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The Study of Slow Bend Test and Hardness Test for Welded Rail Joints in Between Alumino Thermic and Flash Butt in Electrified Double Track Project (EDTP) Gemas-JB

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Abstract: The development of railway projects in Malaysia is accelerating from time to time, with various railway projects being developed by Malaysia. Among the Malaysian railway projects still progressively ongoing this year is the Gemas - Jb EDTP, enforced under SIPPYTL's company, YTL Construction. The speed designed for this project is 160 km/h. Engineers working on this project must consider many requirements, including links between rails, to reach that design speed. Most of their previous projects used fishplate to connect rail connections. However, the Gemas - JB EDTP project uses the welding method to connect the rail, which is a total of 192 km with an allocation of RM7.5B from the government. Even so, most of the railway projects in Malaysia now use two types of welding, ATW and FBW, which have the same purpose but vastly different mechanisms. The mechanism used for ATW is the chemical reaction element, while FBW is the electrode reaction. This study aims to identify why most railway projects in Malaysia now need to use two types of rail connection welding by studying the differences between these two welds through the results of laboratory tests conducted for both types of welding. The researcher also studies the laboratory test methods to better understand these two welding methods. The Laboratory test that involves are Slow Bend Test and Hardness Test. It enables the researcher to know the differences, advantages, disadvantages and reasons easily. As a result, the researchers could compare these two welds and identified FBW to be much better than ATW in terms of quality. However, ATW has some advantages that FBW cannot afford in this project. Both methods are important for completing any railway project in Malaysia today, especially the Gemas-JB EDTP.

Keywords: ATW, FBW, EDTP, SIPPYTL, Welding, Joint, Railway,

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1. Introduction

Effective public transit is essential in successful cities. It makes it possible for people in the area to engage in a variety of activities that benefit both community members overall. [1] Nowadays, as for rail transportation mode there has been moving toward electrification as one of the main energy consumers, as electrical energy delivers a lot of environmental benefits due to the significant absorption of renewable energies in electric power systems. [2] In 2016, based on Figure 1.1 below the project contract was awarded to the Chinese consortium of CRCC, CREC, and CCCC, three companies that formed the local vehicle CRCC-CREC-CCCC Consortium Sdn. Bhd. on March 24, 2016. [3]

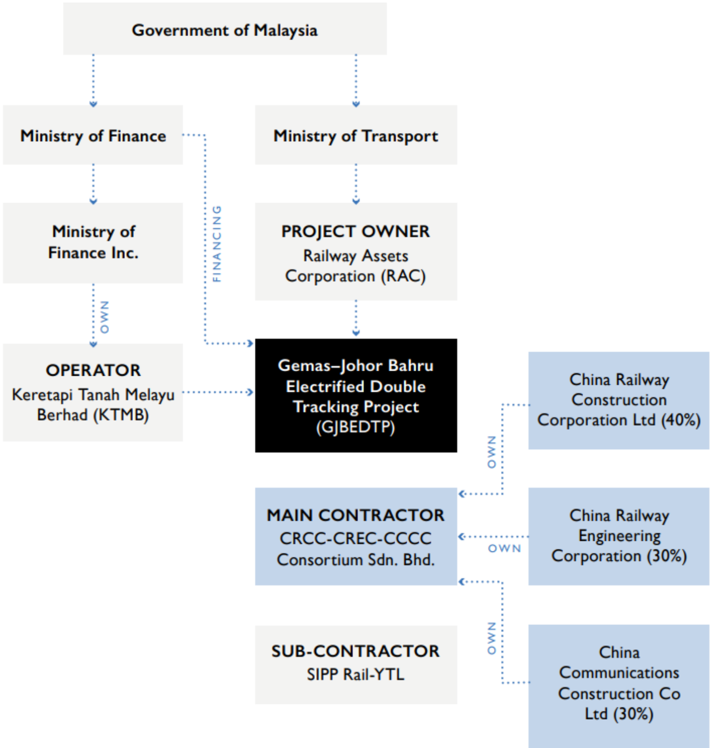

Figure1: The project structure of Gemas-Johor Bahru EDTP[3]

