Evaluation of Welding Current Impact on Residual Stresses Status in Ship-Building Steel Weldments Using Barkhausen Noise

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Abstract — **The paper intends to determine the relationship between heat input and the residual stresses distribution in shipbuilding steel weldments using the Magnetic Barkhausen Noise (MBN) technique. The rate of fusion during welding was controlled by amount and time of fusion for a given weld bead width. Barkhausen noise measurements were performed parallel to the weld bead at the back of the plates welded using variable welding currents along the line that crosses the weld bead. The heat affected zones were differentiated by a variation in MBN peak height. The high welding current was characterized by high MBN amplitude compared with the medium and the low currents. The results showed that the heat affected zone was narrower with high welding current and increases with decreasing current. The results indicate that residual stresses introduced in steel by welding could be mapped nondestructively by magnetic Barkhausen noise.**

Index Terms: **Magnetic Barkhausen noise (MBN), Residual Stresses, Heat affected zone (HAZ), Welding current.**

I. INTRODUCTION

Residual stresses distribution is altered by welding process. This is an issue in the shipbuilding and maintenance industry where welding is the main assembling process. In welding, residual stress variation along a line that crosses the weld is caused by the compressive yielding that occurs around the molten zone as the material heats and expands during welding. When the weld metal cools, it contracts which causes a tensile residual stress, particularly in the longitudinal direction. Residual tensile stress remains across the weld centerline and causes a balancing compressive stress further from the weld [1]. It is known that MBN increases under the influence of tensile stresses and decreases with compressive stresses [2]. This fact can be exploited so that by measuring the intensity of Barkhausen noise the amount of residual stress can be determined. In the stress concentration region caused by welding, the process of stress corrosion cracking and fatigue developing in welded structures and ships bodies while in service and can lead to a catastrophic failure. Therefore, the heat affected zone determination is an important basis for evaluating structural strength and the reliability of the welded structures [3].

Residual stresses can be measured by destructive methods such as hole-drilling, saw cutting, sectioning, and layer removal; or by non-destructive methods like X-ray diffraction, neutron diffraction, ultrasonic, magnetic and a relatively new technique Raman spectrum method. As a non-destructive method, the MBN technique is applicable to characterize various treatments and forming applied to steels [4]. It is the aim of this paper to describe the use of the Barkhausen emission technique for the evaluation of residual stress in a welded marine steel plate.

Barkhausen noise is produced by the irreversible movement of domain walls in a magnetization cycle. Domain walls are pinned temporarily by microstructural inhomogeneities and then released in the increasing magnetic field [5, 6]. The discrete changes in local magnetization that results can be detected as voltage pulses in a search coil or magnetic read head. Precipitates, grain boundaries and dislocations act as effective barriers to domain wall motion so that MBN is sensitive to microstructure and plastic deformation in the material. The influence of magnetostriction on magnetization also makes emission sensitive to applied or residual stress [7].

Welding is a vital production process during the manufacturing of shipbuilding industries, and generates residual stresses at a remarkable level. Temperature gradients, plastic deformation and metallurgical changes are main mechanisms generating residual stresses; and usually a combination of these effects is responsible for the final residual stress state [8]. During the welding process, high local heat input is introduced to the material being welded. As a result, non-uniform heat distributions, plastic deformations and phase transformations occur on the material. These changes generate different residual stresses patterns in solidified weld beads and in the heat affected zone (HAZ) [9]. In many cases, residual stresses are one of the key factors determining the engineering properties of structural components, and should be taken into account during the design and manufacturing of various products and parts [10]. In welded mechanical elements, for example, residual stress plays a significant role in terms of fatigue life [11]. Consequently, in order to design and fabricate a soundly welded structure, it is essential to consider proper welding procedures.

Several studies had shown that analysis of residual stress is a compulsory stage in the design of parts and structural elements and in the estimation of their reliability under real service conditions [12]. The MBN technique is one of the powerful tools to measure residual stress, and can provide reliable results [13]. This non-destructive method relies on the interaction between magnetization and elastic strain in ferromagnetic materials [14]. It is a fast, reliable,

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economic method, which can be applied on-site. It is appropriate either for laboratory or for industrial scale [15].

II. EXPEREMENTAL PROCEDURE

Three identical steel plates of low carbon steel were cut from the stock material of the type used in shipbuilding with dimensions of 200mm ×150mm ×8mm. The chemical composition of this steel is given in Table1. The steel is produced by warm rolling in which partial recrystallization takes place and the steel maintains a good mechanical properties.

Table 1.Composition (wt%) of Stock Material

C	Mn	Ni	Cr	Mo	Cu	Si	P	S
0.14	0.5	3.3	0.9	0.11	0.19	0.27	0.005	0.014

Groves of V shape of 6 mm width and 4 mm depth were created at one surface of each plate. The plates were clamped to prevent distortion. The gas metal arc welding (MIG) method was used to produce weld beads of 10 mm width with GSi1 electrodes. Mapping of longitudinal residual stresses at the back of each plate was established by the MBN technique in a parallel direction to the weld beads as shown schematically in Figure. 1. The welding parameters were developed by trial and error based on the practical specification implemented by the maintenance workshop of the dry dock in Misurata. Three welding currents were used ranging from the lowest to medium up to highest current the machine could deliver.

