Visual Abstract

Evaluation on fatigue behaviour of spot-welded joint under low blow impact treatment

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ABSTRACT. Welding is used widely in modern industries to combine parts needed complete a product. In this paper, we investigated the effect of post-weld impact treatment (PWIT) on spot-weld joints and evaluate the tensile and fatigue properties of the specimens. Currently, there is no simple failure criterion capable of predicting the strength of a spot weld under different loading conditions. The reliability of spot-welded structures treated with PWIT in terms of fatigue integrity could be understood more by the end of this research. The result showed that not only the tensile properties of PWIT specimens give an improvement, but there was also a significant increase in the fatigue life of the treated specimens.

KEYWORDS. Fatigue; Post-weld; Welding; PWIT

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INTRODUCTION

Spot welding is used in many areas such as electronics, orthodontics, and the automobile industry. Industrial production of technical goods, especially of investment goods, is hardly conceivable without joining technology [1]. Statistically, there are about 2000 to 5000 spot weld joints on a modern vehicle, hence the durability and safety design of cars, the strength of the spot weld under quasi-static conditions of impact, and fatigue loading are therefore immensely crucial [2]. During the spot welding process, high temperatures will be experienced by the welding material. Once a material undergoes any process involving significant temperature increases such as welding, the mechanical properties of the said object will vary due to microstructure changes and thermal stress within the structure will be built. As it starts cooling, the metal is subjected to shrinkage caused by sudden thermal stress. These stresses can, in turn, distort and warp the welded assembly. The welding situation is complicated because heating is much localized, and the base metal will melt during the process. The process left the structure in residual tension and reactionary compressive stress is established in parts regions away from the weld. This phenomenon will occur in almost all welding processes. In addition to residual stress and distortion, other defects may occur in welding [3, 4].

Post-welding treatment on the welded material is carried out to reduce and redistribute the residual stress in the material introduced by welding. Post-welding treatment is one of the crucial steps for producing high-quality welding. The treatment aims at improving the mechanical properties of the joint and reducing the thermal stress created during the welding process [7]. Post weld treatment can be classified into two main groups which are Post Weld Heat Treatment (PWHT) and Post Weld Impact Treatment (PWIT). PWHT, also known as artificial aging and solution treatment is performed on the welding specimen after the welding process has been carried out. Post heating is used to minimize the possible cracking of hydrogen [12]. PWIT is necessary to improve the tensile strengths of the welded structure in the spot-welding process because the mechanical properties of the welded joint was reduced due to the distortion and stress corrosion cracking caused by the welding process[6]. Stress relief shall eliminate any internal or residual stress from the operation. Post-welding stress relief is required to minimize the risk of brittle fracture, prevent further deformation or eliminate the potential of stress corrosion [8, 5]. PWIT consists of several processes, such as shot-peening, hammer-peening, and impact. PWIT can be performed via Low Blow Impact Treatment (LBIT). The LBIT involved low-speed impact without destroying the samples [9].

Goods or things that we purchase usually come with a warranty period. On the other hand, this can also be defined as the fatigue life of each product. Fatigue life simply means the number of stress cycles it can stand before the structure start to crack [10]. There are three types of fatigue loadings; fully reversed, repeated, or fluctuating. For fully reversed, the stress ratio, R = -1, stress ratio is the value of minimum stress (σ_{min}) divided by maximum stress (σ_{max}) experienced by the structure, shown in Eqn. (1)

$$R = \frac{\sigma_{min}}{\sigma_{max}} \tag{1}$$

Engineering components and structures are subjected to cyclic loadings with the presence of mean stress. The fatigue behavior of metals can be predicted by various mean stress models. Normally, for zero mean stress (R = -1), the Basquin equation is used to determine the fatigue life of any given specimen as described in Eqn. (2),

$$\sigma_a = \sigma_f^{'}(2N_f)^b \tag{2}$$

Where σ_a is the stress amplitude, σ'_f is the fatigue strength coefficient, N_f is the fatigue life (cycles) and b is the fatigue strength exponent. As tension-tension type of loadings is used for our experiment i.e non-zero mean stress, several approaches can be used to find the fatigue life. For the simplicity of this research, only two approaches are chosen which are the Morrow and the Smith, Watson, and Topper (SWT) mean stress models. The Morrow model predicts that the mean stress gives a more significant effect on longer lives compared to the shorter lives fatigue cycle, where the plastic strain is large. The equation for Morrow is given in Eqn. (3) [13]

$$\frac{\sigma_a}{\sigma_{ar}} + \frac{\sigma_m}{\sigma_f^{'}} = 1 \tag{3}$$

where σ_m= mean stress and σ_{ar} is the equivalent stress amplitude resulting from the same fatigue life.

