Semi-automated Aluminothermic Rail Welding as a Model for the Future in Track Construction and Maintenance

Increasing quality, productivity, safety and versatility with data and automation

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Abstract: The global trend in mobility reflects an increase in railway usage, placing significant pressure on railway operators to both expand networks and maintain existing lines. Stakeholders must achieve a delicate balance in their use of existing welding technologies. On one end of the scale, aluminothermic welding (ATW) offers a cost-effective and flexible solution. However, the process relies heavily on skilled welders, who are increasingly scarce due to a labour shortage in the railway industry. On the other end of the scale, there is flash butt welding (FBW). This provides high productivity but requires substantial capital expenditure (capex) and is only financially sustainable for large-scale projects.

Addressing these challenges, Pandrol has worked on technologies to automatise key steps of the ATW process. This retains the low capex advantage of ATW and enhances the welding efficiency and performance of traditional aluminothermic welding. The overarching goal is to assist railway networks and contractors in meeting their operational targets within realistic budget constraints.

The need for automation in railway maintenance

Established rail markets, primarily in Western countries, face the imperative of investing in aging assets to accommodate increased traffic with enhanced efficiency. Concurrently, emerging economies, particularly in Asia, are experiencing a surge in new rail projects, with significant emphasis on metro and light rail investments. Both scenarios confront a substantial challenge: the scarcity of skilled personnel required for railway infrastructure maintenance.

In Asia, despite rapid urbanisation and robust economic growth, concerns persist regarding the issue of attracting future generations to manual labour, which often involves working in adverse conditions. In traditional markets such as Europe and North America, the railway industry is already experiencing a significant demographic issue. Maintenance workers, like many other operational railway staff, are aging and their replacements are proving difficult to find. Younger generations are less attracted to manual labour and those who do choose this profession tend to change careers after a certain time.

Automation is one of the keys to overcoming this issue. It is no longer merely an optional enhancement but has become a critical business necessity. Nevertheless, railway operators face the challenges of reducing life cycle costs and track availability and so the investment required by those automatic welding technologies must be taken into consideration. Various welding technologies play a crucial role in addressing these issues, each offering distinct advantages and limitations in execution. Having recognised the benefits of innovation, leading companies in track maintenance are actively showcasing their advancements and development projects to drive technological progress in the industry.

Current rail welding technologies

The debate regarding the most efficient on-site welding solution has persisted for years, often focusing on the comparison between flash butt welding and aluminothermic welding, each having its proponents and detractors. As of 2024, it must be noted that other technologies exist or are emerging. Manual arc welding is frequently utilised in some countries for welding urban groove rail. Additionally, some companies are advocating for induction welding, while others are promoting automated gas metal arc welding, both aiming to optimise costs in comparison to flash butt welding.

The technology choice is often determined from an operational standpoint. There are numerous welding scenarios (Table 1), and the most suitable technology for a given job is determined by factors such as ease of access, available time for maintenance, and the number of welds required. Ultimately, all those technologies can be divided into two groups based on their versatility, productivity and the capital expenditure required.

Table 1: Technologies commonly used per type of welding job

Scenario	Type	Number of welds	Common technology
2h emergency repair	Maintenance	1-2 welds	ATW
Classic repair with plug	Maintenance	4 welds	ATW
Project (Turnout)	New line	4 welds	ATW
New line tramway	New line	8 welds	ATW/FBW/ARC
Long shift repair	Maintenance	8 welds	ATW/FBW
Major re-rail operation	Maintenance	8 welds	ATW/FBW
Maintenance weekend	Maintenance	15 welds	ATW
Project (Plain line)	New line	>20 welds	FBW

Productivity is the number of welds a technology can perform in an amount of time with a number of workers. Versatility is the capability for a technology to perform any type of welds, regardless of the external parameters such as environment, worn rails, rail stressors etc. Capital expenditure (capex) is the money that must be spent for the initial purchase of the welding equipment. This impacts the fixed cost of the welding business entity.The first group contains manual technologies which offer great versatility and require little capex but offer a lower productivity. This group includes manual arc welding and ATW. The second group includes technologies such as FBW, induction welding or automated arc welding which offer little versatility, require high capex, but allow a much higher productivity. (Fig. :1)

