

Minor hysteresis loops measurements for characterization of cast iron

G. Vértesy^{a,*}, T. Uchimoto^b, T. Takagi^b, I. Tomáš^c, O. Stupakov^c, I. Mészáros^d, J. Pávó^d

^aResearch Institute for Technical Physics and Materials Science, Budapest, Hungary

^bInstitute of Fluid Science, Tohoku University, Sendai, Japan

^cInstitute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic

^dBudapest University of Technology and Economics, Budapest, Hungary

Abstract

Structural variation in a series of cast iron samples was non-destructively characterized by means of sets of magnetic minor hysteresis loops. The flat samples were magnetized by an attached yoke, and reliable parameters were obtained from the series of minor loops, without magnetic saturation of the samples. It was found, that some magnetic quantities, well known to be closely connected to the samples' structure variation, especially relative coercivity and remanent induction, could be distinguished more sensitively from minor loops, than from the major one.

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1. Introduction

Magnetic measurements are suitable for characterization of changes in the structure of ferromagnetic materials, because their magnetization processes are closely related to the microstructure of the materials. This fact also makes magnetic measurements an evident candidate for non-destructive testing, for detection and characterization of any modification and/or defects in materials and manufactured products made of such materials. Structural non-magnetic properties of ferromagnetic materials have been non-destructively tested by the traditional magnetic hysteresis investigation for a long time with fair success. A number of techniques were suggested, developed and currently used in industry, see e.g. [1,2]. They are mostly based on detection of structural variations via the classical macroscopic parameters of hysteresis loops.

An alternative, more sensitive and more experimentally friendly approach to this topic was considered recently in Refs. [3] and [4], based on magnetic minor loops measurement. In Ref. [3] the method of Magnetic Adaptive Testing (MAT) was presented, which introduced general magnetic descriptors to diverse variations of non-magnetic

properties of ferromagnetic materials, optimally adapted to the just investigated property and material. In Ref. [4] the sets of minor hysteresis loops were scrutinized, and sensitive descriptors of plastic deformation of the material (independent on the minor loops amplitudes) were identified.

In the present work quasiclassical characteristic parameters of a system of minor loops, measured on a series of cast iron samples [5], are analyzed, and their sensitivity is evaluated. The minor loops were measured (on thoroughly pre-demagnetized samples) in field, h_a , applied by an attached magnetizing yoke, which was varied within amplitudes, h_b . The amplitudes begun with a finite value, Δh_b , and consequently they were step-by-step increased by the same value, Δh_b , more than 25 times. This type of experiment can be readily used in any relative measurement where the investigated samples are compared to a reference one.

2. Experimental

A step block specimen with 5 steps was prepared with shell mould castings and a high frequency induction furnace, as shown in Fig. 1. Both width and length of each step are 100 mm. Thickness of the steps are 5, 10, 20,

*Corresponding author. Fax: +36 1 3922226.

E-mail address: vertesyg@mfa.kfki.hu (G. Vértesy).

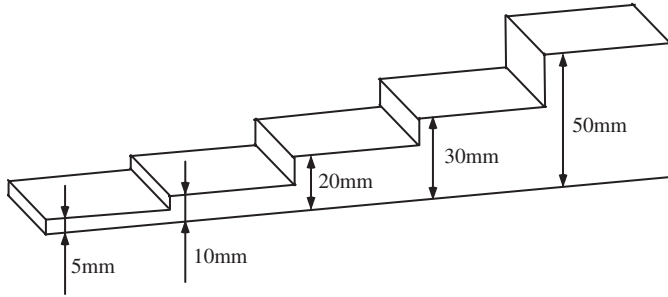


Fig. 1. Step block specimens of cast irons.

Table 1
Hardness of the different steps of the investigated specimen

Thickness of the step [mm]	HRB
5	90.4
10	90.2
20	93.4
30	98.2
50	95.8

30 and 50 mm, respectively. Difference of thickness brings about change in cooling rate of each step during casting, which leads to different structures and graphite sizes. Chemical composition of the used alloy was C: 3.69%, Si: 2.06%, Cu: 0.29%, Mn: 0.197%, Mg: 0.045%, Sn: 0.019%, Ni: 0.011%, P: 0.009, S: 0.006%. (Values are given in wt%.)

