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EXPLOSIVELY WELDED Ti-Ni BIMETALLIC PLATE CHARACTERIZATION USING BARKHAUSEN NOISE

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Analysis of Barkhausen noise in explosively cladded titanium-nickel bimetallic plate was studied to test feasibility of using this magnetic nondestructive technique for evaluation of its properties as stress or strain state. The research on the influence of applied strain on Barkhausen Noise (BN) in nickel layer was carried out, and the impact of magnetization frequency on BN envelope was investigated too. Finally, the radial plots of BN intensity correspond to stress state were determined. Obtained results let to conclude that BN analysis method can be additional reliable testing tool for Ti-Ni plates characterization.

Keywords: Barkhausen noise, bimetallic plate, non-destructive materials testing

1 INTRODUCTION

Titanium - nickel (Ti-Ni) bimetallic plates due to unique properties have growing applications in many industries, *eg* chemistry or aviation also as “memory shape” elements. As material, titanium is characterised by the unusual lightness (45% more than steel) in relation to its mechanical strength and good corrosion resistivity. Nickel layer is characterized by high hardness and very good corrosion resistivity. The only way to join these two metals is a process of explosive cladding [1, 2]. The area of intermediate layer of joint consists of Ti_xNi_y phases with various percentages of components. Explosive wave propagation and optionally additional metal forming operations such as rolling or straightening of bimetallic plates are sources of strong deformation which can affect functional properties of the elements made from them.

Testing of the semi final product in form of the thin sheets, beside of destructive investigation of mechanical properties as tensile tests, is oriented on non destructive ultrasound testing of quality and presence of bimetallic joint. Ferromagnetic property of the nickel component [3] creates opportunity to apply non-destructive testing (NDT) of the plate by Barkhausen noise (BN) analysis, similarly as steel sheets [4, 5]. It allows to obtain more information about accumulated strains, and stresses resulted from technology of manufacturing process.

BN results from the well known phenomena of jerky magnetic domains movements (Barkhausen jumps) under applied alternating magnetic field. It produces micro fluctuation in magnetic flux density in magnetized material which can be detected by pickup coil as characteristic noise in form of series of electrical pulses [6]. Parameters of this noise, such as amount and amplitude spectrum of pulses corresponding to Barkhausen jumps, energy expressed by root mean square value or shape of BN envelope are determined by lot of factors as type of the microstructure, dislocations density and character and level of internal (residual) stresses. In case of the nickel investigations, characterized by negative magnetostriction, it is expected that BN intensity diminishes under influence of tensile stresses [7] and increases for compressive stresses, unlikely it is observed in steel.

It must be mentioned clearly that possibility of magnetic testing of Ti-Ni plates are related only to the nickel layer. However, taking into account high strength of bimetallic connections, *eg* the results of strains investigations could be related carefully also to the titanium layer. From the point of view of magnetic properties, during the investigation, thin titanium layer may be considered only as the air gap between magnetization yoke and inside side of the nickel layer. Due to its conductivity, it can also shield the BN signal, but a scale of this effect has not been studied in this work.

2 MATERIAL AND RESEARCH METHOD

2.1 Material

Material used in this study was a specimen in form of the strip, cut off from the edge of explosively joined Ti-Ni sheet in as-received state. The sample has dimension 590 mm × 50 mm × 2 mm and was also characterised by radius of curvature of the strip about 2100 mm. Both compounds – nickel (purity 99,4%) and titanium (Grade 1) layers had the same, average 1 mm thickness and metallographic investigations revealed bimetallic joint of a good quality with characteristic corrugation of intermediate layer. Any additional heat treatment, straightening or surface polishing were not applied to the sample, to keep raw conditions as may be expected during industrial investigations.

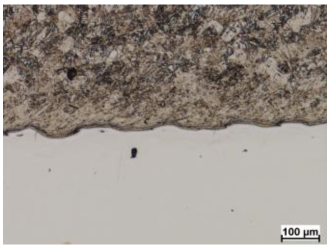

Fig. 1. Microscopic view of bimetallic TiNi joint

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2.2 Measurement apparatus

For measuring parameters of the Barkhausen noise special equipment for excitation, detection and processing of BN has been developed and made by the author [8]. Its functional block scheme is shown in Figure 2a. It consists of three main parts: a magnetization block, a BN measuring circuit and signal processing block. Moreover, the measuring head that integrates both function of material magnetization and Barkhausen jumps detection, is integral part of it.

