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BASIC CONSIDERATIONS IN THE USE OF THE 3MA SYSTEM FOR THE ASSESSMENT OF AL-SI COATED PRESS HARDENED STEELS

Philip Meilland[1], Raisa Grigorieva, Pascal Drillet
ArcelorMittal Maizières Research
Maizières-lès-Metz, France

ABSTRACT

IzfP's 3MA system is a system widely used for evaluating properties of automotive parts formed with PHS (Press Hardened Steels). However, from the satisfying original situation with uncoated steel, the performance of the 3MA has degraded when parts began to be produced with Al-Si coated PHS. After a brief description of the inter-diffusion layer which appears during the thermal cycle of PHS part forming at the steel/coating interface, this paper focuses on its impact on the 3MA measurements. Discussions are supported by measurements on samples as well as a simple modelling of the impact of this diffusional layer on the 3MA outputs.

Keywords: Electromagnetism, Non-Destructive Evaluation, Al-Si Press Hardened Steels.

NOMENCLATURE

PHS	Press Hardened Steel
µm	micrometer
Al-Si	Aluminium-Silicon
SEM	Scanning Electronic Microscope
T	Tesla
A/m	Ampère/m
MPa	MegaPascal
° C	Celsius degree
Hz, kHz	Hertz, kiloHertz
ε	epsilon

1. INTRODUCTION

Press Hardened Steels have since over a decade brought in considerable improvements in decreasing the weight of the body-in-white in the automotive industry. For the first uncoated parts the 3MA system brought in quickly accurate assessments of the formed part's mechanical properties, allowing stampers customers to quickly control the quality and stability of their process regarding the as-quenched mechanical properties. In this frame, ArcelorMittal has developed an aluminized boron steel (Usibor® 1500 Al-Si), for direct hot stamping applications [1]. This Al-Si pre-coated solution initially proposed to prevent from scaling and decarburization during the austenitization step gives also a very good protection against corrosion, particularly in terms of perforating corrosion [2]. During the austenitization, the Al-Si coating transforms completely by inter-diffusion and solidification reactions [3], which define the final microstructure and particularly the top layer responsible for the in-use properties (like painting adhesion and spot weldability). The control of the process window is then a key point for the use of such pre-coated solutions. The interfacial layer thickness is the best indicator to ensure these final properties and control the maximum time inside the oven, but its thickness is usually determined after a destructive analysis on the final part (Cross Section Micrography). Customers are looking for a non-destructive method on-line to measure this interfacial layer thickness, for which IzfP have already carried out investigations [4]. Figure 1 displays a typical micrography in which the diffusional layer separating the bulk material and the external coating is easy to identify.

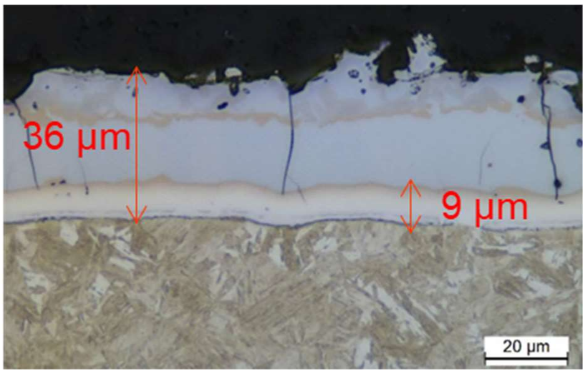


FIGURE 1: MICROGRAPHY OF AN AS-COATED PHS AFTER 8 MIN DWELLING AT 900 °C

[1] Contact author: philip.meilland@arcelormittal.com

2. MATERIALS AND METHODS

2.1 Sample preparation

To examine the effect of the ferritic inter-diffusion layer, several samples from a 1.5 mm thick Usibor® 1500 with an AlSi coating of 150g/m^2 (AS 150) were prepared with different dwelling times and temperatures, and SEM observations allowed determining the thicknesses of the total coating and the inter-diffusion layer, ranging from 1 to 30 µm.

2.2 Recall on 3MA Principles

The 3MA system, developed by IzfP [5], supported by exhaustive modelling [6-8], relies on the differences in magnetic properties of steels, with first-order trends related to mechanical properties. It is designed to allow a single-side contact measurement to produce a magnetic excitation of a material nearby. As shown in fig. 2, it includes:

- a U-shaped yoke, with windings to create a low-frequency excitation field and induce a magnetic flux in a significant thickness of the material;
- a Hall effect sensor for the control of the excitation;
- a secondary winding to read the flux (and the magnetic reaction of the steel)
- a high frequency eddy-current pick-up coil for a reading of the material's magnetic reaction, in a limited thickness at the material's surface

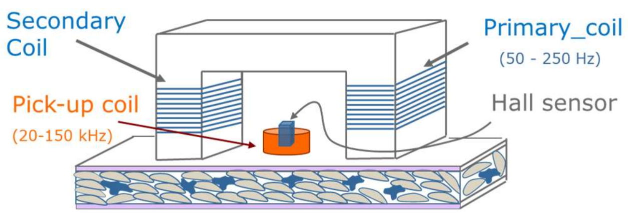


FIGURE 2: SCHEMATICS OF THE 3MA PROBE LAYOUT

The focus of this study was to assess the behavior of the 3MA outputs considered most relevant when building regression models to assess product properties:

- the coercive field Hco derived from Harmonics Analysis, which relates to bulk material substrate properties
- the coercive field Hcu derived from Incremental Permeability, which has a sensitivity to surface layer variations.

