

# Comparative Analysis of Accepted Criteria for Routine Test of Aluminothermic Welds for Electrified Double Track Project (EDTP) Gemas to Johor Bahru

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## Abstract

Thermite welding, commonly referred to as aluminothermic welding, is a method of joining metal pieces by creating molten metal through a chemical reaction between aluminium oxide and aluminium powder. The correct management of porosity to weld is a common problem in aluminothermic welding. Another problem is precisely controlling the bend of weld joints which is make the railway rail joint crack. Furthermore, it's imperative to make sure the thermite mixture is distributed uniformly to prevent uneven heating and partial fusion. The study investigates the comparative analysis of acceptance criteria for routine tests of aluminothermic welds at Electrified Double Track Project (EDTP) from Gemas to Johor Bahru. Aluminothermic welding, crucial for ensuring the structural integrity of rail junctions, requires high precision and sensitivity. This study aims to identify the acceptance criteria for routine tests of aluminothermic welds, to analyse a set of routine test results, and identify areas for improvement in the welding process and recommend best practices to ensure compliance with the AS standard. The methodology includes process of preparation of primary data, selection of study area, data collection on routine test results and analyse collected data. The findings indicate that while there is a minimal failure rate and 85% accepted criteria based one specified AS standard and the overall welding quality meets the project's design standards. The study concludes that the welding process applied in the EDTP project demonstrates promising results in terms of weld quality, rail alignment, and joint durability, adhering to the specified standards. Recommendations for further improvement focus on enhancing process reliability and frequent test routines based on specified AS standards.

## 1. Introduction

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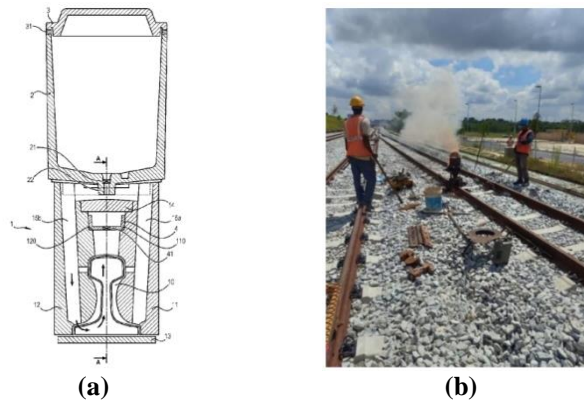


The project of the Electrified Double Track from Gemas to Johor Bahru (EDTP Gemas – Johor Bahru) consists of 197 km for entire length of the rail. The entire length of the rail needs to joint to combine to become one way rail to use by rolling stock. When finished, the EDTP will enable the new Electric Train Service (ETS) to move at a top speed of 140 kilometers per hour. Because passenger train services between Kuala Lumpur and Johor Bahru would stop at stations along the route, the average speed is expected to be around 100 miles per hour. While not a high-speed rail link, the ETS is twice as fast as present diesel passenger trains.[1] Despite its widespread use, ensuring the consistent quality of aluminothermic welds remains a challenge due to various factors, including variations in welding techniques, environmental conditions, and operator skills. The quality of these welds must meet stringent acceptance criteria to prevent potential failures that could lead to operational disruptions, safety hazards, and increased maintenance costs. The Australian Standard AS 1085.20 sets forth comprehensive acceptance criteria for routine tests of aluminothermic welds, encompassing visual inspections, non-destructive testing (NDT), and mechanical testing. However, the direct application and effectiveness of these standards in the context of the EDTP from Gemas to Johor Bahru have not been thoroughly examined. Objectives to identify the acceptance criteria for routine tests of aluminothermic welds, to analyse a set of routine test results, and identify areas for improvement in the welding process and recommend best practices to ensure compliance with the AS standard. This following study will cover aluminothermic welding routine test for joining of rails through specified testing of test samples which are accordingly prepared at the work site Electrified Double Track from Gemas to Johor Bahru (EDTP Gemas – Johor Bahru) at all section, Johor Darul Takzim. Each set of test samples shall be depending on rail sections, rail hardness, and combination of rail hardness and its limit to straight line rail joint. The study will show how important it is to ensure the long-term durability and reliability of the rail network. It is crucial to thoroughly understand the performance characteristics of Aluminothermic Welding (ATW) used in the project.

