Pertanika J. Sci. & Technol. 25 (S): 105 - 114 (2017)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Improvement of Mechanical Properties and Fatigue Failure of Spot-Welded Joint through Pneumatic Impact Treatment (PIT)

Ghazali, F. A.[1]*, Salleh, Z.[2], Hyie, K. M.[3], Taib, Y. M.[4] and Nik Rozlin, N. M.[2]

[1]Fabrication and Joining Department, 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]Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) Pulau Pinang, 13500 Permatang Pauh, Pulau Pinang, Malaysia
[4]Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) PasirGudang, 81750 Masai, Johor, Malaysia

ABSTRACT

This study focuses on examining the influence of post weld impact treatment (PWIT) using Pneumatic Impact Treatment (PIT) for spot welded joint on mechanical properties and fatigue failure. PWIT is one of the methods for improving mechanical properties and fatigue strength of welded joints. One of the versatile techniques of PWIT used for this study is PIT. The material investigated in this study was carbon steel with welded single lap shear joint with the constant thickness of 1.2mm. All the welded samples were later performing the tensile shear test, hardness test, and fatigue test. The tensile shear test was conducted on the spot welded both treated and untreated samples using crosshead speed of 2 mm/min, while hardness test was performed using 1kgf load via Vickers hardness indenter. Fatigue test was conducted using R=0.1 and frequency of 10 Hz. The effects of PIT on tensile-shear properties, hardness, and fatigue failure were evaluated. It was found that the implementation of PIT has increased tensile shear and hardness significantly and prolonged lifetime of spot welded joint.

Keywords: Fatigue failure, pneumatic impact treatment (PIT), post weld impact treatment, resistance spot weld, spot-welded

ARTICLE INFO

Article history:
Received: 19 February 2017
Accepted: 17 July 2017

E-mail addresses:
farizahadliza@unikl.edu.my (Ghazali, F. A.),
a_kzue@yahoo.com (Salleh, Z.),
hyie1105@yahoo.com (Hyie, K. M.),
ymtaib@gmail.com (Taib, Y. M.),
nikrozlin@yahoo.com (Nik Rozlin, N. M.)
*Corresponding Author

ISSN: 0128-7680 © 2017 Universiti Putra Malaysia Press.

INTRODUCTION

Resistance spot welding (RSW) is widely used for producing a typical vehicle body-in-white (BIW), normally made of thin metal sheets that are connected together by clamping the sheets with two pincers while applying force and transmitting current; eventually, a nugget develops and the interface locally disappears. The important changes occur in mechanical and metallurgical properties of the spot welds area is during the process of spot weld itself such as the weld fusion zone size, weld mechanical performance and failure mode (Charde, 2012). The investigation of this change is the most important for the safety and quality of the welded joints (Vural & Akkus, 2004). One single typical automotive car body contains about 300 sheet metal parts, joined by about thousand spot welds (Mali, Inamdar, Mali, & Inamdar, 2012). Due to this reason, quality, performance and failure characteristics of resistance spot welds are important to be evaluated for determining the durability and the safe design of the vehicles, as they transfer load through the structure during dynamical load and crash (Pouranvari & Marashi, 2013; Pouranvari, Mousavizadeh, Marashi, Goodarzi, & Ghorbani, 2011).

During the welding process, the steel is heated and segregated into several zones consist of base metal, heat affected zone (HAZ) and fusion zone. In HAZ, the cooling rate is different and comprises different regions of microstructure and often considered as a source of failure in welded joint (Srivastava, Tewari& Prakash, 2010; Xue, Benson, Meyers, Nesterenko, & Olevsky, 2003).

The enhancement of the static and fatigue resistance of welded joints is becoming increasingly significant in many areas such as the automotive, aerospace and railway industries. A recent method of enhancing the static and fatigue resistance of welded structures is to use modern post-weld treatment processes. Post–weld impact treatment (PWIT) is a process which was done after the welding process either the method of applied heat or impact used for stress relief. Improving the resistance of welded joints by conventional improvement methods such as grinding, shot peening, air hammer peening or tungsten inert gas (TIG) dressing are well established (Yildirim & Marquis, 2013). The purpose of stress relieving is to remove any internal or residual stresses that may be present from the welding operation. Stress relief after welding may be necessary in order to reduce the risk of brittle fracture, to avoid subsequent distortion or to eradicate the risk of stress corrosion. In parallel to the development of this treatment method, there have been an increasing number of publications dealing with high-frequency mechanical impact treatment (HFMI) technologies using Pneumatic Impact Treatment (PIT). The PIT is the versatile and modern technique used in modified the properties of welded joint. There are several researchers studied in this PIT area with a different field of welding.