SWT approach assumed that the product of maximum stress, σ_{max} and the strain amplitude, ε_a in the strain-life model controls the life. The SWT model gives a good estimation of fatigue life in the high cycles fatigue region. A life equation for SWT in Eqn. (4);

$$\sigma_{ar} = \sqrt{\sigma_{max}\sigma_a} \tag{4}$$

where σ_{max}= maximum stress

Currently, there is no simple failure criterion capable of predicting the strength of a spot weld under different loading conditions. The basic relationship between PWIT and fatigue properties can be established by completing this project and acting as a reference to other researchers. The need for post-welding treatment is driven by code and application and service environment.

Fatigue improvement procedures are now being used in many different industries. The crane, aircraft, spacecraft, and automobile industries are some examples. Material usage in the automotive industry has been significantly lowered in recent years with the application of fatigue improvements. This has brought positive impacts to the industry such as minimal fuel consumption, maximizing power output, increased security, etc. PWT is accepted as the standard method of extending offshore structures throughout the last seven years [15].

In this paper, the effect of PWIT on spot-weld joints and fatigue properties of PWIT specimens are to be investigated. To achieve that, several scopes are outlined for this research. 40 specimens made from mild steel are prepared according to American Welding Standard (AWS). One specimen is made up of 4 different parts which are spot welded together. The first 2 parts are made from the same dimensions which are (105 mm x 45 mm x 1 mm) and the dimension for another 2 parts is (45 mm X 45 mm x 1mm).

The welding process is performed using a spot welder machine with a rated capacity of 75 KVA and electrode tip of 5 mm. 33 specimens will then undergo post-weld treatment known as Low Blow Impact Treatment (LBIT). During LBIT, six different heights are chosen which are 12 cm, 16 cm, 20 cm, 24 cm, 28 cm, and 32 cm. A tensile test will be conducted on 20 specimens (18 treated & 2 untreated), and the maximum load for each of six different heights is recorded. Another 20 specimens (15 treated & 5 untreated) will then be brought into the fatigue testing. However, only 3 heights are chosen which are 12 cm, 20 cm, and 28 cm. The specimens will then be tested for $0.9\sigma_{max}$, $0.8\sigma_{max}$, $0.7\sigma_{max}$, $0.6\sigma_{max}$ and $0.5\sigma_{max}$ with a load ratio, R = 0.1

METHODOLOGY

Detailed studies on fatigue properties of welded samples can only be carried out correctly if the samples are prepared properly according to American Welding Societies (AWS). A Series of processes must be gone through by the samples to ensure an accurate result is obtained. Fig. 1 shows the flow chart of the methodology.

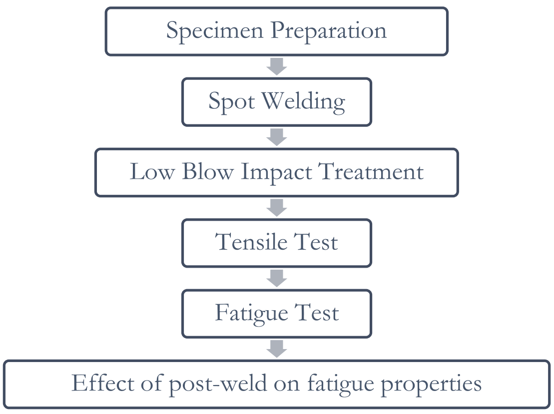


Figure 1: Flow Chart of Methodology

Specimen Preparation

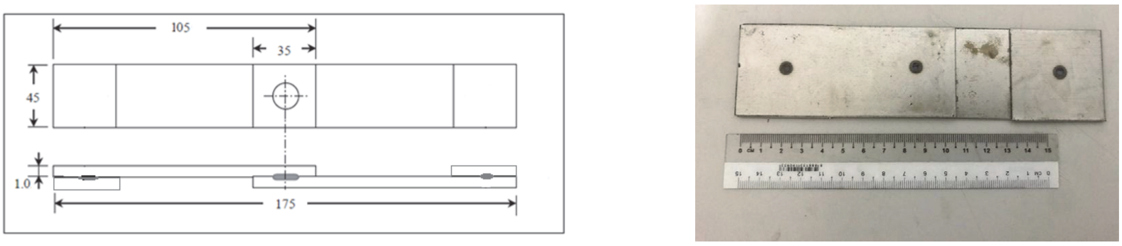
Forty specimens were prepared from mild steel. These specimens were prepared according to American Welding Standard (AWS). Each specimen is comprised of 2 rectangular parts and 2 square parts of equal size. The dimension for the rectangular part is (105 mm x 45 mm x 1.0 mm) meanwhile for the square part is (45 mm x 45 mm x 1.0 mm) as shown in Fig. 2(a). The parts were cut by using a shear machine as shown in Fig. 2(b).

