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Magnetic Technique Estimation of Weld Residual Stress Failure Due to Tensile Loading

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Abstract

In Nigeria, most welding activities are carried out by road side welders, majority of this welders are ignorant of weld residual stress and its adverse effect on weldment. Residual stress (RS) measuring device is vital in the measurement of inherent stresses in material. The aim of this research was to employ proof of principle in analyzing the weld residual stresses in a material. This was achieved by measuring samples with magnetic residual stress device and then subjecting the weld samples to mechanical tensile test with hope that materials with more residual stresses fail first. Finally the result from both procedures was compared to establish a relationship. Four (4) pieces of mild steel coupons measuring 100 × 40 × 3 mm were welded, producing two specimens, A_{11} and B_{11} of 200 × 40 × 3 mm, respectively. The specimens were measured using the Magnetic device developed and 37 signals were obtained per specimen, thereafter, the welded specimens were subjected to tensile testing and results analyzed. From the results obtained, Specimen A_{11} was observed to have the highest signal peak at the weld zone with RS signal of 20.3983 mV compared to B_{11} with 19.358 mV. While under tensile loading, it took 1.63 kN to cause failure to specimen A_{11} and 8.65 kN for specimen B_{11}. From this simple experiment, it implies that the Magnetic RS device was able to mimic the behavior of residual stress and also predicted that A_{11} would fail first.

Keywords

Residual Stress (R.S), Magnetic Barkhausen Noise (MBN), Signals, Tensile Test

1. Introduction

Welding can be regarded as the joining of two or more separate metals to form a single piece of metal with a permanent joint [1]. Residual stresses develop in welded materials due to sharp changes of temperature during welding [2]. Welding processes create heat at elevated temperatures which are transferred to the parent metal's matting interface for melting of the joints for bonding. If the heat is too high, it creates excessive heat input in the workpiece which results into a poorly welded joint as well as increase in residual stress, in and around the joint. On the other hand, low heat input also creates poor bonding of parent metal [3]. Therefore, the need to use a proper process parameter cannot be over emphasized. Usually, failures that result from these types of stresses are difficult to monitor by visual inspection, hence the need of a sophisticated device. Currently, there are no known welding process parameters that can totally eliminate residual stress in welded material [4] and [5]. In Nigeria, most welding activities are carried out by road side welders, and the majority of them are ignorant of weld residual stress and its adverse effect on welded joints. This type of stresses is known to encourage corrosion and reduce the load carrying capacity of weldment, it is very possible that some of the structural failures experienced in Nigeria, might result from this type of stresses [6] and [7].

The measuring of residual stress (R.S) can be done using three basic methods which are the "destructive", "semi-destructive" and "the non-destructive methods" [8]-[13]. For the Nigerian roadside welders, the non-destructive method is ideal and preferred in measuring/estimating stresses as materials would not need to be destroyed during measurement. The Magnetic Barkhausen Noise (MBN) residual stress measuring device is affordable and less complicated compared to the x-ray diffraction method. Although the x-ray diffraction method offers more accuracies and is more robust, but can only be applied in the lab as against the Magnetic Barkhausen Noise (MBN) which can be used outdoor. The Magnetic Barkhausen Noise (MBN) device can be locally fabricated using proof of principle.

The aim of this research was to measure residual stress signals in welded materials using magnetic residual stress device, employ proof of principle to analyze weld residual stress by subjecting weld samples to mechanical tensile test, with hope that materials with more residual stresses fail first and also compare both results obtained to establish the efficiency of the device.

2. Materials and Methods

2.1. Materials

6 mm Mild steel plate was purchased locally, the material was cut into four (4) pieces coupons measuring 100 × 40 × 3 mm, and welded. The process parameters in **Table 1** were emplyed in the welding process, using the stick arc welding machine having a constant voltage of 62 volts and an adjustable current. The reason for varying the current was to introduce different magnitude of residual stresses to the weldment. The four (4) pieces were welded to form two specimen, A_{11} and B_{11} of 200 × 40 × 3 mm respectively. This specimen was measured using

Table 1. Weld process parameters.

Sample	Current (Amp)	Voltage (V)	Weld Speed (mm/s)
A_{11}	130	62	2.063
B_{11}	120	62	2.497

the magnetic device developed locally by [14], the unit readings obtained from this measuring device are in milli-volts. During measurment, minute voltages which result from magnetic domain flip in the mild steel material, are detected by the pickup coil as the device moved over the surface of the specimen. The pulsating voltages are continously fed to the inbult amplifier in the device for magnification, presented in **Figure 1** is the setup of the device for measurement. The graphical user interphase (GUI) was developed using LabVIEW as shown in **Figure 2**. The Residual stress measuring device was designed using arduino nano, and enhanced to 16 bits resolution using ADS1115 which was connected directly to the pickup coil in **Figure 3**. The welded specimens were tack welded as seen in **Figure 4** before actual welding and chamfering to the dogbone shaped shown in **Figure 5**. The tensile testing machine used for the mechanical test is presented in **Figure 6**.

