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Resistance Spot Welding Properties Improvement through Post Weld Impact Treatment

[1]Farizah Adliza Ghazali, [2]Zuraidah Salleh, [2]Aminuddin Zulkifli,
[3]Mahfodzah Md. Padzi and [1]Norazwani Muhammad Zain
[1]Fabrication and Joining Section, Universiti Kuala Lumpur Malaysia France Institute (UniKL MFI), 43650 Bandar Baru Bangi, Selangor, Malaysia
[2]Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40000 Shah Alam, Selangor, Malaysia
[3]Mechanical Engineering Section, Universiti Kuala Lumpur Malaysia France Institute (UniKL MFI), 43650 Bandar Baru Bangi, Selangor, Malaysia

Abstract: This study investigates the effects of post weld impact treatment of spot welding on the mechanical properties and fatigue characteristics of the spot welded joint. The impact treatment process generates the compressive residual stresses in resistance spot-welded low carbon steel using two different impact treatment process using a specially designed Low Blow Impact Treatment (LBIT) apparatus and Pneumatic Impact Treatment (PIT) equipment. LBIT impact energy of 6 Joule and PIT using air pressure of 4 bar were applied to the welded joint. The effect of the impact treatment on mechanical properties of the spot-welded joint was investigated. Assessments of the mechanical properties and qualitative results between as-welded samples and the post weld impact treatment samples have been examined. Fatigue test was also conducted to evaluate the fatigue characteristics of spot-weld joint. The tensile-shear load of RSW PIT exhibits the highest value (8.81 kN) as compared to the RSW LBIT (8.42 kN) and RSW as-weld (8.20 kN). The fatigue life of RSW PIT was more than 4 times longer than those of as-weld samples throughout the whole load range. While, the fatigue life of RSW LBIT was 3 times longer than as-weld samples. Results showed that an improvement in the mechanical properties and fatigue strength has achieved through the post weld impact treatment.

Key words: Resistance spot welding, post weld impact treatment, fatigue life, strength, samples, steel

INTRODUCTION

In the automotive industries now a days, Resistance Spot Welding (RSW) is considered a vital welding processes throughout the whole assembly of a car where welds are formed by the combination of controlled pressure, heat and time. Localized heating is caused by the current flow of the materials to achieve complete coalescence (Qiu *et al*., 2009; Pouranvari and Marashi, 2013).

RSW comprises of sequenced weld cycle in order to achieve a good weld. Starting by clamping the workpieces with the electrode, the operator then applies an amount of desired weld current for a specific time period, followed by letting the workpieces still clamped together with the weld current off, only then releasing the clamping pressure upon the workpieces. As the weld current flows through the clamped workpieces, high resistance is developed at the contacting surface. This produces heat causing an increase in the resistance and a rapid rise of the temperature. Only then will the metal starts to melt from the center of the current path. Hence, a pool of molten metal on the workpieces begins to expand outwards. When the current is turned off, the molten metal slowly cools down and solidifies from its outer edges. Metal that has undergone heating, melting, fusion and solidification is called the weld nugget. Various researches have shown that the grain structure in the nugget is impedingly coarser than the parent metal. A spot weld then cools down to room temperature non-uniformly. However, internal stresses is developed due to the large temperature gradients created by intense localized heating. These internal or remaining stresses are known as residual stresses (Khanna *et al*., 2001; Martinson *et al*., 2009).

Corresponding Author: Farizah Adliza Ghazali, Fabrication and Joining Section, Universiti Kuala Lumpur Malaysia France Institute (UniKL MFI), 43650 Bandar Baru Bangi, Selangor, Malaysia

In RSW, the stress distribution occurred inside of the materials will affect the mechanical properties of the joined metals (Zhang *et al*., 2014). That being said, the mechanical properties are the tensile strength, fatigue strength, ductility, hardness, impact resistance, metallurgical and fracture toughness. Because of the small size of the weld region, it is challenging to obtain the mechanical properties of resistance spot weldment. The steel is heated and segregated into several zones during the welding process. These zones are known as the base metal, the Heat Affected Zone (HAZ) and the fusion zone. The source of failure in a resistance spot welded material is mainly detected in weld zone as the cooling rate varies and comprises of multiple regions of microstructure.