An essential part of the AS 1085 series, which regulates railway track materials, is Australian Standard AS 1085.20. on order to guarantee the performance and safety of welded rail joints on railway tracks, this standard specifies extensive standards and processes specifically pertaining to the welding of steel rails. It covers a variety of welding techniques, such as arc welding, thermit welding, and flash butt welding, each with specific instructions to guarantee quality and consistency. Strict requirements for the equipment and materials utilised are mandated by the standard, guaranteeing that only approved welding consumables and appropriate rail materials are used. To preserve the integrity of the welds, it highlights how crucial exact welding procedures, careful pre-welding preparation, and comprehensive post-welding care are .AS 1085.20 places a strong emphasis on quality control, providing detailed instructions for visual inspections and non-destructive testing techniques such ultrasonic testing to guarantee welds fulfil safety requirements. The standard also contains guidance to reduce environmental effect and safety procedures to safeguard employees. For welding operations to be traceable and accountable, documentation and record-keeping are crucial elements. It also specifies the qualifications and training needs for welding staff, guaranteeing that only qualified and experienced people carry out welding duties. Overall, AS 1085.20's strict guidelines for welding procedures are essential to preserving the dependability and security of railway infrastructure. [2]

## 2. Literature Review

The introduction of the thermit process and aluminothermic weld is regarded as a watershed moment in the evolution of continuously welded rail. When German scientist Hans Goldschmidt started exploring the interaction of metal oxides with aluminium powder in 1895, he patented the thermite reaction and its uses. [1] The thermite reaction is an exothermic process that releases a huge amount of thermal energy, enough to generate molten metal for casting and welding procedures. The ATW thermit method involves the interaction of fine aluminium and iron oxide powders in a crucible. The following reactions are often employed in ATW procedures. [2] The second process achieves a practical temperature of around 1930 degree Celsius, which is substantially over the melting point of iron. After the above-mentioned reaction has been completed and the slag has floated on the top of the crucible, the molten steel is poured into a two- or three-piece hardened sand mould that has already been clamped and sealed around the two rail ends. The rail ends that have been heated through a preheating stage are partially melted and fused with the hot molten steel, generating the full weld, for example see Fig. 2.1. After that, the setup is then allowed to cool before the moulds are removed, the risers are cut, and the weld head is honed to the constant rail head shape. All the steps listed above are completed on time and in accordance with certain requirements to ensure consistent quality of the welds produced. [3] Different preheating durations, post-weld cooling conditions, chunk hardness, weld gap width, weld collar design, and, more recently, single-use crucibles are all variations of the ATW process. In any event, the suitability of a new AT weld must be validated by tight criteria and performance testing in accordance with established railway and welding standards such as AS1085-Part 20 or BS-EN 14730. [4] [5]



**Fig. 2.1** (a) Section view of ATW Process using single-use crucible; (b) On-site ATW installation

### 2.1 Electrified Double Track from Gemas to Johor Bahru

The project of the Electrified Double Track from Gemas to Johor Bahru (EDTP Gemas – Johor Bahru) consists of 197 km for entire length of the rail. [6] The entire length of the rail needs to joint to combine to become one way rail to use by rolling stock. When finished, the EDTP will enable the new Electric Train Service (ETS) to move at a top speed of 140 kilometers per hour. Because passenger train services between Kuala Lumpur and Johor Bahru would stop at stations along the route, the average speed is expected to be around 100 miles per hour. While not a high-speed rail link, the ETS is twice as fast as present diesel passenger trains. As a result, the travel time between Kuala Lumpur and Johor Bahru along this route will be reduced from 7 to 4 hours. This will be a more appealing option than interstate buses, which now take 4.5 hours to travel between the two cities even without traffic congestion. [7] The Gemas-Johor Bahru EDTP is billed as a catalyst for economic growth in Johor's central region. The North-South Road runs across the West Coast districts of Johor, aiding logistical and industrial activity between Johor Bahru and towns such as Batu Pahat and Muar. The Gemas-Johor Bahru route, on the other hand, runs across central Johor, passing through the districts of Segamat, Kluang, and Kulai, which are underserved by current transportation linkages as Fig. 2.2.



**Fig. 2.2** The length rail of entire project

### 2.2 Welding Procedure

The process for welding and the related specifications for welding circumstances. The first step in the process is determining which particular welding technique will be applied. Welding operations may only be carried out by individuals who meet the qualifications requirements outlined in qualification people. The kind of rail being utilised, such as a 60 kg head-hardened rail, must be specified. A thorough inventory of all the tools required for the operation must be supplied, as well as complete schematics that show the welding process. After that, welding quality is greatly impacted by weather, especially for activities carried out in open spaces, thus there needs to be

a defined boundary for acceptable weather. The welding procedure must define the acceptable proximity of boltholes and the minimum distances to other flash butt or aluminothermic welds to ensure safety and structural integrity. The surfaces to be welded must meet a defined minimum surface finish requirement to ensure proper adhesion and strength of the weld. [8] An important step is to position the rails precisely before welding, both vertically and horizontally, and to prepare for electrical contact. Pressing the weld to ensure alignment is a critical step that must be included in the procedure. After welding, any excess metal must be removed, and the running surface and both sides of the rail head must be finished by grinding. This final grinding process must be conducted in a manner that prevents the rail temperature from rising to levels that could cause metallurgical changes. Additionally, shearing or grinding may be necessary on other surfaces, such as the web, underside of the rail head, or foot, and the outer edges of the foot. Post-weld inspection and testing are required and must be carried out as the AS qualification. [9]