The Malaysian government aims to implement the EDTP to upgrade railway infrastructure between Gemas and Johor Bahru, including signaling, telecommunications, and electrification works. The EDTP include installing electrical cabling over a 197-kilometre section of track as well as replacing a single rail line with a double track. It is the last piece of the current Keretapi Tanah Melayu Berhad (KTMB) network to be modernised, and once finished, it would give a continuous connection from the Peninsula's southern tip to Padang Besar in the north. [4]

Good rail track is when there are very minimize of shaking when the passenger was using the service even the Electrified train are on the maximum design speed limit. This paper will elaborate more about comparison between method of welding of joint which are Alumino Thermic and Flash Butt on rail track. There are two method of rail joint welding that will be discussed in this paper, ATW and FBW. [5] Aluminothermic rail welding was a huge success from the start, known for its low cost, which was still the case in Germany in 1895. This technology is currently widely used for railway construction, maintenance, and modernization all over the world [6]. In flash-butt welding, electric power is applied between the end faces of the rails being joined, and the free rail is moved forward at low speed, and flash and arc are generated[7].

Problem Statement for this research, rail Joint is one of the most important parts in railway. Without a better knowledge about rail joint, the excellent of track may not produce. There is various method of rail welding that have been implemented in Construction of Railway nowadays include in EDTP

Gemas-JB. There are two method of rail welding that have been used in permanent track which are Alumino Thermic Welding (ATW) and Flash Butt Welding (FBW). This paper is to identify why in this EDTP Gemas-JB project are needed two type of method welding rail joints to completed the project. Both methods will be compared to solve the problem.

Objective for this research is to observe the data of lab testing between Alumino Thermic and Flash Butt in EDTP Gemas-JB, to study the Slow Bend Test and Hardness Test of testing mentioned in Inspection of Test Plan for Alumino Thermic and Flash Butt in EDTP Gemas-JB, to identify and analyses the different of method of welding rail joints in between Alumino Thermic and Flash Butt in EDTP Gemas-JB.

This research cover about two method of rail welding which are Alumino Thermic and Flash Butt that have been used in Electrified Double Track Project (EDTP) Gemas-JB. The focus of this study is mainly towards welded rail joint for double track from Gemas to Johor Bahru and the data collection genuinely based on the lab test report and site implementation from EDTP Gemas-JB. The guidelines recommended by SIPPYTL, Department of Trackwork to emphasize the advantage and disadvantages/ pros and cons of ATW and FBW in this project. Another guideline that may referred are Statements of Needs (SON), KTMB's Permanent Way Manual Volume 1 and 2 and Technical and Performance Specifications that provide specifically for EDTP Gemas-JB.

2. Previous Study

A crucial component of the railway system is the rail joint. Local settlement occurs because the rail joints are less rigid and strong than the rail centers. [8] Welded joints must have the same qualities as the rails themselves in order to fulfil the purpose and provide constant performance. [9]

Goldschmidt's aluminothermic technique, invented in 1898, is used to join lengthy strings of flash butt welded rails in the field, as well as to repair worn or broken rails. [10] Thermite welding is used on railroads to join rails together. [11] Flash-butt welding is characterized by a high stable quality of welded joints that are nearly equal in strength to the parent metal [12] . Table 2.1 show the comparison between ATW and FBW in general.