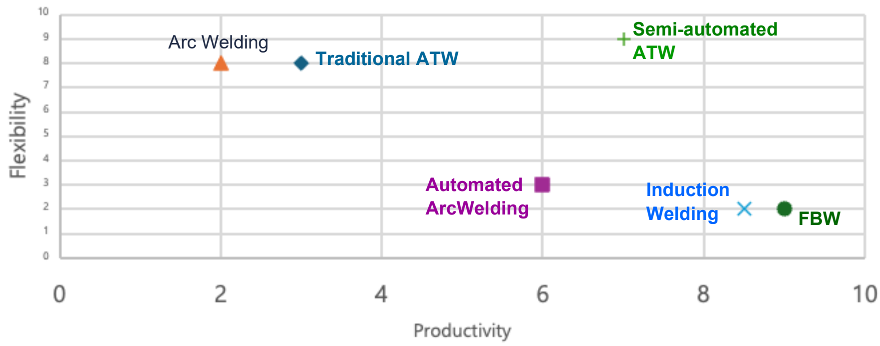

Fig. 1 Comparison of welding solutions in terms of flexibility and productivity

The best example to illustrate this contrast is ATW and FBW. ATW, which has been employed on railway networks for over a century, is notable for its flexibility. Typically, a team consists of a two-person crew travelling in a medium-sized utility vehicle. The capex allows for numerous crews to cover wide areas for small to medium-sized tasks. Completing a weld generally takes around 40 minutes of active time (excluding cooling), with an average crew achieving 4 to 6 welds per shift. This predominantly manual process offers significant adaptability to various environmental conditions, such as worn rails or narrow areas. Critics, however, highlight the need for qualified welders to perform the welds and the dependency of weld quality on the welder's skills.High-capex welding solutions as FBW typically involve a medium-sized truck and a three-person crew, offering the advantage of high output. Including preparation and finishing, welding time is approximately 10 minutes, enabling crews to achieve three times the output of an ATW welding crew. However, this figure is theoretical as only a fraction of worksites can fully utilise such high output and sometimes welds need to be bended afterwards to meet geometrical criteria. It is commonly accepted that the break-even point for FBW is reached when an average of 15-20 welds per day can be performed for several days in a row. Additional disadvantages of this solution include its lack of versatility, with limitations in performing welds on rails with wear exceeding a certain value (often 3mm), in turnouts, and in executing closure welds for entry-level machines.

Automation of aluminothermic welding

As a leading manufacturer of ATW welding kits and track equipment, Pandrol has anticipated the increasing demand for automation. Since a few years Pandrol has a dedicated team specialising in automation and data to develop innovative tools aimed at automating ATW.

The ATW procedure can be broken down into a sequence of sub-operations, all of which can be automated to various degrees (Table: 2). This advanced welding process, branded as i+weld, equips welders with an innovative set of tools that replaces the conventional manual ones.

Seven technologies are used:

1. The automatic aligners (i+align) automatise the very critical step of aligning the rails, saving time and improving accuracy.
2. The sealing mould technology (i+seal) uses an expansive strip which expands during the preheating of the rail and creates a tight seal, making the cumbersome step of luting the mould unnecessary.
3. The automatic preheater (i+heat) makes the preheating error-proof and improves preheating quality globally.
4. The portion ignition device (i+ignite) simplifies ignition.
5. The water-cooling unit (i+cool) is designed to accelerate cooling of the weld, cutting down the welding time.
6. The defect detection technology (i+detect) uses an ultrasonic stick to automate the process.
7. The cloud-based application (i+connect) gathers all welding data and allows for precise documentation and monitoring of the welds and operation.

Table 2: Comparison between classic ATW and semi-automated ATW

Sub-operation	Traditional ATW	Semi-automated ATW	Data collected
Rail alignment	Adjust rails manually with wedges	Set automatic aligners and press a button to start the sequence	Geometrical data, date, time
Sealing moulds	Apply refractory paste or sand	Moulds are sealed automatically during preheating	Batch number
Preheating	Adjust pressures, then monitor the flame and duration	Set the preheater above the weld and press a button to start the sequence – little or no monitoring	Gas pressure, duration, location, date, time
Portion ignition	Light an ignitor with the preheater	Position the handgun and press the trigger	Ignition time
Weld cooling	Air cooling – takes 30 minutes to 2 hours	Launch the water-cooling units – the sequence is automated	Cooling time
Detecting defects	A trained tester spends 10 minutes scanning a weld	Scan the head of the rail with an ultrasonic stick	3D picture of the defect
Data recording	Office staff digitise and archive data written on labels	Data recording via mobile devices, with some automatic recording	All data regarding the weld (location, consumable batch numbers)

The integration of automation and data collection in ATW welding offers numerous benefits. These advancements bring performance closer to that of high-capex welding solutions, while maintaining high flexibility and versatility.

Quality improvements: ATW traditionally relies heavily on a welder's skills, with errors in the welding operation leading to lower weld performance and increased defect rates, often resulting in weld rejection. Common causes of defective welds include:

- Preheating errors: In the United Kingdom, where weld preheating relies on oxy-propane, 20% of rejected welds are due to preheating errors.
- Geometry issues: Proper rail alignment and weld grinding are critical. Misalignment makes grinding more difficult or even impossible, leading to increased defect rates.

