Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 2, 2016, vol. LXII
article No. 2018

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RESIDUAL STRESSES ANALYSIS METHODOLOGY DURING CYCLIC PLASTIC DEFORMATION CARBON STEEL

METODIKA ANALÝZY ZBYTKOVÝCH NAPĚTÍ V PRŮBĚHU CYKLICKÉ PLASTICKÉ DEFORMACE UHLÍKOVÉ OCELI

Abstract

One of the trends in development of new metal materials, respectively the increase of their mechanical properties, is the use of cyclical plastic deformation. Evaluation of resulting properties of given materials conducted only at the end of the process does not, however, enable to phase individual steps of the cyclical process in order to optimize technological parameters. A very suitable approach to describe the behaviour of materials during repeated plastic deformation seems to consist in a non-destructive analysis of residual stresses. The paper describes the method of analysis of residual stress based on the Barkhausen noise which is applied in the process of increasing mechanical properties of steel plates using the DRECE (Dual Rolling Equal Channel Extrusion) method [1-2].

Abstrakt

Jedním z trendů vývoje nových kovových materiálů resp. zvyšování jejich mechanických vlastností je použití cyklické plastické deformace. Hodnocení výsledných vlastností daných materiálu pouze na konci procesu neumožňuje však rozfázovat jednotlivé kroky cyklického procesu za účelem optimalizace technologických parametrů. Jako velice vhodné pro popis chování materiálů v průběhu opakované plastická deformace se jeví nedestruktivní analýza zbytkových napětí. Příspěvek popisuje metodiku analýzy zbytkových napětí založenou na Barkhausenově šumu aplikovanou při zvyšování mechanických vlastnosti ocelových pásů metodou DRECE (Dual Rolling Equal Channel Extrusion) [1-2].

Keywords

Residual stress, Barkhausen noise, severe plastic deformation, DRECE, steel.

1 INTRODUCTION

All technological operations such as welding, forming, machining or grinding leave marks in the material that vary in size, orientation and depth profile of residual stresses. Residual stresses are mechanical stresses that exist in an object without any effect of outside forces and are always the result of non-homogenous elastic of elastic-plastic deformations. These stresses superimpose with stresses from loading. In most cases, tensile stresses generally worsen mechanical properties of materials and decrease the service life time of components.

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2 RESIDUAL STRESS MEASUREMENT TECHNIQUE

To analyse residual stresses, we use a number of indirect methods, which are variously limited by material, depth of measurement, size of measured area. Fig. 1 shows basic methods of analysis od residual stresses including the depth of measurement, the area analysed and classification as either destructive or non-destructive methods. None of the known types of analysis of residual stresses is fully universal, as individual methods can usually be only applied successfully to certain types of materials (crystalline, transparent, ferromagnetic etc.). The basic precondition for correct interpretation of conclusions obtained through different tensometric procedures is the understanding of conditions, under which either the deformations or the values which can be affected by stress were set.

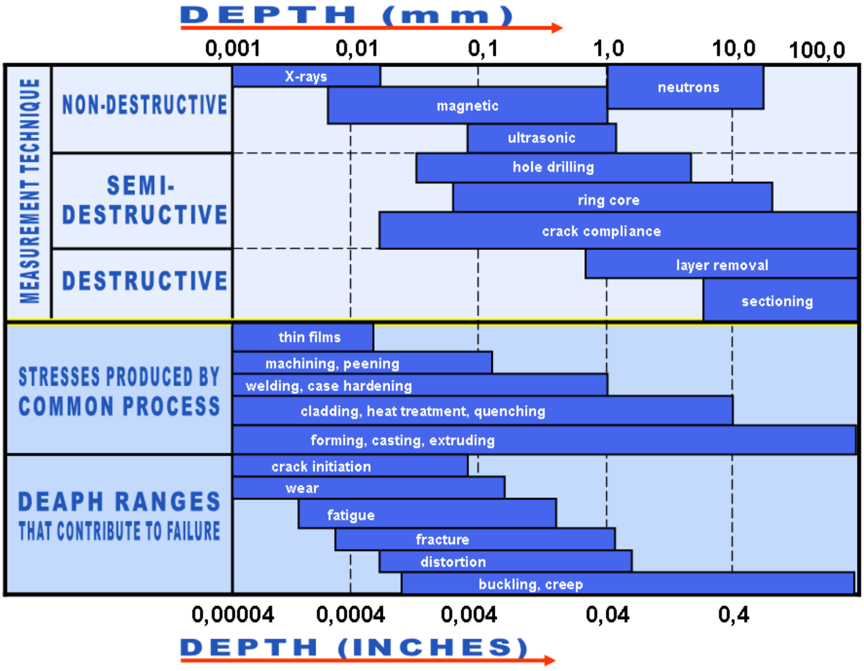


Fig. 1 Residual measurement techniques [7]