Table 1: Comparison of welding rail joint

Description	ATW	FBW
Type of welding	Chemical reaction	Electro-contact
Performed	Manually (human force)	FBW Machine
Quality	Depend on competency of welder	Depend on machine efficiency
Mobility	Easy to mobilize	Hard to mobilize
% of Failure	68%	4%
Advantage	No need for an electrical power supply when welding on-site.	Weld large cross-sectioned shape materials quickly

Based on study and research, both methods had same purpose which to joint the rail to build a long track with most efficient but with different method. FBW had a lot of advantages in rail joint of welding because it may weld large cross-sectioned shape materials quickly, without the need for interface preparation cleaning, and with adequate weld strength. Flash butt welding is extensively utilized in the automotive, aerospace, and other engineering industries. [13] The platen travel is constant from the time of flashing until upset, when the platens are swiftly pressed together for upsetting during the upset period, and the current may be promptly interrupted. The schematic of typical flash butt welding process parameters such as flash current, platen weight position, and upset force is shown in Figure 2.2. [13]

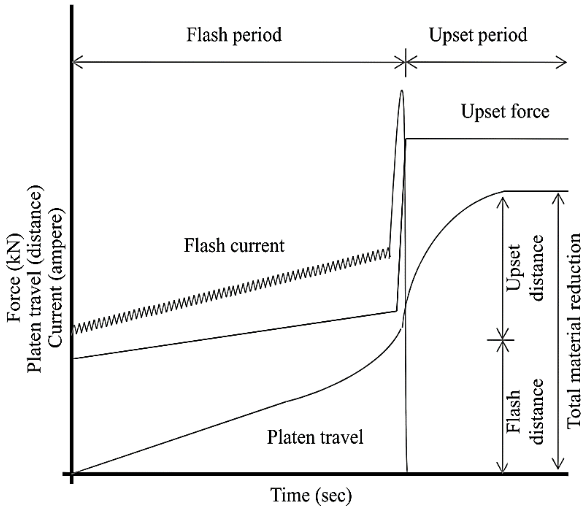

Figure 2: Schematic of Typical Flash Butt Welding Process[13]

Before, FBW exists or worldwide using, ATW was the number one option for rail welding joint because the material for this method easy to get and final cost for this welding less expensive compare to FBW. It also no need current supply when the welding needs to weld on site. This method doesn't have any problem with any location the welder wants to weld. [10]

To compare both of method as specifically, the researcher learns about lab testing that both of rail joint method will undergo which are Slow Bend Test and Hardness Test. Both of test are include in test qualification for rail joint welding. Slow bend test is used to determine the quality of the rail weld. Rail is either bent or breaks when subjected to a qualifying criterion load. The fracture surfaces are investigated for macrostructure, such as visible flaws like as inclusions and weld failure, after the rail fracture.[14] Hardness test is to determine the width of the softened zone, the maximum and minimum hardness in the heat-affected zone, and any asymmetry in the hardness distribution.

3. Methodology

The type of this project Research method is Exploratory Research. Exploratory studies are based on principles and their explanations, but they don't offer any conclusions about the research issue. The theory is not tested, and the outcome will be of little use to the rest of the world. This research might help future engineer to more understand and easy to differentiate between of this two welding. The flow of this research may refer to Figure 3.

The data from this project was provided from SIPPYTL from EDTP Gemas – JB and the scope for this research was on 2021 and specifically for Northern area only. This is because the progress of construction for Northern and Southern has a bit different which are both towards for Permanent Track while at Southern there is still a lot for temporary track. The testing that involved in this research are Slow Bend Test and Hardness Vickers Test only. Both of the test had a similarity which were run in lab and the data much clearer to analyses.