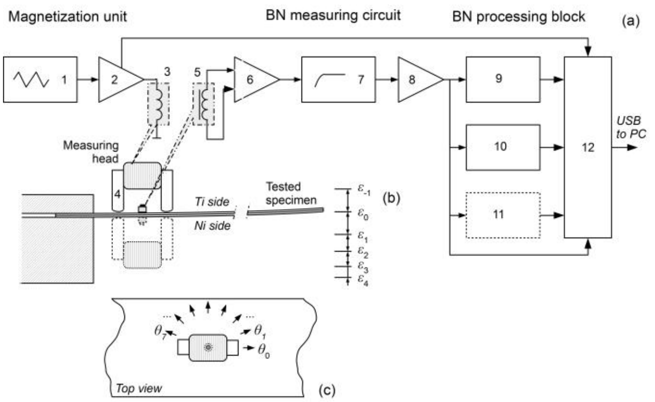

Fig. 2. Schematic view of experimental set-up (a) measuring apparatus block scheme, (b), (c) - experiments

The magnetization unit is based on the symmetric saw tooth generator (1) and a current power amplifier (2). It provides current I_m, feeding the magnetization windings (3) wounded on a yoke (4) of the measuring head. Six predefined frequencies f_m: 1, 3, 6, 12, 22 and 38 Hz can be chosen and the amplitude of the current I_m can be regulated in range 0 …±1,5 A. The BN signal excited in the tested specimen, is picked by a detection coil (5), placed between yoke poles and transmitted to the measuring block. At first, raw signal is amplified with help of specialized low-noise measuring preamplifier (6) with controlled gain k_{u1max} up to 80 dB. Then, the signal is passed through a high-pass filter (7) with cut-off frequency of 1 kHz, where power line interferences and higher harmonics of magnetization current are eliminated. Finally, extracted from the background BN, is gained additionally by the final amplifier (8) with k_{u2max} = 40 dB and fed to a processing block. During the experiments in this study, constant, 110 dB total gain of measuring circuit was set.

Processing in specialized circuits included the root-mean-square value of BN (BN_{RMS}) determining (9) and its envelope voltage signal shaping (10). Moreover, digital pulses corresponding to the Barkhausen jumps with amplitude over specific reference voltage are created in (11) although this parameter was not analysed in this study. These signals as well as a raw BN and the magnetization current in form of voltage signal are acquired by data acquisition card (12) type DAQ3000 1 MHz and sent to the computer through USB interface for further processing, saving and displaying.

For the tests a measuring head was used, constructed on the base of pocket of C-shape segments made from transformer sheet and linear dimension 18 mm × 5 mm. The poles of the yoke were rounded faintly to obtain repeatable contact conditions with different curvature radius of the tested strip. The magnetization windings had 200 turns. Between the electromagnet poles the detection coil wounded on small rectangle ferrite rod core with cross section 6 mm^2 was fixed elastically in a way enabling slightly vertical movement.

2.3 Scope of the experiment

The scope of the research carried out included:
- preliminary study of the BN signal and empirical search of optimal magnetization conditions for testing Ni layer from both sides of the bimetallic plate
- analysis of the effect of external strain induced stress state in plate, applied by the deflection of the end of the specimen (ε_{-1} = -50 mm ε_1 = 50 mm, ε_2 = 80 mm, ε_3 = 100 mm, ε_4 = 110 mm)
- analysis of the influence of the frequency of magnetization (1, 3, 6, & 12 Hz) on BN envelope shape evolution
- determination of directional diagrams of BN intensity corresponding to the stress state with angular step 22,5°

Some details of experiment were explained in Figure 2b & 2c and real view during testing was shown in Figure 3.

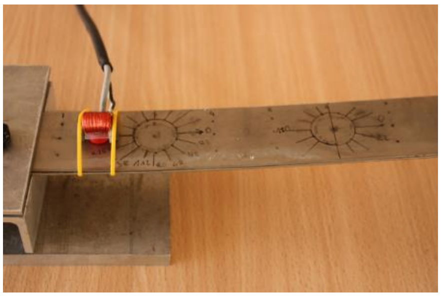

Fig. 3. A view of the experiment

3 RESULTS AND DISCUSSION

Preliminary testing revealed strong inequality of BN intensity distribution along the length of the centre line of the specimen, especially measured at Ti side. Although at some points, for the same magnetization current BN signal has similar amplitude, in most cases amplitudes at Ni side were significantly bigger. It was an effect of presence of paramagnetic layer of titanium between nickel and yoke, weakening the magnetic field. It should be also remembered that lift-off of pick-up coil from nickel caused additional diminishing of BN signal. As a result of empirical research, to cover different stress states influencing BN intensity and keep constant gain of measuring circuit, for the further measurements at Ni side, value of magnetization current I_m was about two times less than for Ti side.