2.2. Method

Specimen A_{11} and B_{11} were measured using the magnetic residual stress (R.S) measuring device [14]. Five repeated readings were collected and compared for consistency, with combined time series plot for A_{11} and B_{11} presented in **Figure 7** and **Figure 8**. Thirty-seven signals were generated per reading from the welded metal in milliVolts. Thereafter, the two specimens were subjected to tensile test with the hope that the specimen with more residual stress would fail first under tensile loading. The weld RS was measured along the longitudinal directions of the plate as shown in **Figure 9**. Measurements using the magnetic device were carried out on the specimens, before the materials were subjected to mechanical test.

3. Results and Discussion

3.1. Results

Table 2 shows the magnetic R.S signals generated in millivolts from the welded specimen A_{11} and B_{11} using the device.

The 1st, 2nd, 3rd, 4th and 5th reading presented in **Figure 7** and **Figure 8** for A_{11} and B_{11} shows a good agreement. First (1st) magnetic readings from A_{11} and B_{11} were selected to form **Table 2**. The A_{11} and B_{11} from **Table 2**, were then employed to plot the time series graph shown in **Figure 10**. From this graph, it was observed that Specimen A_{11} had the highest peak signal at the weld zone with magnetic R.S signal of 20.3983 mV compared to B_{11} with 19.358 mV. After the readings where obtained, the two specimen were subjected to tensile test. After the readings were obtained from the specimen, the two specimen were subjected to tensile test, with results presented in **Table 3**.

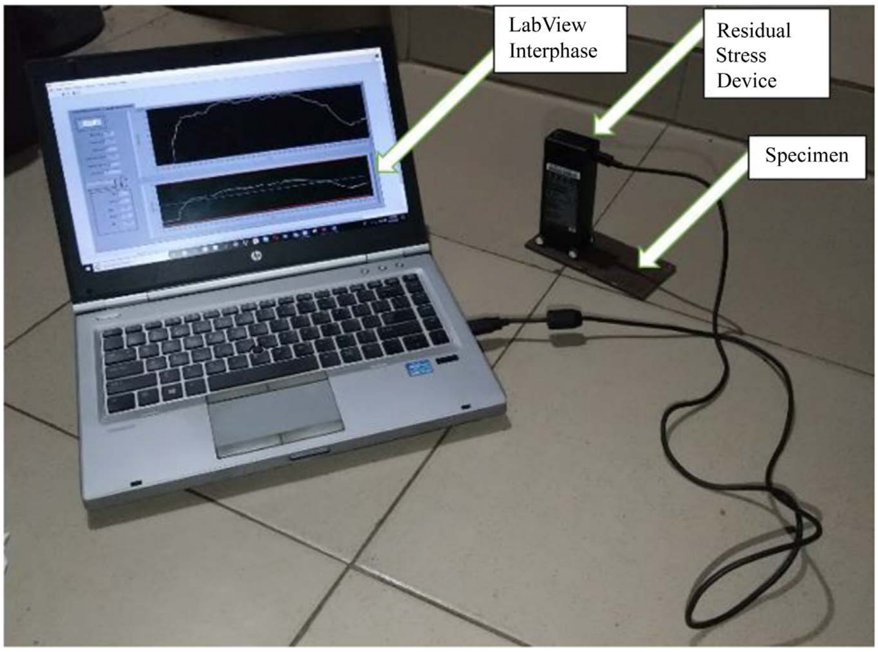

Figure 1. Magnetic measuring device.