Semi-automated ATW addresses these issues through automatic preheating and rail alignment. Field trials with i+heat demonstrated a 100% acceptance rate on over 100 welds. Similar results were obtained in Switzerland on tramway projects, with over 1,000 welds completed over eight months. The introduction of automatic aligners will further reduce alignment errors and enhance accuracy, particularly important for high-speed lines. In addition, better-quality data recorded during operations enhances process reliability by documenting anomalies and triggering alarms.

Safety improvements: Automatic equipment reduces the physical strain on welders. The time a welder spends kneeling into the ballast to cast a weld is reduced from around 25 minutes to 5 minutes with automatic rail aligners and self-sealing moulds. This also decreases the incidence of hand injuries, a known risk when aligning welds. Consequently, a significant reduction in accidents leading to lost workdays can be expected.

Productivity improvements: A traditional aluminothermic weld takes around 1 hour to complete in total (from the start to completing grinding). Of this time, 45 minutes can be considered active labour time and 15 minutes cooling down time.

Fig.2: Welding on track with i+weld set up

Semi-automated ATW reduces this time to approximately 45 minutes and saves around 15 minutes of active labour time. A total of 5 to 10 minutes is spared with automatic alignment, 5 minutes are saved with self-sealing moulds and 5 to 6 additional minutes can be spared with the automatic preheater as this does not need constant monitoring. As a result, across a five-weld shift, the time saved amounts to 75 minutes. This time could be used to cast two extra welds – a 40% increase in output.

Furthermore, on quick repair jobs, water cooling can reduce the weld temperature to about 50°C within 20 minutes after casting, allowing for immediate finish grinding and minimal disruption of traffic.

Operational improvements: Automation simplifies the welding operation, enabling quicker training and a more versatile workforce. Track workers can be trained in just three days to set up self-sealing moulds, automatic aligners, and execute preheating, which make them able to fully a cast welds under the supervision of a qualified welder.

Qualified welder training also requires less time as some operations such as preheating are very easy to learn. This simplified training, fewer safety hazards, and reduced physical strain make it easier to find, train, and retain welders compared to the standard process.

Cost of the welds

The cost per weld for each technology is highly dependent on the specific use case and will vary depending on local labour cost. Numbers in Fig 3 are approximation and must be adapted to each area.

The cost of ATW predominantly increases with the number of welds casted, necessitating additional crews (a qualified welder and an assistant welder) each time the maximum capability of a crew is reached, usually 5 to 6 welds.

FBW involves substantial fixed costs (investment & maintenance) as well as costs for mobilizing the equipment. To be cost effective against ATW, these costs need to be balanced. Mobilization cost will require a project of at least 75-100 welds to be profitable, and to cover the fixed costs 2500-3000 welds per year shall be performed.

Semi-Automation increases ATW output and makes it the most financially appealing for worksite up to 25 welds per shift. (Fig 3)

Fig.3: Comparison of welding cost for different technologies

Versatility and scalability are key to addressing future challenges in rail welding

The primary challenge in rail welding is to maintain quality standards while controlling life cycle costs and addressing the shortage of skilled workers. Both FBW and ATW have their optimal use cases. ATW excels in maintenance jobs requiring flexibility but is less suited to new line construction for two main reasons: costs increase proportionally with the number of welds, and it is difficult to find enough skilled welders for time-sensitive large projects. In general, there are no qualified welders in the temporary labour pool, and having an in-house workforce sized for large projects means a lot of the staff would be idling when the activity is low.

FBW, while not constrained by the availability of skilled workers, incurs high acquisition costs, making it impractical for daily maintenance tasks. Railway networks require the ability to dispatch welding crews to hundreds of locations nightly for one-off repairs. No network, regardless of its profitability and funding, can sustain a fleet equipped with high-capex welding solutions operating outside their cost efficiency zone. FBW should therefore be reserved for major projects with 30 or more welds, justifying the investment for a limited number of machines to ensure a sufficient return on investment (ROI).

Currently, railway operators must strike a delicate balance between:

- Using costly FBW equipment, often below the breakeven point.
- Staffing many ATW welding crews, which is increasingly difficult.

However, semi-automated ATW welding presents a transformative breakthrough. With significantly lower capex requirements compared to FBW, and higher productivity than traditional ATW, semi-automated ATW welding is an easy-to-use alternative. Any worker can be trained in a few days, providing immense flexibility. For entities aiming to optimise their operations, it is advisable that they seriously consider a shift to semi-automated ATW.

Conclusion

Welding is a critical process in rail maintenance. Railway network operators and contractors must find solutions to maintain high service standards while controlling life cycle costs and addressing worker shortages. This necessitates optimising work operations. One promising solution is adopting flexible and versatile welding technologies suitable for both small and large projects. Semi-automated ATW, with its low capex and ease of use, allows for the employment of a non-specialised workforce, increasing productivity during busy periods. This makes it a scalable technology at a controlled cost, ensuring efficient and sustainable rail welding operat

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