Hence, post-weld is implemented to minimize the modification of the mechanical properties in the welding joint. Post Weld Heat Treatment (PWHT) is a technique that has been used in the welding industries for centuries to counter measure mechanical properties and microstructure alteration that may lead to failure during service (Hernandez *et al*., 2012; Liu *et al*., 2016). While, Post Weld Impact Treatment (PWIT) is an innovative surface treatment produced the compressive stress via the impact which highlighting to improve mechanical properties, fatigue life and microstructure formation cold working process involves with driven indentation was performed using indenter on spot-welded area to impart the beneficial residual compressive stress have been investigated by Spitsen *et al*. (2005). The results showed that the compressive residual stress induced was significantly improvement in the fatigue strength of spot welds. Chang *et al*. (2007) was investigated the effect of forging force on fatigue strength resistance of spot weld joint. The results showed that the residual stresses obtained in HAZ was reduced by applying the forging force. The alleviation of compressive residual stress by forging force decreases the driving force for crack propagation and leads to longer fatigue life.

MATERIALS AND METHODS

The material investigated in this study was low carbon steel grade JIS G3141 sheet with a thickness of 1.2 mm. The chemical compositions of the steel are listed in Table 1.

Welding and post-weld impact treatment: Lap shear samples were prepared according to AWS (American Welding Standard) standard which is D8.9M. The sheet metals were prepared in rectangular shape with size of the length (110 mm) and width (45 mm) as showed in Fig. 1 (Ghazali *et al*., 2015a, b). The process involved joining of two sheet metals using RSW machine model JPC 75-kVA.

Table 1: Chemical composition and mechanical properties 11

Elements	Chemical composition
C	0.050
Si	0.010
Mn	0.210
P	0.011
S	0.005
Fe	Bal.

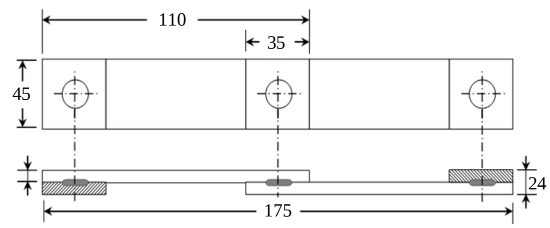

Fig. 1: Configuration of lap shear sample

Welding was carried out using a 45° truncated cone Class 2 electrode with a 6 mm face diameter. The welding parameters chosen in this series of experiments were based on the previous study on optimization of the same materials welding parameters (Ghazali *et al*., 2014).

In this study, two methods of post-weld impact treatment was performed after spot welding. The methods used were Pneumatic Impact Treatment (PIT) and Low Blow Impact Treatment (LBIT). Figure 2a shows the schematic of the post-weld impact treatment process by using pneumatic impact treatment while Figure 2b shows the low blow impact treatment.

Pneumatic impact treatment was performed using High Frequency Mechanical Impact (HFMI) hammer operates with a hardened pin with a ball resting on the spot weld with a diameter of 3 mm. This pin is hammered with an adjustable intensity at 90 Hz at the weld toe and pressure applied from compressor is 4.5 bar. Local mechanical deformations occur in the form of a treatment track.

Low blow impact was performed manually by mini falling weight impact tester. The samples were clamped between two steel plates having 18 mm diameter hole at the center. The impactor was adjusted before conducting impact tests to ensure that the dropping impactor hit the weld region of each sample. The localized damaged that imposed on the spot weld samples were then study as one of the treatment methods.

Testing method: The tensile-shear tests were performed at cross-head speed of 2 mm/min with a 250 kN testing machine. Fatigue testing of both treatment methods was conducted to evaluate the fatigue performance. Fatigue tests were performed using 25 kN servo-hydraulic universal tensile machine under sinusoidal load, R = 0.1 and the testing cyclic frequency was set at 10 Hz.

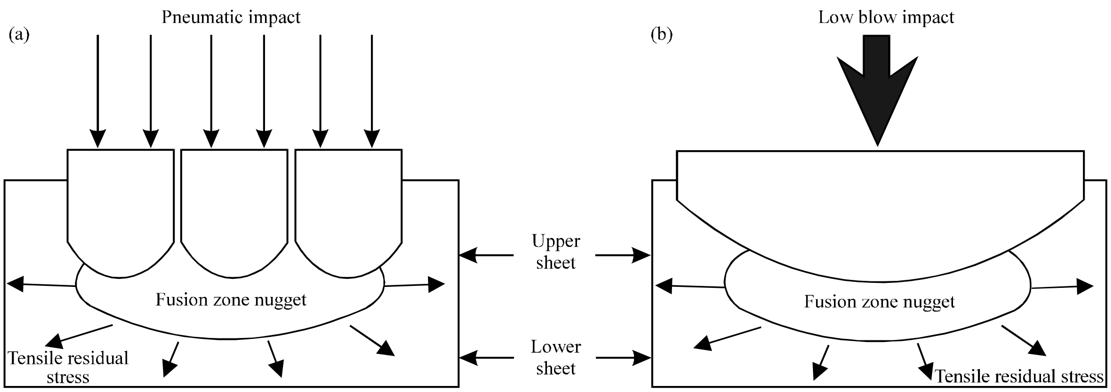

Fig. 2: Schematic illustration on post-weld impact treatment process: a) Pneumatic impact treatment and b) Low blow impact treatment