Spot Welding

The welding process was performed using a spot welder machine with a rated capacity of 75 KVA and an electrode tip of 5 mm. Firstly, two parts with equal sizing (105 mm x 45 mm) were spot-welded together as shown in Fig. 3(b)[11]. Then another two parts of equal sizing (45 mm X 45 mm) were welded at each end of the welded structure. The dimension for a welded specimen is illustrated in Fig. 3(a).

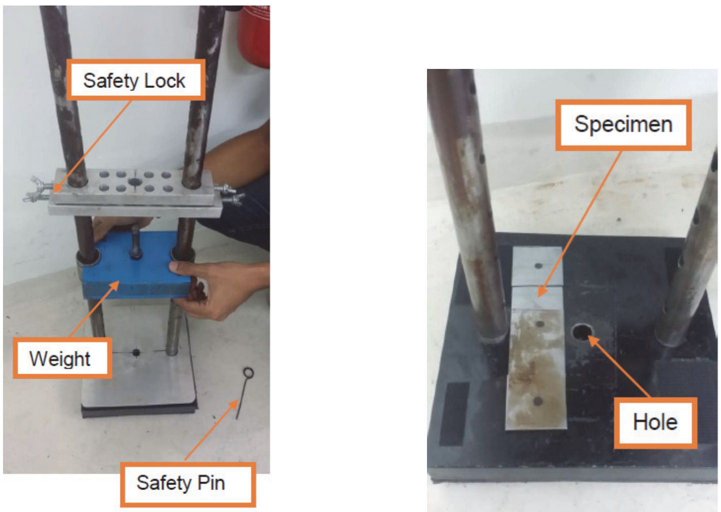
(a) (b)

Figure 2: Specimen preparation: (a)Dimension for rectangular and square parts; (b) Shear machine



(a) (b)

Figure 3: Spot Weld Specimen: (a) Dimension of a Welded Specimen; (b) Spot welded specimen



(a) (b)

Figure 4: LBIT Process: (a) LBIT equipment and (b) Specimen located for LBIT treatment

PWIT

Once all the specimens have gone through the welding process, they were then brought into post-weld treatment known as Low Blow Impact Treatment (LBIT). Six different heights were selected which were 120 mm, 160 mm, 200 mm, 240 mm, 280 mm, and 320 mm [9]. For each height, two specimens were impacted by the LBIT. Fig. 4 shows the LBIT equipment used for the PWIT. The safety lock and weight were lifted so the specimen could be placed at the bottom of the impactor (Fig. 4(a)). The safety lock was to hold the weight safely. The specimen was aligned correctly so the welding area would be located inside the circle parameter (hole) (Fig. 4(b)).

Tensile Testing

A tensile test was carried out on 20 specimens (18 treated and 2 untreated). There will be three samples for each height which were 120 mm, 160 mm, 200 mm, 240 mm, 280 mm, and 320 mm. The tensile test was done using Tensile Testing Machine following the American Society for Testing and Materials (ASTM E-8) [16]. The specimens will be subjected to axial and longitudinal forces. These forces will be exerted on the subject until certain deformations occur which will lead to failure.

Fatigue Testing

Fatigue testing of spot-welded samples was conducted by using Shimadzu ServoPulser with a load ratio $R = 0.1$. A sinusoidal waveform was applied at $f = 15$Hz [17]. A set of five different loadings were used to investigate the life cycle for 90% σ_{max}, 80% σ_{max}, 70% σ_{max}, 60% σ_{max}, and 50% σ_{max}. The final separation of the specimen was considered a failure. The fatigue lives obtained from the experiment are then compared with the theoretical value of Morrow and SWT approach models. The value for σ'_f and b is obtained from the graph S-N curve plotted. σ'_f is the y-intercept and b is the slope.

RESULTS AND DISCUSSIONS

During LBIT, different specimens are treated with different heights of impact. For each height, there are three specimens selected to undergo the treatment. Tab. 1 shows the depth measured at each of the impact points on the specimens.