Yildirim, Marquis and Sonsino (2015) studied on the fatigue strength improvement using PIT of longitudinal stiffeners of the steel grade S700. Experimental results perceived that the fatigue strength of improved welds increases with existing of weld modification through PIT. Mohamed, Manurung, Shah and Othman (2015) study presented an unconventional method to optimize the governing process parameters of Pneumatic Impact Treatment (PIT) and found that PIT treatment is a post weld treatment that can be used to significantly enhance the fatigue resistance level of FSW AA6061. However, the used of this kind of treatment towards the spot welded area still not yet established.

This study focuses on examining the influences of the application of post weld impact treatment (PWIT) using Pneumatic Impact Treatment (PIT) for spot welded joint through the tensile shear and fatigue failure. Regarding this concern, all the welded samples were later subjected by performing PIT to test the strength of the welded joint to fail or tear apart in terms of its load and the properties through the failure modes to the energy-absorbing capacity of a weldment. Microhardness distribution from base metal (BM) to fusion zone (FZ) was measured. Fatigue failure was evaluated in order to predict the life of the welded joint.

MATERIALS AND METHOD

Resistance spot weld (RSW) joints may be exposed to stress under tensile-shear conditions. The experiment is designed to determine the shear load, hardness and fatigue failure of the welded zone.

Materials and Equipment

The material investigated in this study was low carbon steel grade JIS G3141 sheet. Lap shear samples were prepared according to AWS (American Welding Standard) standard which is D8.9M. The sheet metals were prepared in a rectangular shape with a size of the length (110 mm), width (45 mm) and thickness (1.2 mm) as shown in Figure 1. The welded joints were performed using the 75 KVA spot welding machine with electrode tips of 5 mm in diameter.

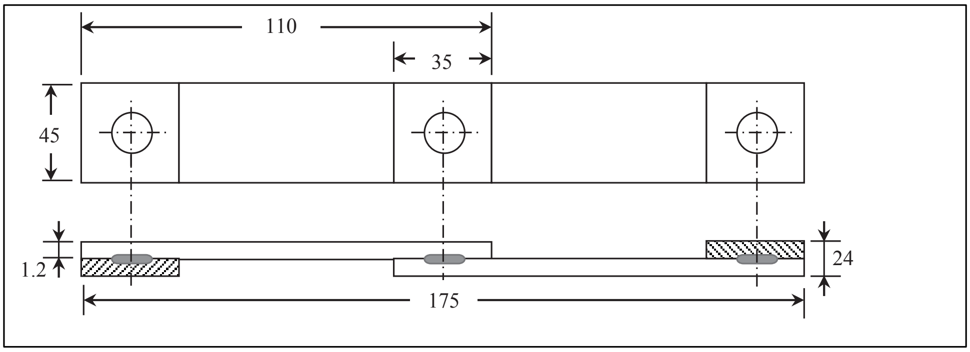

Figure 1. The spot welded sample (Ghazali, Manurung, Mohamed, Mohamed, & Abdullah, 2015)

Post Weld Impact Treatment

Treatment was performed using pneumatic impact treatment (PIT) on the spot welded samples. The PIT device operates with a hardened pin with a ball resting on the work piece with a diameter of 3 mm. The PIT device used in the PWIT process is depicted in Figure 2.

Figure 2. The PIT controller and handheld device (Mohamed, Manurung, Shah, & Othman (2015))

This pin was hammered with an adjustable intensity at 90 Hz at the welded zones and air pressure applied from the compressor is 4.5 bar. Local mechanical deformations occur in the form of a treatment track. The impact zone of the sample was analyzed using an optical 3D surface measurement device.

