Pertanika J. Sci. & Technol. 25 (S): 115 - 124 (2017)

SCIENCE & TECHNOLOGY

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

# Effect of Low Blow Impact Treatment on Fatigue and Mechanical Properties of Spot-Welded Joints

**Farizah Adliza Ghazali[1]*, Zuraidah Salleh[2], Ya'kub Md Taib[2], Koay Mei Hyie[3] and Nik Rozlin Nik Mohd Masdek[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*

## ABSTRACT

Post Weld Impact Treatment (PWIT) is necessary in order to improve the tensile shear and hardness strengths on the welded joints of spot welding process. PWIT can be performed via Low Blow Impact Treatment (LBIT), which is the main focus in this research. In this present study, two plates of low carbon steel (LCS) with dimensions of 110 mm × 45 mm × 1.2 mm underwent a resistance spot welding. All welded samples were later tested for their mechanical properties by performing the tensile-shear, hardness test and qualitative analysis. Tensile shear test was conducted on the spot welded area for both treated and untreated samples using crosshead speed of 2 mm/min, while hardness test was performed using 1 kgf load Vickers hardness indenter. The effects of LBIT on tensile-shear properties, hardness and fatigue strength were evaluated and it was found that the implementation of LBIT increased the tensile shear strength, fatigue strength and hardness on the welded joint significantly.

*Keywords:* Hardness test, LBIT, LCS, PWIT, tensile-shear test

ARTICLE INFO

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

*E-mail addresses:*
farizahadliza@unikl.edu.my (Farizah Adliza Ghazali),
a_kzue@yahoo.com (Zuraidah Salleh),
yakubtaib@johor.uitm.edu.my (Ya'kub Md Taib),
hyie1105@yahoo.com (Koay Mei Hyie),
nikrozlin@yahoo.com (Nik Rozlin Nik Mohd Masdek)
*Corresponding Author

ISSN: 0128-7680 

## INTRODUCTION

Resistance spot welding (RSW) has been employed for a long time by the automotive industries. The weld regions are formed by the combination of pressure, heat and time elements. The resistance to a current flow of materials to be welded causes a localised heating in the materials in order to achieve a complete coalescence (Vural & Akkus, 2004).

Quality and strength of weld are defined by the weld joints. In RSW, the stress distribution occurs inside the material, which in turn affects the mechanical properties of the joined metals. For spot welding, the mechanical properties that are usually observed after a load is applied to the spot welded joint includes the tensile strength, hardness, and microstructure. However, the mechanical properties of the resistance spot welding are difficult to measure and quantified because of the small size of the weld region.

During the welding process, the steel is heated and segregated into several zones, which consist of base metal, heat affected zone (HAZ) and fusion zone (FZ). In HAZ, the cooling rate is different and comprises different regions of microstructure and is often considered as a source of failure in welded joint (Mali & Inamdar, 2012; Pouranvari & Marashi, 2013). Hence, post-weld treatment is implemented to improve the properties at the welded joint. There are a few techniques used in post-weld treatment such as 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. This treatment helps in improving the mechanical properties and modifies the microstructure of the joint (Pouranvari, Mousavizadeh, Marashi, Goodarzi, & Ghorbani, 2011). PWIT consists of several processes, such as shot-peening, hammer-peening, and impact.

Many works have been cited on various post weld treatments. Ma, Qin, Geng and Fu (2015) studied the different heat treatment effects on the mechanical properties and microstructure of the dissimilar sheet steels (1045 carbon steel and 304 stainless steel) friction spot welded samples. The joint was heat treated at different post-weld heat treatment (PWHT) temperature. Tensile strength and elongation of the joint were improved substantially after PWHT at 400°C, attaining the equivalent strength of stainless steel and elongation of carbon steel. This occurs as the microstructure became homogeneous to some extent and a number of chromium carbides barely increased. The joint was heat treated at different post-weld heat treatment (PWHT) temperature. Tensile strength and elongation of the joint were improved substantially after PWHT at 400°C, which could reach up to the equivalent strength of stainless steel and elongation of carbon steel as the microstructure became homogeneous to some extent and a number of chromium carbides barely increased.

Xue, Benson, Meyers, Nesterenko and Olevsky (2003) examined the influences of post-weld heat treatment on Q235 steel resistance spot weld. The effect of cross-current on the nugget shape, microstructure, and mechanical properties were investigated. It was found that the cross-current PWHT enhances the efficiency of PWHT and improves the mechanical performance of nugget. The quasi-equiaxed grains of martensite due to the heat applied during PWHT in the weld nugget drastically increase the microhardness of weld nugget and the tensile-shear force of the weld joint.

