Effect of Pre-Weld Sand Blasting on Residual Stress Distribution in Ship Steel Using Magnetic Barkhausen Noise Technique

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Abstract —**This paper aims at investigating the effect of pre-weld sandblasting on residual stresses distribution in ship steel plates using magnetic Barkhausen noise (MBN) technique. The measurements have been conducted along a line crossing the weld as a function of distance from the weld bead at the back of the plate. Four tests have been performed in the experiment in four conditions. The as-received, sand blasted, as received-welded and the sand blasted–welded plates are tested. The as-received plate shows a statistically constant Barkhausen noise level indicative of the specimen processing history. The sand blasted plate shows a similar Barkhausen noise behavior but of lower intensity. The welded specimen shows a pattern of the Barkhausen response characteristic of the heat affected zone (HAZ) as a result of residual stresses redistribution. The sand blasted-welded specimen shows also a similar pattern but of lower intensity. The difference in the induced signals is attributed to the impedance and accumulation of residual compressive stresses due to sandblasting. The result indicates that the resultant residual tensile stresses at the heat affected zone could be reduced by using pre-weld sandblasting process.**

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

I. INTRODUCTION

Welding is used in ship/vessel construction as a way of joining steel plates together to construct the body. A major drawback of welding is the creation of residual tensile stresses near the weld bead. Residual stresses are locked-in stresses present in the engineering components when there is no applied load. The main cause of tensile stresses in welding is the high heat input during welding. It results in non-uniform heat distributions, plastic deformations and phase transformations in the partially melted zone and the heat affected zone. The welded part cools down to room temperature, but cannot fully contract because it is attached to the rest of the material body. As a result, the residual stresses created from welding are tensile at the weld and heat affected zone and are compressive away from the weld to produce the equilibrium [1-5].

The engineering properties of structural components, especially fatigue life, distortion, dimensional stability and corrosion resistance can be considerably influenced by residual stresses. Such effects usually bring to considerable expenditure in repairs and restoration of parts, equipment, and structures . Accordingly, residual stresses analysis is a compulsory stage in the design of parts and structural elements and in the estimation of their reliability under real service conditions. Systematic studies had shown that, for instance, welding residual stresses might lead to a drastic reduction in the fatigue strength of welded elements. Residual stresses are one of the main factors determining the engineering properties of welded elements, and should be taken into account during the design and manufacturing of different structural products [6]. The presence of tensile residual stresses in a part or structural element are generally harmful since they can contribute to, and are often the main cause of fatigue failure and stress corrosion cracking. Indeed, compressive residual stresses induced by sandblasting or shot peening in the sub/surface layers of material are usually beneficial since they prevent origination and propagation of fatigue cracks, and increase wear and corrosion resistance

Tosha and Iida [7] indicated that blasting process as shot peening produces a work hardened layer and induces compressive residual stress on the surface and surface layer. Blasting process is important for the automobile and the aircraft industries, because the parts produced by blasting process is improved the characteristics on the fatigue strength, wear and stress corrosion [7]. They found that the residual stress on the grit blasted surface is compressive and its value is less than that of shot peening from 10 to 40 %.

Bouledroua *et. al.*, [8] studied the effect of sandblasting on mechanical properties and material failure master curves (MFMC) of API 5L X52 and API 5L X70 pipeline steels. They found that sandblasting has slightly increased the yield stress, the ultimate strength and the fracture toughness and, at the same time, had an adverse effect on elongation, young’s modulus, hardness and thickness of the tested pipeline. Despite the erosion of these layers, under the sand impacting, failure strain and rate of degradation are improved.

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During manufacturing of mechanical components and/or structural bodies various stresses are generated which may be desirable (compressive) or undesirable (tensile). Most of the time these stresses are responsible for failure of mechanical components. Hence residual stress analysis is an important stage while designing the mechanical components. During analysis, various methods are available such as destructive (counter method, sectioning technique), semi destructive (hole drilling, deep hole drilling) and non-destructive (X-ray diffraction, neutron diffraction and magnetic methods) [9].

Techniques based on the phenomenon of Barkhausen noise are potentially useful for non-destructive evaluation of ferromagnetic materials [10]. For instance, residual tensile stress and over-tempering can be detected in ground-finished surfaces using measurements of magnetic Barkhausen noise (MBN) [11]. Because of the large number of influential variables, the technique produces only relative comparisons between different material states. For a given alloy, measurements have to be calibrated against a standard microstructural state for that particular alloy.

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. 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 Barkhausen noise sensitive to applied or residual stress [12].

This experiment aimed at investigation the effect of pre-welding sandblasting instead of post weld remedy procedure. This study deals with the exploration of a novel proposal to ship yards to implement this scheme to increase residual compressive stresses in the plates to suppress the generation of residual tensile stresses.