### 2.3 Operator Training

Welders who meet the qualifications requirements must requalify. Re-qualification for flash butt welding is necessary if fewer than 500 welds are completed in a 12-month period or every two years. Welders who execute less than 50 welds in a 12-month period or every two years must re-qualify for aluminothermic welding. If a welder has been working within their qualifying range and producing welds of acceptable quality, or if no welds have been conducted in the preceding six months, they must re-qualify every two years for metal arc welding. AS 2980 offers guidelines for the original qualification, re-qualifying, and extension of welders for fusion welding. By adhering to this standard, welders are guaranteed to continuously produce welds of the highest calibre. [10]

### 2.4 Environmental Conditions

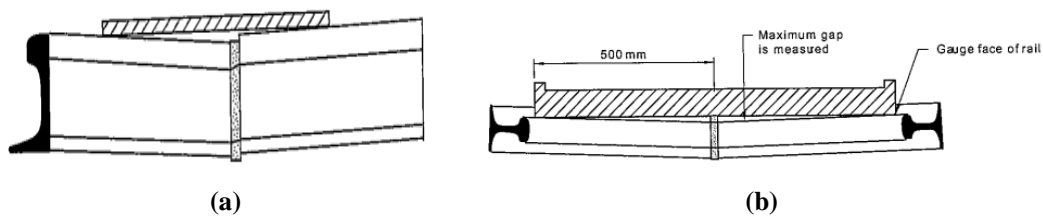
Ensuring appropriate environmental conditions during the welding process is essential to producing high-quality, flawless welds. The weather is one of the most important factors, particularly when welding outside. Adverse weather conditions, such as rain, snow, or strong winds, might introduce impurities and compromise the integrity of the weld. Therefore, limits for acceptable weather conditions, such as temperature, humidity, and wind speed, must be set. To provide a controlled environment under such situations, protective measures like tents or wind shields could be required. Controlling the temperature is another important aspect. It is not advisable to weld in extremely low temperatures since the quick cooling process can cause fissures. On the other hand, elevated temperatures may lead to overheating and modify the metallurgical characteristics of the substance. [11] By using preheating and controlled cooling procedures, the best possible conditions may be kept throughout welding. Another important factor is how well the welding surfaces are maintained. Welding flaws can be caused by dirty, rusted, oily, or greasy surfaces; instead, clean, dry, and free of impurities are the requirements. A clean, smooth surface that is ready for welding is guaranteed by proper surface preparation, which includes extensive cleaning and grinding. To eliminate the dangerous gases and fumes produced during welding, especially in small or enclosed areas, adequate ventilation is necessary. It is important to employ exhaust fans or appropriate ventilation systems to keep dangerous materials from building up and to protect welders. Additionally, sufficient lighting is necessary to provide welders with a clear view of the work area. Poor lighting can lead to mistakes and defects, so additional lighting sources should be provided in dimly lit areas to maintain adequate visibility. [12] Lastly, welding needs to be done a safe distance away from other operations that can contaminate the area or impede the process. To avoid contamination, dust and debris producing tasks like cutting and grinding should be carried out elsewhere, away from the welding area. High-quality welds can be produced by carefully regulating various environmental factors, allowing for a safe and efficient welding procedure. In order to reduce any environmental influences that can jeopardise the integrity of the weld, careful planning and preparation are crucial. [13]

### 2.5 Aluminothermic Welds as a Major Source of Failure

Despite its primary role as a welding technique and operational choice, ATW is regarded as a manual cast welding process and, as a result, suffers from differences in the generated weld quality. ATW operations require multiple phases, including rail end alignment, gap adjustment, mould installation, sealing, and preheating, in which the operator plays a crucial role, and any deviation from the recommendations may result in a poor weld. Meanwhile, because ATW is a casting process, the fused material has a coarser microstructure and occasionally contains traces of non-metallic inclusions and porosity, which contribute to the ATWs' lower ductility and fracture toughness when compared to the parent rail. [14]

## 2.6 Routine Test

There are 6 routine tests which are visual test, surface alignment, UT test, weld hardness (Vickers Test) & hardness traverse (Brinell Test), chemical analysis and slow bend test. During this visual, the welded connection is visually inspected to look for any surface defects such as fractures, porosity, or incomplete fusion. AS 1085.20 states that certified inspectors evaluate the weld's appearance to make sure it satisfies predetermined acceptance standards. After welding and finishing grinding, the entire weld must be inspected, including the ground weld surface, the heat-affected areas surrounding the weld, and the as-cast weld surface if relevant. [4] Welded rails are properly aligned both horizontally and vertically thanks to surface alignment inspections. According to the requirements of the standard, this process is essential for preserving the track's structural integrity and smooth operational performance. A crucial factor in guaranteeing the structural soundness and operational safety of rail components is the weld straightness. Weld straightness is measured vertically and horizontally across a predetermined length of 500 mm on either side of the weld centerline, in accordance with AS 1085.20 regulations as fig. 2.3. A metal straightedge or a specific tool made for this purpose is used to perform this examination. To ensure precision and dependability in measurements, the straightedge or instrument needs to be calibrated in compliance with prescribed requirements. [4]