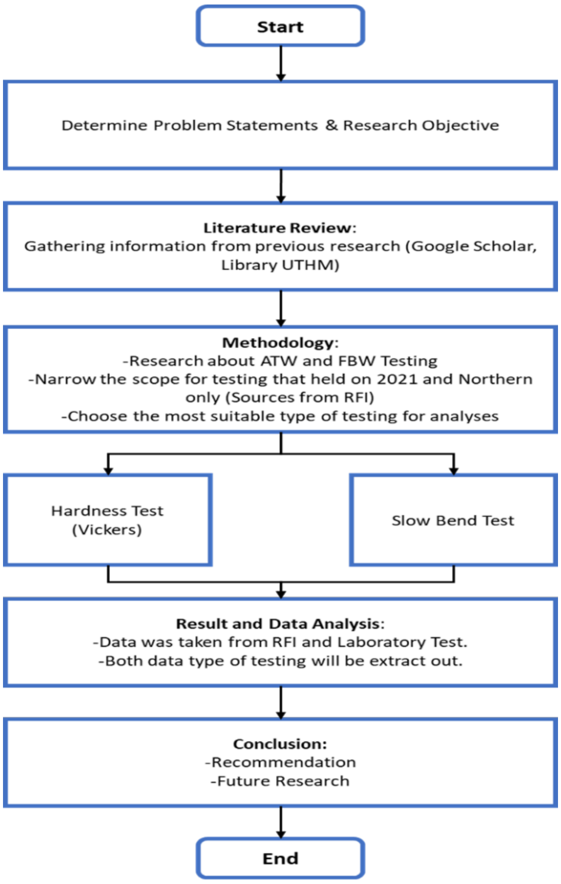

Figure 3: Flow chart of the analysis procedure

All of data was extract by researcher to get a better view of point to analysis the comparison of both method of testing. The detail of result by testing has been listed below:

The data of **Slow Bend Test** that will be analyses in this research are:-

1. Mean Rate of Loading (kN/s)

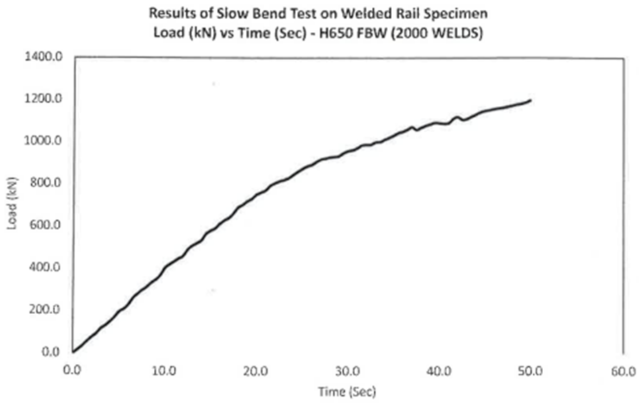

Figure 4: Mean Rate of Loading (KN/s) graph

From Figure 4, it shows that the mean rate of Loading for welding rail joint can be define as load (kN) and Time (s) is directly proportional when force is given.

From Figure 5 below, the deflection at termination test can be identify by refer to the last number at Linear Displacement Transducer Reading at mean (mm). The maximum load that can be handle by joint may be found at the last row of Applied Load. Maximum Stress in the foot can be find by follow the equation (4.1) .

Results of Slow Bend Test on Welded Rail Specimen

Time (Sec)	Applied Load		Linear Displacement Transducer Reading			Remarks
	(kN)	(ton)	LDT1 (mm)	LDT2 (mm)	Mean (mm)	
26.5	979.0	99.8	-17.06	-11.47	-14.27	
27.0	984.0	100.3	-17.06	-12.02	-14.54	
27.5	991.5	101.1	-17.59	-12.02	-14.81	
28.0	999.1	101.8	-17.59	-12.57	-15.08	
28.5	1006.0	102.5	-18.13	-12.57	-15.35	
29.0	1014.0	103.4	-18.67	-13.13	-15.90	
29.5	1021.0	104.1	-18.67	-13.13	15.90	
30.0	1028.0	104.8	-19.20	-13.67	-16.44	
30.5	1036.0	105.6	-19.20	-14.23	-16.72	
31.0	1042.0	106.2	-19.75	-14.23	-16.99	
31.5	1050.0	107.0	-19.75	-14.78	-17.27	
32.0	1055.0	107.5	-20.29	-14.78	-17.54	
32.5	1063.0	108.4	-20.29	-15.33	-17.81	
33.0	1068.0	108.9	-20.83	-15.33	-18.08	
33.5	1074.0	109.5	-21.38	-15.87	-18.63	
34.0	1081.0	110.2	-21.38	-16.42	-18.90	
34.5	1088.0	110.9	-21.92	-16.42	-19.17	
35.0	1093.0	111.4	-21.92	-16.96	-19.44	
35.5	1097.0	111.8	-22.46	-16.96	-19.71	
36.0	1103.0	112.4	-22.46	-17.50	-19.98	
36.5	1109.0	113.0	-22.99	-17.50	-20.25	
37.0	1114.0	113.6	-23.53	-18.04	-20.79	
37.5	1119.0	114.1	-23.53	-18.04	-20.79	
38.0	1123.0	114.5	-24.06	-18.58	-21.32	
38.5	1129.0	115.1	-24.06	-19.13	-21.60	
39.0	1134.0	115.6	-24.59	-19.13	-21.86	
39.5	1139.0	116.1	-24.59	-19.67	-22.13	
40.0	1144.0	116.6	-25.13	-19.67	-22.40	
40.5	1149.0	117.1	-25.13	-20.21	-22.67	
41.0	1154.0	117.6	-25.66	-20.21	-22.94	
41.5	1164.0	118.7	-26.20	-20.74	-23.47	