The effects of second pulse current in RSW on the microstructure changes and mechanical behavior of transformation-induced plasticity (TRIP) steel were studied (Baltazar, Okita, & Zhou, 2013). The local post weld heat treatments through the second impulse current were applied to the RSW TRIP steel in order to alter the fusion zone microstructure and consequently, the mechanical performance. The most important result of this study is the ability in improving the mechanical properties with desirable pullout failure mode. It is accomplished when the FZ microstructure consists of a recrystallised structure of martensite achieved in the medium level of the second pulse current PWHT.

This present research focuses on evaluating low blow impact treatment (LBIT) as application in post weld impact treatment (PWIT) on spot welded joint. All the welded samples were subjected to LBIT prior to the tensile shear, hardness and fatigue tests. The energy-absorbing capacity of weldment was identified and the microhardness was determined within base metal (BM) to fusion zone (FZ).

## MATERIALS AND METHOD

### Material and Equipment

Low carbon steel (LCS) grades of JIS G3141 sheets were used in this research. Lap shear samples were prepared according to AWS (American Welding Standard) standard, which is D8.9M. The sheet metals were prepared in rectangular shape of equal size (110 mm x 45 mm x1.2 mm) as shown in Figure 1. The welded joints were performed using the 75 KVA of spot welding machine with electrode tips of 5 mm in diameter.

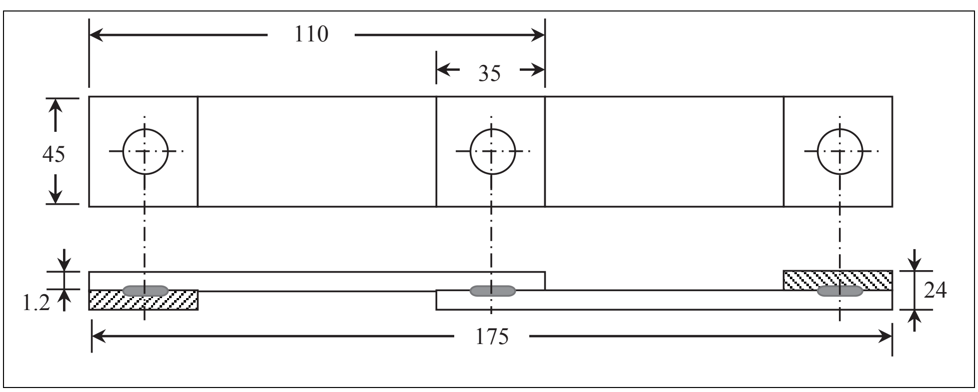


*Figure 1.* The spot welded sample (Ghazali, Manurung, Mohamed, & Abdullah, 2015)

### Post-Weld Impact Treatment

Low blow impact treatment (LBIT) was performed manually using a specially built mini falling weight impact tester as shown in Figure 2. The samples were clamped between two steel plates that had 18 mm diameter hole at the center. A falling weight or impactor then impinged at the predetermined location on the sample. Steel weights were subsequently added on the impactor in order to obtain the required impact energy.

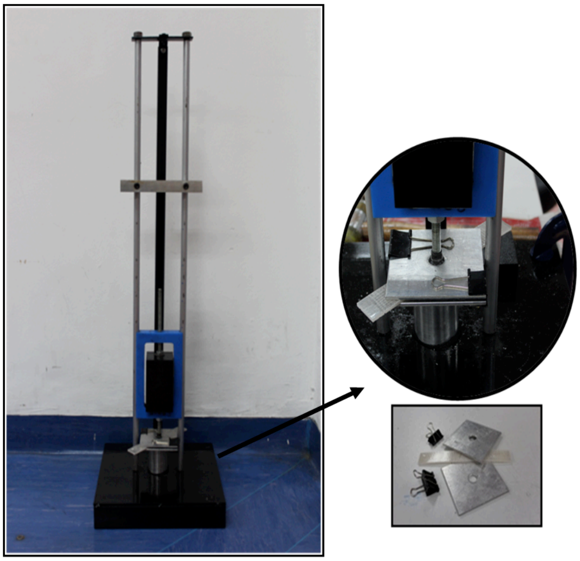

*Figure 2.* Mini falling weight impact tester

## Experimental Set Up

The tensile shear test was conducted on a universal testing machine at a constant cross head displacement rate of 2 mm/min. The peak load was taken as the maximum tensile-shear load, from the load–extension curve. An average maximum tensile shear value of the five samples was recorded.