2.1 Micromagnetic method

Micromagnetic (also magnetoelastic, MBN) methods based on the Barkhausen noise are suitable for evaluation of non-destructive measurement of residual stresses. We conducted an analysis of residual stresses on selected materials using the this method. A similar characteristic of methods of residual stress measurement and the characteristic of the micromagnetic method are included in lit. [3-5]. The MBN signal is affected by many microstructural features and also by applied or residual stress. The fundamentals of the relation between MBN and stress are relatively well understood as illustrated in Fig. 2[6]. Ferromagnetic materials experience the magnetostriction phenomenon depending on the magnetic field and stress state. For ferromagnetic materials, such as steels and cobalt, which have a positive magnetostriction coefficient λ, the MBN signal shows an increasing trend in the direction of the applied elastic tensile stress. On the other hand, an applied elastic compressive stress will decrease the magnetization in materials with positive magnetostriction. Materials with negative magnetostriction coefficient show the reverse effect [7]. This method is based on the continuous rotation of magnetic field that results into the non-continuous magnetization of material. This discontinuity is named as the Barkhausen noise. Barkhausen noise is damped with increasing depth. The main reason is the damping effect of eddy current influencing electromagnetic fields of the moved Bloch walls. The Bloch walls rotate under the external load to the orientation of magnetic flow. The compressive stresses decreases intensity of Barkhausen noise and the tensile stresses increase this movement (Fig. 2.) [6].

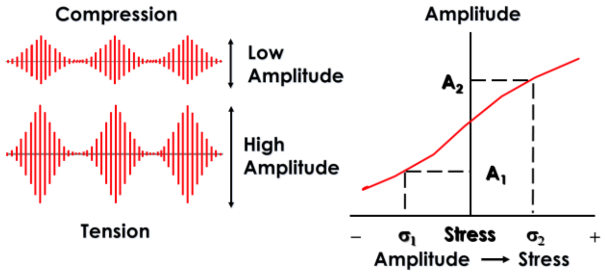


Fig.2 Barkhausen noise response to tensile and compressive stress [6]

3 SEVERE PLASTIC DEFORMATION METHOD DRECE

One of the current trends in the development of new materials is increasing their utility properties through cyclic plastic deformation. One of the technological variants tested at the Department of Mechanical Engineering, VŠB TUO is the DRECE (Dual Rolling Equal Channel Extrusion) technology [1-2] Fig. 3 and Fig. 4. Two low-carbon steels with different utility properties were chosen for verification of selected qualities of materials after the application of DRECE technology. Afterwards, the steels were subject to multiple processing. During the DRECE technology, the evolution of residual stresses in the steel strip was tracked by using the magnetoelastic method. The analysis of residual stresses was performed on given strips in a default state and during multiple processing.

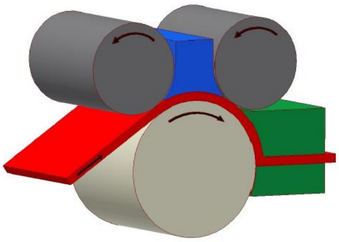


Fig.3 New conception of DRECE technology

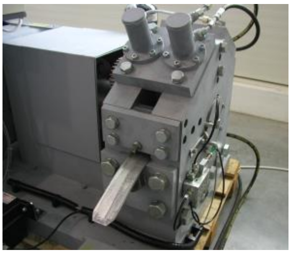


Fig.4 Prototype of the DRECE equipment

3.1 Experimental material

As an experimental material, we used steel strips made from low-carbon steel measuring 48x2x1000mm, which were labelled A and B (A-DC01 according to EN 101130-91, B-C55E according to EN 132-79). The chemical composition and default mechanical properties are shown in Tab. 1 and 2. Each strip had different utility properties, which were put through multiple processing by the DRECE technology. More detailed data about technological parameters of the applied DRECE technology, attained mechanical properties and structure are given in [2].