In the latter (incremental permeability) mode, the voltage related to the impedance of an eddy-current pick-up coil during the hysteresis cycle is plotted as a function of the excitation field H. The curve displayed usually appears as camel humps, with the maximum position related to the coercive field (fig. 3).

Measurements were performed with a large size measurement head, set with 80 Hz and 70 kHz respectively as excitation and pick-up coil frequencies. Only the effect of the diffusional layer thickness is presented and discussed, as there is little variation of the total thickness.

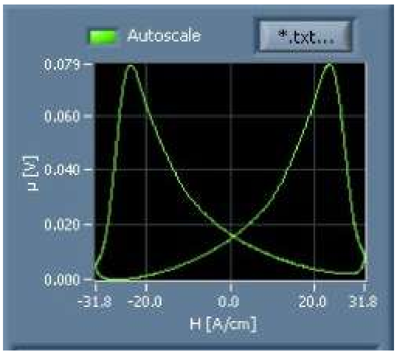


FIGURE 3: INCREMENTAL PERMEABILITY DISPLAY OF THE 3MA USER INTERFACE. THE OUTPOUT OF THE PICK-UP COIL (IN µV) IS RELATED TO THE APPERENT LOCAL PERMABILITY dB/dH, WHICH VARIES DURING THE APPLICATION OF THE EXCITATION FIELD.

3. RESULTS AND DISCUSSION

Figure 4 displays the overall results, leading to immediate conclusions:

- the effect of the layer thickness is the same for measurements for the 900°C and 950°C heat treated samples;
- the coercive field Hco shows insignificant variations and can be considered independent of the inter-diffusion layer thickness;
- the coercive field Hcu decreases as the inter-diffusion layer thickness increases, with a probable slope change (higher drop) when the thickness is around 15 µm.

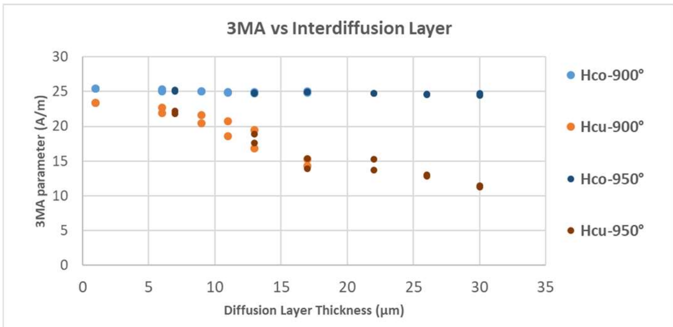
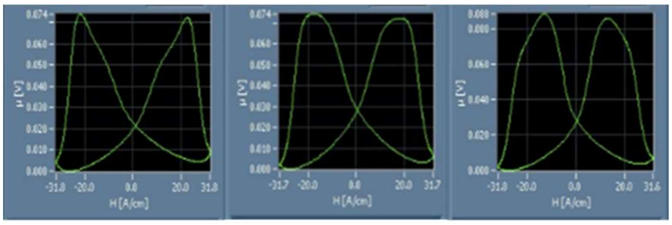


FIGURE 4: VARIATIONS OF THE Hco AND Hcu PARAMETERS WITH THE INTER-DIFFUSION LAYER THICKNESS

The experimental behavior of Hcu is S shaped, with a high decrease rate for inter-diffusion layer thicknesses around 13 µm. To confirm this, examining the shape of the incremental permeability curves leads to the observation of a double peak in each of the camel-humps, in relation with the thickness of the inter-diffusion layer.



6 µm 13 µm 17 µm

FIGURE 5: IMPACT OF THE INTER-DIFFUSION LAYER THICKNESS ON THE SHAPE OF THE INCREMENTAL PERMABILITY CURVES, WITH A SHOULDER AND PEAK STRUCTURE

A phenomenological approach to describe the shoulder and peak shape proposes to use the sum of 2 double Gaussian-shaped contributions:

- with a low Hcu for the ferritic diffusional layer
- with a high Hcu for the bulk material

With appropriate coefficients, sound approximations of the incremental permeability curves in fig. 5 are obtained. For each of the situations, the value of Hcu is computed, allowing to derive the negative S-shaped curve in fig. 4, with the sharper decrease around 13 µm. Such considerations lead to the need of a non-linear interpolator instead of a purely multilinear approach which is typically proposed up to now. Also, as noise is always present in actual measurements, the S-shape will induce apparent scatter increase for values around 13 µm in fig. 4.

A final observation is that for thicknesses above 17 µm, the ferritic layer is predominant and will screen out the contribution of the bulk material, therefore degrading the 3MA's performance in predicting end user-properties.

4. CONCLUSION

This paper reviewed a specific case of a non-linear behavior of the 3MA's significant outputs, with an in-depth analysis leading on the relevance of Hcu for predicting end-user properties. When the thickness of the inter-diffusion layer doesn't exceed 10 µm, using Hcu is most likely relevant. For thicknesses above 17 µm, Hcu doesn't reflect the bulk material properties which is screened by the ferritic layer. In the intermediate range, Hcu is subject to a high uncertainty, and cannot be reliably used to determine material properties.

These observations are currently fed back to IzfP, to allow improving the interface by:

- Identifying validity domains for the different models
- Including warnings in the event of measurements obviously outside such validity domains.

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