COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów
Publishing House AKAPIT
Vol. 15, 2015, No. 1

MEASUREMENT OF RESIDUAL STRESSES IN HOT-ROLLED STEEL SHEETS FOR LASER CUTTING

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Abstract

Due to the specific nature of this process, the sheet metal designated for laser cutting must have appropriate chemical composition, structure, and low level of residual stresses. A key role in understanding the causes of the formation of residual stresses and in their control play various computer programs, targeted at this particular problem. One of the most important input data to such a programme is the distribution of residual stresses occurring in the material at different stages of the production process.

The most recognized method of measuring residual stress is the X-ray method $\sin^2\psi$, expensive and selective due to the measurement time. This method can be replaced with cheaper and faster, but less accurate and requires calibration method magnetic Barkhausen noise technique

The purpose of this study was to compare the results of stress measurements taken by the X-ray $\sin^2\psi$ method with the results obtained by magnetic Barkhausen noise technique.

Key words: residual stress measurement, hot-rolled steel sheets, laser cutting

1. INTRODUCTION

High efficiency of the laser cutting process has rapidly increased the use of this method in recent years (Manohar, 2006). Due to the specific nature of this process, the sheet metal designated for laser cutting must have appropriate chemical composition, structure, and low level of residual stresses.

Previous experience gained in the development of laser cutting methods proves that in this process the state of the material is of primary importance (Totten et al., 2002). Studies show that the sheet metal behaviour during cutting process depends on factors such as the parameters of the steelmaking process, chemical composition of steel, and the type of applied thermo-plastic treatment. Properly adapted to the method of laser cutting, these factors help us obtain the material with special properties dedicated to this method. Their effect is noticeable especially when high cutting speeds are used during cutting of thick sections, in the punching operation, or when the quality of laser beam drops (clogging of lens and nozzles). Even if the sheet intended for laser cutting has a high uniformity of chemical composition, structure and mechanical properties, it still must meet two basic conditions for the proper run of the cutting process, namely, it should have (Andersen, 2000):

- very low level of residual stresses (even slight twisting of the sheet changes the focal point and angle of incidence, and this, in turn, changes the

ISSN 1641-8581

beam power at the point of contact with the processed material),
- adequate surface quality and uniformity of physicochemical properties (phenomena occurring on the surface are very important for the edge quality).

Achieving a low and stable level of residual stresses in the sheets is possible through the use of appropriate cooling conditions, checking the strip dimensions and using appropriate temper rolling at the end of the manufacturing process.

A key role in understanding the causes of the formation of residual stresses and in their control play various computer programs, targeted at this particular problem. A disadvantage of these programmes, however, is the difficulty in their adaptation to the technological process. Therefore, the aim of the scientist is to develop a dedicated software which would enable simulation of the development of microstructure and residual stresses to predict the final structure and mechanical properties in advanced hot rolling process of sheet metal. This will help control the level of stress in the sheets, significantly increasing their quality parameters. One of the most important input data to such a programme is the distribution of residual stresses occurring in the material at different stages of the production process.

The measurement of residual stresses is not a typical test method due to some difficulties in the interpretation of results and the specific type of apparatus used for these studies. Additionally, previous studies carried out on samples cut out from larger items using typical diffractometers would not reflect the correct state of stress in the material. Among numerous methods used for the measurement of residual stress, the X-ray $\sin^2\Psi$ method is the most recognised (Kocańda et al., 1990; Lech-Grega & Kłyszewski, 1991; Lech-Grega, 2003; Krason et al., 2005; Jurcius et al., 2010). Therefore, the development of test apparatus is moving towards the possibility of measurements taken on large items. An apparatus of this type is the industrial, mobile X-ray diffractometer made by PROTO Manufacturing Ltd.Windsor, Ontario, Canada. Owing to this apparatus it will be possible to determine by the same method the state of stress in both laboratory samples and in the entire sheet. The results obtained by this method are, however, still expensive and selective. Therefore, this study compares the results of stress measurements by the X-ray technique with the results of the stress measurements using magnetic Barkhausen noise technique. This is faster and less expensive method to use because of the price of equipment, but it requires a complicated calibration and interpretation of the results obtained. Another key limitation is the fact that it can be applied only to ferromagnetic materials.

