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STAINLESS STEEL RAILCARS FOR METRO AND EMU RAILWAYS

- NORTH AMERICAN EXPERIENCE -

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ABSTRACT

This paper explores and explains the noticeable move from Carbon Steel to Stainless Steel in the fabrication of car shells for Metro and EMU railway applications, from the North American perspective. Based upon this North American experience, valuable data exists (and is summarized herein) to illustrate the long term cost effectiveness of this shift in material specification. This is presented in terms of ease of maintenance, surface protection requirements, ease of repair, as well as the inherent structural properties that this material provides, enhancing both strength and safety characteristics of the carbodies fabricated with Stainless Steel.

Key Words: stainless steel, carbon steel, Corten, LAHT, railway applications, cost effectiveness

1.0 INTRODUCTION

Most of the Metro Rail and EMU cars built (and being built) in North America use stainless steel carbodies. The initial capital cost for stainless steel carbodies is higher that for carbon steel, so the question arises, “Why is the world moving to stainless steel for carbodies?”

It will be seen upon review of this paper, that there are considerable savings to be realised in terms of significant reductions in Life Cycle Costs (LCC), appreciable cost benefits arising from increased life expectancy of the stainless steel carbodies, increased material strength providing an inherently higher level of passenger safety and stainless steel retains its mechanical properties better at high temperatures, thus providing superior fire resistance capabilities.

2.0 USE OF STAINLESS STEEL FOR RAIL CARS

Since the introduction of stainless steel as a carbody material for the US rail sector by the Budd Company in 1932, stainless steel has become a significant contributor to the railway industry. Its selection as a carbody material in competition with either Aluminum extrusions and carbon steel cannot be attributable to any particular characteristic, because in North America, there has not been a direct competition of these carbody materials against the same specification, from which to deduce relative benefits.

In North America, most tender requests include a detailed technical specification. This specification, often containing as many as 600 pages of technical requirements, will stipulate the type of carbody material to be employed. Few tender specifications leave the selection of carbody material open to the car-builder. Regardless, in most cases the car builder has the ability to manufacture a car shell from any of these traditional materials, consequently, on the rare occasion when the specification is open, the car builder will select the material that is most likely to win the contract, not necessarily the one that offers the best long term economic choice .

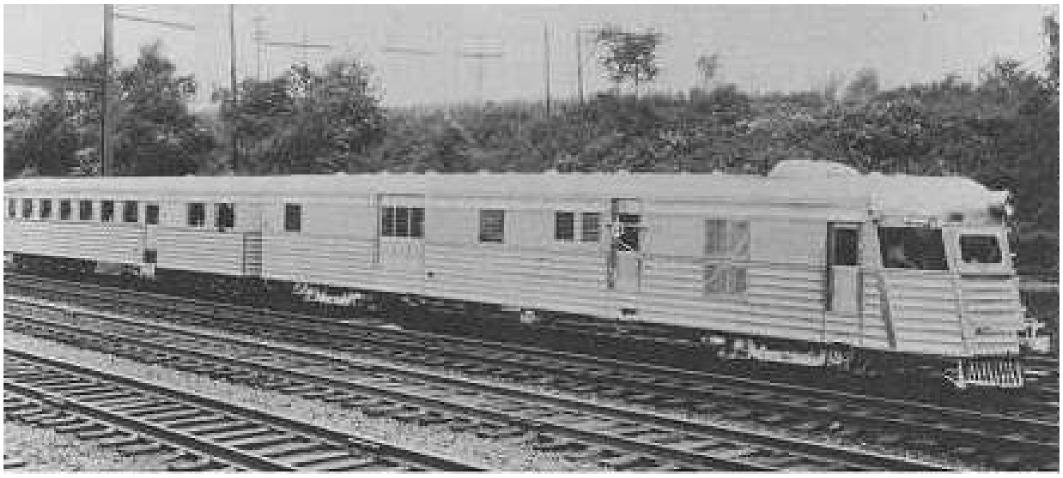
Washington Metropolitan Transit Administration recently released a request for bids for an order of subway cars with no stipulated car shell material. The winning bid conformed to the design of the existing cars, which had an aluminum extrusion car shell, that it was selected to replace. There was no request for a life cycle cost analysis, which tends to favour the stainless steel car shells. Consequently, all bids included only aluminium extrusions for the car body construction, because that was perceived to be the most likely to win the contract.