Hardness of the samples was measured by the Rockwell hardness test method (Scale B). The values are given in Table 1.

A specially designed Permeameter [6] with a magnetizing yoke was applied for measurement of families of minor loops of the magnetic circuit differential permeability. The block-scheme of the device and the sketch of the yoke can be seen in Fig. 2. The yoke was 47 mm long, 24 mm high, and diameter of its legs was 14 mm. It was made from M2TN-B type soft ferrite material with $B = 300$ mT saturation induction.

The magnetizing coil wound on the ferrite yoke gets a triangular waveform current with step-wise increasing amplitudes and with a fixed slope magnitude in all the triangles. This produces a triangular time-variation of the effective field, $h_a(t)$, in the magnetizing circuit and a signal is induced in the pick-up coil. As long as $h_a(t)$ sweeps linearly with time, t , the voltage signal $U(h_a, h_{bj})$, in the pick-up coil is proportional to the differential permeability, $\mu(h_a, h_b)$, of the magnetic circuit

$$\begin{aligned} \mu(h_a, h_b) &= \text{const } U(h_a, h_b) \\ &= \text{const } \partial B(h_a, h_{bj}) / \partial h_a * \partial h_a / \partial t. \end{aligned} \quad (1)$$

The Permeameter works under full control of a PC computer, which sends the steering information to the

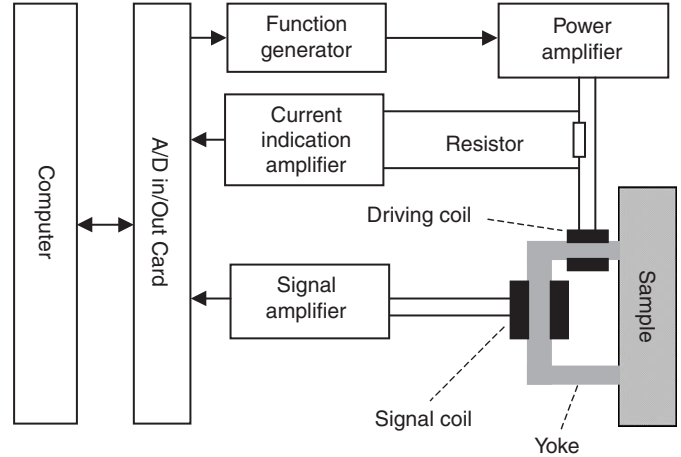


Fig. 2. Block-scheme of the Permeameter and sketch of the yoke.

function generator, and collects the measured data. An input–output data acquisition card accomplishes the measurement. The computer registers data files for each measured family of the minor “permeability” loops. They contain detailed information about all the pre-selected parameters of the voltage signal induced in the pick-up coil. The step of the magnetic circuit effective field amplitudes was $\Delta h_b = 84$ A/m, and the magnetizing current time-rate of change was ± 12 A/s.

The described regime of the Permeameter yields a characteristic signal in the pick-up coil. The signal values start at the origin of the plot (the magnetic circuit was demagnetized before the measurement), then it increases into positive values (up to the positive starting field amplitude, $+1 \cdot \Delta h_b$), then it drops down into negative values as the applied field changes the direction of its rate, it proceeds in the negative values until the negative starting field amplitude $-1 \cdot \Delta h_b$ is reached, changes its rate direction and polarity again, rises up to $+2 \cdot \Delta h_b$, etc. The recorded signal data are processed by a data-evaluation program, one family of minor loops for each measured sample.

The data pools of the minor loops determined for every sample made it possible to apply MAT and to measure “classical” magnetic parameters, like remanent and maximal induction, initial and maximal permeability, and coercive fields. The parameters were determined for each of the minor loops as functions of the loop index for each specimen s5, s10, s20, s30 and s50 (each steps of 5 steps sample).

3. Results and discussion

The magnetic measurements were carried out with the aid of the magnetic yoke. Even if quality of the magnetic contact between the samples and the yoke was assumed to be stable (careful positioning of the samples on the yoke was taken care of), the magnetic circuit was certainly non-uniform and the magnetic values obtained from each

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