Tab.1 Chemical composition of the low carbon steels A(DC01), B(C55E)

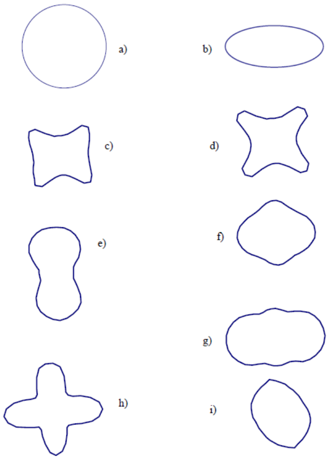
Steel	C [wt.%]	Si [wt.%]	Mn [wt.%]	Al [wt.%]	P [wt.%]	S [wt.%]
A	0,1	-	0,43	-	0,03	0,03
B	0,53	0,03	0,43	0,02	0,030	0,035

Tab.2 Mechanical properties of the low carbon steels A(DC01), B(C55E)-initial state

Steel	R_{m} [MPa]	$R_{p0,2}$ [MPa]	A_{80mm} [%]	HV10
A	313	174	50,3	88
B	549	373	21,1	176

3.2 Residual Stress analysis after SPD process DRECE

To evaluate the impact of the DRECE technology on the distribution of residual stresses, we used samples of monitored steels - in a default state and after a sextuple draft. We conducted an assessment of residual stresses, in accordance with the methods [3-7], in the centre (C) and in the left and right (L, R) part of the strip (located in ¼ and ¾ of the width of the strip). Polar graphs depicting the magnetic parameter MBN are depicted in fig. 7-12. The graphs show that material B in a default state is substantially less homogeneous than material A, regarding the redistribution of residual stresses over the width of the strip, as in Fig.5 [8]. Application of six DRECE drafts led to levelling of different residual stress values over the width of the strip and to an increase of compression stress in the direction of drafting. Afterwards, we carried out a planar scanning of the magnetic parameter on surface of strips in 8 directions 5mm far from each other, as well as on 5 cuts by 10 mm, shown in Fig.6. Fig. 7 until 9 show the polar graph distribution MBN on strips in a default state and in six time DRECE for B steel. Same results for steel A show the Fig.10 until 12. Fig.12 shows value residual stresses after calibration procedure in MPa. Fig. 13 and 14 show the planar distribution MBN on strips in a default state; Fig. 15 and 16 show the distribution after six drafts by DRECE technology.



a) isotropic state;
b) uni-axial tension or compression;
c) bi-axial compression by two non-equal orthogonal loads;
d) bi-axial compression by two equal orthogonal loads;
e) large uni-axial bending;
f) bi-axial tension by two non- equal orthogonal loads;
g) small uni-axial bending;
h) bi-axial tension by two equal orthogonal loads;
i) weakly textured specimen with small applied tension.

Fig.5 Typical examples of directional diagrams shapes for magnetic materials in various conditions [12]

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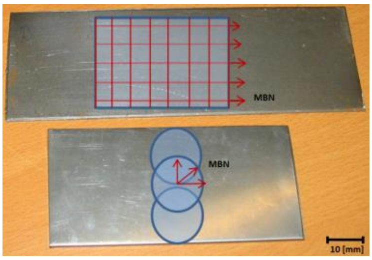

Fig.6 Areas of MBN measurement on surface of the sample

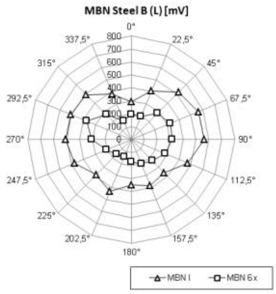

Fig.7 Polar graph of the MBN distribution, initial state and six time DRECE, 1/3 strip, width, steel B