Although there are no definitive comparisons, there are some discernible trends. The larger subway and commuter rail operators tend to favour stainless steel. They also tend to place large quantity orders and keep their fleets active for more than 30 years. Many of these large operators are also located in marine locations where corrosion is an issue. Therefore, their preference for stainless steel can be deduced as related to the need for longevity and the ability to obtain lower costs for large production runs where the automatic welding needed for a quality stainless steel car shell is economic.

The remainder of this paper will attempt to quantify the relative merits of stainless steel from the perspective of its properties.

3.0 N0RTH AMERICAN EXPERIENCE

The first use of Stainless Steel in mass transit equipment was in 1932 (Budd-Micheline Light-Weight car)



Other examples of Stainless Steel carbodies in North America are illustrated in the following photographs:

4.0 ADVANTAGES OF STAINLESS STEEL OVER CORTEN STEEL AND ALUMINUM RAILCARS

There are three major materials used for the construction of transit vehicles: low-alloy, high-tensile (LAHT) steel; stainless steel; and aluminum alloys. Stainless steel and aluminum alloys enjoy a reputation as the most advanced materials, both have a proven record of application and both have been successfully used in construction of passenger rail vehicles for the past 50 years.

The advanced structural materials owe their reputation to their excellent corrosion resistance and their exceptionally high strength-to-weight ratio, which separate them from the LAHT steels by a factor of two (Table 1). In fact, the characteristics described here make it logical to analyze the available construction materials in two groups: advanced materials and LAHTs.

Table 1. Major Characteristics of Vehicle Construction Materials

	Yield Kg/mm² (psi)	Ultimate Strength Kg/mm² (psi)	% of Elong.	Specific Gravity	Yield/ Specific Gravity
LAHT Steel (Corten)	350 (50,000)	490 (70,000)	18	7.9	44.3
St. Steel (301, ½ Hard)	**770 (110,000)**	**1.050 (150,000)**	**15**	**7.9**	**97.4**
Al Alloy (6061-T6)	245 (35,000)	266 (38,000)	8	2.7	90.7

4.1 Advanced Structural Materials

The question that comes naturally to mind when two materials are both characterized as advanced is which of the two is better, stainless steel or aluminum alloy? Surprisingly, the issue is neither easy to analyze nor the answer unequivocal. In addition, frequently the designation of a “stainless steel” or “aluminum” car applies essentially to the structure above the underframe. The major components of the underframes such as end weldments, center sills, or crossbearers are frequently made from LAHT steel for both stainless steel and aluminum cars. This is mainly due to LAHT’s excellent weldability and well-established fatigue limits. To facilitate comparison between aluminum and stainless steel structures, their major features will be contrasted in the “Material Value Matrix”, (Table 2 below).

Table 2. Material Value Matrix-Underground Rapid Transit Car in Humid Tropic

			LAHT Steel		Stainless Steel		Aluminum Alloys	
	Column 2	3	4	5	6	7	8	9
Item	Feature	Rating Weight (Percent)	Rating (1-10)	Weighed Rating (3)x(4)	Rating (1-10)	Weighed Rating (3)x(6)	Rating (1-10)	Weighed Rating (3)x(8)
1	Strength	5	5	25	10	50	3	15
2	Strength/weight	10	5	50	10	100	10	100
3	Fire Resistance	15	6	90	10	150	2	30
4	Corrosion resistance	15	6	90	10	150	9	135
	Cost advantage							
5	(a) Material	10	10	100	3	30	6	60
6	(b) Manufacturing	10	8	80	3	30	10	100
7	Maintainability advantage	10	5	50	10	100	8	80
8	Ease of repair	10	10	100	5	50	5	50
9	No, of Sources of Material	15	8	120	8	120	7	105
	Totals	100		705		**780**		675

Column 2 is always the same and is the list of material characteristics considered in the process.

Column 3 assigns percentage values (or “rating weight”) of specific characteristics for a given car application. Thus, fire resistance of the underground rapid transit cars (Table 3) has a higher value of 15 points over 10 points for surface operating LRVs (Table 2). The sum of the “rating weights” must be 100 percent.

