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# Residual Stresses Measurements Using Strain Gages - Aluminum Wheels

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**Abstract:** Many engineering specifications, manufacturing procedures, inspection and quality control have begun to require that the residual stress of a particular component be evaluated. This is becoming as commonplace as the demands on the mechanical properties. In the country there are few research laboratories qualified to perform these tests and also found a worrying lack of skilled labor. Studying the formation and distribution of residual stress fields will improve the operational criteria of wheel safety, among other gains. It is known that these residual stress fields could be added to the effects of system load (tare weight plus occupation of vehicle traction, braking and torque combined). The results obtained used drilling method and rosette type strain gages, are convergent with similarity to those obtained using FEA simulation over critical region for global and superficial in principal stresses mode. The relevance of the present study and research on residual stresses meets safety improvements in car's wheel industry.

## Introduction

This study is aimed to promote experimental measuring of residual stresses in automotive wheels and compares the results with values reported by systems such as FEA (finite element analysis) computer simulation. These residual stresses specific simulations are used together to scale the mechanical stress on the wheel when subjected to loads in operation [4]. In general, residual stress evaluate by the strain gage hole drilling method is affected by several errors or sources of inaccuracy, some of which have to be limited by improving procedural quality while others can be corrected by proper presentation of the results [1,2].

The use of computer programs (CAD/CAE/CAM) has been increasingly used in industry. One major benefit is that one can use data and information stored in projects carried out previously and may be edited for obtaining new projects [3]. The mass of data generated makes it possible also the feedback of the same systems, increasing its database. The software application of mathematical modeling and FEA, allow the use of the cumulative potential of stored data, possibility of being reused, production units head-to-series and especially reducing time and cost in production. This dynamic and effectiveness achieved in the development phase of any product by the application of computational tools promotes significant time reduction in the phases of design [1,5]. The use of means of laboratory tests, experiments and field tests possible to verify the similarities between physical behavior of prototype models, implemented in the database, adjustments physical and mechanical parameters as well as new features allowing the use of FEA to design and simulate tests on virtual prototypes that need not necessarily be produced. Although the main purpose of the simulations make it possible to infer about the actual behavior of a prototype in operation. However, it is required experimental validation of similarity and equivalence between the simulation and physical behavior (operational) prototypes [5]. The information generated by these innovations will provide gage reliability giving the final design by FEA guarantees the successful production of any product line.

## Materials and methods

The hole drilling method is widely used to measure average residual stress. In the classical system of blind hole a rosette type strain gages is used (ASTM E 837-01) that have a center mark locator for drilling and measuring the deformation occurred in the region adjacent to the hole [2]. A comparison study among the blind hole drilling testing, sectioning and X-ray diffraction in comparison to simulation analysis using FEA, of the residual stress in automotive wheels was undertaken. Although the FEA provides the simulation advantage and it is very helpfully for projects and factory improvement, some experimental procedures are required to verify and validate the simulation [3,6].

The objective of this work was the study of procedures for analyzing residual stress fields produced in automotive wheels. These experimental tests were made specifically in aluminum alloy wheels (AlSi) for use in light vehicles (cars and pickup's) taken from the production line of a wheel manufacturer [4,5]. The FEA with the input parameters used, indicate the possibility of crack nucleation in specific regions (spoke) identified as critical to the wheel but in its entirety. The simulation module of residual stresses (Fig. 1) from MAGMASoft® shows values from 100 to 145 MPa in the spoke region.

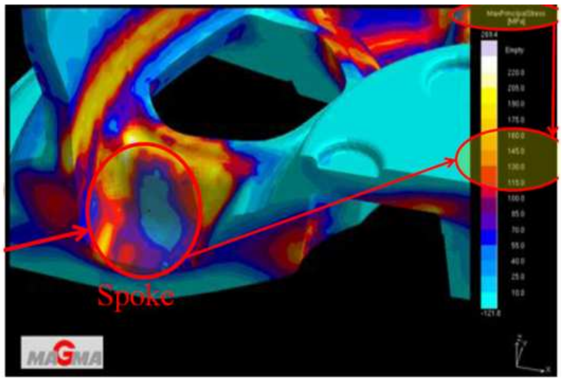


Fig. 1. FEA simulation of the residual stresses.

