Abstract

In quality assurance nondestructive eddy-current techniques are widely used. A system consisting of an eddy-current online measurement system, using a Foerster Magnatest D device, and suitable mathematical models is introduced to acquire the mechanical material properties during production in the press shop of a car manufacturer. The eddy-current data were measured online before the blank cutting process, the mechanical material properties immediately calculated and displayed. The achieved accuracy was within +/-2% for tensile strength and +/-4% for breaking elongation. Each blank was marked to allow a clear assignment of the calculated values. Four complete coils were measured to show the variations of the mechanical properties. Several samples from each coil were taken to perform a tensile test, and good accordance between calculated values and the tensile test was found.

Keywords: eddy current, regression, mechanical properties, quality assurance

1. Introduction

The increasing unification of technical standards and the wide model range in the automotive industry lead to customers differentiating the products by their outer shape rather than their technical specifications. Especially the body shell of the car, as the visible and emotionally perceived reference, is subject to highly dynamic changes due to short design cycles. [1] Body shell parts are becoming increasingly complex but they nevertheless need to be produced in the press shop with high shape accuracy and no rejections at low cost.

Figure 1. Influences on quality in the press shop
There are several factors that influence the quality in the press shop, as shown in Figure 1. All of these factors can vary, some at low rates, e.g. the tooling or humidity, some fast, like the mechanical properties of the raw material. The examined material is DC06 with a thickness of 0.8mm and a zinc coating on both sides. According to the specifications, the mechanical properties of this material can vary in a wide range: \( R_{p0.2} = 120 \) to \( 180 \) MPa, \( R_m = 270 \) to \( 330 \) MPa, \( A_{80} > 41\% \).

Here is also a strong demand for a 100% control of used materials and parts in the automotive industry. Therefore systems are required to compensate variations of the factors that affect the quality of the produced parts, which can be integrated in production.

![Microstructure](image)

Figure 2. Influence of the material microstructure

As it is well known, the microstructure has an impact on the mechanical as well as the electromagnetic material properties (Figure 2) and a correlation between these properties exists. [2] [3] Eddy-current measurements are a common technique in nondestructive testing to detect material defects or sometimes to sort materials. In using a multifrequency eddy current device, a fingerprint of the inspected material is obtained, which combined with appropriate mathematical algorithms allows to train models to calculate the mechanical properties of a material. Thus, the eddy current system with its high sensitivity to changes in the material microstructure and its short measurement duration is predestined for this application. The calculation of mechanical properties with high accuracy for round stock from eddy current data was shown in [4]. In this contribution we focus on the online acquisition of eddy current data in production with high sensitivity and reproducibility and the calculation of the mechanical material properties with high accuracy. The results can be used in the press shop to adapt the press settings and in the tool shop to create a sufficient database for sensitivity analysis in draw die development.

2. The eddy current measurement system

The system has to fulfill four main functions: move the eddy current probe up and down, measure the eddy current values for each blank, mark each blank to assure
correct identification after cutting, and calculate the mechanical properties. The setup used for these measurements consists of a PC, the eddy current device, the test coil, an inkjet printer, a linear drive and the electronics to communicate with the press and the drive (Figure 3). The adjustment of the eddy current device settings (amplification and attenuation) for the used combination of material, coil and frequencies is done automatically the Magnatest D using one sample of the material for calibrating the system.

The eddy current device used is a Magnatest D device from Institut Dr. Förster. It is a multifrequency device, working in serial mode which also allows the evaluation of the signal harmonics. Frequencies used were 1024Hz, 512Hz, 256Hz, 128Hz, 64Hz, 32Hz and 16Hz including the evaluation of the 3rd, 5th and for the lower frequencies also the 7th harmonic. In total one set of eddy current data consists of 48 scalar values.
The test probe is a custom made absolute probe, made of two single surface probes that are connected in differential mode. This configuration enables also the measurement of anisotropic material properties by changing the direction of the coil with respect to the rolling direction.

