

Measurements of Residual Stresses in Aluminum Wheels Using the Techniques of XRD, Strain Gages and FEA Simulation - A Comparison

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ABSTRACT

Studying the formation and distribution of residual stress fields will improve the wheel safety operational criteria among other gains. Many engineering specifications, manufacturing procedures, inspection and quality control have begun to require that the residual stress of a particular component to be evaluated. It is known that these residual stress fields could be added to the effects of a system load (tare weight plus occupation of vehicle, traction, braking and torque combined). The mathematical tools for modeling and simulations using finite elements had evolved following the increasing computing power and hardware cost reduction. On the other hand, the experimental testing, offers specific physical component behavior and with the use of statistical tools, it is possible to predict the real behavior of the component when in operation. The experiments undertaken used the X-ray diffraction technique and the drilling method with rosette type strain gages. The experimental results were convergent with similarity to those obtained using FEA simulation over critical region for global and superficial in the principal stresses mode. The relevance of the present study and research on residual stresses meets safety improvements in car's wheel industry.

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INTRODUCTION

This paper is a study of the residual stress in automotive wheels, using XRD and strain gages experimental testing in comparison to simulation analysis using finite element (FEA). The results of residual stress experiments will retro feed FEA simulation and the total load over wheels can be reevaluated to avoid fracture under operation. Although the FEA provides the simulation advantage, it is required experimental testing to verify and validate the simulation (Fig. 1). Usually it is distinguished three types of stress states, according to their size radio [1]. First: macroscopic, high range stresses acting on a macroscopic region covering a large portion of the component. Second: structural micro-stress, located in a wide number of grains and its surroundings. Third: a little portion of a grain, involving the structure at the atomic level [2]. For each type of stress state it is associate one or a combination of methods to get better response from the experiments. The most usual methods are: X-ray and neutron diffraction, blind hole, cut ring, cut by section removing layers. In this paper it is presented the methods of X-ray diffraction and hole drilling to analyses of local

residual stress data. The XRD is considered a nondestructive method for superficial residual stress measurements [3]. When a part or portion below the surface is the interest region, material must be removed and the XRD method becomes destructive. The XRD used method was multiple exposure technique, which it is possible to obtain more precise determination of φ using more than two φ orientations and φ plotting the measured strain values for each φ orientation as function of $\sin^2\varphi$, where the psi (φ) is the angle between specimen surface normal (Ns) and the normal diffracting planes [4]. Applied stress, as an external load, is usually highest at the surface where the failures start over. All experiments were undertaken in residual tension auto-static equilibrium, where the resultant internal forces and moments are zero. It is known that the tensile residual stress can be added vectorially to a static load by the principle of superposition (Eq. 1) [5].

$$\sigma_n = \sigma_A + \sigma_r \quad (1)$$

where, σ_n , σ_A and σ_r is the resultant stress, external stress and residual stress, respectively.



The hole drilling method is an in situ technique and involves the removal of material under tension by making a blind hole depth, always smaller than the diameter of the drill (0.4 D) in the center of the rosette strain gauge and measuring the deformation occurred in the region adjacent to the hole [6]. The method by itself induces a residual stress and needs an initial calibration. An advantage of using the rosette with central hole is a better sampling of the main deformation.

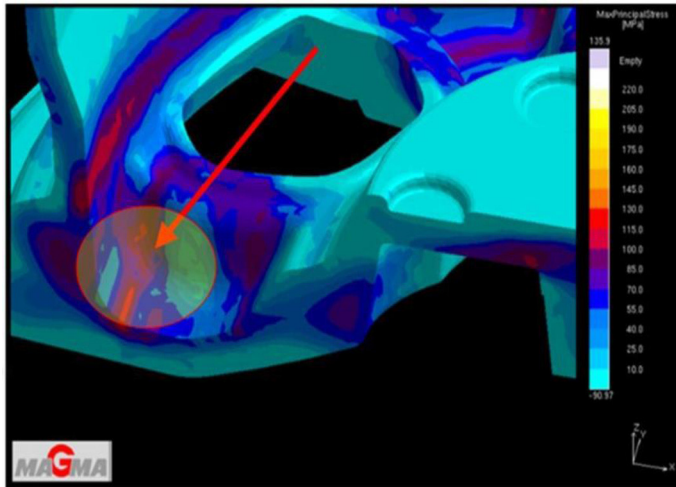


Figure 1. Finite element analysis - FEA simulation of residual stresses in light alloy wheel. The indicated arrow and area show a critical stress area of the wheel named spoke.