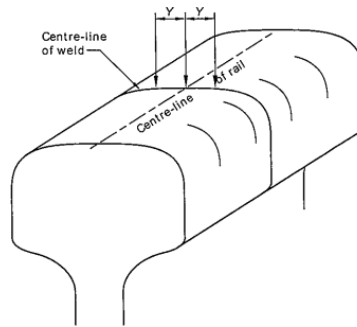
**Fig. 2.3** (a) Surface alignment method vertical; (b) Surface alignment method lateral

Ultrasonic flaw detection as fig. 2.4 is a crucial method for inspecting aluminothermic welded joints in rails. The technique involves the use of high-frequency sound waves to identify and size sub-surface defects, making it suitable for discovering, locating, and identifying faults in the complex welded joints of rails. The process can detect internal flaws such as cracks, non-metallic inclusions, and other anomalies, providing a comprehensive analysis of the entire weld, including the head, web, and foot of the rail. [15]



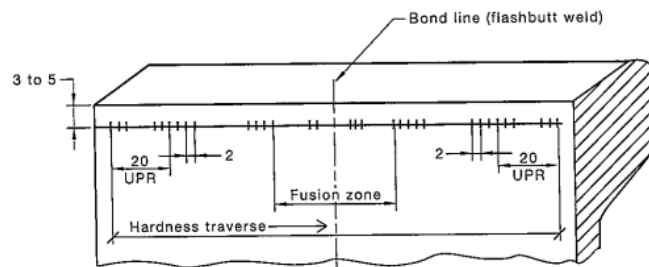
**Fig. 2.4** UT testing on rail

According to AS 1816.1, Brinell hardness tests must be performed with a 10 mm diameter tungsten carbide ball under a 3000 kg force. According to fig. 2.5, impressions with a spacing (Y) of 15 mm must be created on a smooth surface tangential to the rail crown at the point of junction with the rail vertical axis. For every weld, three hardness values must be established. [4]



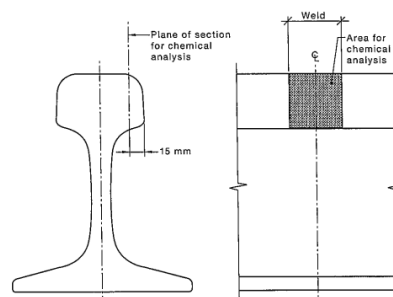
**Fig. 2.5** Location of external hardness tests

Sectioning the weld longitudinally along the welded rail's center line is the first step in the process described below for evaluating the quality of the weld in railway tracks. As shown in fig. 2.6, this cut must include at least 20 mm of undamaged parent rail on each side and the full heat-affected zone (HAZ) on both sides of the weld. This stage guarantees a thorough inspection of the weld and surrounding regions. Lightly etching the sectioned weld is advised to help with precise placement of the hardness indentations by emphasising the weld zone. The Vickers hardness test method is used to perform a hardness traverse in accordance with AS 2205.6.1's guidelines. The longitudinal axis of the rail should be paralleled by a line that is 3 to 5 mm below the rail running surface for the purpose of taking the hardness measurements. Establishing a reference location is necessary for accuracy and consistency. In flash butt welds, this is the bond line; in aluminothermic welds, it is the centre of the fusion zone. Maintaining the integrity and safety of railway tracks depends on the accurate and trustworthy evaluation of the weld's hardness profile, which is ensured by this meticulous process. [4]



**Fig. 2.5** Longitudinal hardness test location

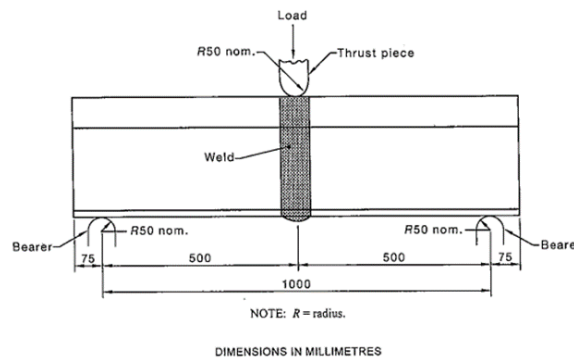
Chemical analysis also helps with problem diagnosis and troubleshooting, welding process optimisation, and the creation of novel materials and methods. Hazardous material identification and efficient waste management address environmental and health concerns. All things considered, chemical analysis is essential to producing high-quality, safe, and dependable aluminothermic welds that satisfy all requirements. Analyse the chemical composition of aluminothermic welds on a sample taken from the railhead's fusion zone, at least five millimetres from the weld's transverse centre line, or on a riser that originates from the weld as fig. 2.6. [4]



**Fig. 2.6** Position for chemical analysis of weld material

The foot is put in longitudinal tension by applying static stress to the welded rail segment while it is undergoing three-point bending. Up until the welded rail piece fails, the load is gradually raised. Recorded are the