Testing Conditions

The tensile shear test was conducted with an Instron universal testing machine at a constant cross head displacement rate of 2 mm/min. The peak load was measured as the maximum point in the tensile-shear curve was extracted from the load–extension curve. An average tensile shear value of the 5 samples was recorded.

Vickers hardness with 5 repetitions of the joint is measured across the fusion zone, heat affected zone (HAZ) and base metal with the load of 1kgf acting on the samples surface. The dwell time of 15 seconds was used to 0.5 mm distance between the indents.

Fatigue testing of spot-welded samples was conducted under load-control with a load ratio of R = 0.1 and a sinusoidal waveform were applied with 10 Hz (Shen, Ding, Chen, & Gerlich, 2016). Final separation of coupons was considered as a failure. Tests were stopped after 10^7 cycles and considered run-outs. The numbers of cycles, as well as the failure modes, were recorded in all fatigue tests.

RESULTS AND DISCUSSION

The weld zone was deformed plastically and bonded due to impact from PIT which captures before and after the process as depicted in Figure 3.

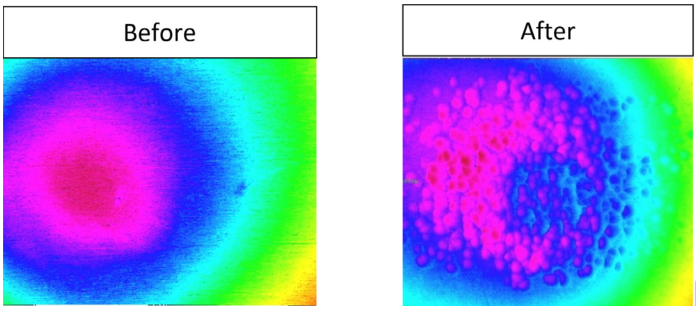

Figure 3. The impacted zones of spot welded joint

Table 1 gives the comparison between the tensile-shear results of the RSW PIT and RSW as-weld samples. The tensile-shear load force of RSW as-weld samples is increased as the treatment applied to the samples. Correspondingly, the average peak load increased due to the strong bond of base metal and the introduction of hardening precipitates, as well as the increment in pre-existing dislocations mainly, cause the increment in the tensile-shear load of the RSW PIT condition (Ghazanfari & Naderi, 2013)

Table 1
Comparison of shear-load of RSW PIT and RSW as-welded samples

Peak Load (kN)	RSW PIT	RSW as-weld
	8.81(0.07)	7.71(0.12)

Figure 4 shows the measured through-thickness hardness values for RSW PIT and RSW as-weld samples. As the result, the hardness is somewhat higher at the treated zone than near the untreated zone. This increase in hardness is clear which is from an average of 206 HV to 268 HV at the fusion zone. The hardness of thebase metal is about the same between 149 and 155 HV for both conditions. No phase transformation occurred because base metal (BM) of carbon steel was not affected during the pneumatic treatment (Joy-A-Ka et al., 2013). The hardness value for PIT samples experienced vast increased rather than as-welded samples. The hardness of base metal seemed to be lower than Heat Affected Zone (HAZ) and fusion zone (FZ) region due to the unaffected region during solidification process for both samples and also during the pneumatic treatment (Mikkola, Marquis, Lehto, Remes, & Hänninen, 2016).

For RSW PIT samples, it shows a huge difference in the range of FZ and HAZ. Both show higher difference value compared to RSW as weld samples. Hardness at fusion zone and HAZ were showed considerably higher values than that at base steel. Due to melting conditions during the welding process, re-solidify metal in fusion zone displayed relatively large volume fraction of ferrite morphologies which induced to softening of the zone. For the hardness properties, it can be stated that PIT samples were harder than as-weld samples.