The purpose of this study was to compare the results of stress measurements taken by the X-ray $\sin^2\psi$ method with the results obtained by magnetic Barkhausen noise technique.

2. APPARATUS

For the X-ray stress measurements, an X-ray diffractometer made by PROTO Manufacturing Ltd. (figure 1) was used. Both the measurement and the calculation method were in accordance with the SAE J84a and ASTM E915 standards. The apparatus is a portable X-ray diffractometer, fully computerised, used only for the measurement of residual stress and retained austenite content. All the measurement parameters of x-ray apparatus and tested material are shown in table 1.

Stress measurements using magnetic Barkhausen noise were taken with the STRESSCAN 500C apparatus, whose operation is based on the Barkhausen effect (figure 2). Tests included measurement of the value of the MP parameter. The higher is the value of this parameter, the higher (more positive) are the stresses. The data on the stress level were derived from the examination of layers with different thicknesses of 0.02 mm, 0.07 mm, and approx. 0.2 mm.

Table 1. *Measurement parameters of x-ray apparatus and tested material.*

Parameter	Value applied
Voltage	20 kV
Tube current	4 mA
X-ray tube applied	Cr
Length of radiation λ_{Cr}	2.103, Å
Mirror planes	Fe 211
Measured angular range 2θ	145° - 165°
Size of the X-ray beam incident on the sample	5x1 mm
Tested material	ferritic steel
Bragg angle in unstressed material $2\theta_o$	156,41°
Young's modulus	$21\cdot10^3$, kG/mm^2
Poisson's ratio	0.28
X-ray penetration depth	≈10 µm

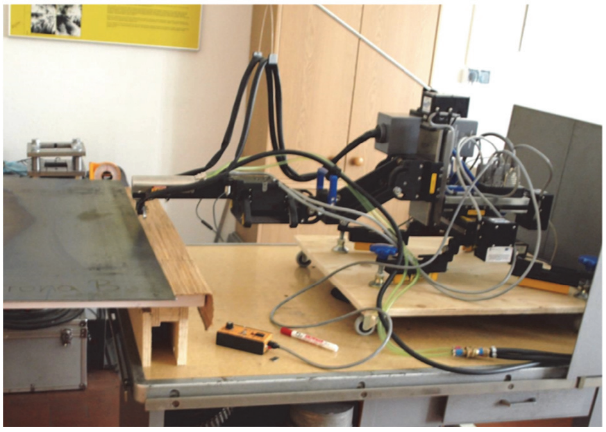


Fig. 1. *PROTO iXRD X-ray diffractometer during the measurement of stress in sheet metal.*

Fig. 2. *STRESSCAN 500C apparatus for the stress measurement by magnetic Barkhausen noise method.*

a)