Due to the fact, that the probe has to be placed directly on the inspected material without a gap between probe and material to maximize sensitivity and reproducibility, the sheet metal must not move during the eddy current measurement. The linear drive with the attached probe was mounted on a crossbeam in front of the feeder unit and the subsequent cutting process, where the sheet movement is discontinued (Figure 4). As soon as the sheet metal stops, the probe is moved down and pressed on the sheet. The measurement takes place at the same time as the cutting process and afterwards the probe moves upwards and the sheet metal starts moving again. An inkjet printer was used to automatically mark the sheet metal with a number to identify the blanks when taken from the pack at the end of the cutting press.

3. Training of the mathematical models

To calculate the mechanical properties i.e. yield strength $R_{p0.2}$, tensile strength $Rm$, uniform elongation $A_{el}$ and breaking elongation ($l_0 = 80\text{mm}$) $A_{80}$, appropriate mathematical models are necessary. Because an explicit formulation of the relationship between the electromagnetic and the mechanical materials properties shown in Figure 2 is not feasible, another representation has to be found. With modern multidimensional regression algorithms it is possible to reproduce this correlation and calculate the mechanical properties with high accuracy.

These models have to be trained in advance with data measured under the same conditions as in the effective measurement environment, and for each target value a separate model must be generated.
Experience has shown the minimum amount of data required for training of the models are 100 samples from 10 different batches taken from normal production. After elimination of incomplete measurements and outliers 103 pairs of eddy current data and mechanical values were available. These data were divided into two groups, training data with 50 samples for training of the models and test data with 53 samples for validation. It is often recommended [5] to reserve 20 – 30% of the samples for validation, but a larger group is more significant and in this specific case more training data do not result in a better mathematical model.

Due to logistic reasons, the measurement of the eddy current training data took place in the laboratory. Therefore it was necessary to ensure the conditions in laboratory were as close as possible to the conditions in the production line. The linear drive with the attached eddy current probe was mounted on a special measurement desk to allow normal operation as in production, except the printer, which was not needed in laboratory.

The achieved accuracies for the test data are +/-2.5% for Rp0.2, +/-2% for Rm +/-4.5% for Ag1 and +/-4% for A80. The results for Rm are shown in Figure 5 and Figure 6.

4. Online measurements

After training of the mathematical models, the system was installed in the blank cutting press and four complete coils were measured with one measurement for each blank. The duration of one eddy current measurement including calculation of the mechanical properties is 0.58 seconds; the complete cycle including the coil movement takes 0.76 seconds. If, due to some reason, the measurement takes longer than 0.8 seconds it is aborted and the probe lifted of the sheet to prevent damage of the coil since the cutting press and the feeder cannot be stopped immediately.
When the system was tested the first time in production environment, comparative measurements were made with three specimens that were measured in the laboratory before. These measurements showed an offset of the eddy current values due to changes in measurement conditions, which was compensated in the software. The behavior of yield strength $R_{p0.2}$ and tensile strength $R_m$ for one coil is shown in Figure 7.

5. Results

During data acquisition in production from each coil at least 6 blanks were gathered to perform tensile tests. The values calculated online from the eddy current data then were compared with the tensile test results.
In Figure 8 and Figure 9 these data are shown for \( Rp_{0.2} \) and \( R_m \). The results for \( R_m \) are slightly better, as it could be expected from experience with the test data, but the overall correlation is very good. The accuracy of the measurement system strongly depends on the accuracy of the training data. The eddy current data should also be acquired in the production line to minimize errors arising through changes in the measurement conditions. The acquisition of the target values is also of big importance and has to be done thoroughly.

![Figure 9. Calculated values vs. tensile test for tensile strength](image)

6. Conclusions and outlook

The material properties vary along one coil in a range which is inside the specifications but can nevertheless have a significant effect on the deep drawing process. The accuracy of the introduced system is already sufficient to acquire data that can be used in the press shop to check whether or not the material meets the requirements for process capability or to adjust the press settings to achieve less scrap. Also, when installed in the press shop, a sufficient database for sensitivity analysis in the tool shop for draw die development can be created, which was not available until now.

Future work will be concentrated in connecting Forming Limit Curves (FLC’s) to the eddy current data as this is a more significant measure in sheet metal forming. This will allow an even better interpretation of the material properties and will link them to the numerical simulation of forming processes.

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References