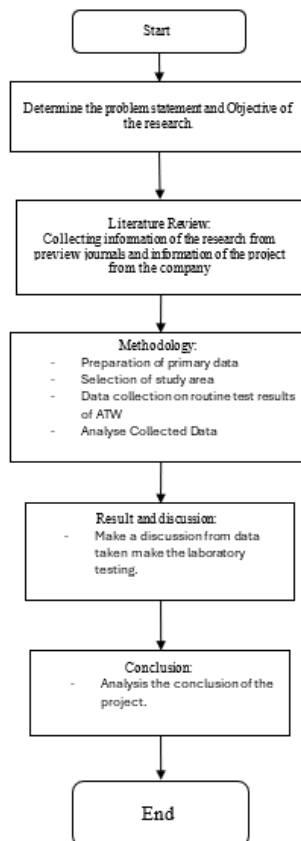
break load and deflection at fracture. To verify the integrity and performance of the weld, testing aluminothermic welds entails several crucial processes. As shown in fig. 2.7, the test specimen must first be firmly fixed in the test stand and placed in the centre of the designated span width. After the specimen is correctly positioned, a thrust piece is used to apply a constant load—between 20 and 80 kN/s—directly to the weld centerline until the weld breaks. [4]



**Fig. 2.7** Position for chemical analysis of weld material

### 3. Methodology

The information was gathered from a review of the literature. All the workflow of the research methodology are and will be based on the flowchart from Fig. 3.1.



**Fig. 3.1** Flowchart Methodology of study

### 3.1 Selection of Study Area

Selecting the study area for research on aluminothermic welds (ATW) involves careful consideration to ensure relevance and applicability to the study objectives. Focusing on the Electrified Double Track Project from Gemas to Johor Bahru in Malaysia provides a strategic choice, as this project is pivotal for enhancing railway connectivity and efficiency in Malaysia's southern corridor. This study area encompasses not only the mainline tracks but also includes critical components such as the destressing zones and turnout areas where aluminothermic welding plays a crucial role in maintaining track integrity and operational safety. By selecting this area, researchers gain access to detailed records and comprehensive data related to welding procedures, inspection protocols, and testing outcomes specific to aluminothermic welds. This includes gathering empirical data from routine tests such as visual inspections for surface defects, ultrasonic testing (UT) scans for internal flaws, hardness tests using Vickers and Brinell methods, chemical analyses for material composition, and slow bend tests to assess weld ductility and resistance to cracking. The availability of such data facilitates a thorough comparative analysis against acceptance criteria specified in relevant standards, notably AS 1085.20, ensuring insights into compliance levels and identifying areas for improvement in welding practices. Moreover, focusing on destressing zones and turnout areas allows for a nuanced examination of welding challenges and operational demands unique to these critical railway infrastructure elements, thereby enabling the formulation of targeted recommendations to optimize weld quality and standards adherence across Malaysia's railway network and potentially in similar global railway contexts.

### 3.2 Data collection on routine test results of ATW

Collecting data on routine test results of aluminothermic welds (ATW) from the Electrified Double Track Project (EDTP) from Gemas to Johor Bahru is a detailed and feasible process that requires collaboration with various stakeholders, including railway authorities, project managers, and contractors. This involves obtaining welding records, inspection reports, and testing data to ensure compliance with relevant standards such as AS 1085.20. Key steps include accessing and organizing welding logs, inspection documents, and test results from RFIs, and ensuring that all data is accurate, complete, and up to date. Effective data management and protection of sensitive information are essential, as is securing the necessary permissions for data access. Using tools like database management systems and data analysis software can streamline the process, facilitating a systematic approach to ensure comprehensive and reliable data collection for quality assurance and project success. Firstly, it is crucial to gather welding records, inspection reports, and testing data from the specific project under study, such as the Electrified Double Track Project from Gemas to Johor Bahru. This includes collaborating with railway authorities, project managers, and contractors responsible for maintaining detailed records of aluminothermic welding activities. The data collection process focuses on retrieving specific test results mandated by relevant standards like AS 1085.20. This encompasses visual inspection reports detailing surface conditions, ultrasonic testing (UT) scans revealing internal flaws, hardness test results (including Vickers and Brinell tests) to assess material strength, chemical composition reports to ensure compliance with material requirements, and slow bend test outcomes evaluating weld ductility and resistance to cracking. Ensuring data integrity involves verifying sources for accuracy and completeness, organizing data systematically into databases or spreadsheets, and documenting test procedures and conditions that may influence results. Compliance with confidentiality agreements and legal requirements is essential throughout the data collection process, and validation checks are conducted to ensure data reliability and support robust analysis for informing improvements in welding practices and adherence to quality standards in railway infrastructure projects.