In columns 4 (LAHT steel), 6 (stainless steel), and 8 (aluminum alloy), a rating from 1 to 10 is assigned to each material for a given application. Please note that considering “Number of sources of material,” Table 2 places a premium of 10 points for LAHT in contrast with 8 points in Table 3 because availability of LAHT in this hypothetical case has been higher.

Multiplying figures in columns 4, 6, and 8 by those of “rating weight” in column 3 results in the final figures in columns 5, 7, and 9, which are then summarized at the bottom of the table.

4.2 Maintainability

Considering material maintainability in the context of transit vehicle construction, one usually has in mind the resistance of the material's finished surface to the environment and to the washing operations encountered in service.

Both stainless steel and aluminum alloys have superior resistance to the influence of atmospheric elements. In both cases, the finish applied to the surface of the carbody outer skin is routinely that provided by rotating brushes or fine-grade sandpapers. Such a surface usually does not require painting and displays excellent resistance to the effects of aging in its natural state as delivered from the mill.

Welded aluminum structures require finishing operations to be applied to the outer skin surface after the assembly of the structure has been completed. This frequently entails painting. A stainless steel outer skin surface neither requires nor easily accepts painting. Decals are usually used when color is desired on stainless steel, however, totally painted stainless steel railcar have become popular in recent years for decorative reasons.

4.3 Weight and Other Mechanical Characteristics

While aluminum alloys are approximately three times lighter than stainless steel, the latter displays approximately three times higher strength (Table 1). Thus, theoretically it should be possible to build a stainless steel carbody shell as light as aluminum one. In fact however, aluminum vehicles have a record of being lighter. This is attributed to the fact that it is difficult to fully utilize the strength of thin stainless steel sheets without making them vulnerable to a loss of stability. Consequently, stainless steel components may sometimes be heavier because of the need for stability, rather than for strength. This issue warrants further investigation, but of the three latest North American bi-level commuter cars, one of aluminum and two of stainless steel, the aluminum car weighs 108,000 lbs. and the stainless steel cars weigh 129,000 and 140,000 lbs. (It is worthy of note however, that these cars were designed and built to different specifications, which accounts for some of this variance.) Two underground rapid transit cars of a similar size and performance, the Toronto aluminum car and the Los Angeles stainless steel car, weigh 66,000 lbs. and 82,000 lbs. respectively. The difference is a factor that will influence the cost of energy consumption, highlighting the importance of making the material choice decision in terms of the local condtions, such as the relative cost of electrical energy..

4.4 Resistance to Elements of the Environment

From the point of view of corrosion resistance, both stainless steel and aluminum alloys enjoy a highly positive reputation. Stainless steel also rusts, but instead of a destructive iron oxide film, an invisible and highly protective chrome oxide film forms on the surface. Similarly, aluminum alloy surfaces when exposed to the atmosphere develop a thin, invisible oxide skin, which protects the metal from further oxidation. This self-protecting characteristic gives aluminum its high resistance to corrosion, however, care has to be taken in joining aluminum alloys with other metals. When joined without proper protective barriers (solid shields or specially formulated pastes), aluminum alloys develop a corrosive bridge with the adjacent materials and undergo deterioration.

The type of corrosion caused by automobile exhausts is related to the high acidic content. This is another local effect that must be included in the choice of materials. Many of the large urban developments in India suffer from high level of atmospheric pollution caused by automobile exhausts. Stainless steel offers greater corrosion protection than aluminum in such atmospheres.

4.5 Fire Resistance

Stainless steels are highly resistant to flame and heat. While stainless steels of the 300 Series still perform satisfactorily in the temperature range of 600-800ºF, the tensile strength of aluminum alloys of the 6000 Series at 700ºF falls below 10% of the strength at room temperature. Stainless steel melts at 2500-2700ºF, and aluminum melts at 1200ºF, however, it must be remembered that the areas most exposed to fire hazard, those under the car, are frequently made of steel, even in cars with aluminum bodies.