This work are intended to demonstrate a relationship between the information provided by simulations on FEA and experimental analysis of the critical points by using resistive strain gages (Fig. 2) to collect data on existing strains following the use of relaxation techniques [4]. Three types of stress states are distinguished, according to their size radii. First: macroscopic, covering a wide number of grains. Second: structural micro-stress, located in a grain and its surroundings. Third: molecular, involving the structure at the atomic level [1,2].

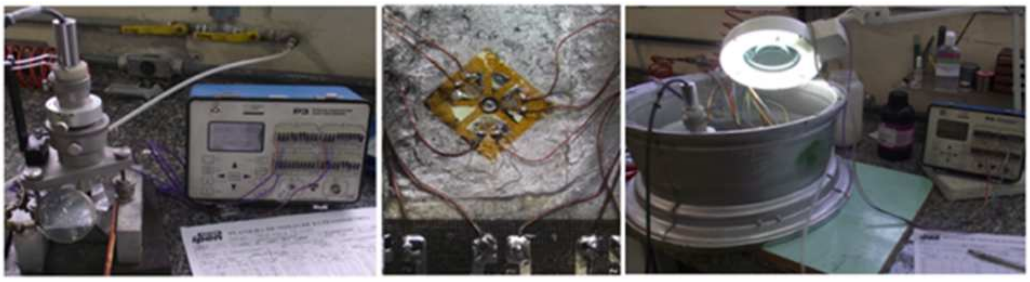

Fig. 2. Sequence of the experimental strain gage with blind hole methods

The output data of the FEA numerical modeling receive contributions of laboratory tests, making possible replenish the database, adjusting the input parameters for further simulations. When making adjustments to input data from the FEA software, simulations get closer to physical reality, and simulation processes of the components approach the behavior of these components in actual operation. So FEA simulations can predict critical points of cyclic fatigue. FEA software design and provide detailed information for production, optimize product development phase, reducing spending on individual calculations procedures, preparation and testing of several prototypes, reducing the need for destructive tests on prototypes [3]. For more complete analysis in this work the blind hole method were evaluated and compared with X-ray diffraction and sectioning (Fig. 3) to get a better response from the experiments.

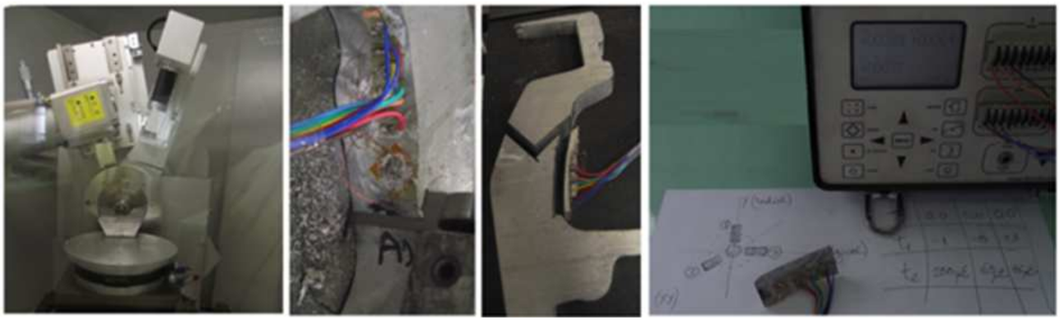

Fig. 3. Experimental X-ray diffraction and section compared with blind hole methods

**Results**

The Fig. 4, shows data of experiment analysis of micro-deformations under grain size area it was used X-ray diffraction and the stress average value from -40 MPa to -187 MPa. The software HDrill from Micro-Measurements® was used to calculate the values of stresses in each strain gage direction according to the drill depth from surface. For the acquired data and after the relaxation steps of the tension caused by the sectioning, the Hooke's law of elasticity was used to calculate the residual stresses [5].