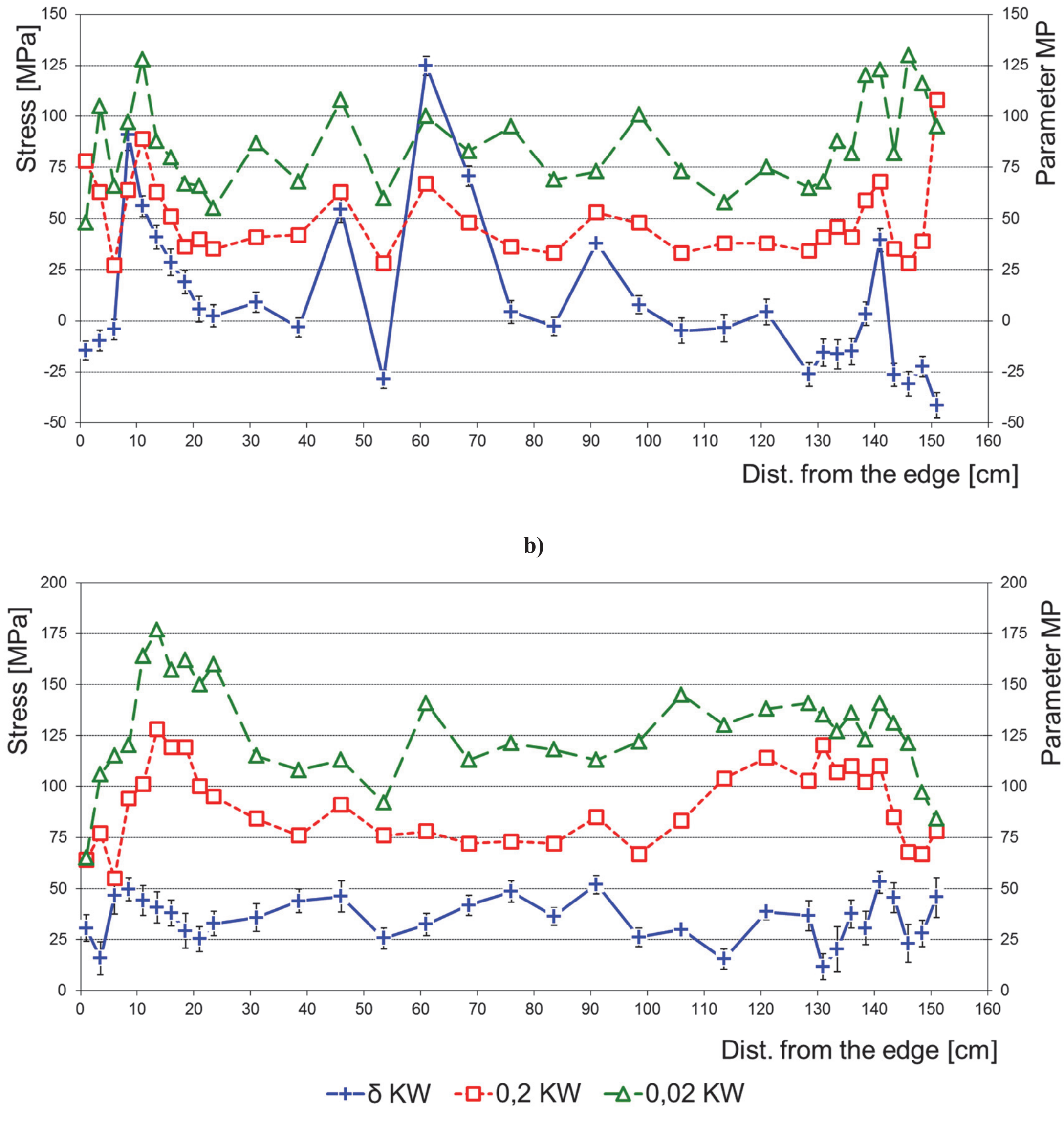


Fig. 3. *The results of stress measurements taken in the rolling direction in sample of the N375900 strip, side A, prior to (a) and after (b) straightening, σKW-measurements by X-ray method, 0.2 and 0.02- measurements by magnetic method in layers of 0.2 and 0.02 mm thickness.*

3. TEST MATERIALS AND RESULTS

Stress measurements were carried out on sample sheets of SA31steel cut out from the strips prior to and after straightening. The study involved samples taken from two strips designated as N375900 and N375904 with the thickness of 4mm and 3mm, respectively. Each of the strips was 1500 mm wide. Samples were collected from the strips at a distance of approximately 15m from the beginning of the strip prior to and after straightening. Stresses were measured on the entire width of the strip on both sides in the direction of rolling.

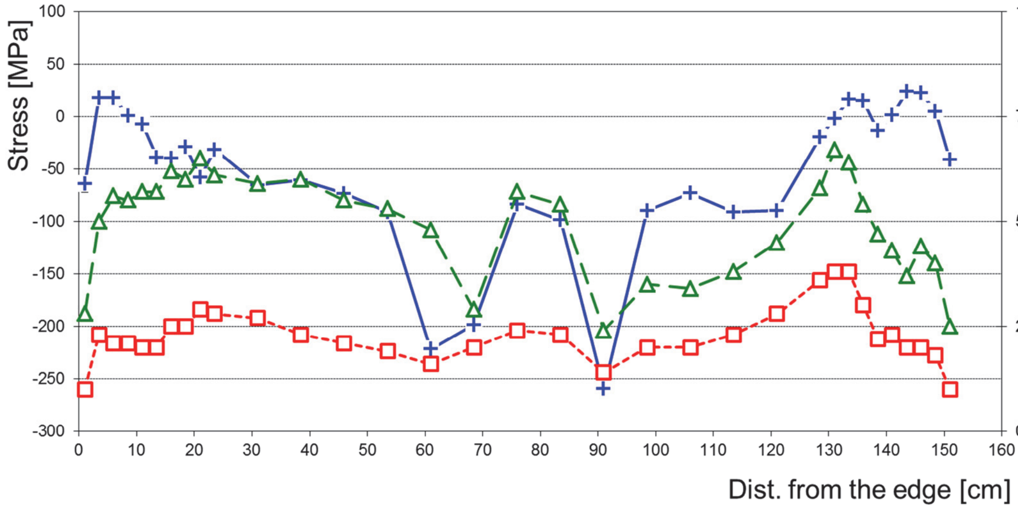
The test results are shown in figures 3 – 6.