Figure 5: Result of Slow Bend Test

2. Deflection at termination test (mm)
3. Maximum Load, P (kN)
4. Maximum Stress in the foot, σ

Table 3.1 below will be use as template for analysis the data of slow bend test. Sample references is needed to include to avoid any confusion during the research. Since all of the data was obtained my RFI, the RFI References number is must if the researcher or future research want to recheck the data. Date in that table just to show that all of the data was only from 2021 only. Every specification for type of rail is different for different type of rail. Because of it the type of rail needs to mention since each type of rail had different type of material and sizing. While the others are needed and required while to compare between FBW and ATW.

Table 3.1: Sample of table slow bend test data analysis

Sample Ref	C8548 H1000 (8500 Welds)
RFI Reference	S0.0-FBW-00082
Date	1/11/2021
Type of rail	54E1
Mean Rate of Loading (kN/s)	*28.05*
Deflection at termination test (mm)	23.47
Maximum Load, P (kN)	1164
Maximum Stress in the foot, *σ*	929.93

The data of **Hardness test** that will be analysis are:-

1. Maximum Fusion Zone

The fusion zone is defined as the portion of a material that has melted. The heat affected zone (the material that has been altered by the welding heat but has not fully melted) is not considered the fusion zone.

2. Width of heat-softened zone

Table 3.2 below will be use as template for analysis the data of hardness test.

Table 2: Sample of table hardness data analysis

Sample Ref	A001
RFI Ref	S0.0-ATW-00114
Date	23/11/22
Type of Rail	54E1

Max Fusion Zone	321 HV < 430HV
Width of heat-softened zone	A1, B1= 4mm A2, B2 = 18mm

4. Analysis Data and Discussion

The data was extract from Request For Inspection (RFI) from this EDTP Project. This research will only focus on Permanent Track since Northern area didn't do any ATW testing that related with BS80A in 2021. The time frame for this testing was focused in 2021 and Northern area only. All rail joint of welding for Temporary Track will only solely use ATW method so there will no testing for FBW welding whether at Insitu or Depot.

4.1. Slow Bend Test

Slow Bend Test is one of the qualifications of for rail joint welding. Data from Lab which is Test Sdn Bhd will be analyze to compare the data for find out the comparison between FBW and ATW. The specification to define the data will be refer from several documents which are AS1085.20-2012 Appendix I, Appendix M, Table M1 and M2, EDTP Gemas-JB Technical Specification Clause 10.3.7.2.