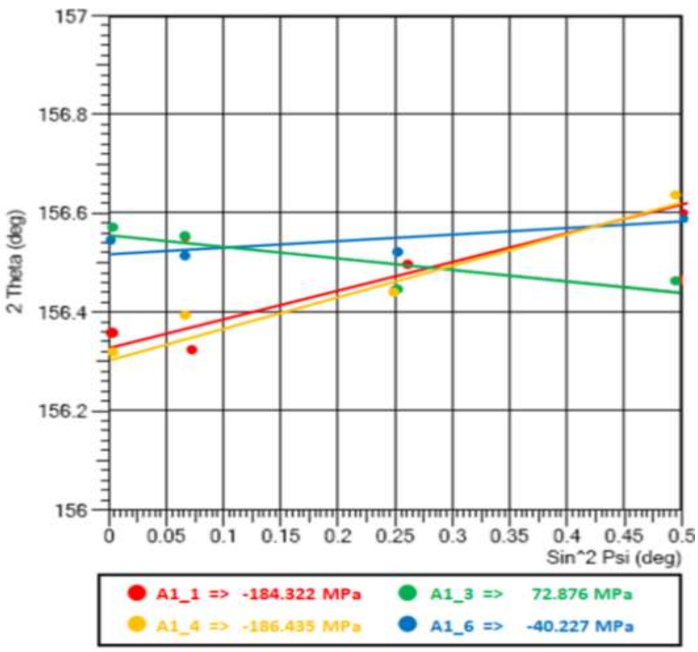


Fig. 4. Results for X-ray and blind hole by HDrill

The Fig. 5, show experimental rosette and hole drilling data analysis with HDrill software, it was found a strain average value from -300 MPa to 100 MPa. As show the data collected the behavior of stress changes with depth, geometry and range of analysis. A maximum peak of -300 MPa could be observed as a result of plasticity effect due to the drill action. Could be observed two peaks of residual stress in 0.16 mm and 0.20 mm that consequently show a limitation of the calculus procedure.

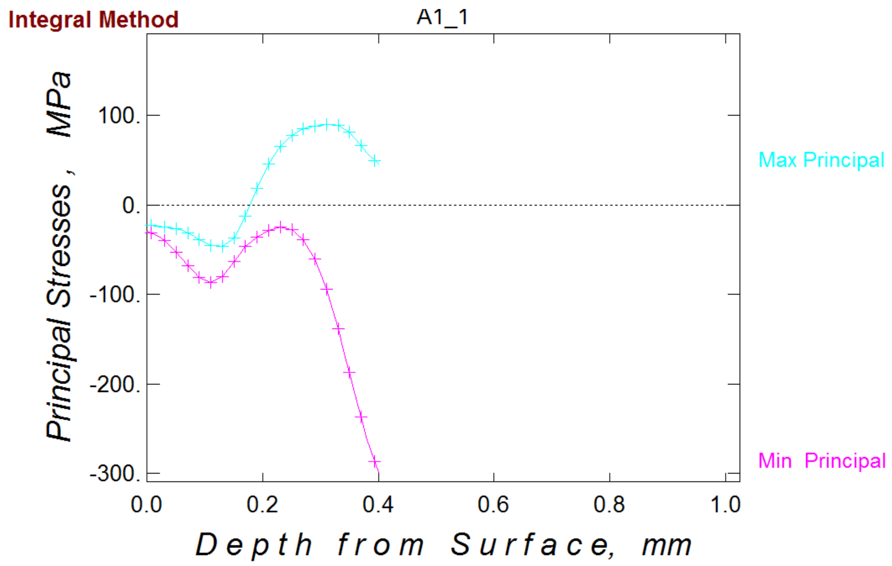


Fig. 5. Method of blind hole - principal stresses response by Hdrill

The Fig. 6, show the graphic with plasticity effect corrected for previous set of data showed in Fig. 5 for residual stress in depth. These are caused by plastic deformations, thermal and mechanical action during drilling process. This effect of plasticity affects output data strongly and should be corrected. The function of plasticity factor used with von Mises criteria in MathLab® procedure to rebuild data. Data from HDrill was reworked to be self-consistent by plasticity factor [7].

