

ALUMINUM/STAINLESS STEEL CONDUCTOR TECHNOLOGY: A CASE FOR ITS ADOPTION IN THE US

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ABSTRACT

Numerous technologies exist for providing electrical power to transit systems. Where overhead space is costly or where overhead structures may be deemed obtrusive, 3rd rail is a reliable and cost-effective way to provide considerable power to transit vehicles. Since the early years of railway electrification, 3rd rail conductors have evolved from steel to aluminum/steel composite to aluminum/stainless steel compositions. Aluminum stainless steel conductors are currently used in approximately 40% of the over 10,000km of 3rd rail systems worldwide. Adoption of this technology in the United States, however, stands at less than 5%.

This paper examines aluminum/stainless steel 3rd rail technology from technical and economic perspectives. The author makes a case for its adoption in new and existing 3rd rail systems in the United States.

INTRODUCTION

After electricity, water and waste disposal systems, modern transit systems are among the most critical of urban infrastructure elements. For hundreds of millions of commuters around the world, metros, subways, or undergrounds are essential to their lives and livelihoods. Third rail conductors are a time-tested and cost-effective means of powering these essential transit systems. The use of third rail electrification for urban transit began in the 1890's in London and Liverpool in the UK and in Chicago in the United States. Currently in the US, there are approximately 2700km of third rail systems in operation.

The third rail is usually located on the side of the running rails. On the train or vehicle is mounted a collector which includes a sliding shoe that contacts the third rail and draws

current to drive the train's traction motors. The return current flows through one or both running rails to complete the circuit as shown in Figure 1.

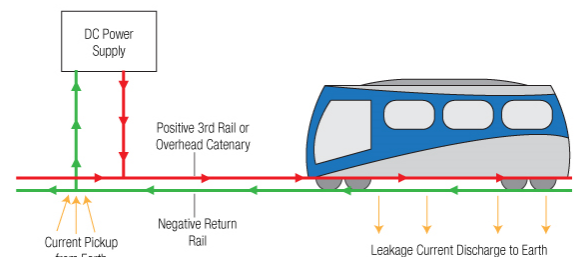


Figure 1: Typical Third Rail Configuration¹

Third rail systems are fed electrically from traction substations placed along the track. In the US, substations typically supply a DC voltage of 600 or 750 volts, with BART being an exception at 1000VDC. Substation spacing can vary based on the vehicle power requirements, headways, and allowable voltage drop. Figure 2 indicates average track length per substation for the three larger MTA systems.

System	Avg track per substation (km)
NYCT	3.1
LIRR	2.9
MNR	4.9

Figure 2: Substation Spacing MTA²

The most important factor determining the efficiency of third rail systems, and ultimately determining the number and spacing of substations is voltage drop. Voltage drop results from the resistive losses in the circuit as the current travels the length of the third rail. The lost power is dissipated as heat and is described as I^2R loss where I = current and R = resistance of

the conductors. The greater the resistance of the conductor or the greater the length of the circuit, the greater the power loss and the lower the available voltage at the vehicle. Energy losses in third rail account for between 3 and 8 percent of the total energy consumption of the railway.²

Other factors critical to the performance of third rail systems include resistance to mechanical wear of the collector shoes and resistance to electrical arcing. These will be discussed later in this paper.

THIRD RAIL TYPES

There are three primary types of rail currently used in third rail systems. Steel rail represents the traditional technology, dating as far back as the 1890's and constituting a majority of the 3rd rail currently in operation in the United States. Steel rail has the longest performance record and has served reliably on many systems for over 50 years. Due to commonality with steel running rail, transit entities have both the knowledge and experience to install and maintain steel conductor rail. Steel conductor rail typically is 115 or 150 lb/yd. Figure 3 shows a common steel conductor rail profile as installed on an insulator.