Vickers hardness with five repetitions of the joint was measured across the fusion zone, heat affected zone (HAZ) and base metal with the load of 1 kgf acting on the sample surface, as shown in Figure 3. The dwell time of 15 seconds was used for 0.5 mm distance between the indents.

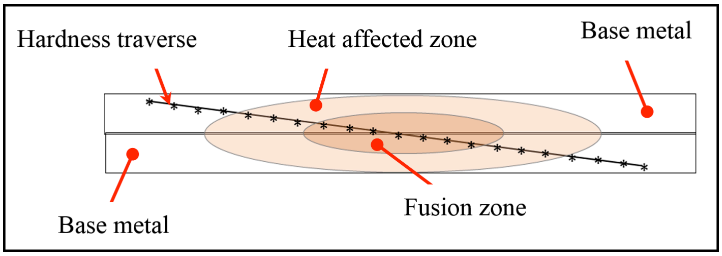


*Figure 3.* Cross-sectioned hardness traverse

Fatigue testing of spot-welded samples using flat coupon specimen type was conducted under load-control with a load ratio R = 0.1. A sinusoidal waveform was applied at 10 Hz. Final separation of coupons was considered as a failure. Tests were stopped after 1 × 107 cycles if there was no separation and considered as run-out. The number of cycles to failure was noted in these tests.

## RESULTS AND DISCUSSION

The tensile-shear of RSW samples improved when the low blow impact treatment was conducted on the samples. The tensile-shear description on load of RSW LBIT and RSW as-weld are provided in Table 1. The RSW LBIT samples show a significant increase of 3% in tensile-shear load compared to the as-welded sample. The strong bond of the treated welded joint mainly contributed to the increase in the tensile-shear load of the RSW LBIT and introduction of plastic deformation during the compressive stress applied by low blow impact, reducing the residual stress existing in spot weld joint.

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

| No | Description of tensile specimen condition | Load (N) |
|---|---|---|
| 1 | RSW LBIT | 8420 |
| 2 | RSW as-welded | 8203 |

There were some changes in hardness of spot-welded joint due to the impact treatment. Figure 4 shows the hardness profile of spot-welded joint with acting loading of 1 kgf. Points of the indentation were primarily taken in the FZ in order to analyse treated region of the samples.

It was found that the hardness of base metal material for both RSW as-welded and LBIT treated samples was about the same (~ 149 and 155 HV). It was observed that the hardness of HAZ was higher than the fusion zone and base metal. The HAZ experienced solid state phase transformation but no melting was induced during the welding process. In addition, the area closer to the fusion zone revealed a definite drop. This phenomenon is identified as HAZ softening, mainly caused by martensite tempering development (Mali & Inamdar, 2012; Pouranvari, Marashi, & Safanama, 2011; Zhao, Wang, Zhang, & Zhang, 2013). 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 (Yildirim & Marquis, 2013). This in turn, causes a decrease of the hardness values in the vicinity of the fusion zone. The mean hardness value of the fusion zone in the as-welded condition is recorded at 211 HV compared to the average value of 229 HV obtained for the LBIT treated.

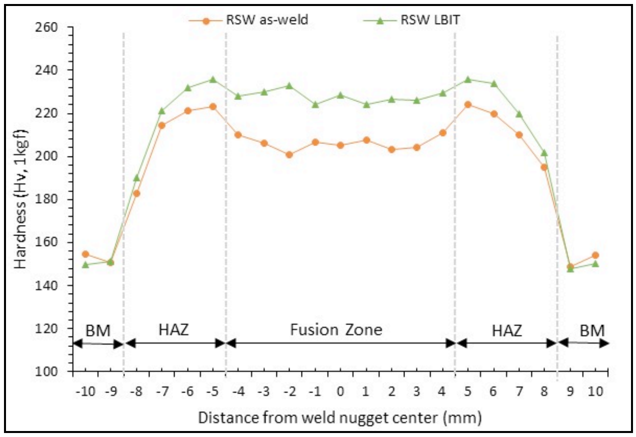


*Figure 4.* Hardness profile for RSW LBIT and RSW as-weld samples

The hardness value for LBIT samples is generally higher at both FZ and HAZ than as-welded samples. The hardness of base metal is lower than HAZ and FZ due to the unaffected region during solidification process for both samples and also during the low blow impact treatment. For LBIT samples, there is significant difference in the range of FZ and HAZ. No phase transformation occurred because the base metal of carbon steel was not affected during the low blow impact treatment. Hardness at fusion zone and HAZ showed considerably higher values than that at the base steel. It is envisaged that melting and during re-solidification of the welding process displayed relatively large volume fraction of ferrite morphologies, which induced softening of the zone. The average hardness value for three different zones in RSW LBIT spot welded joint is shown in Figure 5. These hardness results are partially in good agreement with the literature (Liu, Zheng, He, Wang, & Wei, 2016).