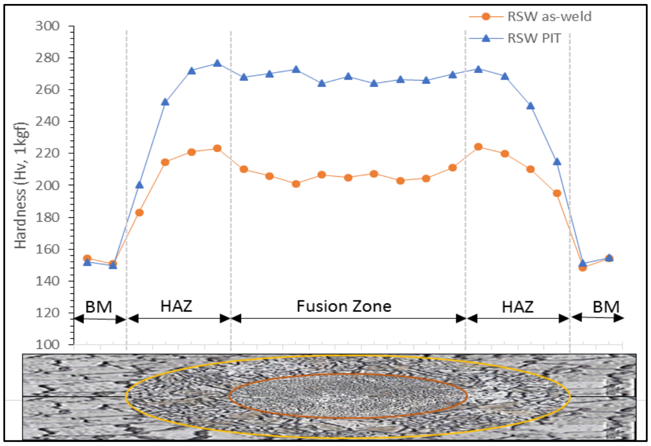

Figure 4. Hardness profile for RSW PIT and RSW as-weld samples

It could be seen that the hardness of HAZ was higher than the fusion zone and base metal. The HAZ experienced solid state phase transformation but no melting induced during the welding process. The hardness of HAZ as moved toward the fusion zone experiences perceptible drop. The drop phenomenon observed was identified as HAZ softening which mainly caused by martensite tempering development (Zhao, Wang, Zhang, & Zhang, 2013; Liu, Zheng, He, Wang, & Wei, 2016; Sun, Stephens, & Khaleel, 2008). Compared to the HAZ region, the effect of melting, the microstructure in fusion zone resolidified in RSW joints plays a major role in the elimination of strain hardening which significantly softens the weld zone (Pouranvari, Marashi, & Safanama, 2011). This, in turn, causes a decrement of the hardness values in the vicinity of the fusion zone.

For spot weld joint, results of fatigue tests are generally presented as load range vs. fatigue life (Hongyan et al., 2006; Spitsen, Kim, Flinn, Ramulu, & Easterbrook, 2005; Wang et al., 2008). The results of load-number of cycles containing RSW PIT and RSW as-welded joint were presented in L-N curves. The best-fit regression line depicted in Figure 5shows a gradual decline in fatigue load with an increase in the number of fatigue life cycles. The load range was determined based on the maximum load applied. The maximum load of the RSW PIT and RSW as-weld sample is plotted on the curve at 1 cycle (log 1=0). RSW PIT exhibits higher fatigue strength than RSW as-weld in the entire applied load range. The regression line predicted endurance limit of about 2.4 kN (approximately 27% of maximum load) for the RSW PIT samples at 1 million cycles which corresponded to well with the experimental data as shown by an arrowhead. Hence a load level of up to 3 kN can be taken as a safe value for endurance limit for these RSW PIT sample. It should be noted that RSW PIT joints have different joining features due to the treatment applied from RSW as-weld joints, which resulted in the different crack initiation and growth behaviour between both joints.

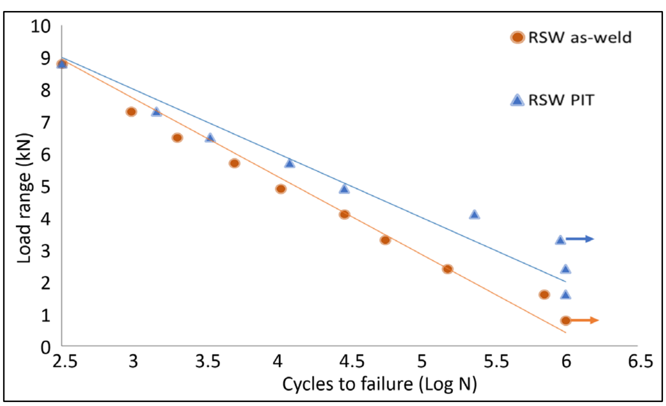

Figure 5. L-N curve for RSW PIT and RSW as-weld samples

In order to determine the fatigue sensitivity of the weld samples, it is more suitable to use normalized load versus cycles to failure curve. The L-N curve has been normalized with respect to the ultimate failure load of samples. The normalized load (maximum tensile load divided by shear load) versus cycles to failure curve is shown in Figure 6. The curve shows that the RSW PIT sample lost their static strength by almost 11.7% per decade of cycles, while the RSW as-weld, almost 15% static strength lost per decade.