RESULTS AND DISCUSSION

Tensile-shear and failure mode: Tensile-shear test was done to determine the shear strength of the samples as for RSW as-weld, PIT and LBIT of spot-welded joint. RSW as-weld samples failed early and reached the break point when the loading is 8.20 kN. Meanwhile for the PIT samples experienced higher loading acting on the sample which is 8.81 kN in order to reach the breakpoint (Fig. 3).

RSW PIT samples experienced a vast increased in weld strength due to the rise of permanent dislocation of the atomic structures in weld metal which required much more load in tension to destruction or tear apart. The increased in tensile-shear strength mainly due to compressive stress applied during pneumatic impact which is reduced and negate any residual stress generation during hammer peening process (Togasaki *et al*., 2010).

Comparing the result of RSW LBIT and as-weld sample, the RSW LBIT samples show increment of 3% in tensile-shear load from the as-welded sample. The reason is strong bond produced during compressive stress causes the increment in the tensile-shear load of the RSW LBIT. The compressive stress which was applied by low blow impact intentionally to reduce the residual stress existed in spot weld joint (Khanna and Long, 2008).

The tensile-shear failure of RSW PIT, RSW LBIT and RSW as-welded were shown in Fig. 4. As compared the pullout failure of all joint types, RSW PIT and RSW LBIT samples having the pullout failure occurs through FZ nugget and then failure continued by base metal tearing. The ductility value also shows the failure mode of the samples. As the ductility was high, the tearing pullout failure obtained fairly large.

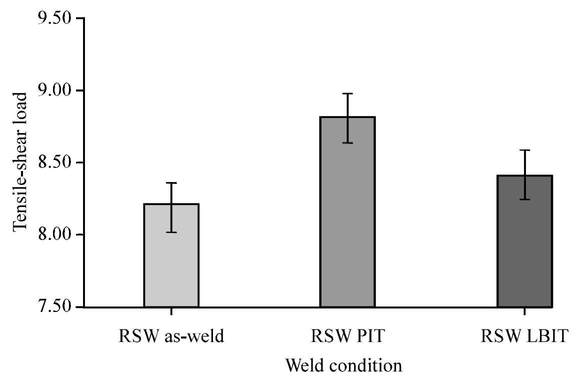

Fig. 3: The tensile-shear load

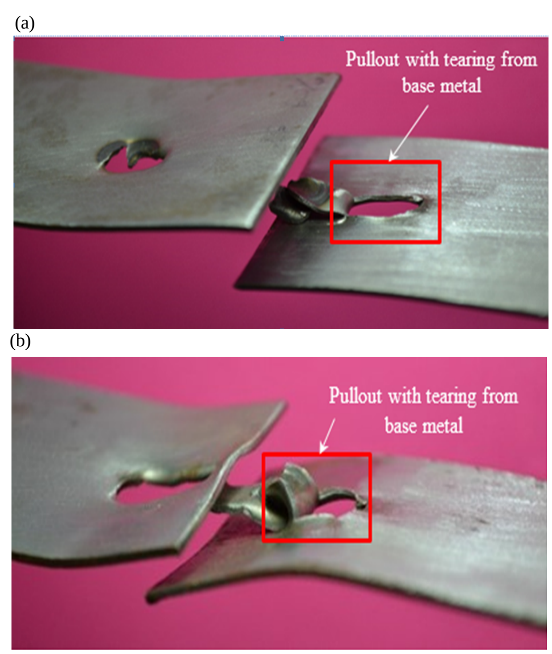

Fig. 4: Pullout failure mode: a) RSW PIT samples and b) RSW LBIT

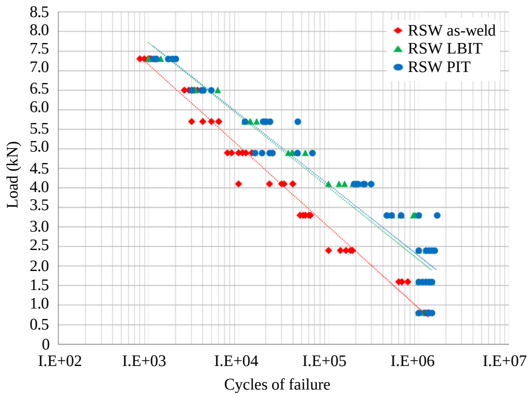

Fig. 5: L-N curve for RSW PIT, RSW LBIT and RSW as-weld samples

The pullout failure of RSW PIT as depicted in Fig. 4a, occurs around HAZ and then failure continued by base metal tearing with evidence of plastic deformation (Pouranvari *et al*., 2007; Khan *et al*., 2008). This is normally due to strain hardening which was the effects of pneumatic impact towards the welded samples. This kind of failure mode was preferred fracture.