### 3.3 Analyse collected data

To conduct routine testing of welding quality assurance, it will be using the data acquired to analyse it using a methodical approach that includes several testing processes and acceptance criteria, as shown in the table. First, the weld's external appearance is examined visually for any faults, including gouges, cracks, tears, porosity, weld protrusion, shear drag, or signs of a short head. To pass this test, the weld must have a good appearance that is devoid of these flaws. After that, the surface alignment is measured precisely with instruments to make sure the alignment is within  $\pm 0.5\text{mm}$  for the horizontal and  $\pm 0.3\text{mm}$  for the vertical. This guarantees that there are no appreciable deviations in the weld's alignment. Subsequently, a non-destructive ultrasonic test (UT test) is conducted to identify any interior defects or discontinuities. The criteria need to less than 12 points from the checklist. It is essential to have these defects free to pass these criteria. Then, the weld hardness is assessed using the Brinell test for the hardness traverse (which should be between 260 and 300 HBN) and the Vickers test for the highest fusion zone hardness, which should not exceed 430HV. The endurance and resistance to deformation of the weld are validated by these hardness tests. To confirm that the weld's composition is within predetermined ranges for components including carbon, silicon, manganese, phosphorus, sulphur, chromium, molybdenum,

nickel, aluminium, copper, tin, titanium, and niobium, chemical analysis is performed. This guarantees that the material qualities of the weld fulfil the necessary requirements. Finally, the slow bend test confirms the mechanical strength of the weld by measuring the stress in the foot, which should be at least 750 MPa.

### 4.0 Result and Findings

For to identify the acceptance criteria for routine tests of aluminothermic welds the routine test had been conducted on the several number of batches. Based on fig. 4.1 and fig. 4.2, the aluminothermic welding routine test need conducted for every 200 welds. The Australia Standard was used for the routine test because the production of ATW portion named Goldschmidt used the Australian Standard for quality testing. The data gathered from several test batches show trends of both compliance and non-compliance with the given requirements. Visual examinations revealed external shapes and appearances that were largely excellent, while slight porosity and other minor problems were found and required grinding and other correction measures. The proper alignment of welded components was ensured by the fact that surface alignment tests conducted across batches consistently fell within the allowed vertical and horizontal ranges. Non-destructive testing results were mostly compliant, with only a few instances of detected flaws that necessitated further investigation. Weld hardness tests, measured by both Vickers and Brinell methods, varied among the batches. While most batches met the hardness requirements, occasional deviations were observed, particularly in the Vickers test where some values fell below the required fusion zone range.

Chemical analysis highlighted the importance of maintaining precise compositions to ensure material integrity. Most elements were within acceptable limits; however, certain batches exceeded the maximum allowable concentrations of elements like niobium and titanium, resulting in non-compliance. These deviations underscore the need for stringent control over chemical inputs during the welding process. The stress tests demonstrated that most of the batches surpassed the minimum stress requirements, indicating robust welds capable of withstanding operational stresses. Nevertheless, isolated incidents of non-compliance in both visual and chemical criteria underline the necessity for continuous monitoring and improvement of welding procedures.

Accepted Criteria	Routine test ATW												
	Visual		Surface Alignment				UT test		Brinell Test		Vicker Test		Slow Bend Test
	Satisfactory		Vertical		Horizontal		Point		Brinell Value (HBN)		Fusion zone (HVN)		Stress in foot (Mpa)
	Crack	Porosity	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
	No	No	-0.3	0.3	-0.5	0.5	0	12	260	300	340	420	750
Batch no.													
25922	No	Small	0.1	0.3	-0.2	0.4	0		285		334		850
29321	No	Small	0.1	0.2	0.1	0.2	0		269		364		811
28906	No	Small	0.1	0.2	0.1	0.2	0		285		321		818
26654	No	Small	0.1	0.2	0.1	0.3	0		285		326		773
29943	No	Small	0.1	0.3	0.2	0.2	0		N/A		N/A		N/A
29345	No	Holes	0	0	0	0	0		N/A		N/A		N/A

Fig. 4.1 Routine test comparison

Element	Routine test ATW														
	Chemical Analysis (%)														
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Sn	Ti	Nb	V	
Accepted Criteria	0.4 - 1.0	0 - 1.2	0.5 - 1.4	0 - 0.03	0 - 0.03	0 - 0.2	0 - 0.4	0 - 0.10	0.02 - 0.6	0 - 0.2	0 - 0.02	0 - 0.01	0 - 0.1	0 - 0.4	
Batch no.															
25922	0.521	0.526	1.09	0.0259	0.0045	0.142	0.026	0.0509	0.0948	0.0109	0.004	0.026	0.142	0.095	
29321	0.656	1.2	0.746	0.0115	0.0035	0.149	0.0374	0.0641	0.081	0.0118	0.0041	0.00083	0.0079	0.0127	
28906	0.519	0.426	0.691	0.019	0.0068	0.169	0.0307	0.0575	0.0534	0.0144	0.0039	0.0002	0.0084	0.0123	
26654	0.675	0.404	0.804	0.0187	0.0051	0.132	0.0307	0.0657	0.0429	0.0093	0.0474	0.0307	0.132	0.0657	

Fig. 4.2 Routine test for Chemical Analysis

### 4.1 Analyse a set of routine test results for aluminothermic welds

The batches clearly satisfy the strict requirements for alignment, non-destructive testing (NDT), and stress criteria when the normal test results for aluminothermic welds are compared to the prescribed acceptance criteria from the Australian Standard (AS) to batches show adherence into both horizontal and vertical alignment tolerances, guaranteeing accurate surface alignment. Minimal internal faults are shown by the ultrasonic flaw detection (NDT) results, which are within permissible point limits among the batches. Firstly, batch 0025922 was subjected to a comprehensive series of routine tests to determine its compliance with established acceptance criteria. The visual inspection revealed generally good welds with minor porosities, which were deemed acceptable provided the porosity is ground away. Surface alignment tests showed vertical alignment between 0.1mm and 0.3mm and

horizontal alignment ranging from -0.2mm to 0.4mm, all within the acceptable limits. The ultrasonic flaw detection test confirmed the absence of internal defects, meeting the criteria.