4.6 Cost of Material

Both advanced materials, stainless steel and aluminum alloy, are more expensive than low-alloy, high-tensile steel. The cost of material varies depending on demand and availability, but in general terms, the cost of LAHT steel to aluminum alloy to stainless steel remains in an approximate relation of 1 to 2 to 4. Thus, from the point of view of the cost of material, aluminum and LAHT alloys have an advantage over stainless steel.

4.7 Cost of Cutting, Forming, and Joining

Stainless steel and aluminum require training, skill, and specialized methods in manufacturing, however, in terms of the energy required in cutting, forming, and joining, stainless steel is more expensive than aluminum alloy.

The same applies to the cost of the required tools and forming machines. While aluminum alloys can easily be cut and formed with tools used for ordinary carbon steel, stainless steel requires specialized and more expensive equipment, such as plasma arc cutters or hard-ended drill bits. These tools do, however, lend themselves to achieving higher level of repeatable quality for long production runs. Tools for aluminum cost often 1/3 to 1/10 that for comparable stainless steel items.

4.8 LAHT Steel for Light Rail Vehicles

The Light Rail market in North America is characterized by small order quantities and a great diversity of designs. There is almost no opportunity for standardized design as with the Presidents' Conference Committee (PCC) design, therefore each order has high non-recurring engineering costs, which forces economies in other areas. With the fleets being small (20 to 50 cars), investment in maintenance and the skill of maintenance staff favour the choice of LAHT. Therefore, LAHT steels are quite visible in the LRV market due to the ease of repair and competitiveness due to lower cost of production and the wealth of purchasing sources.

The fact that the outer finish of LAHT steel sheet requires painting is a favourable aspect in the case of light rail vehicles (LRVs). As part of the urban scene and shape of the architectural image in the downtown setting, the natural finish of stainless steel or aluminum can lose its appeal. Suddenly, in the middle of the street in the sunshine or under bright city lights, its image becomes rigidly mechanical and acquires an industrial quality. For this reason, painting of stainless steel carbodies may become a desirable option for LRVs. Today's highly sophisticated and durable paints, among them, polyurethane paints with outstanding performance lasting 15 to 20 years, provide attractive and wear-resistant finishes to railcars on all continents and in all climatic conditions.

5.0 REPAIR AND MAINTENANCE

5.1 Repair

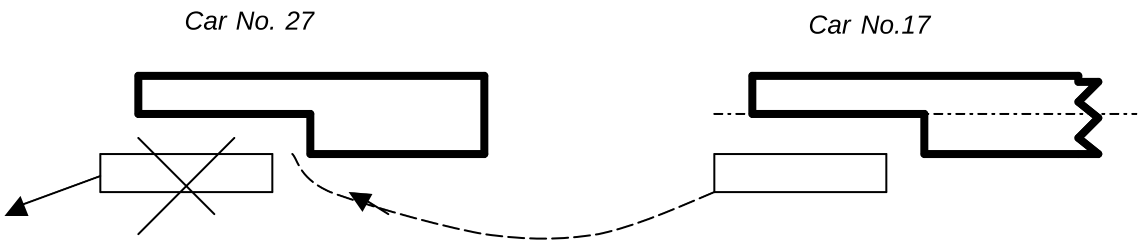
Repairing damaged railcars always constitutes a challenge to the transit operating authorities. Although stainless steel has excellent mechanical characteristics, it does require a good knowledge of its response to repair techniques to provide the anticipated performance when returned to service. Following is the story of how two stainless steel cars, severely damaged in a collision, were repaired.

In 1993, two trains of the Northern Indiana Commuter Transit District (NICTD) collided on a gauntlet track bridge. One train was at rest but extended too far ahead to allow a free, undisturbed passing of the other train traveling in the opposite direction. The front left corners of the leading EMU stainless steel cars Nos. 27 and 36 were totally destroyed resulting in seven fatalities. The corner sections of both cars, measuring from their centerlines to the left side and from the front to the middle of their length were essentially wasted (see below).

Eva Lewalski, PE, President of Transit Performance Engineering (bottom middle) inspects the damaged car No. 27.

