PREDICTION OF SURFACE RESIDUAL STRESSES IN BUTT-WELDED STEEL PLATES BY MAGNETIC BARKHAUSEN NOISE ANALYSIS

C. Hakan GÜR [1, 3], H. İlker YELBAY [3], İbrahim CAM [2]

[1] Metallurgical and Materials Engineering Department, METU, Ankara, TURKEY
[2] Central Laboratory, METU, Ankara
[3] Welding Technology & Non-Destructive Testing Research/Appl. Center, METU, Ankara
yelbay@metu.edu.tr chgur@metu.edu.tr icam@metu.edu.tr

Abstract
Residual stresses have significant inflences on the service performance of the welded components. Various studies have been continuing to develop nondestructive methods for determination of residual stresses with portable equipment and short measurement time, as an alternative to the existing techniques such as X-ray diffraction. This study aims to investigate the applicability of Magnetic Barkhausen Noise method on predicting surface residual stresses in the welded steel plates.

Keywords: *Welding, Residual stress, Non-destructive evaluation, Barkhausen Noise*

1. Introduction

Most of the objects such as vehicles, pipe lines, ships, airplanes, computers and medical devices, could not be produced without welding. In most welding applications on steels since there is a high heat input, non-uniform temperature distribution and phase transformation generate different residual stress patterns in the weld and the heat affected zone (HAZ). Each stress generating mechanism has its own effects on the residual stress distribution [1,2].

Residual stresses, self-balanced elastic stresses remained in the material after removal of external influences, should be considered at the design state as an additive value to the service stresses. Previous studies have shown that fatigue and stress corrosion failures can often be traced back to the residual stresses. Therefore, determination of residual stresses is important for quality, integrity and service performance of the welded components and structures.

Residual stresses can be measured by destructive methods such as hole-drilling and layer removal; or by non-destructive methods like X-ray diffraction, ultrasonic, and magnetic methods [3]. Magnetic Barkhausen Noise (MBN) technique is applicable to ferromagnetic materials, which are composed of small order magnetic regions called magnetic domains. Each domain is spontaneously magnetized along the easy axes of the crystallographic magnetization direction. However, magnetization vectors inside the domains oriented in such a way that the total magnetization of the material is zero except for natural magnets. Domains are separated from each other by domain walls, i.e., Bloch walls. Since 180° domain walls show greater mobility than 90° domain walls their contribution to MBN emission is higher [5]. If an external magnetic field is applied to a ferromagnetic substance, the magnetization of the sample changes due to the domain wall movements. Domains with alignments parallel or nearly paralel to the applied field vector expand

and others annihilate during magnetization. Saturation occurs when all of the magnetization vectors in the domains align themselves in the direction of applied field by domain wall movements [6].

In ferromagnetic materials grain boundaries, second phases, and dislocations act as a barrier to the movement of domain walls. By the application of higher magnetization force values, force on the domain wall exceed the restraining force due to pinning sites, so there is an increase in the magnetization in small jumps, which also give rise to hysteresis [6]. This magnetisation change can be detected by an inductive coil. When the electrical pulses produced by all domain movements added together a noise like signal called as Magnetic Barkhausen Noise (MBN) is generated [7].

It is known that elastic tensile stresses increase the MBN values whereas elastic compressive stresses decrease them. Therefore, the measured MBN values can be converted to the residual stress values after establishing a calibration curve [3, 4, 6, 8, 9]. In this study, residual stresses on the butt-welded steel plates were measured by an automated MBN measurement system following the calibration procedure. These results were evaluated by considering the results of hole drilling method, metallographic investigations and hardness measurements.

2. Experimental Study

API 5L X70 steel (0.04%C, 0.39%Si, 1.48%Mn, 0.08%Ni, 0.031%Al, 0.16%Cu, 0.03%Cr, 0.02%Ti, 0.05%Nb) plates with dimensions of 300x80x15 mm were used. It has the elastic modulus of 213 GPa and the yield strength of 597 MPa.

After surface preparation by abrasive machining, V-shaped groove was opened with a width of 10 mm and depth of 10 mm. Plates were tack welded to the table for eliminating any distortion during welding and cooling. Metal Active Gas welding technique was applied with G3Si1 electrodes using 22 V, 140 A.