II. EXPERIMENTAL PROCEDURE

A. *Material*

Two identical plates from steel used in shipbuilding were cut from the stock material with dimensions of 250mm ×150mm ×8mm. The chemical composition of the most important alloying elements of this steel is given in Table 1. The steel is produced by warm rolling process in which recrystallization takes place partially in the last stage. Thus, this steel has proper ductility and strength.

Table 1. Chemical Composition (wt%) of Steel Used (Balance Fe).

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

Grooves of V-shape of 6 mm width and 4 mm depth were machined at one surface of each plate to accommodate the weld material. In order to guarantee the quality of next steps, the two plates were cleaned chemically using hydrochloric acid.

B. *Sandblasting*

One of the two plates was sandblasted on the direction of the V-groove. This procedure was conducted using a compressed current of very small particles of grit of the type used in Dar-Assina'a ship yard in Misurata, Libya.

C. *Welding*

Gas metal arc welding (MIG) was used to produce weld beads of 10 mm width with GSi1 electrodes. The two plates, X and Y were put next to each other and fixed tightly to ensure welding in one pass and to prevent distortion as shown in Figure. 1.

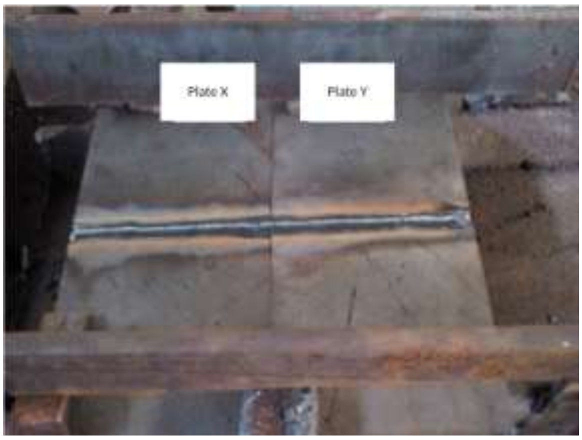

Figure 1. The Welded Plates.

D. *Magnetic Barkhausen Noise MBN Measurement*

Barkhausen noise technique has been used to investigate the nature of residual stresses in the predetermined condition of plates according to the experiment plan. Plate X is investigated in the as received and in the welded conditions. Plate Y is investigated in the sand blasted and the welded conditions. Mapping of longitudinal residual stresses at the back of each plate was established by in a parallel direction to the weld beads as shown schematically in Fig. 2.

The MBN measurements were made using a laboratory based equipment [13] as schematically 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.

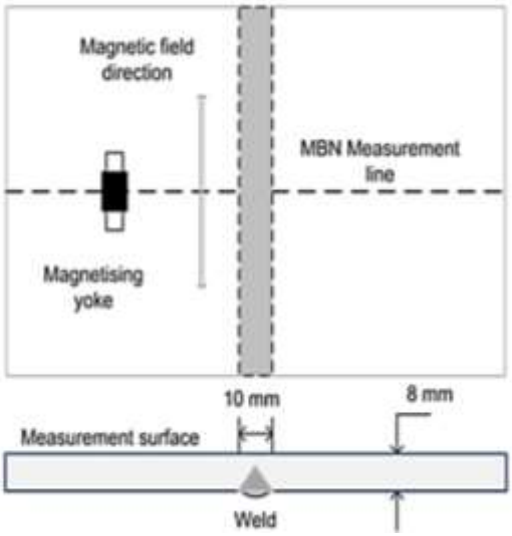

Figure 2. Schematic Layout of the MBN Measurement Arrangement

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 the inset of Figure. 3 to produce a measure of the peak height of the envelope enclosing the signal.

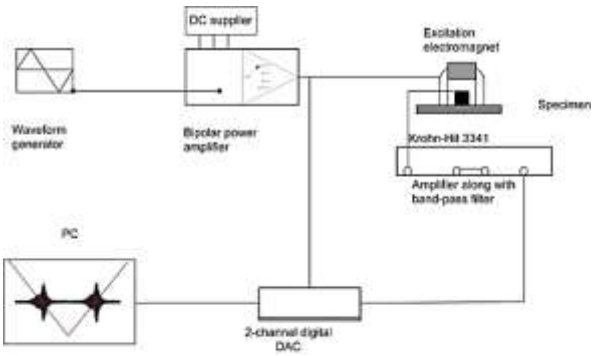

Figure 3. Schematic Layout of the MBN Measurement Apparatus [13]

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. The data was processed and smoothened using a Matlab script to generate the root mean square profiles characteristic of the captured signal.

III. RESULTS AND DISCUSSION

According to the experiment plan, plate X is cleaned and tested in the as received condition then welded and tested. Plate Y is cleaned, sand blasted and tested then it is welded and tested.