4. SUMMARY

Studies have shown that straightening reduced the level of residual stresses in the examined material in the rolling direction and caused homogenisation of their distribution across the width of the strip.

The results of stress measurements by magnetic Barkhausen noise technique expressed as an MP parameter and by the X-ray $\sin^2\psi$ method show a very similar nature of changes across the width of the strip (figures 3a-b, 4a, 5a-b and 6a), which indicates the correctness of the used test methods.

a)



b)

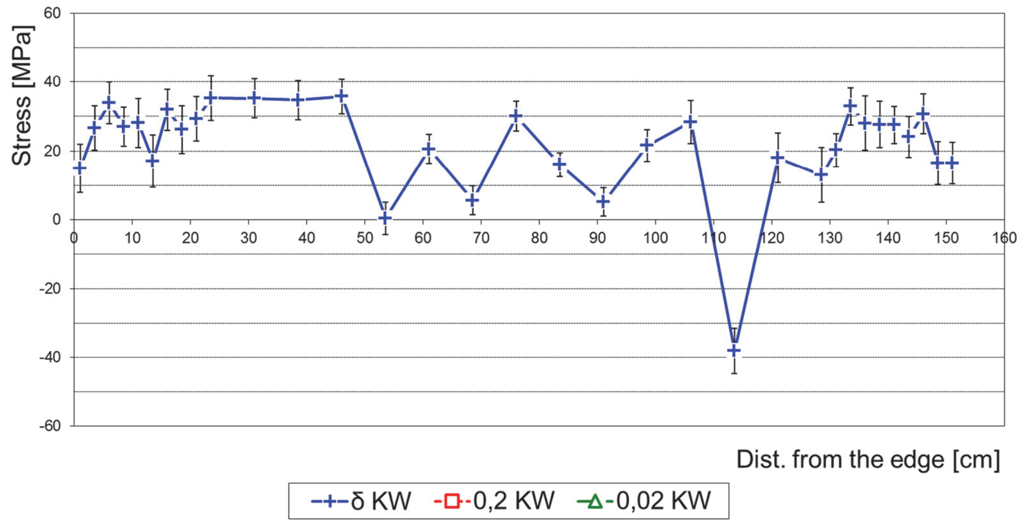
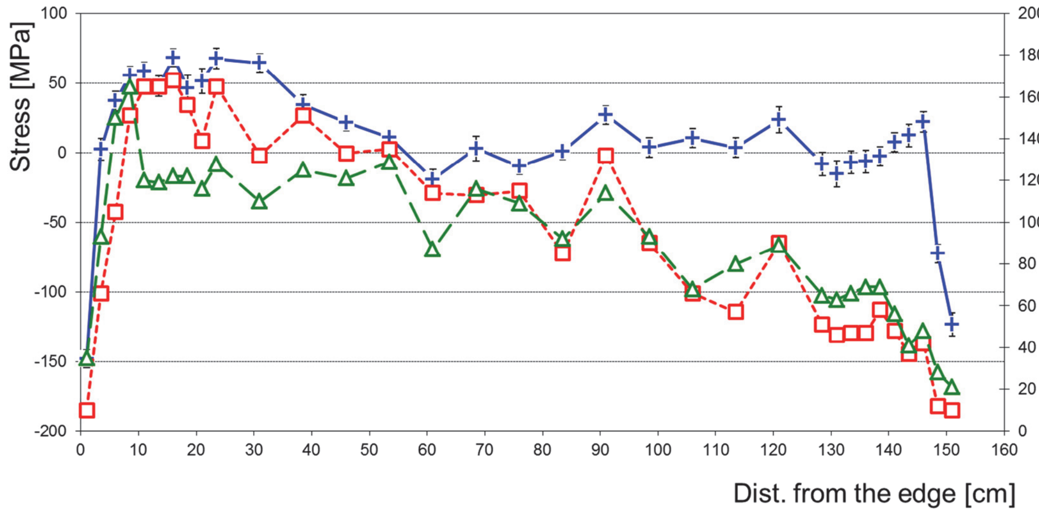