After demagnetizing the samples to eliminate the effects of remanent magnetization, stress measurements were performed using Rollscan 500-2 and S1–138–13-01 probe with 20 dB amplification. The excitation frequency was 125 Hz, and the signals were filtered in the range of 70-200 kHz. The probe was attached to a motor driven platform for precise and continuous measurement. Three measurement lines which are separated 20 mm from each other were defined. The plate was put on this platform which was driven at a constant speed of 2 mm/sec. For each measurement, the position of the probe was carefully aligned to get a full contact with the surface. About 1500 MBN data were recorded along each line.

MBN values were converted to the residual stress values via calibration curves. One calibration sample was prepared from the heat affected zone which is also used for HAZ based calibration method, and the other one was prepared from the base metal. After adhering a single element strain gauge to the calibration samples, tensile and compressive stresses in the elastic deformation range were applied to the specimens in a step-wise manner by a loading set-up. Then, the strain values transformed to the stress values by using elasticity equations. In parallel to the strain-gauge measurements MBN values were measured, and the calibration curve for elastic stress versus MBN parameter was established. For the MBN values outside the calibration curve, extrapolation method was applied to predict the corresponding stress values, which might be a source of error.

For metallographic investigations each specimen was finely ground, polished, and then, etched in %2 Nital solution. Vickers hardness measurements were conducted with 10 kg load.

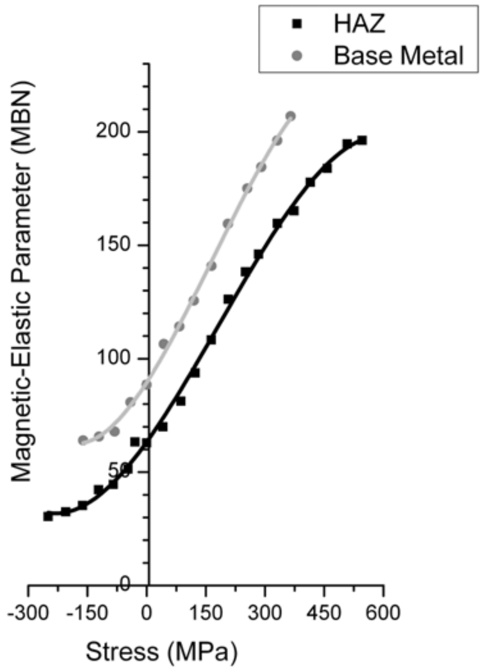

Figure 3. Calibration curves

3. Results and Discussion

In the metallographic examinations, the four main zones were observed: base metal consisting of elongated ferrite-pearlite with an average grain size of 10-15 μm; weld metal having acicular ferrite with average grain size of 5 μm; coarse grained (25-30 μm) and fine grained (3-5 μm) HAZ regions. Figure 4 shows the representative micrographs of the base metal and HAZ.