A. As-received (plate X)

The induced MBN signal from this plate shows almost a steady uniform MBN intensity along the test line as shown in Figure 5. Since, warm rolling process induces residual compressive stresses [14], it is used to make ship steel and thus the stresses produced are compressive. These stresses are uniform along the test line with no variation. This is the start point because any changes of this pattern reflects the effect of any mechanical processing applied to the plates.

B. Effect of welding (plate X)

Figure 4 shows some smoothened MBN profiles from this experiment in which a clear effect of the applied welding heat is apparent. MBN profiles show how the level of Barkhausen noise changes over the course of the magnetization cycle.

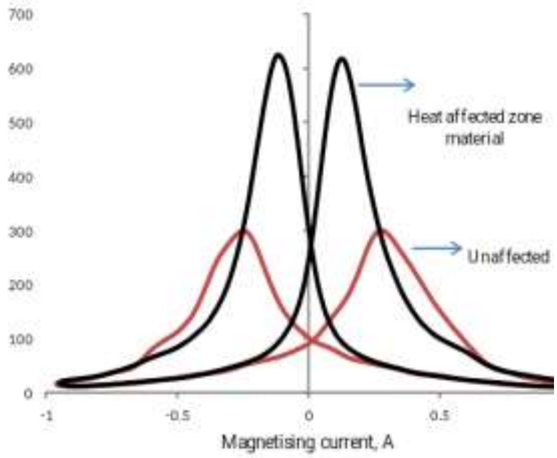

Figure 4. Examples of One Cycle MBN Profiles from Different Locations

In order to summarize the data for a subjective comparison of the material state, the peak height of every MBN profile is related to its measurement location on the test line perpendicular to the weld bead. Figure 5 shows MBN profile's peak height as a function of distance from the weld line. A clear pattern is noticed reflecting the heat affected zone. This is a sign of the accumulation of residual tensile stresses in those areas.

Before welding the stresses of the as-received plate were compressive while after welding the stresses in the weld and both sides of the HAZ were converted to residual tensile stresses. These stresses resulted because the welded part cools down to room temperature, but cannot fully contract as it is attached to the rest of the plate. On the other hand, the rest of the plate away from the residual tensile stresses formed showed a uniform stress pattern.

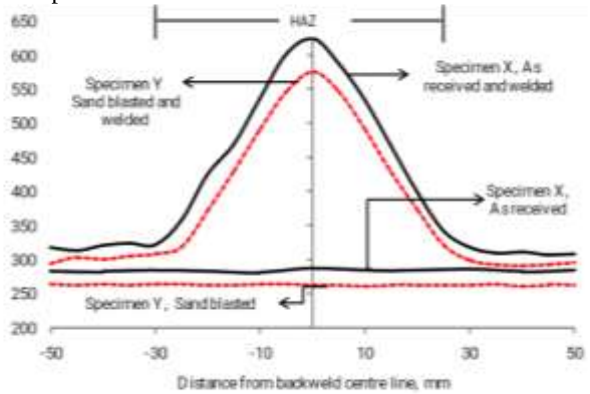

Figure 5. MBN Peak′s Height of Tested Plates

The MBN signal from steel increased under tensile stress but decreased under compressive stress [11]. This is why there was an increase in the MBN intensity in the weld and both sides of the heat affected zone as residual tensile stresses induced in these areas while the signal is uniform away from these areas.

C. Effect of sandblasting (plate Y)

It is generally agreed that shot peening and sandblasting are used to improve fatigue life, reduce the susceptibility to stress corrosion cracking of weldments besides their cleaning effect [15, 16]. Sandblasting was applied to plate Y and MBN signals resulted is shown in Figure 5. It can be clearly seen that the induced MBN signal showed almost a uniform MBN emission along the test line and not noticeable deviations can be observed. This is the result of applying sandblasting on the entire surface. This effect was proven in terms of the uniformity of residual compressive stresses induced. Sandblasting induces compressive stresses on the surface and that increases hardness [17] and the relationship between hardness and MBN is inversely proportional [11]. That is why the MBN level of the sandblasting plate is lower than the MBN signal of the as-received plate.

D. Effect of pre-weld sandblasting (plate Y)

This plate has been sand blasted before welding. The residual stresses in the as-received sample are compressive. Sandblasting adds more compressive stresses and decreases the MBN emission [10, 11]. The MBN measurements show that after welding the sandblasted plate, a pattern also appears in the relation of MBN peak height and the distance from the weld bead similar to that in plate X but of lower levels. That is an indication of the HAZ creation as a result to welding. The reduction is attributed to generation of compressive stresses due to sandblasting. These stresses decrease the amount of residual tensile stresses resulted from welding.

It can also be noticed that the difference between the response from the two plates are symmetric along the test line. Moreover, this difference is similar to that between the as-received and sand blasted plates before welding. This reflects the effect of sandblasting and suggests that welding after sandblasting results in a lower level of induced residual tensile stresses and hence reducing the risk of fatigue in structural components.