EXPERIMENTAL METHODS

XRD Method

The measured stress was only the normal stresses. The experimental procedures for the XRD took data over five groups of wheel parts. There was shear stress present also, but it was not directly measured by XRD. In this work it was applied an X-ray beam over four small part of straight area of the wheel. These parts were selected from previous critical area pointed by using software simulation FEA. After XRD measurements over those selected area, the area was prepared hole drilling method of measurement. That is, the gages were applied over the same area (Fig. 2) that was used to XRD measurements. The main difference between XRD residual stress measurement and gages measurements is that the gages sense a portion of deformation (strain) under its footprint.

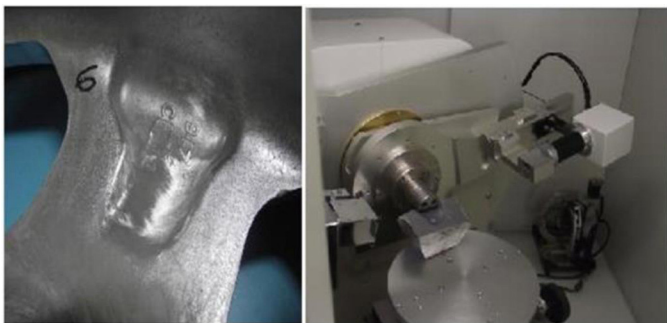


Figure 2. XRD experimental method set up. The image shows a portion of the spoke of an aluminum silicon wheel inside de X-ray diffractometer.

Hole Drilling Method

The hole drilling method is widely used to measure average residual stress. There are three gages in one device for hole drilling method. This method is destructive because a 0.3 mm in deep drilling is required. The technique use tension relief to measured deformation under the gages. In general, tension relief takes place larger and deeper than the XRD method. In this case to obtain the residual stress, it is used the Hooke's law, where the deformation value (ϵ) is multiplied by the aluminum Young's modulus (E) (Eq. 2).

$$\sigma = \epsilon E \quad (2)$$

In the classical system of hole drilling method (blind hole) rosette type strain gauges is used (ASTM E 837) that have a center mark locator for drilling (Fig. 3).

To acquire residual stress with hole drilling method, three gages with specific geometric are bundled in one rosette device. The equipment used to acquire data from the gages was setup to integral method stress. The integral calculus was used in the analysis of strain gauge experiments and the show the data collected and respective graphics response is shown in Fig. 4. The equipment used to acquire data was ADS-2164 and software to analyze was AqDados 7.2 Lynx.



Figure 3. Hole drilling method experimental sequence of trial. The images show the rosette and the arrow points to the center mark.

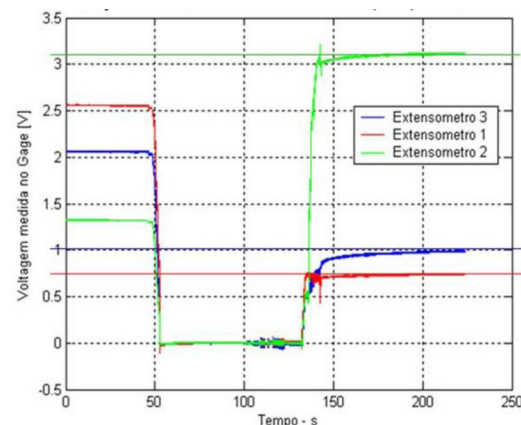


Figure 4. Method of blind hole - graphics response from software analysis.