At this stage of study, for f_m = 6 Hz, significant difference in the BN shapes for both sides was observed too. Figure 4a shows the example oscillogram of BN captured at Ni side and the Figure 4b presents plot at Ti side. BN measured through Ti layer has peak position more delayed; indicating that on the side of the joint material is magnetically harder than on the other side.

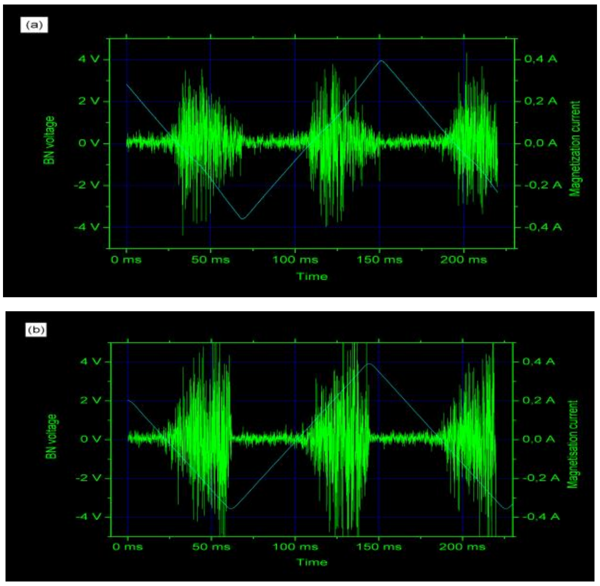

Fig. 4. BN oscillograms, f_m = 6 Hz, (a) – at Ni side, (b) – at Ti side

This bigger coercive force seems to be results mainly of strong deformations of nickel [7] caused by explosion and presence of TiNi phases.

Deflection with scheme presented in Figure 2b introduced complex stress state inside the sample in relation to different mechanical properties of both connected layers. If the sample was deflected down (ε_1 … ε_4) compressive stresses were introduced in nickel layer and at ε_{-1}.the tensile. In Figure 5 one-shot voltage profiles of BN envelopes with slope of the magnetization current at these deformation stages of the sample were shown.

For a more detailed study, lower magnetization frequency (f_m = 1 Hz) was used. The Barkhausen noise intensity was found to increase with increasing of compressive stress at both sides of the sheet and to decrease with the tensile stress.

These results are similar to results reported in [7]. Moreover, interesting fact of appearance of the second peak on BN envelopes at Ti side with high tensile stress was noticed (Fig. 5a). Comparison of theses envelopes with analogical ones captured at Ni side (Fig. 5b) allows to conclude that this peak comes from BN signal generated in the bulk of material. To confirm if observed second peak is an effect of tensile deformation of external layers of nickel, evolution of BN peaks with frequency of magnetisation which affects measurement depths was studied. Three, additional higher frequency of magnetisation current 3 Hz, 6 Hz and 12 Hz were applied. The second peak (2) (Fig.6) as was expected diminished with increasing of frequency.