IV. CONCLUSIONS

1. Welding of the ship steel plates introduces residual tensile stresses in the heat affected zone.
2. Sandblasting introduces residual compressive stresses in ship steel plates.
3. Pre-welding sandblasting is beneficial in decreasing residual tensile stresses in the heat affected zone.
4. The amount of compressive residual stresses induced by sandblasting is maintained in the plate after welding.

REFERENCES

[1] Sindo Kou, “*Welding metallurgy*,” John Willey, 2nd edition, USA, 2003, pp. 122-140.
[2] R. Blondeau, D. Kaplan and G. Murry, *“Metallurgy and Mechanica of welding,”* ISTE Ltd and John Wiley & Sons Inc., 2008, pp. 89-126.
[3] E. Macherauch and K. H. Kloos, “*Origin, Measurements and Evaluation of Residual Stresses*,” Residual Stresses in Science and Technology, 1987, pp 3–26.
[4] H. I. Yelbay, I. Cam and C. H. Gür, “*Non-destructive determination of residual stress state in steel weldments by Magnetic Barkhausen Noise technique*,” NDT & E Int.43 (1), 2010, pp. 29-33.
[5] P. Colegrove, C. Ikeagu, A. S. Thistlethwait, S. Williams, T. Nagy, W. Wojciech A. Steuwer and T. Pirling, “*The welding process impact on residual stress and distortion*,” Sci. Tech. Weld. Join. 14 (8), 2009, pp. 717-725.
[6] N. S. Rossinia, M. Dassistia, K. Y. Benyounisb and A. G. Olab, “*Review Methods of measuring residual stresses in components*,” J. Mat. and Des. 35, 2012, pp. 572–588
[7] K. Tosha and K. Iida, “*Residual Stress on the Grit Blasted Surface*,” Met. Beh. & Surf. Eng. IITT International, 1989, pp. 323-328.
[8] O. Bouledroua, M. Hadj Meliani, Z. Azari, A. Sorour, N. Merah and G. Pluvinage, “*Effect of Sandblasting on Tensile Properties, Hardness and Fracture Resistance of a Line Pipe Steel Used in Algeria for Oil Transport*,” J. Fail. Anal. and Preven., DOI 10.1007/s11668-017-0313-4, 2017.
[9] D. Vikas, L. Snehal, L. Kishor, and Y. Kumar, “*Study Paper on Methods of Measurement of Residual Stress in Mechanical Components,”* Int. J. Res. App. Sci. & Eng. Tech. Vol. 5, Issue IV, 2017, pp. 1320-1324.
[10] M. Willcox and T. Mysak, “*An Introduction to Barkhausen Noise and its Application*,” Insight NDT Equipment Limited, 2004.
[11] B. Shaw, J. Evans, A. Wojtas and L. Suominen, *“Grinding process control using the magnetic Barkhausen noise method*,” In: Third International Workshop on Electromagnetic Non-Destructive Evaluation. IOS Press in the Series in App. Electr. Mech., 1998, pp. 82-85.
[12] D. C. Jiles, “*Dynamics of Domain magnetization and the Barkhausen Effect*,” Czech J Phys, 50 (8), 2000, pp. 893-988.

[13] *M. Blaow and B. Shaw, "Magnetic Barkhausen Noise Profile Analysis: Effect of Excitation Field Strength and Detection Coil Sensitivity in Case Carburized Steel*," Mat. Sci. Appl. 5(5), 2014, pp. 258-266.

[14] K. Kesaven, K. Ravisankar, S. Parivallal and P. Sreeshylam, "*Non-destructive evaluation of residual stresses in welded plates using the Barkhausen noise technique*," Exp. Tech, 2005, pp. 17-21.

[15] S. Chataigner, L. Dieng, K. Guiot and M. Grasset, "*Improving welded joint fatigue life using sandblasting or grinding*," in *TRB 92nd Annual Meeting*, France, 2013, pp. 8p, schémas, graphiques, ill. en coul., bibliogr.

[16] M. Obata and A. Sudo, "*Effect of shot peening on residual stress and stress corrosion cracking for cold worked austenitic stainless steel*," Nuclear Engineering Lab., TOSHIBA Corp., Japan, 1993, pp. 257-264.

[17] R. Yang, X. Zhang, D. Mallipeddi, N. Angelou, H. L. Toftegaard, Y. Li, J. Ahlström, L. Lorentzen, G. Wu and X. Huang, "*Effect of sandblasting on the residual stress and mechanical behaviour of low-temperature and high-temperature annealed martensitic gear steel 18CrNiMo7-6,*" *IOP Conference Series: Materials Science and Engineering*, vol. 219, p. 012046, 2017/07 2017.