Length of test plan, **L** = 1000 mm
Second moment of area of the rail section, l

1. BS08 = 1205 x 10^4 mm
2. 54E1 (UIC54) = 2346 x 10^4 mm

Distance of the extreme fibre in the foot from the neutral axis, $\mathbf{y_{foot}}$:

1. BS80A = 66.67 mm
2. 54E1 = 74.97 mm

Maximum stress in the foot :-

$$\boldsymbol{\sigma} = \frac{PLy_{foot}}{4l} \qquad Eq.\ 1$$

$\boldsymbol{\sigma}$ = Width of heat-softened zone
P = Maximum Load (kN)
y_{foot} = Distance of the extreme fibre in the foot from the neutral axis,

4.1.1. Flash Butt Rails Welding at Depot

Flash Butt Welding Depot will produce of welding rail joint for 25m or less to produce Long Welded Rail (LWR) strings of approximately 150m long or less. These production of LWR strings shall be executed by using FBW machine at specially prepared yard. Minimum of stress in the foot for FBW is 900 Mpa while the minimum for deflection is 20 mm. Table 4.1 shown data from Lab that have been extract from this project for Flash Butt Rails Welding at Depot.

Table 3: Data on Slow Bend Test for Flash Butt Rails Welding at Depot

Sample Ref	C6523 H1000 (6500 Welds)	C8548 H1000 (8500 Welds)	C8551 H1000 (8500 Welds)
RFI Reference	S0.0-FBW-00079	S0.0-FBW-00082	S0.0-FBW-00086
Date	14/10/2021	1/11/2021	8/11/21
Type of rail	54E1	54E1	54E1
Mean Rate of Loading (kN/s)	26.00	28.05	26.8
Deflection at termination test (mm)	23.49	23.47	22.85
Maximum Load, P (kN)	1157	1164	1168
Maximum Stress in the foot, σ (Mpa)	924.34	929.93	933.13

Table 3 below is the example of the calculation for find Stress. *Eq.*1

C6523 H1000 (6500 Welds)

$$\boldsymbol{\sigma} = \frac{(1164\ x\ 10^3)(1000)(74.97)}{4(2346\ x\ 10^4)}$$

$$\boldsymbol{\sigma} = 924.34\ Mpa > 900\ Mpa$$

The rail joint of welding passes the requirement as AS 1085.20-2012.

4.1.2.Mobile Flash Butt Rails Welding (Insitu FBW)

Insitu FBW will form Continues Welded Rail (CWR) panel by joint LWR that laid on track site. Minimum of stress in the foot for FBW is 900 Mpa while the minimum for deflection is 20 mm. There has been no different for this requirement because both of FBW use the same method. Table 4.2 shown data from Lab that have been extract from this project for Insitu FBW.

Table 4: Data analysis of Slow Bend Test for Mobile Flash Butt Rails Welding

Sample Ref	H650 FBW (2000 Welds)
RFI Reference	S0.0-FBW-00056
Date	3/3/21
Type of rail	54E1
Mean Rate of Loading (kN/s)	23.35
Deflection at termination test (mm)	23.47
Maximum Load, P (kN)	1197
Maximum Stress in the foot, σ	956.30

4.1.3.Alumino Thermit Welding (ATW)

According to SON, ATW is only permitted for turnouts and only at location that required for the purpose of rail de-stressing and for installation of Glued Insulated Rail Joints (GIRJ). According to ITP for this project the minimum of stress in the foot for FBW is 750 Mpa. As for this project, the one sample will be taken for every 200 productions of ATW. Below are the Table 5 of data related RFI from this project.

Table 5: Data analysis of Slow Bend Test for Alumino Thermit Welding

Sample Ref	A003 ATW B/N 0028906
RFI Reference	S0.0-ATW-00113
Date	3/12/21
Type of rail	54E1
Mean Rate of Loading (kN/s)	37.24
Deflection at termination test (mm)	11.54
Maximum Load, P (kN)	1024
Maximum Stress in the foot, σ	818.09

4.1.4.FBW Depot vs Insitu FBW vs ATW

Based on the analysis above clearly see that the maximum load that FBW Depot and Insitu FBW was highest compare to ATW. The deflection at termination test was depends on the maximum load that rail welding of joint can afford. The highest maximum of load will produce highest maximum stress in the foot. Based on the AS standard also we can compare that the requirement for minimum stress for ATW is 750 Mpa while FBW is 900 Mpa. It shown that FBW method much more quality and long-lasting compare to ATW.