Figure 3: 115 lb Steel Conductor on Insulator⁵

Another common conductor is known as 84C where strips of aluminum are bonded by Huck bolts or rivets to the web of a steel rail. This composite construction allows for size matching with 115 or 150 lb/yd steel rail with the added benefit of lower electrical resistance than steel rail due to the aluminum ballast. Composite rail is used extensively in the United States including PATH, WMATA and NYCT.

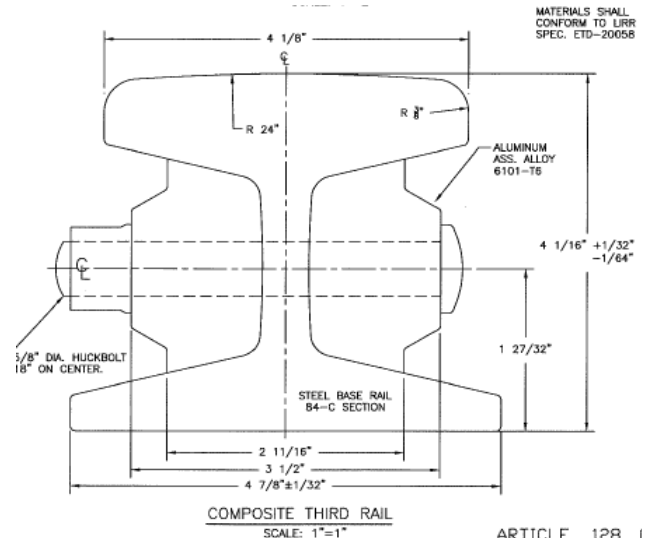


Figure 4: Composite Third Rail Section

Aluminum/Stainless Steel (ALSS) rail is an alternative to steel and aluminum/steel composite rails. Introduced in the US in the 1960's,⁴ it consists of a stainless steel cap affixed to an aluminum extrusion by a variety of methods. Original designs consisted of a 2mm thick hardened stainless cap crimped to the aluminum extrusion.⁶ Over the years, and through the involvement of a variety of suppliers, this has evolved to wide range of co-extruded, welded and improved crimped configurations. There are currently over 4000km of ALSS conductors in use in metro systems worldwide.



Figure 5: ALSS Conductor⁸

COMPARISON OF THIRD RAIL TYPES

In comparing these third rail types, we'll look at several key areas:

- Electrical
- Cost
- Mechanical
- Installation
- Environmental

Figure 6 shows a comparison of the three predominant conductor types with a fourth 2500A ALSS conductor which matches the 150lb rail in resistance. A strict cost or resistance comparison is not entirely useful.

Per unit length electrical resistance of third rail conductors is the product of the volume resistivity times the area of the conductor cross-section. While the lower resistance of ALSS conductors is somewhat offset by the higher cost, from a conductivity-cost perspective, ALSS has advantages.

Type	area (mm ²)	mass (kg/m)	R (ohms/km)	Installed Cost (\$/m) (1)
150lb steel	9290	74.4	0.0117	\$ 255
84C composite	9239	52.8	0.00656	\$ 280
6000A ALSS	7652	26.2	0.00463	\$ 260
2500A ALSS (2)	3144	10.9	0.0118	\$ 107

(1) cost can vary widely based on project scale, labor rates, etc.
(2) for comparison only with 150 lb steel

Figure 6: Rail Type Comparison⁷

The conductivity advantage of ALSS per km is clearly evident in Figure 7.

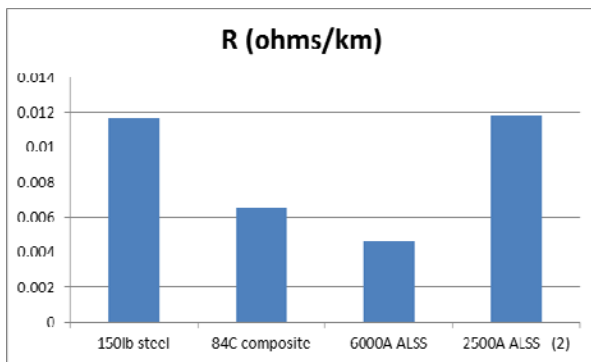


Figure 7: Resistance by Conductor Type

Cost per installed meter by rail type alone can be a somewhat misleading metric as material handling methods and labor rates can vary widely from system to system. It does, however, indicate that ALSS rail offers life-cycle cost benefits over the other two rail types.