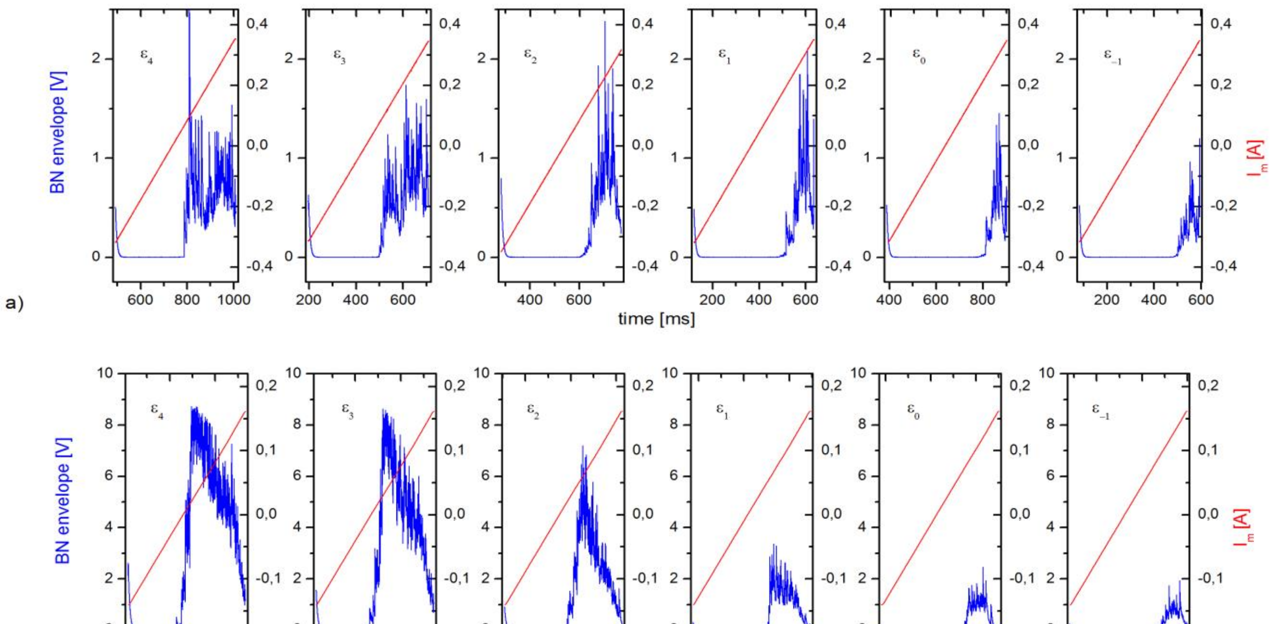

Fig. 5. Evolution of BN envelope shape with applied strain (a) – at the Ti side, (b) – at the Ni side

The conclusion is that for the accurately testing of subsurface layer of thin nickel sheet higher magnetization frequency is rather more appropriate to avoid crosstalk.

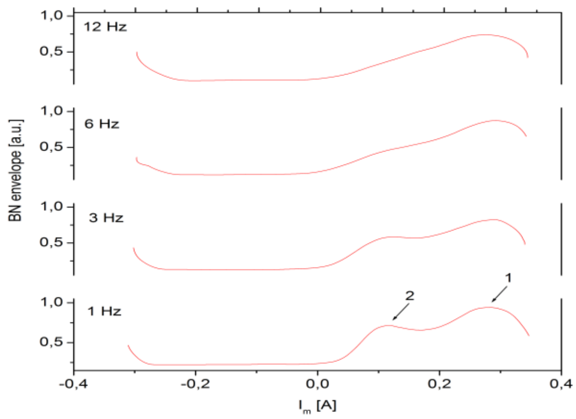

Fig. 6. BN envelope *vs* magnetization current frequency

It resulted from weaker magnetisation in deeper layer [9] and isolation by eddy current of Barkhausen signal from those regions. Taking into account these findings, radial distributions of BN intensity expressed by RMS value corresponding to the strain/stress state were investigated at f_m = 12 Hz. In Fig. 7, example of obtained normalized directional diagram was presented.

In nickel, inside the plate (measurements at Ti side), significant anisotropy was observed indicating the presence on orthogonal biaxial stress state with opposite signs [10, 11]. This layer was deformed by process of joining, and, the main directions of strains (at ~ 22,5˚ tensile and 112,5˚ compressive) probably result from direction of explosive wave propagation but it is not confirmed fully at this moment. At the outer side of the nickel not affected directly by explosion (Ni side), shape of the radial plot points on slightly biaxial stress state with the same character and orientation.

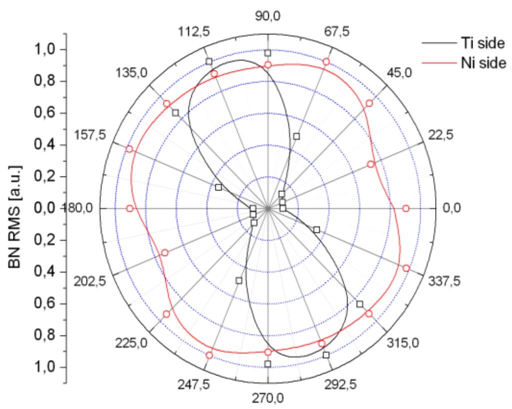

Fig. 7. Examples of directional diagrams of Barkhausen noise

Both presented directional plots are representative also for measurement points in other regions, although the orientation of principle directions of BN_{RMS} was different.

4 SUMMARY

Obtained results let to conclude, the Barkhausen noise analysis can be supplementary testing tool of Ti-Ni plates alongside existing ultrasound non-destructive testing of bimetallic joint quality. The obtained examination results can be useful at the stage of designing the manufacture of products from Ti-Ni plate, considering the actual internal stress and strains state as well as for improving and development the existing production technology of this kind of plates.

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