Not only that, the number of testings for FBW also had much more than ATW because the production that FBW were more than ATW for 2021. As have been inform before, in 2021 the progress for Northern already focus for built at Permanent Track, then the number of ATW purpose will only limit to Plug Rail, De-stressing and GIRJ.

4.2. Hardness Test

In this project, there are several types of hardness that involve in this EDTP project for pass the qualification of FBW and ATW. The specification and qualification for this test are follow by AS 1085.20-2012. Since this data analysis will only be focused for 2021 and Northern only, so the data analysis for hardness test will concentrate in Vickers Test.

4.2.1. Flash Butt Welding (FBW)

According to AS 1085.20-2012, there will be 3 requirement that need to follow as specification. For FBW (according to Table M2 and Lab test): -

i. X=10 HV for as-rolled rail,
ii. Maximum fusion zone hardness must ± 40 to a maximum of 380HV
iii. Width of heat-softened zone (Dimension AB) – On either side of the weld, less than or equal to 40 mm

4.2.2. Alumino Thermit Welding (ATW)

According to AS 1085.20-2012, there will be 3 requirement that need to follow as specification. For ATW (according to Table N3 and Lab Test)

i. X=10 HV for as-rolled rail,
ii. Maximum fusion zone hardness must ± 40 to a maximum of 430HV
iii. Width of heat-softened zone (Dimension AB) – On either side of the weld, less than or equal to 40 mm

4.2.3. FBW vs ATW

Based on the Table 6, all of the sample passed the specification of AS standard. It can be proved if refer to Maximum Fusion Zone and Width of heat-softened zone. All of the test has been run in 2021 with same type of rail which is 54E1. According to AS standard, the specification of Maximum Fusion Zone for FBW and ATW have slightly different which are FBW is 380 HV while ATW is 430 HV. From the specification, it shows that the less value of Maximum Fusion Zone, the higher the quality of joint. From the table it shows that the maximum fusion zone for ATW is much low than FBW. It may due to the technique and competent that have been applied by the welder in this rail welding joint until it can increase the quality of rail joint ATW. It proofs that ATW sometimes can be much better than FBW in certain point if the welder really follows the procedure and standard that have been prepared for this project.

Table 6: Data Analysis of Hardness Vickers Tests

Sample Ref	**FBW H1000 – 2500 Weld Proof Test**	**FBW H650 – 2000 Weld Proof Test**	**A2287 H650 (2000 welds)**	**C4524 H1000 (4500 Welds)**	**C5517 H1000 (5500 Welds)**	**A001**
RFI Ref	S0.0-FBW-00059	S0.0-FBW-00060	S0.0-FBW-066	S0.0-FBW-00067	S0.0-FBW-0067	S0.0-ATW-00114
Date	11/3/22	11/3/22	28/6/21	28/6/21	28/6/21	23/11/22
Type of Rail	54E1	54E1	54E1	54E1	54E1	54E1

Max Fusion Zone	343HV < 380HV	343HV < 380HV	353HV < 380HV	339HV < 380HV	347HV < 380HV	321 HV < 430HV
Width of heat-softened zone	A1, B1= 9mm A2, B2 = 11mm	A1, B2 = 10mm A2, B2 = 7mm	A1, B1 = 13mm A2, B2 = 17mm	A1, B1 = 25mm A2, B2 = 23mm	A1, B1= 23mm A2, B1 =25mm	A1, B1= 4mm A2, B2 = 18mm

The specification for width of heat-softened zone in for both welding is same which are either one must or less than 40 mm. Even in a test, one of the widths exceed 40 mm but the other one still 40 mm or less than 40 mm it will still consider as pass.

