

Mapping Residual Stress Distributions in Advanced High Strength Steel Automotive Body Panels and Structural Components

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ABSTRACT

Automobile manufacturers have experienced increasing consumer and regulatory pressure to improve fuel efficiency and crashworthiness while simultaneously decreasing overall vehicle body weight. As such, the use of advanced high strength steels (AHSS) in body panels and other structural elements is becoming more and more prevalent because these advanced materials present an economical and elegant solution to the problem. To ensure the quality and safety of AHSS components, residual stress (RS) specifications (among others) have been introduced with the intent to minimize failures experienced both in the field and during production. Moreover, when welding processes are applied to AHSS components, the localized loss of ductility in combination with tensile RS can result in localized cracking, distortion, and/or failures. Spot checks at critical locations (often selected using either modeling methods and by experience) are currently being performed however, the highest RS present in the component may be overlooked in some cases. To achieve a more thorough understanding of the range and distribution of potentially harmful RS in AHSS components, large areas can be characterized using RS mapping techniques. This paper will present several examples of RS maps collected on various geometries on AHSS automotive body panels and structural elements demonstrating the variation and range of RS present.

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INTRODUCTION

Advanced High Strength Steels (AHSS) are commonly used for structural components in automobiles. With environmental and safety concerns rising over recent years, AHSS offers several advantages. Firstly, AHSS are stronger than more traditional materials, improving the crashworthiness of vehicles, making them safer for passengers. Secondly, much stronger than low alloy sheet metal components, AHSS components can be made thinner thereby allowing vehicles to be lighter and able to achieve better fuel efficiency, which is good for the environment.

As with many automotive components, special considerations must be taken with regards to engineering specifications. Residual stress (RS) specifications recently introduced for AHSS components must therefore be observed. By monitoring and managing RS it is possible to minimize failures, such as cracking, in both production and in

the field. Critical locations are currently being spot checked for RS in several AHSS components. These locations are typically selected using modeling methods and by experience, but it is unknown if these locations give a true representation of the stresses present within the entire component. It is possible that the areas with the highest, lowest or most relevant RS are being overlooked. These potentially harmful stresses are more likely to be found and characterized via the use of RS mapping techniques. Performing a RS map over a large area can produce much more useful data which can, in turn, be used to make cost effective production decisions.

The X-Ray Diffraction (XRD) technique for measuring RS is an ideal method when mapping critical areas. XRD is used in many industries, such as automotive, aerospace, and power generation, to measure RS on components susceptible to stress related failures. The XRD technique performs a RS measurement at a specific location, as small as 0.5 mm in diameter to as large as 2mm × 5mm. This allows for very



detailed stress maps to be generated without averaging results over large areas and capturing the inherent surface RS gradients present.

Several RS maps generated using XRD were collected at different areas and geometries on various AHSS automotive structural components to demonstrate the variation and range of RS present.

RESIDUAL STRESS MEASUREMENTS USING THE X-RAY DIFFRACTION TECHNIQUE

The x-ray diffraction technique uses the distance between crystallographic planes, i.e. d-spacing, as a strain gage. This method can only be applied to crystalline, polycrystalline and semi-crystalline materials [1]. When the material is in tension, the d-spacing increases and when the material is in compression, the d-spacing decreases. The presence of residual stresses in the material produces a shift in the x-ray diffraction peak angular position that is directly measured by the detector [2].

For a known x-ray wavelength λ and n equal to unity, the diffraction angle 2θ is measured experimentally and the d-spacing is then calculated using Bragg's law:

$$n\lambda = 2d \sin \theta \quad (1)$$

where λ is the wavelength of the radiation.

Once the d-spacing is measured for unstressed (d_0) and stressed (d) conditions, the strain is calculated using the following relationship:

$$\varepsilon = (d - d_0)/d_0 \quad (2)$$

For the $\sin^2 \psi$ method where a number of d-spacings are measured, stresses are calculated from an equation derived from Hooke's law for isotropic, homogeneous, fine grain materials:

$$\varepsilon_{\phi\psi} = \frac{1}{2} S_2 (\sigma_{\phi} - \sigma_{33}) \sin^2 \psi + \frac{1}{2} S_2 \sigma_{33} - S_1 (\sigma_{11} + \sigma_{22} + \sigma_{33}) + \frac{1}{2} S_2 \tau_{\phi} \sin 2\psi \quad (3)$$

where:

$\frac{1}{2} S_2$ and S_1 are the x-ray elastic parameters of the material.

σ_{ϕ} is the stress in the direction of the measurements.

ψ is the angle subtended by the bisector of the incident and diffracted beam and the surface normal.

$\varepsilon_{\phi\psi}$ is the strain at a given ψ tilt.

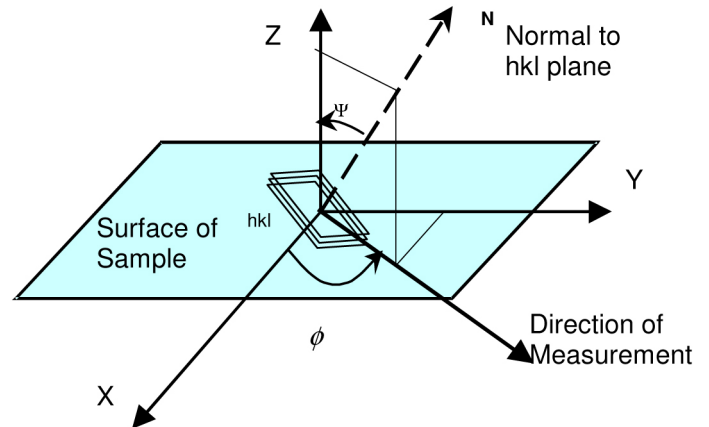


Figure 1. Definition of the axis and the direction of measurement

RS DISTRIBUTION MAPS

Sample 1

A RS map of an AHSS body panel in a region of interest (see Figure 2) was performed to ascertain if a gradient was present. A sample of 165 measurements, performed over a region of 30 mm in the transverse direction and 70 mm in the longitudinal direction, are included in Figure 3.

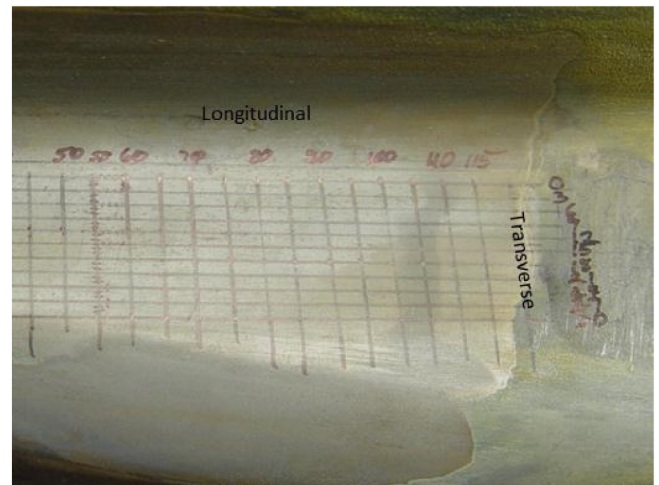


Figure 2. Location of RS map on AHSS body panel.