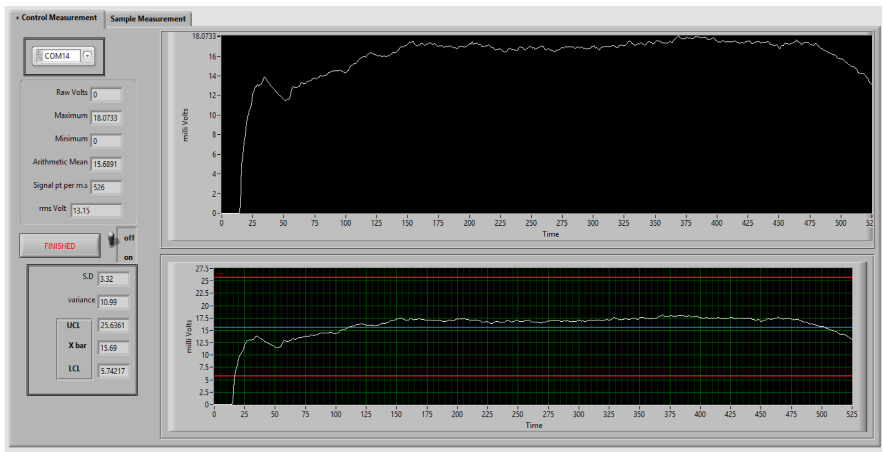

Figure 2. GUI for the local MBN device.

Figure 3. Internal component of magnetic device.

Figure 4. A_{11} and B_{11} tack welded specimen.

Figure 5. Dogbone specimen for A_{11} and B_{11}.

Figure 6. Tensile testing machine.

Figure 7. Combined time plot for 1st, 2nd, 3rd, 4th and 5th signal for A_{11}.

Figure 8. Combined time plot for 1st, 2nd, 3rd, 4th and 5th signal for B_{11}.

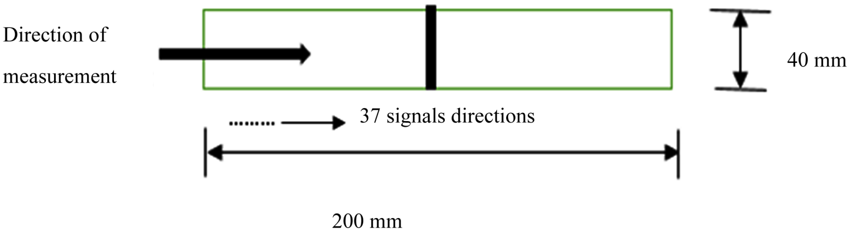

Figure 9. Direction of R.S Measurement on specimen.

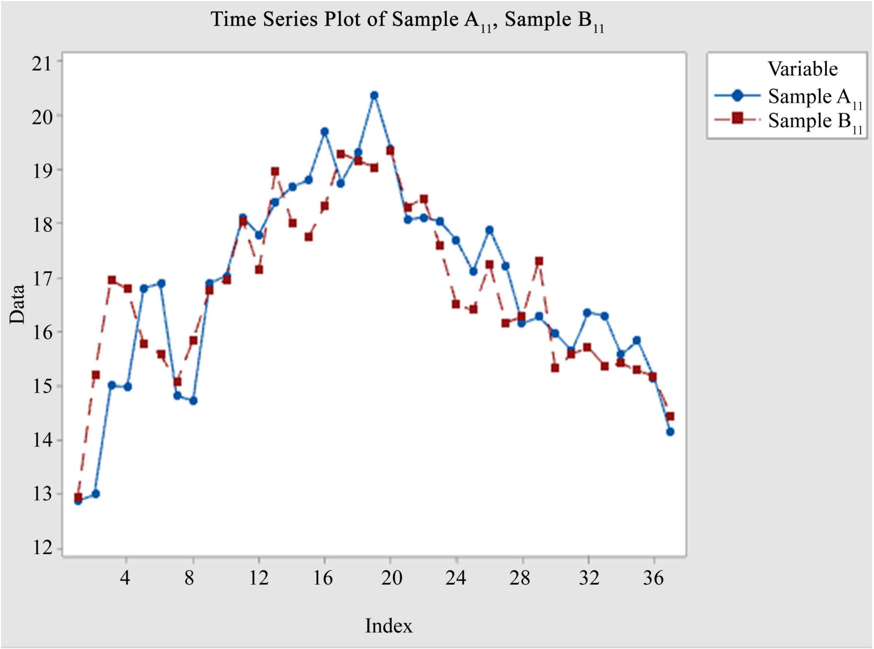

Figure 10. Combined time series plot for sample A_{11} and Sample B_{11} (Experimental).

Table 2. Magnetic RS signal Results from specimen A_{11} and B_{11}.