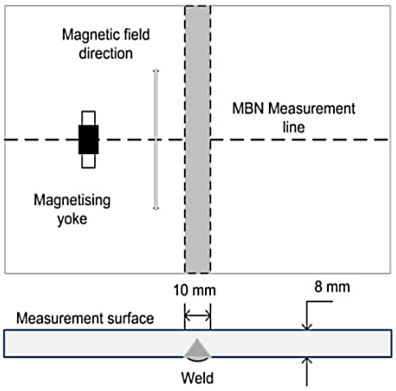

Figure. 1. Schematic Layout of the MBN Measurement Setup

The apparatus used to generate and capture MBN signals was developed by the author [16]. A schematic diagram of the layout is shown in Figure. 2. The specimens were magnetized using a U-core electromagnet placed at the top surface. A signal generator, producing a triangular wave at a frequency of 1 Hz, was used to be fed to the bi-polar amplifier. The amplitude of the driving current of 1 (A), produces a maximum magnetic field strength of 4.5 kAm^{-1}. The current limits were chosen to take the sample to magnetic saturation in each half cycle. MBN noise was detected by a search coil with 1,000 turns of 0.1 mm insulated copper wire wound around an empty plastic cylinder. The output from the search coil was amplified in a two-stage signal amplifier to 40 dB and passed through a band-pass filter (1-100 kHz) in two stages using a two channel Krohn-hite/3343 device. The relatively low excitation frequency was used in the experiment to minimize eddy current opposition to the applied magnetic field and to ensure a relatively slow magnetization rate in the sample cross section and to produce higher MBN activity. It is convenient to smooth emissions of the type shown in Figure. 2 to produce a measure of the amplitude of the envelope enclosing the signal. This was done numerically using a Matlab script. The signal was rectified by calculating the local root mean square for 100 successive points then smoothened using a digital filter for fifteen points to produce the characteristic MBN envelope. An important requirement in MBN measurements is the reproducibility across a large number of magnetic cycles and hence insensitive to any variations in the location of the energizing electromagnet and search coil. This is important because the magnetizing yoke and search coil need to be demounted each time in order to make the following measurements. The MBN signals were acquired using 20 Ms/s Pico Tech 12-bit DAC oscilloscope and stored in a PC. About 97654 data points for each magnetization cycle were recorded for MBN in one channel and the same number of points for the magnetizing triangular waveform in the other channel during MBN measurements.

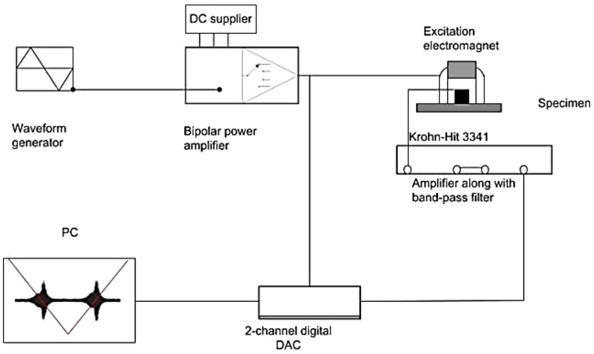

Figure. 2. Schematic Layout of the MBN Measurement Spparatus

The data was processed and smoothened using a Matlab script to generate the rms profiles characteristic of the captured signal. Figure 3 shows some smoothened MBN profiles from this experiment. MBN profiles show how the level of Barkhausen noise changes over the course of the magnetization cycle.

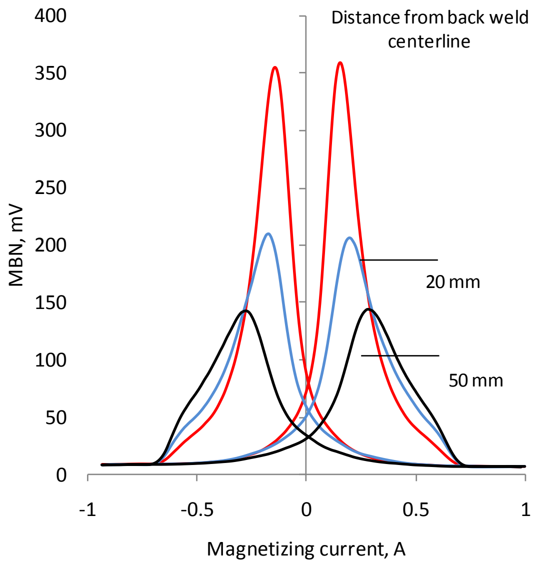

Figure. 3. Examples of One Cycle MBN Profiles from Different Location

III. RESULTS AND DISCUSSION

In the investigation, the longitudinal residual stresses were measured qualitatively based on the differential values of along a line across the width. Relying on the fact that rolling introduces residual compressive stresses in steel especially in the low temperature mode. The obtained results were analyzed to extract the MBN peak height (V_p). Figure 3 shows the results from the plates while magnetizing parallel to the weld direction.