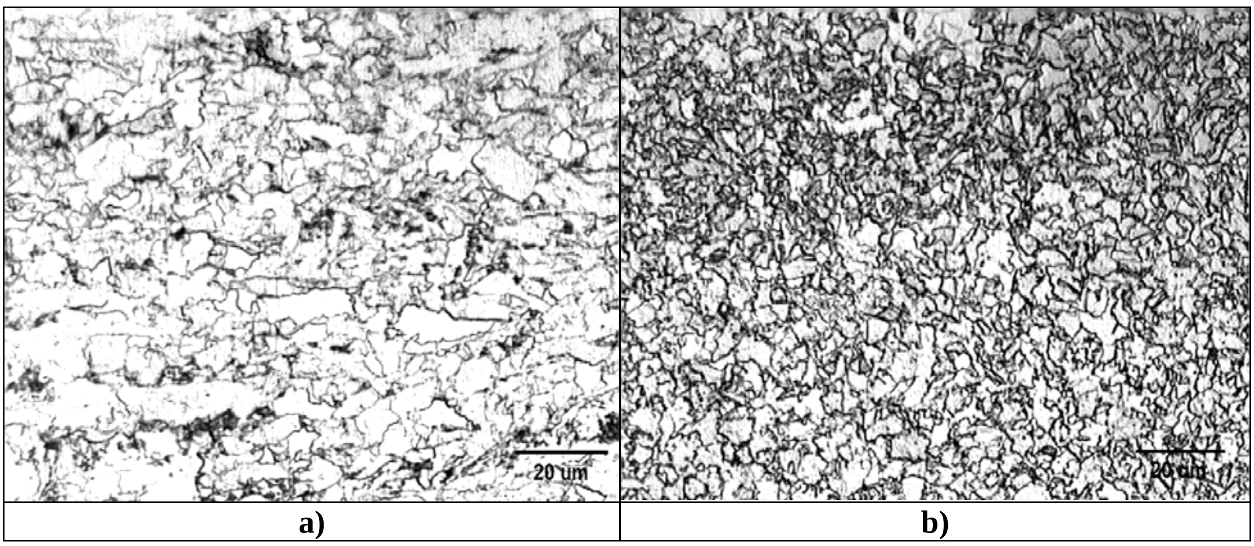

Figure 4. Representative micrographs: a) parent metal, b) coarse-grained HAZ

Hardness measurements with 1 mm interval were conducted along the measurement lines. Hardness profile on the front surface given in Figure 5 shows the effect of grain coarsening near the weld.

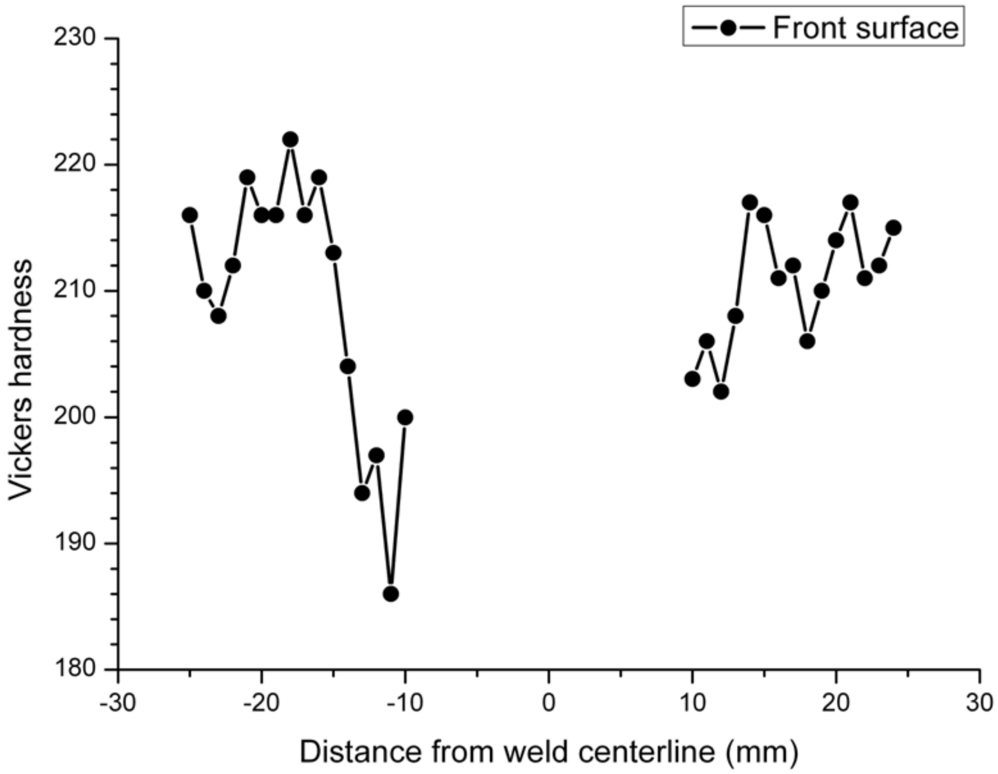

Figure 5. Hardness profile of the welded plate

The surface longitudinal residual stress values obtained for the parent metal based calibration are given in Figure 6. The decline of the stresses near the weld line can be explained by grain coarsening because MBN emission decreases with increasing grain size.

