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Optics and Lasers in Engineering 44 (2006) 68–79
OPTICS and LASERS in ENGINEERING

Determination of residual stress by use of phase shifting moiré interferometry and hole-drilling method

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Received 1 May 2004; received in revised form 1 January 2005; accepted 1 February 2005
Available online 13 June 2005

Abstract

A phase-shifting moiré interferometry and hole-drilling combined system was developed to determine residual stresses. The relationship between the 2D displacement data of three points around the drilled hole and the residual stresses relieved by hole-drilling was established. The experimental setup consisted of a four-beam moiré interferometer and a computer-controlled hole-drilling system. Two phase shifters controlled by computer were fixed in two of the four optic paths to directly get the displacement data. With special residual stresses calculation software, the phase distributions of the u and v field obtained by moiré interferometry were quickly converted into values of residual stresses. To analyze the accuracy of this experimental system, an aluminum specimen with a blind hole in the center was real-time tensioned in this system. The displacement field obtained by phase shifting moiré interferometry was compared with the finite element method solution. Good agreement was found with respect to each other. As an application, the in-depth residual stresses of a shot-peened aluminum plate were measured by this method, and possible error sources were discussed.

Keywords: Moiré interferometry; Phase shifting; Hole-drilling; Residual stresses

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0143-8166/$ - see front matter
doi:10.1016/j.optlaseng.2005.02.006

1. Introduction

The hole-drilling technique is one of the most commonly used semi-destructive mechanical methods for experimental residual stress analysis. It consists of applying a special strain gage rosette, drilling a hole at the rosette center, measuring the relaxed strains and computing the residual stress field by means of appropriate stress–strain relationships. With the development of the finite element method (FEM), it is possible to measure residual stress distributions in depth [1–4]. However, the utilization of strain gage rosettes presents some practical disadvantages: (i) it requires the hole to be drilled exactly in the center of the rosette in order to avoid sizeable errors; (ii) it only gets the average strain in the range of the length of the gage and thus is inaccuracy to the planar stress gradient.

To overcome these difficulties, the change in displacements around the hole has been measured using coherent optics techniques [5–17]. These techniques have an ability to generate fringe patterns from which displacements can be calculated. Their advantages include faster data collection, elimination of the need for precision drilling, access to smaller regions and information on the displacement field associated with the introduction of the hole. The first attempt of measurement using moiré interferometry was realized by McDonach et al. [5] and then Nicoletto [6]. Afterwards, Antonov [7], Bass et al. [8], Nelson and McCrickerd [9] showed independently the feasibility of utilizing holographic interferometry. Li [10] presented an interferometric strain rosette method instead of the traditional strain rosette. Later, Zhang [11] reported on the ESPI technique for the residual stress determination through blind hole-drilling. More recently, moiré interferometry and incremental hole-drilling method [12–17] was investigated to measure the in-plane and in-depth residual stresses, and made some practical applications in engineering.

The purpose of this paper is to demonstrate the feasibility of a real-time phase shifting moiré interferometry and hole-drilling system that performs automatic data analysis to measure the in-plane displacement fields, and to present an FEM calculation for relating these relieved displacement fields to the magnitude of the residual stresses. In this paper, the displacement fields were calculated through the evaluation of the optical phase distributions. This evaluation was carried out using a real-time equal step phase-shifting method from the recording of four moiré interferograms. The test was performed in an aluminium plate with a blind hole under a uniaxial tensile stress state. The displacement data around the hole obtained by experiment were compared with the FEM simulation. As an implementation, the in-depth residual stresses of shot-peened aluminum plate were studied and the main error sources were discussed.

2. Moiré interferometry and hole-drilling combined method

The theory of moiré interferometry hole-drilling method is based on the conventional hole-drilling method. It consists of applying a grating on the surface of the specimen, drilling a hole incrementally at the desired place, recording the