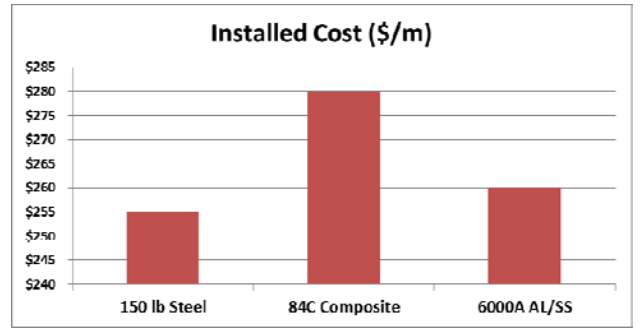


Figure 8: Installed Cost per Meter by Rail Type

The cost to conductivity ratio (Figure 9) gives a general depiction of the electrical efficiency by rail type.

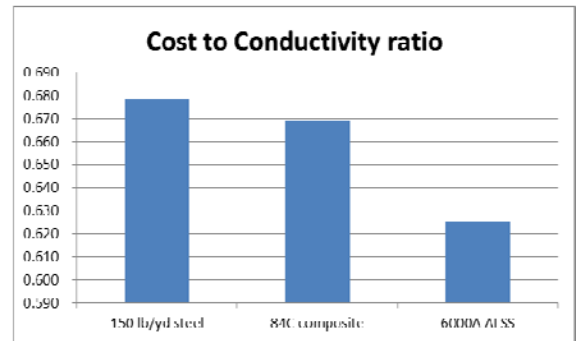


Figure 9: Cost to Conductivity Ratio by Rail Type

Third rail is subjected to a range of mechanical forces. Mechanical forces such as longitudinal thermal expansion across the insulators and through curves must be considered. Collector contact forces – both normal to the collector shoe contact and longitudinally at the end engagements (ramps) - as well as deflection of the rails between insulating supports must be well understood and accounted for in the system design. While all three types of rail are comparable in withstanding expansion and normal collector forces, the lower stiffness and tensile strength of ALSS rail is typically not an issue for 4000A to 6000A ALSS rails with a support pitch less than or equal to 6m.

Mechanical wear is a concern with any third rail system. Existing steel rails are designed and installed on the basis that they wear by approximately 25% during their life. Steel rails wear 0.6 – 1mm per year with an expected service life of 40 years². Unlike ALSS rail, steel rails wear by mechanical and corrosive erosion of the contact surface and by corrosion of the side surfaces. ALSS rails wear at 0.05 – 0.1 mm per year and the aluminum does not corrode appreciably unless there is significant stray current corrosion taking place. The stainless steel in ALSS rails contributes negligible conductivity; therefore, the resistance varies minimally as the stainless steel

contact surface is worn. With steel rail, the resistance will increase by 33% as the rail wears by 25%.

Geometry and strength are of critical importance for third rail end engagements. Early ALSS end engagement designs consisted of bent rail sections. On some systems, these may be prone to failure due to electrical erosion of the 4 or 6mm stainless cap, which could then delaminate. Current end engagement designs of fabricated steel or stainless steel provide durability on par with 150lb rail (Figure 10).



Figure 10: Fabricated End Engagement for ALSS Rail⁸

The lower mass of ALSS conductors offers benefits in transportation, handling and installation. ALSS rails provide a 7 to 1 advantage in conductivity to weight over 150lb steel rail and a nearly 3 to 1 advantage over 84C composite rail as shown in Figure 11. Although detailed studies have not been conducted on installation cost savings of ALSS over steel rail, these are estimated to be in the range of \$3-\$5 per meter.