Since microstructure has a significant effect on MBN activity, HAZ-based calibration method is expected to give different residual stress values. Figure 7 shows the results of HAZ based calibration method in which higher magnitudes for the residual stress values, compared to those of parent metal based calibration, were obtained. Therefore, depending on the severity level of the microstructure effect on MBN emission, the residual stress values determined by MBN measurements may show deviations from the exact values.

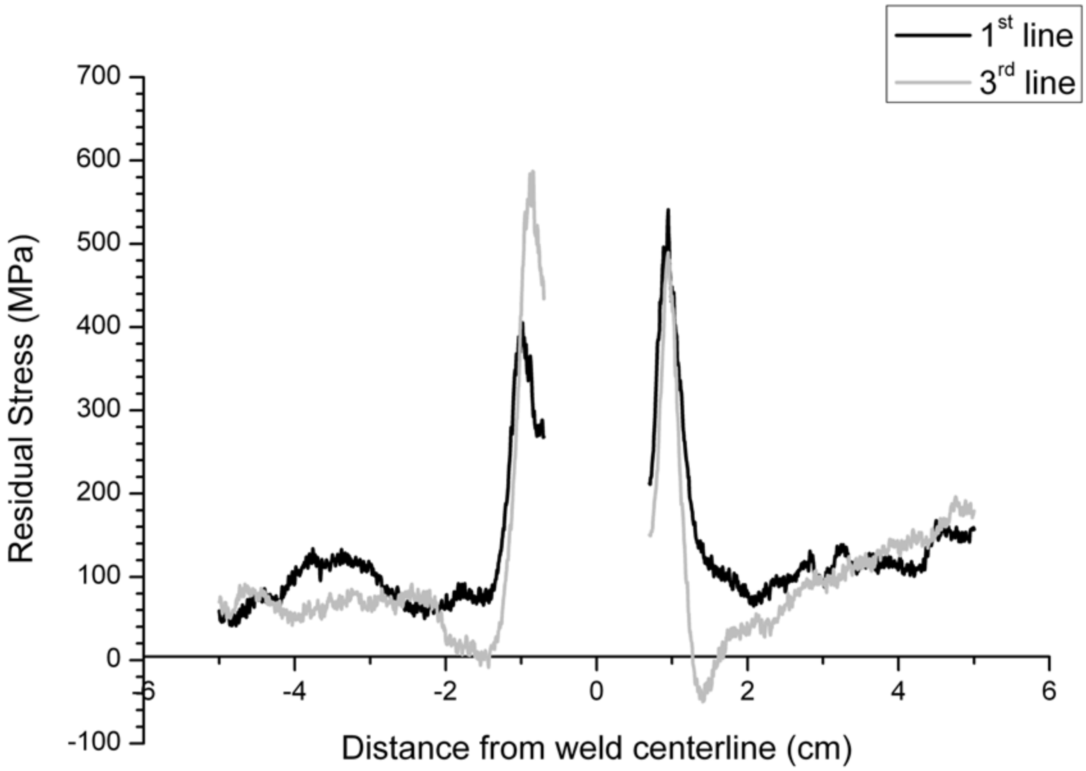

Figure 6. Residual stress profile on the front surface (calibrated on parent metal)