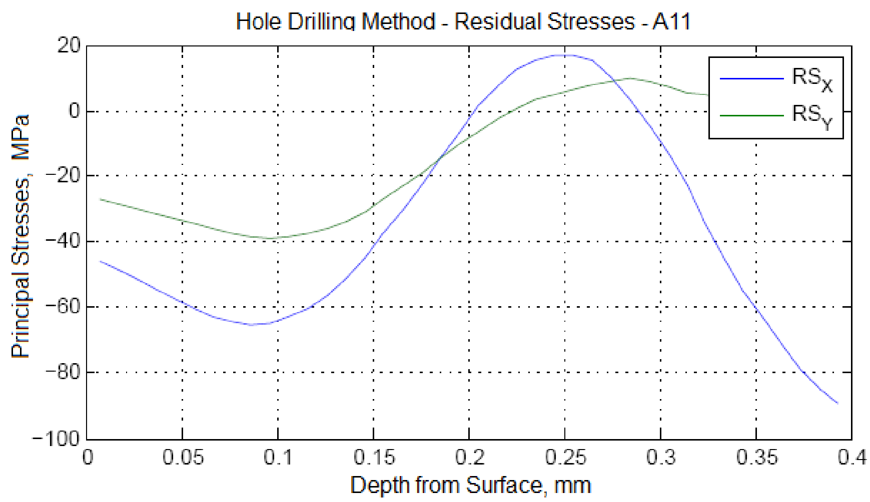


Fig. 6. Principal stresses with effect of plasticity corrected

The graphic on Fig. 7 shows some values of residual stresses $\sigma_r$ ($\sigma_r \leq$ -500 MPa) for X and Y uniform that over then stresses yield of 172 MPa for aluminum. The blind hole method inserts some discontinuous regions and micro plasticity deformation and could give some data error.

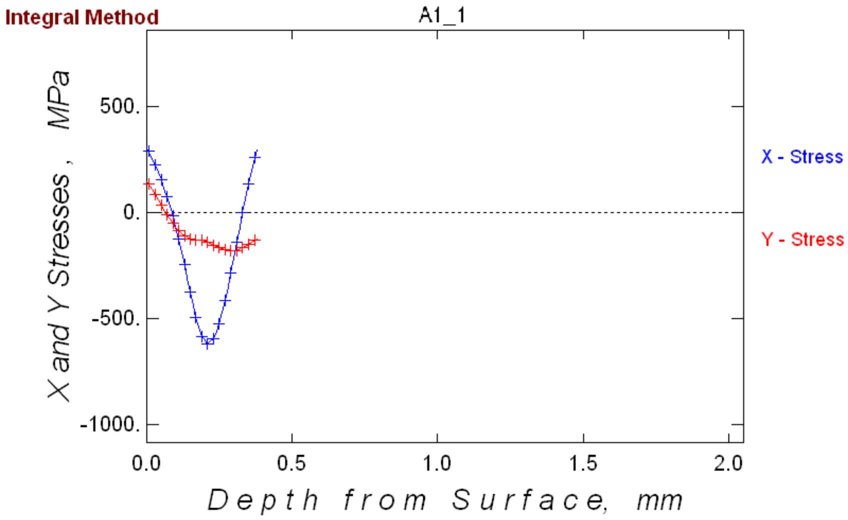


Fig. 7. Residual stress X and Y response by HDrill

The function of plasticity was used to correct the data set of previous graphic. The Fig. 8, shows the new peak values where -145 MPa to X residual stress of 550 MPa and 80 MPa to Y residual stress of 250 MPa.