The failure happened on tensile-shear of RSW LBIT was shown in Fig. 4b. This failure is also the preferred fracture mode in resistance spot welding due to higher plastic deformation and energy absorption (Chao, 2003; Liu *et al*., 2010; Xu *et al*., 2014). In the pullout mode with tearing, failure occurs via. FZ with certain amount of rotation, the tensile formed caused plastic deformation, then withdrawal completely from one of the base metal (Zhang *et al*., 2014; Kianersi *et al*., 2014). This is due to the effects of low blow impact towards the welded samples which was change the properties by means of localized work hardening of impactor.

This findings seem to find that the failure mode of RSW with impact treatment can significantly affect their carrying load. Treated RSW that fail in pullout with tearing at base metal provide higher peak load than RSW as-weld sample that fail in only button pullout failure mode.

Fatigue life performance: The load level applied in the RSW PIT and RSW LBIT fatigue test were similar to the applied load for as-welded samples with the purpose of comparing the fatigue life of spot-welded samples. The load level applied were 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2 and 0.1 P_{max}. Figure 5 shows the L-N curve of spot-welded joints sample at different load level. The greater the applied load range, the shorter the life of the joint.

It could be seen that there are noticeable improvement of fatigue life after being treated. RSW PIT samples show the highest value of fatigue life at 1×10^6 cycles as compared to RSW LBIT and as-welded which was about 12%. RSW LBIT samples also show the improvement of fatigue life at 1×10^6 cycles as compared to as-welded which was about 2%. There are small different between the fatigue life of treated samples.

Table 2: Fatigue sensitivity coefficient and determination coefficient of RSW PIT, RSW LBIT and RSW as-weld sample

Weld configuration	Fatigue sensitivity coefficient	Determination coefficient
RSW PIT	0.140	0.9537
RSW LBIT	0.142	0.9530
RSW as-weld	0.262	0.9717

This is because of the purpose of both treatment are to modify the tensile residual stress occurs in spot-welded then increase the life of the joint. Previous studies by Marquis and Barsoum (2013) suggest that the presence of a slight amount of tensile residual stress in weld joint will ensure of stress concentration and further modification by applying impact treatment will have small magnitudes of compressive residual stresses and increasing the closure level.

One of the ways to estimate the scatter in fatigue number of cycles is to calculate the fatigue sensitivity coefficient. The fatigue sensitivity coefficient and coefficient of determination (R^2) of the as-weld sample are shown in Table 2. The fatigue sensitivity coefficient for RSW PIT exhibit the value of 0.14, followed by RSW LBIT value of 0.142 and RSW as-welded 0.262 which falls in the typical value range. The fatigue sensitivity represents the gradient of weld joint showing negative slope and therefore can be related to the degradation fatigue strength of the materials with decrease in number of failure. The determination coefficient (R^2) value for RSW PIT, RSW LBIT and RSW as-weld is 0.9537, 0.9530 and 0.9717, respectively, being close to 1 indicates that the linear line is a good fit for the data and the predictability of the regression is quite high (Ertas *et al*., 2009).

The application of pneumatic impact treatment and low blow impact treatment on the spot-welded joints were able to produced significantly favourable improvement in characteristics fatigue load of 2.5 kN at 1 million cycles. As considering the spot-welded joint, there is an existing of residual stresses (Bae *et al*., 2003; Afshari *et al*., 2013). When compressive residual stresses is induced by post weld impact treatment, tensile residual stress and applied tensile stresses may be eliminated or partially reduced. The large increment and enhancement in the fatigue life resulting from the PIT, followed by LBIT is attributed to the high levels of compressive residual stress induced in the vicinity of the surface as compared to the as-weld samples.

CONCLUSION

In this study, we will discuss mainly on PWIT. PWIT comprises of several process such as shot peening, hammer-peening, am impact. The study focuses on monitoring and examining what influences the application of PWIT using Pneumatic Impact Treatment (PIT) and Low Blow Impact Treatment (LBIT) for spot welded joint through the tensile shear, fatigue test and hardness test. Subject to that, all the welded samples are later subjected to both methods to identify the strength and cycle to failure of the welded joint during failure mode.

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