When a polycrystalline ferromagnetic specimen is subjected to a tensile stress, because of the positive magnetostriction, the magnetic domains having their magnetic moments parallel to the axis of the applied stress become energetically favorable. Hence, they grow at the expense of the others until the specimen becomes magnetically saturated. In contrast, under a compressive stress, the domains having their magnetic moments perpendicular to the axis of the applied stress become energetically favorable. Thus, when a magnetic field is applied parallel to the stress axis during MBE measurements, the magnetic microstructure reorganization occurs simply by means of the displacement of the existing 180^o domain walls, while in the latter one the creation and motion of 90^o domain walls is also required to reach the completely magnetized state [17].

Under the influence of residual tensile stress, domains with magnetizations most closely aligned with the direction of residual tensile stress increase in size at the expense of neighboring domains with less favorable orientations. Furthermore, magnetic domains experiencing similar increases in volume are likely to become simultaneously active under an applied field. This increases the MBE response. In addition, there are an increased number of 180^o domain walls in the tensile stress direction [18] which contribute to an enhanced signal.

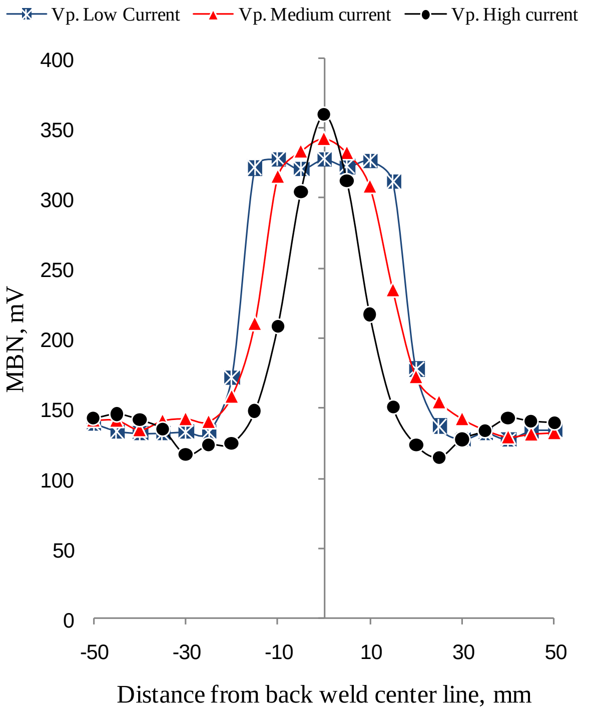

Figure. 4. MBN Profiles Peak height as a Function of Distance from Back Weld Center Line

Before welding, the stresses on the surface are almost compressive in nature [19]. After welding the stresses are measured on both sides of the weld bead. From the results, it is observed that the of MBN peak height as a function of distance from the weld centerline showed a pattern around the back of the weld bead. The increase in V_p is attributed to the domination of residual tensile stresses in the HAZ. It is noticed that the width of the produced pattern is controlled by the intensity of welding current. The result shows that the high current has more effect seen by an increase in V_p in the zone exactly behind the weld bead but has less effect away from that point. The result shows also that the equilibrated residual compressive stresses are seen by a decrease in V_p compared with that of the base metal, this behavior is not seen with the medium and low welding currents. The result shows that the low current is more influential on the residual stresses status than followed by the medium current and lastly by the high current.

The tensile stresses, at the heat affected zone are a result of shrinkage of highly heated areas near the weld zone, being restrained by the surrounding colder zone during the rapid heating and subsequent cooling and welding. But away from the weld zone the obtained stress values are nearly equal to the values before welding. The results for the residual stress measurements indicate that the width of the tensile peak increases with the timing of the process. The low speed process with low current can have relatively high temperatures in the far field away from the centerline because there is more time for the heat to diffuse away from the arc. The low amplitude of welding current results in a longer duration of high heat delivered to the plate and more thermal expansion taking place. The heat affected material experiences compressive plastic deformation due to thermal expansion. When the weld cools, the subsequent thermal shrinkage leads to a larger affected zone. Increasing the welding current to medium and high results in decreasing the welding time and hence decreasing the heat affected zone.

IV. Conclusions

1. The high temperature of welding affects steel microstructure by thermal expansion and diffusion which involves the movement of atoms from position to another which is motivated by temperature and time. However, soaking time is a crucial factor to diffusion and results in material softening and a loss of beneficial residual compressive stresses.
2. The investigation shows that the welding current affects the amount and the rate of fusion during welding in such a way that the lower the current is the more time needed to fill in the V-grove to produce 10 mm weld bead width.
3. The low welding current results in a longer welding time results in more heat delivered to the plate and hence a longer soaking time which is detrimental to the mechanical properties of ship building steel.
4. The high welding current results in a shorter duration of the welding process and therefore, less diffusion and less material expansion and shrinkage near the weld bead.

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