However, the Vickers hardness test result of 334 HV was slightly below the acceptable range of 340-420 HV, indicating a minor shortfall in hardness, although still relatively high for wear resistance. The Brinell hardness test result of 285 HBN was well within the required range of 260-300 HBN, showing adequate material hardness. The chemical analysis revealed that all elements were within acceptable limits except for niobium, which exceeded the maximum allowable content by 0.042%, suggesting a need for closer control over this element in future batches. The slow bend test showed an average stress in the foot of 805 MPa, surpassing the minimum requirement of 750 MPa, indicating sufficient material strength. Overall, Batch 0025922 largely met the acceptance criteria, demonstrating good external and internal quality, satisfactory alignment, and adequate hardness and strength. While the batch is rejected with minor adjustments for porosity and addressing the slight deviations in Vickers hardness and niobium content, these issues should be monitored to ensure full compliance in future batches. Furthermore, batch 0029943 underwent a comprehensive set of routine tests to evaluate its compliance with the specified acceptance criteria. The visual test ensured satisfactory external appearance and shape with no gouges, cracks, tears, porosity, weld protrusions, shear drag, or evidence of a short head. The surface alignment test measured vertical alignment within a range of -0.3 to +0.3 mm and horizontal alignment within  $\pm 0.5$  mm. The other data still on going for test.

Batch 0029321 underwent a series of tests to assess its compliance with the required standards. The visual inspection found the welds in good condition but noted the presence of small porosities. Vertical and horizontal alignment tests showed deviations of 0.1 mm to 0.2 mm, which were within acceptable limits. The Vickers hardness test recorded a maximum fusion zone hardness of 364 HV, while the Brinell hardness test recorded 269 HBN, both within specified ranges. Chemical composition analysis revealed acceptable levels of elements, including carbon at 0.656%, silicon at 1.20%, and manganese at 0.746%. The stress in the foot was measured at an average of 811 MPa, exceeding the minimum requirement of 750 MPa. Overall, Batch 0029321 complied with most criteria, although some porosity required additional grinding. Batch 0029345 was subjected to similar tests, revealing welds in good condition with holes. Vertical and horizontal alignment measurements ranged between 0.1 mm and 0.3 mm. The Batch was rejected due to visual inspection failure. Batch 0028906's evaluation revealed welds in acceptable condition with minor porosities. Vertical alignment ranged from 0.1 mm to 0.2 mm, while horizontal alignment was within the same range. The Vickers hardness test reported a maximum fusion zone of 321 HV, and the Brinell test was within the range of 260-300 HBN. Chemical composition analysis showed compliance with acceptable levels for elements like carbon, silicon, and manganese. The stress in the foot was found to be above the minimum requirement of 750 MPa. Batch 0028906 met all specified criteria, ensuring its reliability and performance without the need for additional corrections. The batch is rejected due to intolerable of Vicker hardness test.

Lastly, batch 0026654 displayed welds in good condition with some porosity noted during visual inspection. Vertical alignment ranged from 0.1 mm to 0.2 mm, while horizontal alignment ranged from 0.1 mm to 0.3 mm. The Vickers hardness test recorded a maximum fusion zone hardness of 326 HV, which did not meet the required threshold. The Brinell hardness test recorded 285 HBN, which was within acceptable limits. Chemical analysis showed carbon at 0.675%, silicon at 0.404%, and manganese at 0.804%. However, niobium content was found to be higher than the required limit at 0.132%. Stress in the foot was measured at an average of 773 MPa. Consequently, Batch 0026654 was rejected due not fully comply due to the Vickers test and niobium content exceeding the acceptable limits, although it generally met other criteria.

## 4.2 Improvement in the welding process ATW

The visual test is essential for assessing the external appearance and shape of welds, focusing on the absence of defects such as gouges, cracks, tears, porosity, weld protrusion, shear drag, and evidence of a short head. For surface alignment, the measurements of vertical and horizontal alignment are crucial, with acceptable ranges being -0.0 to +0.3mm for vertical alignment and  $\pm 0.5$ mm for horizontal alignment. To improve the visual test and surface alignment, it is recommended to implement regular training for welders on visual inspection techniques to ensure consistent detection of defects. Utilizing advanced alignment tools and jigs can help achieve precise surface alignment, reducing the likelihood of misalignment. Additionally, incorporating automated visual inspection systems can enhance early defect detection, ensuring that any issues are addressed promptly. Next, Ultrasonic testing (UT) is a non-destructive method used to detect internal flaws within the weld, such as cracks, voids, and inclusions. To improve UT, it is advisable to invest in high-frequency ultrasonic equipment, which can provide better defect detection sensitivity. Periodic calibration of UT equipment is essential to maintain accuracy, and providing advanced training for technicians on interpreting UT results will ensure reliable identification of subsurface defects. These measures will enhance the overall effectiveness of ultrasonic testing in ensuring weld integrity.