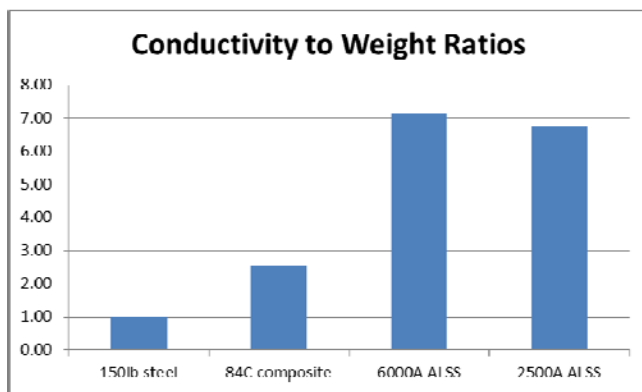


Figure 11: Conductivity to Weight Ratio by Rail Type

Environmental factors such as corrosive elements and icing can have an effect on the performance of third rail. ALSS provides superior corrosion resistance compared to steel rails. This is important not only for the life of the conductor but also affects the efficiency of the third rail system in terms of I²R losses.

Growing use of power consumption tracking systems is providing new insights to power rail electrical losses. On the UK's Network Rail system, DC electrical losses were estimated to be approximately 20% of total electrical consumption. Approximately half of this was attributed to the 3rd rail. In response to pressure to improve energy losses, Network Rail performed a break even analysis for 10 different initiatives, including replacement of steel rail with ALSS power rail. Ultimately, the 1.5% energy savings predicted for ALSS rail at current electricity costs was not sufficient to justify replacement of steel rail with remaining service life.¹¹

RATP Engineering has indicated that the Paris Metro uses steel for now but is moving in the direction of ALSS power rail. Sustainability is a strategic objective and a group value of the RATP. The company has set goals of reducing energy consumption by 15% from 2004 to 2020. RATP estimates the energy saving from ALSS to 5% at current electricity prices. When rectifiers can be downsized and substations eliminated or separated by greater distances, the savings are improved further.¹¹

MORE FOOD FOR THOUGHT ON ALSS RAIL

Steel and steel composite rails are mill-run products typically produced in large quantities. These quantities are in the range of thousands of feet (100 tons or more.) Conductor grade aluminum extrusions can be purchased economically in quantities of a few hundred feet (one ton or more.) The cost of aluminum extrusion tooling is on the order of a few thousand dollars and can be produced in 2 to 3 months. The low overhead costs, flexibility of design and short production lead times (relative to steel or composite rails) increase the value of ALSS rail solutions. See Figure 12 below for examples of common 6000A ALSS conductor profiles currently available from US suppliers.

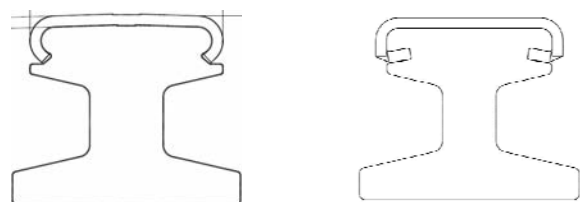


Figure 12: ALSS Rail Profile Examples^{8 & 9}

There are at least two US suppliers of wrap-around ALSS third rail, meeting the requirements of the Buy American provision. This is in contrast to 150lb steel rail which now must be imported.

Fourth rail is a common alternative to 3rd rail systems due to overall lower resistive losses and better management of stray currents. Systems that exhibit the most severe corrosion of

running rails are subways and underground metros. Where running rails are used for the DC current return, corrosion rates can be accelerated⁹. Figure 13 shows the effects of accelerated stray current corrosion.