5. Conclusion

Conclusion from this research, the researcher manages to observe and identify the data of lab testing between ATW and FBW that suitable to analyses which are Slow Bend Test and Hardness Test. The researcher has study both of testing which have been mentioned in ITP for ATW and FBW for this EDTP Gemas-Jb Project. After both of objective have achieved, the researcher able to accomplish the last objective for this research which to identify and analyses the different of method of welding rail joints in between Alumino Thermic and Flash Butt in EDTP Gemas-JB to know the reason most of railway project in Malaysia need to use two types of welding in a railway project. Researcher has concluded that, as for current technology in Malaysia both of method rail joint of welding are really necessary for every Railway Project in Malaysia. Even though, FBW give a very quality result compare to ATW from every testing, but there still some purpose of rail welding joint that can't be fulfill by FBW such as to do Plug Rail, De-stressing, Turnout and GIRJ.

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References

[1] S. Bachok, M. M. Osman, and Z. Ponrahono, "Passenger's Aspiration Towards Sustainable Public Transportation System: Kerian District, Perak, Malaysia," *Procedia - Soc. Behav. Sci.*, vol. 153, pp. 553–565, 2014, doi: 10.1016/j.sbspro.2014.10.088.

[2] X. Liu and K. Li, "Energy storage devices in electrified railway systems: A review," *Transp. Saf. Environ.*, vol. 2, no. 3, pp. 183–201, 2020, doi: 10.1093/tse/tdaa016.

[3] IDEAS, "Gemas – Johor Bahru Electrified Double-Tracking," *BRI Monit.*, 2021.

[4] F. E. Hutchinson and K. Zhang, "The Gemas-Johor Bahru Railway Electrified Double-Tracking Project: Steady Progress towards Completion," *ISEAS*, no. 72, pp. 1–9, 2020.

[5] Keretapi Tanah Melayu (KTM), "Chapter 24 - Welding of Rails," in *Permanent Way Manual*, Rev. 0., 2015.

[6] M. Brânzei and T. Coman, "Structure Improvement of Aluminothermic Welding Joints by Using Modifiers," *Int. J. Chem. Nucl. Metall. Mater. Eng.*, vol. 6, no. 8, pp. 1294–1297, 2012.

[7] M. Fujii, H. Nakanowatari, and K. Nariai, "Rail flash-butt welding technology," *JFE Tech. Rep.*, vol. 20, no. 20, pp. 159–163, 2015.

[8] S. P. H. Prakash Kumar Sen, Mahesh Bhiwapurkar, "Analyzing behaviour of a rail wheel

assembly with alumino thermite weldment with modal analysis simulations in ANSYS," *J. Phys. Conf. Ser.*, 2021, doi: 10.1088/1742-6596/2070/1/012239.

[9] R. A. S. Nikolay A Kozyrev, Olga A Kozyreva, Aleksander A Usoltsev, Roman E Kryukov, "Modern Methods of Rail Welding Nikolay," *FEC-2017*, 2017, doi: 10.1088/1757-899X/253/1/012002.

[10] J. Bijendra, "Thermite welding of rail steel," 1989.

[11] A. S. I. M S Galay, "Improving the technology of aluminothermic rail welding based on software simulation," *ICMSSTE 2021*, 2021, doi: 10.1088/1742-6596/1967/1/012063.

[12] Y. Chvertko, M. Shevchenko, and A. Pirumov, "Monitoring of the process of Flash-Butt Welding," *Soldag. Inspeção*, vol. 18, no. 1, pp. 31–38, 2013, doi: 10.1590/s0104-92242013000100005.

[13] D. C. Kim, W. J. So, and M. J. Kang, "Effect of flash butt welding parameters on weld quality of mooring chain," *Arch. Mater. Sci. Eng.*, vol. 38, no. 2, pp. 112–117, 2009.

[14] M. Saarna and A. Laansoo, "4th International DAAAM Conference RAIL AND RAIL WELD TESTING," no. April, 2004.