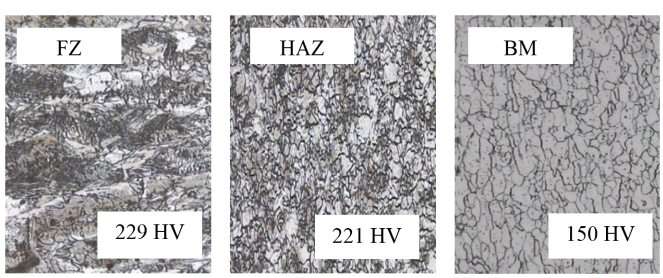


*Figure 5.* Hardness of the RSW LBIT sample zones

The L-N curve of RSW LBIT and as-welded joint presented in this study are shown in Figure 5. A total 45specimens were tested at nine different stress levels, that is, five specimens were tested at each load level, with the maximum load tested at 7.3 kN. It is noted that all specimens were tested until failure and no run-outs were recorded. As expected, the fatigue strength of the LBIT samples were higher than as–welded samples.

Fatigue test was conducted with ten percent increase of load level. The static load of the RSW LBIT and RSW as-weld samples is plotted on the curve at 1 cycle (log 1=0). RSW LBIT 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 for the RSW PIT samples at 1 million cycles that corresponded well with the experimental data as shown by an arrowhead. Hence, it can be deduced that a load level of up to 2 kN can be taken as a safe value for endurance limit for this RSW LBIT sample.

It should be noted that RSW LBIT joints have different joining features due to the treatment applied compared to RSW as-weld joints. From the treatments, the RSW LBIT joint is improved as the propagation of existence in any crack tends to slow and decelerate. This results in different crack initiation and growth behaviour between both joints.

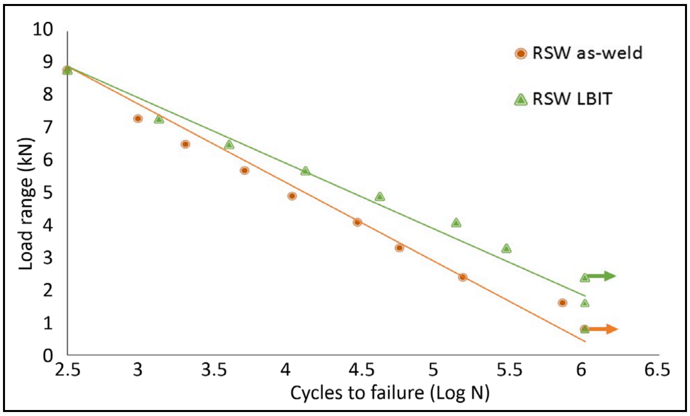


*Figure 6.* L-N curve for RSW LBIT and RSW as-weld samples

In order to determine the fatigue sensitivity of the LBIT weld samples, it is more suitable to use normalised load versus cycles to failure curve. For spot weld joint, results of fatigue tests are generally presented as load range vs. fatigue life (Hongyan & Senkara, 2006; Spitsen, Kim, Flinn, Ramulu, & Easterbrook, 2005; Wang et al., 2014). The normalised load (maximum tensile load divided by shear load) versus cycles to failure curve is shown in Figure 7. The curve shows that the RSW LBIT sample lost their static strength by almost 11.9% per decade of cycles, while for the RSW as-weld, almost 15% static strength was lost per decade. Lower percentage of lost value shows that the fatigue performance is better. Showing that, the fatigue performance for RSW LBIT is better than RSW as-weld. This may be due to the treatment that is applied to the joints which shows that the residual stress of RSW LBIT sample is improved. As noticed, significant improvement in the fatigue life can be obtained by modifying the residual stress levels in the material. There is a similar scatters trend for both RSW condition (RSW LBIT and RSW as-weld) in terms of reduction on normalised fatigue curves (Liu et al., 2013).

The scatter in fatigue life is large even under controllable and repeated testing conditions. Imprecision in testing equipment, loose tolerance in sample dimensions and large variations in environmental conditions may lead to unacceptably large scatter in presenting the data. For this reason, one should ensure that the scatter in experimental data is within the acceptable range and tests are conducted under controllable and repeated conditions. This requires a statistical analysis of data collection. One of the methods to estimate the scatter in fatigue number of cycles is to calculate the fatigue sensitivity coefficient.