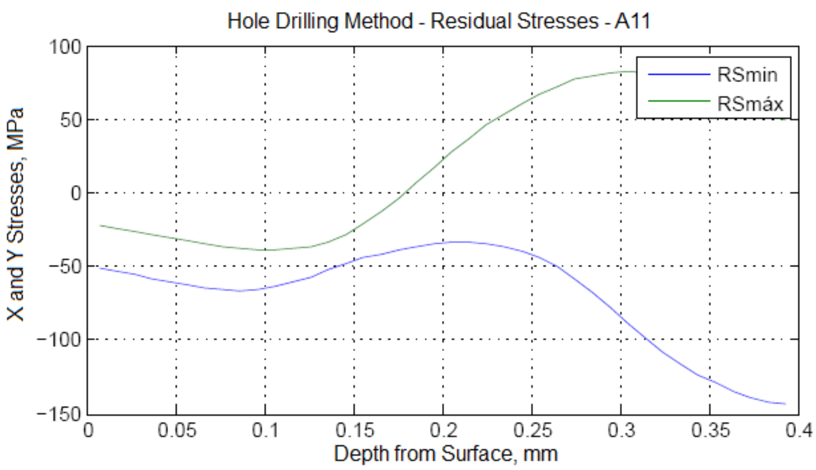


Fig. 8. Residual stress X and Y with effect of plasticity corrected

In the present work, it was develop measurement techniques to reap relevant data on residual stresses in the components industry in order to promote changes in manufacturing components for the automotive industry. The alternatives currently available instrumentation for research on residual stresses are the X-ray diffraction, neutron diffraction, gamma rays, but these processes are difficult to work because they require a major technological apparatus which prevents the collection of data "in loco". Available alternatives for field measurements are limited to passive components that allow the component to be engaged and the indirect method of physical, allow record data of physical power which may be within a restricted range of values to be linearly related the micro-deformations (strain) experienced by the component. Expected to gain an understanding of the behavior of the processes of casting and modeling using aluminum alloys for the manufacture of automotive components, through adjustments to infer the limits of the variables of process so that this knowledge can be used to add additional information to the software FEA allowing considerable gains in productivity and economy.

**Conclusions**

Calculations of the local stresses with values of micro-deformations in each strain gage direction (X-axial, Y-tang, XY-rad), using the hole drilling methods of reliving, found values of the principal stresses of compression or tension, around 500 MPa.

Although the analysis of experimental data combined with the sectioning method indicate a local residual stresses behavior of 25.6 MPa. For entire wheel, with local relive, the strain behavior of compression or tension was around 120 με and it was calculated 200 MPa for residual stresses average.

The data from experiments is convergent with similarity to those obtained using FEA simulation over critical region for global and superficial in principal stresses mode. Experimental tests and other physical parameters must be always computed for validation of data obtained through simulations.

Finally, the data obtained in experimental trials, processed with HDrill in integral theory and corrected by plasticity function had average from 80 to 145 MPa, that is convergent to the FEA simulation and can be used as feedback providing reliability and accuracies information for projects.

**References**

[1] C.C. Perry and H.R. Lissner: *The Strain Gage Primer*. New York - USA: McGraw-Hill Book, 1962.

[2] K. Holffmann: *An Introduction to Measurements using Strain Gages*. Darmstadt - Germany: Hottinger Baldwin Messtechnick GmbH, 1989.

[3] A.E. Assan: *Finite Elements Methods - First Steps*. Campinas - Brazil: Ed. Unicamp, 2003. (In Portuguese)

[4] M.A. Colosio, J.C. Santos: *Influence of residual stresses in aluminum wheel design*. SAE International, São Paulo - Brazil, October 2008. ISSN 2008-36-0139.

[5] C.G. Schön: *Materials Mechanics*. São Paulo - Brazil: EPUSP, 2010. (In Portuguese)

[6] P.E.V. Miranda, J.A. Rodrigues: *Gas in metals and Alloys - Fundamentals and Engineering Applications*. Rio de Janeiro: EDC Edit. Didática e Científica, 1994. (In Portuguese)

[7] M. Beghini, I. Bertini and C.A. Santus: *procedure for evaluating high residual stresses using the blind hole drilling method, including the effect of plasticity*. - Universitá di Pisa - Pisa - Italy, 2010.

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