldsymbol{H}$	point in the hologram plane
i	imaginary number
Im	imaginary part of the discrete Fourier transform
k	thermal conductivity
K	absorption coefficient
L_D	optical path length of the light for the object in the deformed state
L_N	optical path length of the light for the object in the normal state
M_I	standardized central moment
n	frequency increment ($n = 0, 1, \ldots, N$)
$\boldsymbol{n}_H$	unit vector – direction of $\boldsymbol{O}_N\boldsymbol{H}$
$\boldsymbol{n}_S$	unit vector – direction of $\boldsymbol{S}\boldsymbol{O}_N$
$\boldsymbol{O}_D$	point of the surface of the object in its deformed state
$\boldsymbol{O}_N$	point of the surface of the object in its normal state
$\lvert\boldsymbol{O}_N\boldsymbol{O}_D\rvert$	displacement
R	reflectance
Re	real part of the discrete Fourier transform
S	scattering coefficient
$\boldsymbol{S}$	point of the light source
T	temperature