Fig. 4. *The results of stress measurements taken in the rolling direction in sample of the N375900 strip, side B, prior to (a) and after (b) straightening, σKW-measurements by X-ray method, 0.2 and 0.02- measurements by magnetic method in layers of 0.2 and 0.02 mm thickness.*

This means that when the magnetic method cannot be calibrated for the tested material, it is possible to calibrate it through the X-ray method. Then, the magnetic method can be used for routine monitoring under industrial conditions, as a cheaper and faster means of control than the X-ray method.

a)



b)

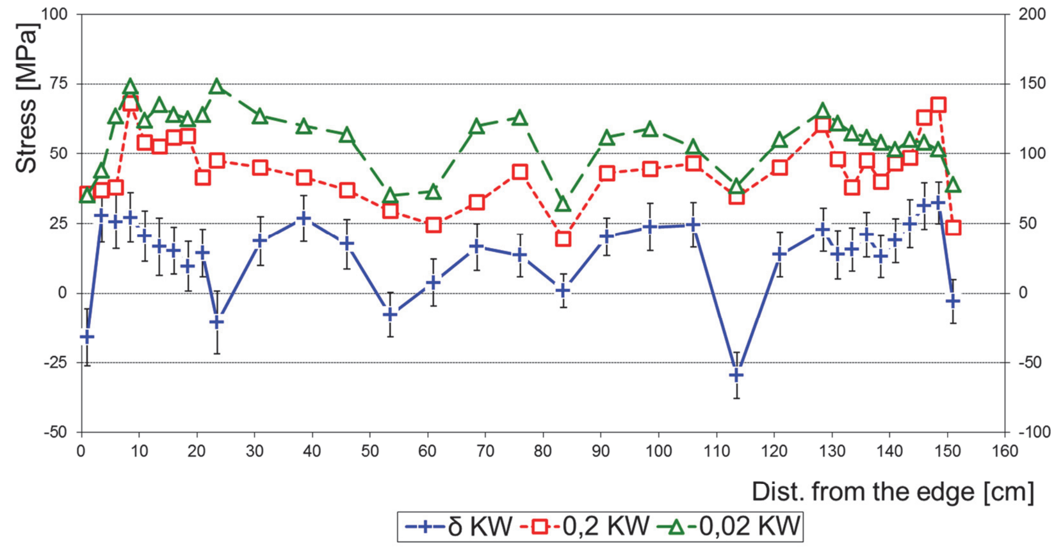


Fig. 5. *The results of stress measurements taken in the rolling direction in sample of the N375904 strip, side A, prior to (a) and after (b) straightening, σKW-measurements by X-ray method, 0.2 and 0.02- measurements by magnetic method in layers of 0.2 and 0.02 mm thickness.*

a)