The Vickers hardness test measures the hardness of the weld in the fusion zone, with an acceptable range of 340 - 420 HV. To improve this test, consistent application of load and correct indenting procedures must be ensured. Regular calibration of the Vickers hardness tester is necessary to maintain measurement accuracy. Analysing trends in hardness values can help identify and address inconsistencies in the welding process, leading to more reliable welds. Next, The Brinell hardness test measures the hardness traverse with an acceptable range of 260 - 300 HBN. Improvements can be made by using standardized procedures for sample preparation and testing, ensuring consistency. Periodic calibration of the Brinell hardness tester is crucial to maintain accuracy. Reviewing and adjusting welding parameters can help maintain hardness within the specified range, enhancing the overall quality of the welds. Furthermore, Chemical analysis assesses the chemical composition of the weld material to ensure it meets specified requirements, including key elements such as carbon, silicon, manganese, phosphorus, sulphur, chromium, molybdenum, nickel, aluminium, copper, tin, titanium, niobium, and vanadium. To improve chemical analysis, strict controls on raw materials should be implemented to ensure they meet composition requirements. Using advanced spectrometers can provide accurate chemical analysis. Regularly reviewing and updating chemical analysis procedures based on industry standards and regulations will help maintain compliance and quality. Lastly, the slow bend test evaluates the ductility and toughness of the weld by bending the sample slowly until failure, with a minimum stress requirement of 750 MPa in the foot. To improve the slow bend test, proper sample preparation and alignment are necessary to avoid premature failures. Conducting the test at a controlled rate ensures accurate results, and analysing the failure mode helps understand and mitigate potential welding issues. This approach ensures that welded joints can perform reliably under operational stresses, leading to safer and more durable constructions.

## 5. Conclusion

According to the study done on the aluminothermic welding (ATW) process, the welding technology used satisfies the project's strict design and quality standards for the Electrified Double Track Project (EDTP) from Gemas to Johor Bahru. Each batch exhibits unique strengths and characteristics based on the various tests conducted. Batch No. 25922, while variable in surface alignment, shows high hardness and reasonable stress resistance, making it ideal for wear-resistant applications. Batch No. 29321, with its highest hardness, is suitable for high durability needs but may require caution regarding brittleness. Batch No. 28906, demonstrating the highest bending resistance, offers a strong balance between hardness and flexibility, suitable for structural applications. Batch No. 26654, with its greater flexibility and lower stress tolerance, is advantageous in dynamic environments needing some bendability. These detailed insights into the material properties assist in making informed decisions for selecting the appropriate batch based on specific application requirements, ensuring optimal performance and reliability for project EDTP Gemas to Johor Bahru.

Several batches of welds consistently experience mild porosity, notably in Batches 0025922, 0029321, and 0028906. Despite this, the porosity is deemed acceptable after further grinding, suggesting that the overall weld quality remains unaffected by these minor flaws. However, tests for hardness and chemical composition reveal some variations. For instance, Batches 0025922 and 0028906 contain niobium levels exceeding the permissible limit of 0.10%. Additionally, Batch 0025922 exhibits a Vickers hardness slightly below the acceptable maximum of 340 HV, recording 334 HV, while Batch 0028906 also fails the Vickers hardness test. These inconsistencies indicate areas that require closer monitoring and potential adjustments in the welding process to ensure full compliance. Batch 0029345 stands out for significant visual failures, highlighting the critical importance of thorough visual inspections to detect severe defects early. Meanwhile, Batch 0029943, currently under testing, shows promise but requires the completion of all test results for a final assessment. While most batches generally meet compliance standards, ongoing issues with porosity, hardness, and specific chemical compositions necessitate targeted improvements to meet the stringent requirements set by the Australian Standard (AS) for aluminothermic welds. This underscores the need for enhanced quality control measures and process adjustments to uphold the highest standards of weld integrity and performance. As the result the accepted criterion for routine test is about 85% complied but all batch that intolerance was rejected

To enhance the welding process, integrating advanced technologies such as automated inspection systems and precision alignment tools is crucial. Comprehensive training programs for welders and inspectors will ensure consistent application of best practices. Regular calibration and maintenance of testing equipment are necessary to ensure accuracy. Thorough reviews of test results should be conducted to identify and address any recurring issues, and maintaining strict quality control measures throughout the welding and testing processes will ensure the highest standards of weld integrity and performance for project EDTP Gemas to Johor Bahru.

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