Electrical erosion can be a problem for any third rail system. Electrical erosion results from arcing between the collector shoe and the rail contact surface. Arcing can be significant when there is intermittent loss of collector shoe contact. When loss of contact occurs repeatedly at the same location on the rail face, the conductor material is electrically eroded. In severe instances, this erosion can be 5mm or more per year. Loss of collector shoe contact is typically the result of one or more of four conditions:

- Engagement-disengagement at ramps under full power
- Insufficient dynamic response of the collector
- Discontinuities in the rail contact surface
- Poor alignment between the running rails and the third rail
- Ice build-up

Consequently, these four conditions play a significant role in the longevity of ALSS third rail and must be managed to the maximum reasonable extent.



Figure 13: Corrosive Effects of Stray Current⁹

Lastly, not all ALSS rails are alike. Experienced system operators know that if bad things can happen, they typically will. Unfortunately, the 3rd rail is not always in the expected position relative to the collector, resulting in out-of tolerance collector shoe to 3rd rail engagement. Unlike co-extruded ALSS profiles, ALSS conductors with a wrap-around stainless cap prevent accidental contact of the collector shoe with any aluminum. (Figure 14) This eliminates the potential for delamination of the stainless cap.

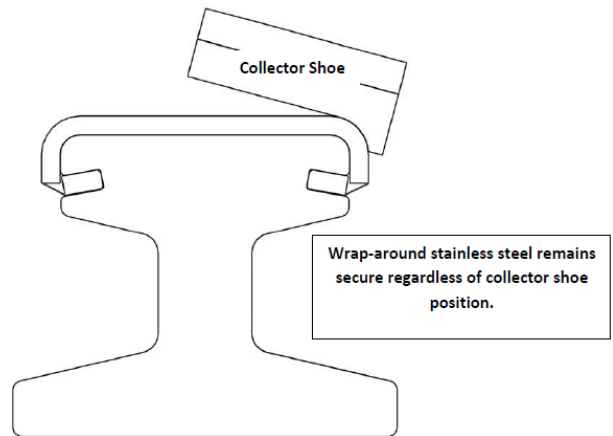


Figure 14: Wrap-around stainless cap design offers high reliability regardless of collector shoe contact.

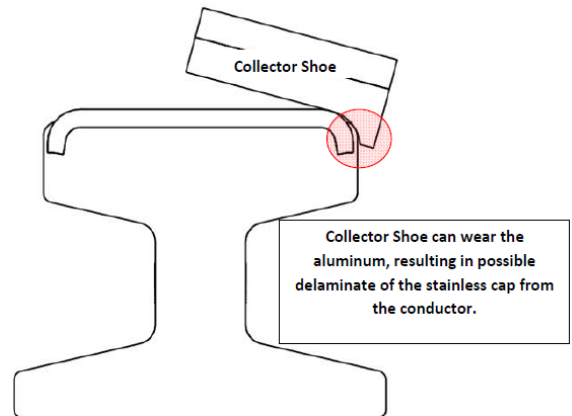


Figure 15: Co-extruded configuration leaves aluminum edge exposed to collector shoe contact.

CONCLUSION

There are three possible scenarios for third rail replacement as shown in Figure 16, below.

Scenario	Benefits to replacement with ALSS
Existing 3rd rail with remaining useful life	Energy savings of 30% over 84C and >50% over 150lb steel rail
Existing 3rd rail at end of useful life or under capacity	lower installation costs energy savings longer service life higher capacity
Clean sheet system design: new or extension	substation size &/or number lower installation costs energy savings longer service life higher capacity

Figure 16: Scenarios for 3rd Rail Replacement

Economics, expressed in life-cycle cost, remain the predominant criteria for selection of ALSS third rail for replacement or new systems. Buy American compliance of ALSS products is also important for US transit systems. There is limited benefit to replacement of existing 150lb rail that has not reached the end of useful life. There may be considerable benefit to use of ALSS third rails where replacement is necessary due to end-of-life or insufficient capacity of the existing third rail. Where a new system will be constructed or an existing system will be substantially expanded, ALSS technology provides additional cost savings in reduced substation size and/or quantities.

In many instances, ALSS rail provides clear advantages over steel rail. Its lower resistance and lighter weight translate into greater energy efficiency, fewer or smaller substations, and lower installation costs.

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