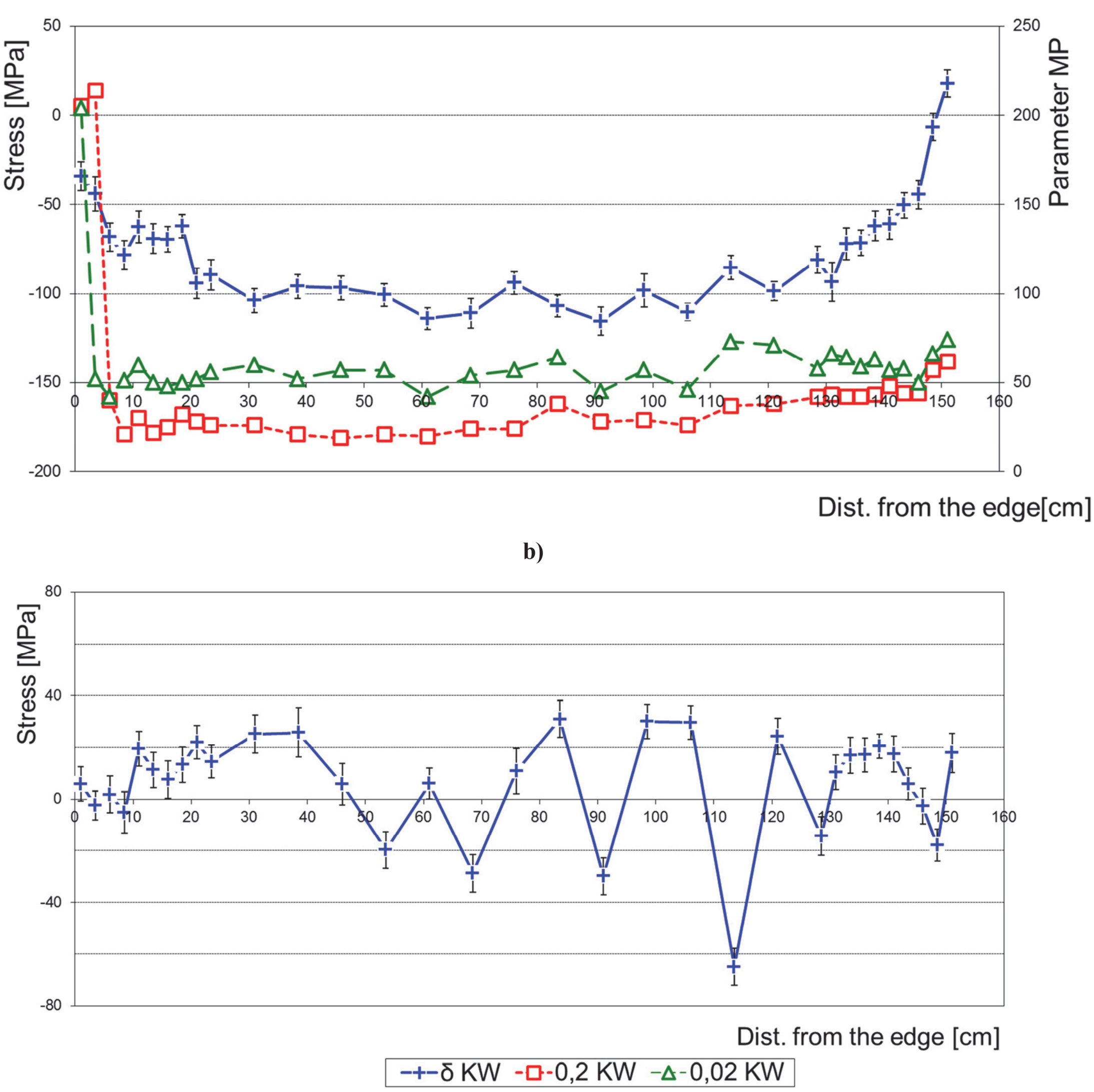


Fig. 6. The results of stress measurements taken in the rolling direction in sample of the N375904 strip, side B, prior to (a) and after (b) straightening, σKW-measurements by X-ray method, 0.2 and 0.02- measurements by magnetic method in layers of 0.2 and 0.02 mm thickness.

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POMIAR NAPRĘŻEŃ WŁASNYCH W STALOWYCH BLACHACH GORĄCOWALCOWANYCH PRZEZNACZONYCH DO CIĘCIA LASEROWEGO

Streszczenie

Z uwagi na specyfikę cięcia laserowego, blachy do cięcia tą metodą muszą charakteryzować się odpowiednim składem chemicznym, strukturą oraz niskim poziomem naprężeń własnych. Kluczową rolę w zrozumieniu przyczyn powstawania i kontroli

naprężeń własnych spełniły opracowane do tego celu programy komputerowe.

Jedną z najistotniejszych danych wejściowych do takiego programu jest rozkład naprężeń własnych występujących w materiale na różnych etapach procesu produkcji. Najbardziej uznaną metodą pomiaru naprężeń własnych jest rentgenowska metoda $\sin^2\psi$, kosztowna, i ze względu na czas pomiaru, selektywna. Można próbować ją zastąpić tańszą i szybszą, ale mniej dokładną i wymagającą kalibracji, metodą magnetyczną szumów Barghausena.

Celem niniejszej pracy było porównanie wyników pomiaru naprężeń metodą rentgenowską $\sin^2\psi$ z wynikami uzyskanymi metodą magnetyczną szumów Barkhausena.

Received: November 5, 2014
Received in a revised form: November 22, 2014
Accepted: December 2, 2014