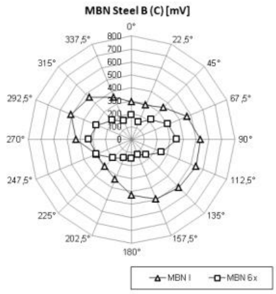

Fig.8 Polar graph of the MBN distribution, initial state and six time DRECE, centre strip, steel B

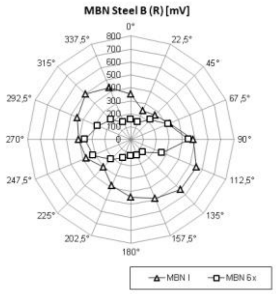

Fig.9 Polar graph of the MBN distribution, initial and six time DRECE, ¾ strip with, steel B

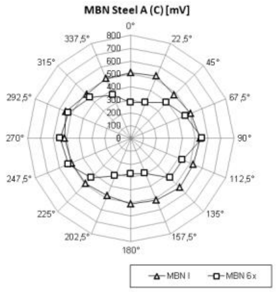

Fig.10 Polar graph of the MBN distribution, initial state and six time DRECE, centre strip, steel A.

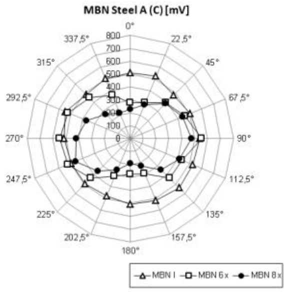

Fig.11 Polar graph of the MBN distribution, initial state, six and eight time DRECE, centre strip width, steel A.

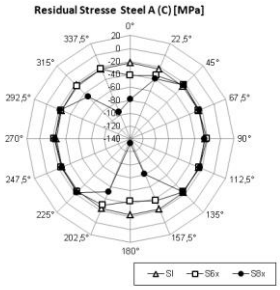

Fig.12 Polar graph of the residual stress distribution initial state, six and eight time DRECE, steel A.

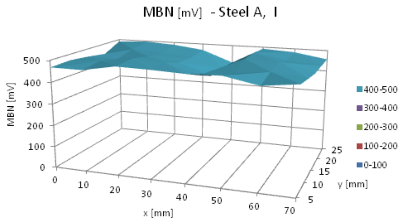

Fig.13 Surface distribution MBN on the strip of sheet steel A-initial state.

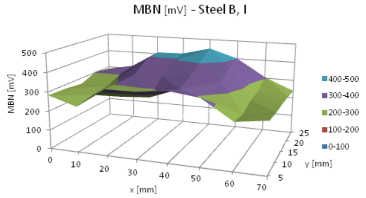

Fig.14 Surface distribution MBN on the strip of sheet steel B-initial state.

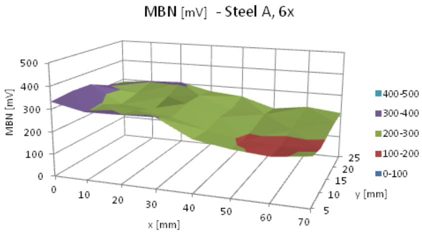

Fig.15 Surface distribution MBN on the strip of sheet steel A-six times DRECE.

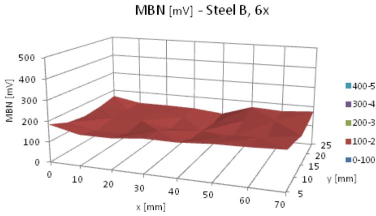

Fig.16 Surface distribution MBN on the strip of sheet steel B-six times DRECE.

4 CONCLUSIONS

Based on the conducted measurements, it is possible to infer the following conclusions. In a default state, steel strip B shows bigger differences of residual stress in the peripheral sections of the strip than steel strip A. The causes of these differences are the mechanical properties of the strip and the technology of primary production of the strip. The application of gradual DRECE cycles leads to levelling of residual stress values on the area of the samples and also to a substantial increase in compressive stresses in direction of the draft. During the DRECE technology, noticeable increase in compressive stresses occurs at material B. Absolute values of compressive stresses for material B are already higher after only six drafts compared to values after eight drafts for material A. The use of the magnetoelastic method enables a detailed projection of individual technological steps for production of new materials as well as a very effective optimisation of individual parameters of a technology. Last but not least, acquired information about the distribution of residual stresses allow an effective deployment of given materials in real industrial applications.

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