The results for tensile tests are needed to proceed to the fatigue test. This is the maximum load that can be retained by the specimens before yield must be determined. So, the parameters needed to start fatigue testing are complete. The comparisons of the load-displacement line for all specimens are illustrated in Fig. 5.

Height (cm)	Readings (mm)			Average
	Specimen 1	Specimen 2	Specimen 3	
12	3.06	3.11	3.07	3.08
16	3.30	3.32	3.31	3.31
20	3.49	3.52	3.31	3.51
24	3.61	3.57	3.65	3.61
28	3.76	3.74	3.76	3.76
32	3.88	4.05	3.84	3.92

Table 1: Depth measurements of the impact locations

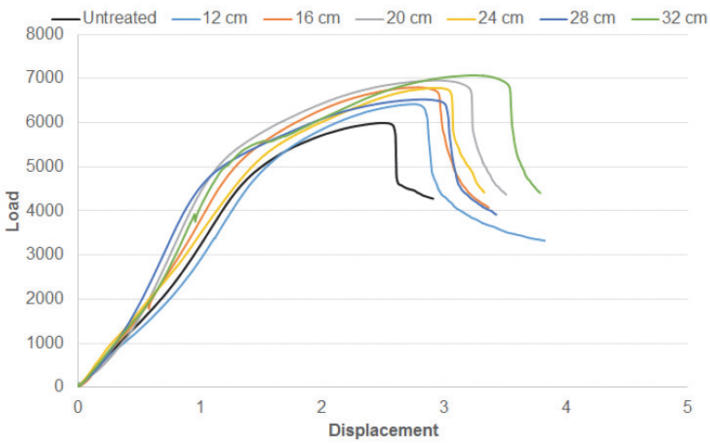


Figure 5: Graph of Load vs Displacement for all Specimens.

The graph plotted in Fig. 5 shows that the untreated specimen exhibits the weakest tensile strength compared to other treated specimens. The second-lowest tensile strength is recorded at 12 cm and 28 cm specimens with 10% of improvement, followed by 16 cm and 24 cm with 13.3% improvement. The ultimate tensile strength of the treated specimen with 20 cm of height is placed at second highest with 15% improvement which is just slightly under 32 cm treated specimen with 16.7% improvement.

Three different heights are chosen for the fatigue test which are 12 cm, 20 cm, and 28 cm. Tab. 2 shows the fatigue life (cycles) in which the specimen can undergo deformation before failure. Fig. 4 shows the S-N curve of the welded samples.

Height	Untreated		12 cm		20 cm		28 cm	
σ_{max}	F (kN)	Life	F (kN)	Life	F (kN)	Life	F (kN)	Life
90%	5.40	107	5.94	81	6.21	68	5.94	377
80%	4.60	252	5.28	3022	5.52	130	5.28	1862
70%	4.20	665	4.62	3446	4.83	193	4.62	2296
60%	3.60	2033	3.96	4993	4.14	6429	3.96	2768
50%	3.00	7621	3.03	6774	3.45	7878	3.3	13753

Table 2: Load and maximum cycle

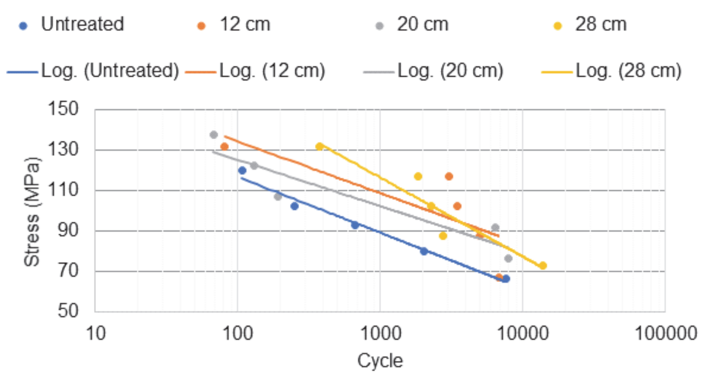
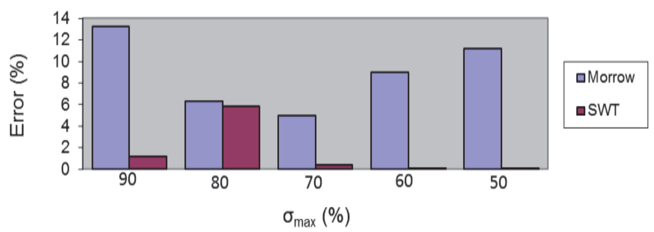