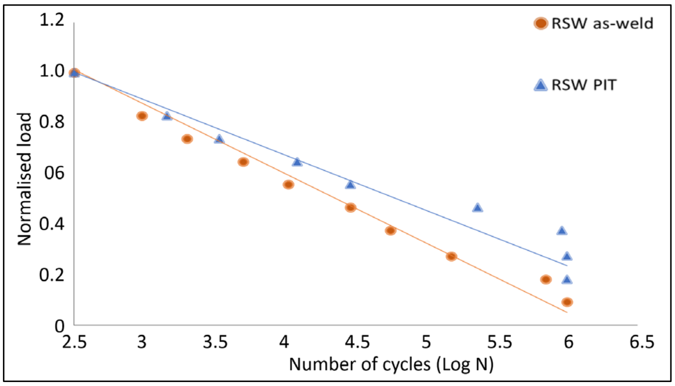

Figure 6. Normalised L-N curve for RSW PIT and RSW as-weld samples

The lower the percentage of lost value shows that the fatigue performance is better. Showing that, the fatigue performance for RSW PIT is better than RSW as-weld. A similar scatters trend for both RSW condition (RSW PIT and RSW as-weld) in term of reduction on normalized fatigue curves was also reported by Liu et al. (2013). These significance differences indicate that compressive residual stress relaxation as a consequence of local plastic deformation could have occurred in RSW PIT samples (Yildirim, Marquis, & Sonsino, 2015). Because the PIT impacted zone is highly cold worked, the true cyclic yield strength of the material in this region is probably much higher than for the RSW as-weld sample. This is explained by in pre-existing dislocations mainly, causes the increment in the fatigue failure of the RSW PIT condition (Mikkola, Marquis, Lehto, Remes, & Hänninen, 2016).

CONCLUSION

Alteration of local material properties changes existing in the post weld impact treatment spot weld sample was investigated by tensile shear test, hardness, and fatigue failure test. Two different spot weld samples conditions were studied: RSW PIT and RSW as-weld. The post weld impact treatment represents pneumatic impact treatment method was used to apply high-frequency mechanical impact on compressive residual stress existing in spot weld zone, meanwhile to improve the weld geometry and strain hardening the treated surface. The results showed that the treatment increased the tensile shear load of spot weld and also increase the hardness of the joint significantly. The pre-existing location due to treatment was lead to an increase in fatigue failure.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Faculty of Mechanical Engineering (UiTM), Advance Manufacturing Technology Excellence Centre (AMTEX) and Universiti Kuala Lumpur-Malaysia France Institute (UniKL-MFI) for the facilities and technical support.

The authors also are grateful acknowledge the financial support from Fundamental Research Grant Scheme (Ref: FRGS/1/2016/TK03/UITM/02/5) for the successful implementation of this project.

REFERENCES

Charde, N. (2012). Characterization of spot weld growth on dissimilar joints with different thicknesses. *Journal of Mechanical Engineering and Sciences, 2*(unknown), 172-180.

Ghazali, F. A., Manurung, Y. H., Mohamed, M. A., Alias, S. K., & Abdullah, S. (2015). Effect of process parameters on the mechanical properties and failure behavior of spot welded low carbon steel. *Journal of Mechanical Engineering and Sciences, 8*, 1489-97.

Ghazanfari, H., & Naderi, M. (2013). Influence of welding parameters on microstructure and mechanical performance of resistance spot welded high strength steels. *Acta Metallurgica Sinica (English Letters), 26*(5), 635-640.

Joy-A-Ka, Hirano, T., Akebono, H., Kato, M., Sugeta, A., Fujii, H., & Sun,Y. F. (2013).3-Dimensional observation of the interior fatigue fracture mechanism on friction stir spot welded using 300 MPa-class automobile steel sheets, in *Proceedings of the 1st International Joint Symposium on Joining and Welding*, 6-8 November 2013.

Liu, C., Zheng, X., He, H., Wang, W., & Wei, X. (2016). Effect of work hardening on mechanical behavior of resistance spot welding joint during tension shear test. *Materials and Design, 100*, 188-197.

Liu, L., Xiao, L., Chen, D. L., Feng, J. C., Kim, S., & Zhou, Y. (2013). Microstructure and fatigue properties of Mg-to-steel dissimilar resistance spot welds. *Materials and Design, 45*, 336-342.