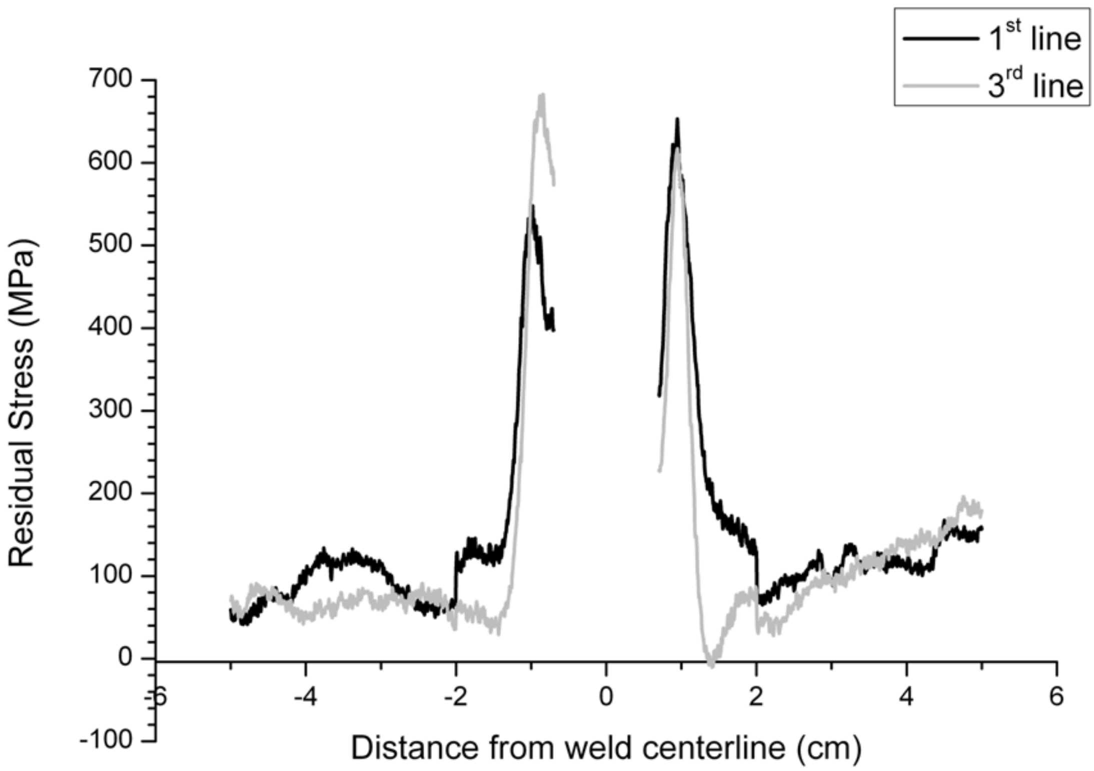

Figure 7. Residual stress profile on the front surface (HAZ-based calibration)

4. Conclusion

Surface residual stress profiles of the welded API 5L X70 steel plates were determined via a Magnetic Barkhasuen Noise (MBN) measurement system having automated scanning ability. The MBN measurement results were analyzed by using a stress versus MBN parameter calibration curve. The results were evaluated by considering the microstructure investigations and hardness measurements.

It is concluded that MBN technique is a promising nondestructive technique for prediction of surface residual stresses on welded ferritic steel plates. MBN parameter versus elastic stress calibration curve is very important for accuracy and reliability of the results. The zones having remarkably different microstructure should be considered in the calibration procedure.

References

1. Withers PJ, Bhadeshia HKDH, “Residual stress-Part 2: Nature and Origin”, Mater Science Technology, 17 (2001) 366-375.
2. Macherauch E, Kloos KH, “Origin, Measurements and Evaluation of Residual Stresses”, Residual Stresses in Science and Technology, DGM Inform. Verlag, 1987, 3-26.
3. Ju JB, Lee SK, Jang J, Kim WS, Kwon D, “Determination of Welding Residual Stress Disrtribution in API X65 Pipeline Using a Modified Magnetic Barkhausen Noise Method”, International Journal of Pressure Vessels And Piping, 2003, 641-646.
4. Kesavan K, Ravisankar K, Parivallal S, Sreeshylam P, “Non Destructive Evaluation of Residual Stresses in Welded Plates Using the Barkhausen Noise Technique”, Experimental Techniques, September/October 2005, 17-21.
5. Altpeter I, Dobmann G, Kröning M, Rabung M, Szielasko S, “Micro-magnetic Evaluation of Micro Residual Stresses of the IInd and IIIrd Order”, NDT&E International, 42 (2009) 283-290.
6. Jiles D, “Introduction to Magnetism and Magnetic Materials”, Chapman and Hall, London; New York, 1991.
7. Lu J, “Handbook of Measurement of Residual Stresses”, Society for Experimental Mechanics, 1996.
8. Gauthier J, Krause TW, Atherton DL, “Measurement Of Residual Stress in Steel Using the Magnetic Barkhausen Noise Technique”, NDT&E International, 31 (1998) 23-31.
9. Yelbay I, Gür CH, “Non Destructive Determination of Residual stress State in Steel Weldments by Magnetic Barkhausen Noise Technique”, NDT&E International, 43 (2010) 29-33.