S/N	Experiment		S/N	Experiment		S/N	Experiment	
	Sample A_{11} (mV)	Sample B_{11} (mV)		Sample A_{11} (mV)	Sample B_{11} (mV)		Sample A_{11} (mV)	Sample B_{11} (mV)
1	12.8809	12.95	14	18.6835	18.0254	27	17.2299	16.177
2	12.9952	15.1971	15	18.8031	17.7502	28	16.1576	16.2796
3	15.0061	16.9532	16	19.6994	18.3294	29	16.2763	17.3237
4	14.9904	16.7997	17	18.7687	19.3058	30	15.9829	15.3248
5	16.8099	15.7911	18	19.3166	19.1585	31	15.6465	15.5936
6	16.9002	15.5948	19	20.3983	19.0515	32	16.3629	15.7148
7	14.8209	15.0768	20	19.3983	19.358	33	16.2984	15.3768
8	14.7334	15.8554	21	18.0721	18.3155	34	15.5793	15.4212
9	16.901	16.7733	22	18.1208	18.4627	35	15.8385	15.2856
10	17.0368	16.9787	23	18.0433	17.5904	36	15.1553	15.1853
11	18.1157	18.0628	24	17.6922	16.5015	37	14.1407	14.4525
12	17.8038	17.1557	25	17.117	16.4052			
13	18.3986	18.9685	26	17.9042	17.2461			

Table 3. Tensile test for A_{11} and B_{11}.

S/N	Specimen	Tensile Test
1	A_{11}	1.63 kN
2	B_{11}	8.65 kN

Tensile Stress Test

Is a great way to examine the strength of a material by pulling on it. During the pulling of the specimen by the machine, the machine scale would indicate how much force it is applying to pull the specimen apart. When tensile test is performed, it is used to measure how much stress is built-up in the material. Specimen A_{11} and B_{11} already have some accumulated residual stresses as result of the weld activity on the material, therefore it is expected that the material with more accumulated R.S would fail first under tensile loading. Table 3 present the results of the tensile test experiment.

From the result presented in Table 3, it was observed that it took a minimum load of 1.63 kN to cause failure to specimen A_{11} under tensile loading while specimen B_{11} withstood up to 8.65 kN before failure which also concur to the Magnetic device estimated readings obtained for sample A_{11} and B_{11}.

3.2. Discussion

Ferromagnetic materials can exhibit attraction when a magnet is brought close to or away from them, which creates a magnetic attractive effect on them. This magnetic effect is generated due to the magnetic domains flipping into positions inside the ferromagnetic material, creating an imbalance on the net magnetic effect inside the material, making the ferromagnetic material behave like a magnet, this imbalance usually cancels out when a lightly tap or shake is delivered to the material. The principle, discovered by bark hausen has been applied to measure residual stresses in ferromagnetic material as it is known that magnetic domain usually experience obstacles while flipping into position due to presence of impurities or inherent stresses in the material [15]. The Magnetic Barkhausen principle was applied in this work using a locally made magnetic device to estimate the magnitude of stresses present in the material. The results were then compared to the tensile test experiment performed on both specimen. It was observed from Figure 7 in the comparison of all A_{11} results that good agreement existed between the 1st, 2nd, 3rd, 4th and 5th readings. Good agreement was also established for B_{11} in Figure 8, the repeated experiment was applied to certify the reliability of the device in reproducing experiments of approximate results. The first responses from A_{11} and B_{11} presented in Table 2 were chosen after Figure 7 and Figure 8 produced a strong correlation between repeated readings respectively. The results in Table 2 were applied to create the time series plot presented in Figure 10, A_{11} was then observed to have higher signal of 20.3983 mV, as compared to B_{11} with 19.358 mV, and according to [16], material that has higher residual stresses tends to fail first under a given load. From the tensile test carried out on both A_{11} and B_{11}, A_{11} failed under a lesser load of 1.63 kN, while B_{11} withstood a better load of up to 8.65 kN as predicted by the device.

4. Conclusion

In this research, specimen A_{11} and B_{11} welded with welding current of 130 Amp and 120 Amp at 62 V each were measured using the locally made magnetic residual stress estimating device. It was observed that the device was able to estimate residual stress signals in weldment and showed that A_{11} had more residual stress, but nosedived in clearly giving a good marginal difference between the two specimens, this shortfall in accuracy was somehow tied to the pickup coil design and its limitation. Hence, a second opinion, like the mechanical test would always be required for accurate conclusion. This technique can be improved upon to suit the Nigeria welding industries and help with better decision making during and after welding, to predict durability of welded components. The Nigerian fabrication industry especially the roadside artisans in time past, welded metals without knowing the nature or magnitude of RS present before or after weld which is regarded as "blind welding", such types of welding have resulted in numerous failure of components at different magnitudes and also aided quick corrosion activities in welded metals. A_{11} was observed to have higher signal of 20.3983 mV and failed under a minimum load of 1.63 kN while B_{11} with 19.358 mV had a lesser residual stress, hence was able to withstand stresses up to 8.65 kN.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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