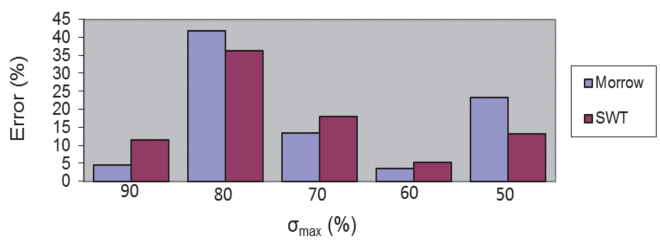
Figure 6: S-N Curve

It can be seen from the log graph in Fig. 6 that the lowest S-N curve is for the untreated specimens and on the other hand, treated specimens with 28 cm of height have the highest S-N curve. Specimen treated with 12 cm of height have a higher S-N curve compared to specimens treated with 20 cm height. This could be an error in this experiment. The values obtained in this experiment are then compared to the calculated values using Morrow and SWT models. The percentage error can be calculated using Eqn. (5). Fig. 7 (a) – (d) illustrates the percent error difference in histograms.

$$\%Error = \left| \frac{Experimental\ value - Theoretical\ value}{Theoretical\ value} \right| x100 \tag{5}$$



(a)



(b)

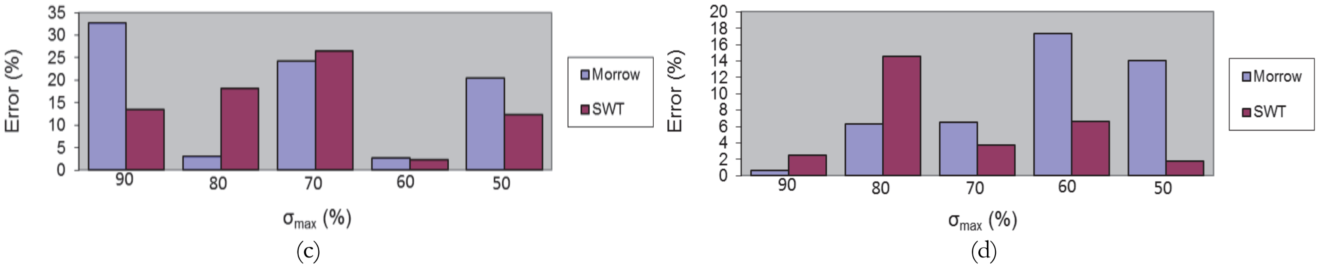


Figure 7: Histograms for percentage error difference against percentage σ_{max}; (a) Untreated, (b) 12 cm, (c) 20 cm and (d) 28 cm

The error for untreated specimens gives the smallest dispersion with the highest error of 13.2%. In addition, we also noticed that the SWT approach produces smaller error differences compared to Morrow's. This is in line with the statement stated by [8], as the SWT approach is the best model for predicting accurate fatigue life for non-zero mean stress.

CONCLUSION

From the result of this experiment, it can be concluded that PWIT produce a significant result in the test specimens. Based on the graph plotted, specimens treated with LBIT were able to withstand higher load before starting to deform. This means they have higher yield strength compared to the untreated specimen. The tensile results also illustrate that the treated specimen has higher ultimate tensile strength compared to the untreated which can be observed from the peak value. The lowest peak value is 6 kN with an extension of 2.5 mm for the untreated specimen and the highest peak value is 7.1 kN with an extension of 3.2 mm recorded for 32 cm of treated specimen. This demonstrates that the LBIT process gives a substantial effect on the mechanical properties of the spot-welded specimens.

On the other hand, a major improvement could be seen in the fatigue properties of the treated specimens. The S-N curve proves specimens that undergo LBIT have higher fatigue lives. The graph shows a good impact of LBIT on the spot weld at a height of 28 cm. For all values of stresses, comparing untreated and treated specimens at 28 cm, fatigue lives increase in a range of 27% to 87%. This shows that LBIT increases the fatigue strength of spot weld joints of mild steel.

To conclude, the objectives of this research are achieved. LBIT not only increases the tensile strength of spot weld joints but also improves the fatigue lives as well. The results from this research prove that LBIT plays a significant role in improving the mechanical and fatigue properties of welded joints.

For future works, it is recommended to repeat with more specimens as there are some errors found such as the ultimate tensile strength of 24 and 28 cm treated specimen is lower than 20 cm specimen. In addition, the fatigue lives of 20 cm specimen also fewer than 12 cm specimen. This contradicts our theory that a higher height of treatment should produce a higher percentage of improvement.

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