Mali, M. P., & Inamdar, K. H. (2012). Effect of spot weld position variation on quality of Automobile sheet metal parts. *International Journal of Mechanical and Materials Engineering, 2*, 23-27.

Mikkola, E., Marquis, G., Lehto, P., Remes, H., & Hänninen, H. (2016). Material characterization of high-frequency mechanical impact (HFMI)-treated high-strength steel. *Materials and Design, 89*, 205-214.

Mohamed, M. A., Manurung, Y. H., Shah, L. H. A., & Othman, N. H. Optimization of HFMI/PIT Parameters with Simultaneous Multiple Response Consideration using Multi-Objective Taguchi Method for Fatigue Life Enhancement of Friction Stir Welding. In *IIW International Conference High-Strength Materials - Challenges and Applications, 68*.DOI: 10.13140/RG.2.1.4115.5047

Pouranvari, M., & Marashi, S. P. H. (2011). Failure mode transition in AHSS resistance spot welds. Part I. Controlling factors. *Materials Science and Engineering: A, 528*(29-30), 8337-8343.

Pouranvari, M., & Marashi, S. P. H. (2013). Critical review of automotive steels spot welding: process, structure and properties. *Science and Technology of Welding and Joining, 18*(5), 361-403.

Pouranvari, M., Mousavizadeh, S. M., Marashi, S. P. H., Goodarzi, M., & Ghorbani, M. (2011). Influence of fusion zone size and failure mode on mechanical performance of dissimilar resistance spot welds of AISI 1008 low carbon steel and DP600 advanced high strength steel. *Materials and Design, 32*(3), 1390-1398.

Shen, Z., Ding, Y., Chen, J., & Gerlich, A. P. (2016). Comparison of fatigue behavior in Mg/Mg similar and Mg/steel dissimilar refill friction stir spot welds. *International Journal of Fatigue, 92*, 78-86.

Spitsen, R., Kim, D., Flinn, B., Ramulu, M., & Easterbrook, E. T. (2005). The effects of post-weld cold working processes on the fatigue strength of low carbon steel resistance spot welds. *Journal of Manufacturing Science and Engineering, 127*(4), 718-723.

Srivastava, B. K., Tewari, S. P., & Prakash, J. (2010). A review on effect of preheating and/or post weld heat treatment (PWHT) on mechanical behavior of ferrous metals. *International Journal of Engineering Science and Technology, 2*(4), 625-631.

Sun, X., Stephens, E. V., & Khaleel, M. A. (2008). Effects of fusion zone size and failure mode on peak load and energy absorption of advanced high strength steel spot welds under lap shear loading conditions. *Engineering Failure Analysis, 15*(4), 356-367.

Vural, M., & Akkus, A. (2004). On the resistance spot weldability of galvanized interstitial free steel sheets with austenitic stainless steel sheets. *Journal of Materials Processing Technology, 153*, 1-6.

Wang, B., Duan, Q. Q., Yao, G., Pang, J. C., Li, X. W., Wang, L., & Zhang, Z. F. (2014). Investigation on fatigue fracture behaviors of spot welded Q&P980 steel. *International Journal of Fatigue, 66*, 20-28.

Xue, Q., Benson, D., Meyers, M. A., Nesterenko, V. F., & Olevsky, E. A. (2003). Constitutive response of welded HSLA 100 steel. *Materials Science and Engineering: A, 354*(1-2), 166-179.

Yildirim, H. C., & Marquis, G. B. (2013). A round robin study of high-frequency mechanical impact (HFMI)-treated welded joints subjected to variable amplitude loading. *Welding in the World, 57*(3), 437-447.

Yıldırım, H. C., Marquis, G., & Sonsino, C. M. (2015). Lightweight potential of welded high-strength steel joints from S700 under constant and variable amplitude loading by high-frequency mechanical impact (HFMI) treatment. *Procedia Engineering, 101*, 467-475.

Zhao, D. W., Wang, Y. X., Zhang, L., & Zhang, P. (2013). Effects of electrode force on microstructure and mechanical behavior of the resistance spot welded DP600 joint. *Materials and Design, 50*, 72-77.