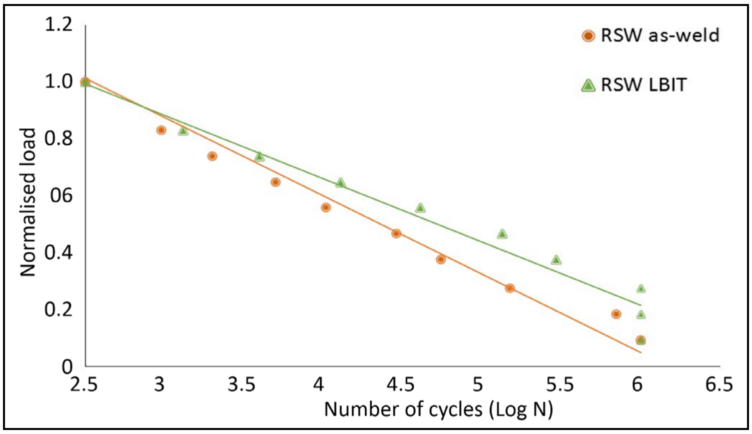


*Figure 7.* Normalised L-N curve for RSW LBIT and RSW as-weld samples

Typical values for fatigue sensitivity of mild steel are in the range from 0.10 to 0.50. However, the fatigue sensitivity for welded joints is even higher. In order to judge whether the scatter is within the acceptable range, one may also examine the regression coefficients obtained through regression analysis of the experimental data. It is known that fatigue life data can typically be fitted to a power-law. 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 as-weld sample exhibits the value of 0.14, which falls in the typical value range. The determination coefficient (R2) value for RSW LBIT is 0.9530, which is close to 1 indicating that the linear line is a good fit for the data, and the predictability of the regression is quite high (Sun, Stephens, & Khaleel, 2008).

Table 2
*Fatigue sensitivity coefficient and determination coefficient of RSW LBIT and RSW as-weld sample*

| Weld configuration | Fatigue sensitivity coefficient | Determination coefficient |
|---|---|---|
| RSW LBIT | 0.142 | 0.9530 |
| RSW as-weld | 0.262 | 0.9717 |

## CONCLUSION

LBIT treatment is a post weld impact treatment that can be applied and used to significantly enhance the tensile shear load and hardness of RSW joint. LBIT helps in strengthening the metals through cold work that may increase the surface hardness and provide increased resistance to failure. As a whole, it has been proven through the experimental analysis that the treatment of LBIT increases the strength for the low carbon steel spot weld joining that could substantially reduce the material cost for loading structures in industries.

Effects of modification of local material properties in the post weld impact treatment of spot weld sample were investigated through tensile shear test, hardness, and fatigue failure tests. Two different spot weld samples conditions were studied: RSW LBIT and RSW as-weld. The results showed that the treatment increased the tensile shear load of spot weld and also increased the hardness of the joint significantly. However, the modification of spot welded surface due to LBIT treatment led to an increase in fatigue failure.

## ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the 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 gratefully acknowledge the financial support from the Fundamental Research Grant Scheme (Ref: FRGS/1/2016/TK03/UITM/02/5) for the successful implementation of this project.

## REFERENCES

Baltazar-Hernandez, V. H., Okita Y., & Zhou, Y. (2013). Second pulse current in resistance spot welded TRIP steel - Effects on the microstructure and mechanical behavior. *Welding Journal, 91*(10), 278s-285s.

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.

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*(0), 336–342.

Ma, H., Qin, G., Geng, P., & Fu, B. (2015). Effect of post-weld heat treatment on friction welded joint of carbon steel to stainless steel. *Journal of Materials Processing Technology, 227*, 24-33.

Mali, M. P., & Inamdar, K. H. (2012). Effect of spot weld position variation on quality of automobile sheet metal parts. *International Journal on Applied Research in Mechanical Engineering, 2*(2).

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*, 42.

Pouranvari, M., Marashi, S. P. H., & Safanama, D. S. (2011). Failure mode transition in AHSS resistance spot welds. Part II: Experimental investigation and model validation. *Materials Science and Engineering: A, 528*, 8.

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.

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.

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*, 11.

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 World Association, 57*(3), 437-447.

Zhang, H., & Senkara, J. (2011). *Resistance welding: fundamentals and applications.* CRC press.

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*, 6.