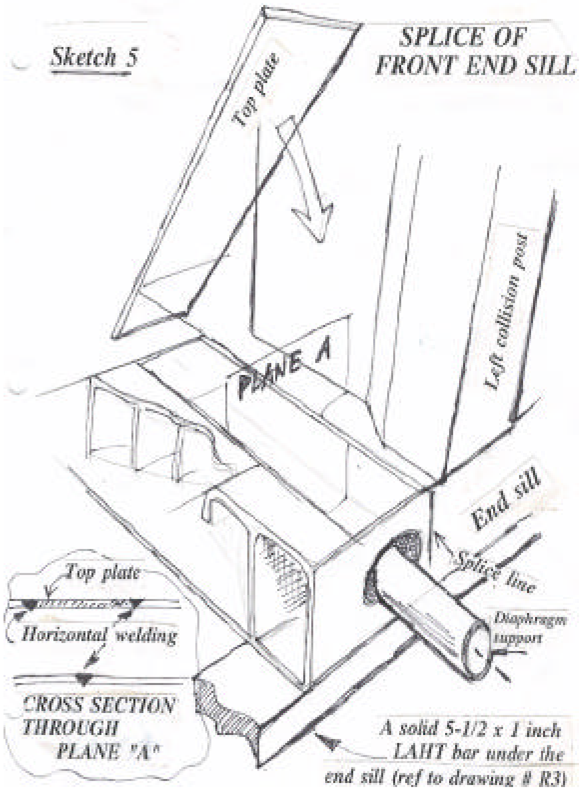
NICTD management contracted Transit Performance Engineering (TPE), an engineering consulting firm, to assess the possibility of repairing the damaged cars. There were clear reasons to consider such an option, since the cost of a new replacement car was in the range of $2.5-3.0 million. NICTD engineering and shop personnel were confident that the damaged cars could be returned to service at half that price. TPE confirmed that assessment.

The idea was to remove the quarters of the damaged car Nos. 27 and 36 and fit them with the quarters removed from car Nos. 17 and 26, taken out of service after a 1984 head-on collision. This idea is illustrated below.



Block diagram of the repair of the damaged cars (view from the top).

The procedures adopted in the repair of the cars were as follows:



1. Both cars (No. 27—“a patient” and No. 17—“a donor”) were carefully inspected for damage and in terms of how the damaged sections in car No. 27 and the replacement sections of car No. 17 would be removed.
2. An independent laboratory was engaged to check the parts to be weld-joined for metallurgical compatibility.
3. Repair welding procedures were written, and the American Welding Society-certified welders selected. Welding procedures specified the joint designs, preparation of joints for welding, types of electrodes to be used, and other parameters.
4. A removal of the quarter of car Nos. 27 and 17 was initiated and completed. The parts separation was made with the use of grind disks and welding torches.
5. The quarter of car No. 17 was welded in place of the removed damaged quarter of car No. 27.
6. A TPE policy was that all new joints were at a minimum of 10 percent stronger than the structures and connections provided by the original design.
7. In the most critical sections of the new joints, the supplementary structural elements were introduced. An example can be a solid 5-1/2 inch bar under the end sill (see the picture above, the bottom/right corner) to secure the added quarter of car No. 17 firmly to the repaired structure.
8. After each stage of car No. 27 repair, TPE inspectors reviewed and signed off on the structural repairs completed.

The photograph below shows car No. 27 after repair. Car No. 36 was repaired the same way, using car No. 26 as a “donor” car.

Car No. 27 after repair.

5.2 Maintenance

The maintenance benefits of Stainless Steel are most accurately summarized in terms of the associated Life Cycle Costs (LCC). Recently, the U.K. Steel Construction Institute was asked to examine the economics of stainless steel structures, vis-à-vis those made from other materials. This involved a comparison of the initial costs as well as the ongoing operating costs related to maintenance, repair and replacement over the projected life cycle of the structures.

The findings show that the relatively high initial material cost of Stainless Steel is counterbalanced by its long corrosion-free life and virtual freedom from any significant maintenance and repair, making its true economics substantially more attractive than one might first assume. A study in Japan done in 1990 showed lowest LCC for stainless steel coaches as compared to Aluminum and Corten steel coaches, in that order.

Because of the smooth finish of stainless steel surfaces, the exterior does not require painting, a saving in maintenance cost. The surface can be cleaned easily and graffiti can be removed by applying active cleaning agents. The stainless steel coaches would retain their good appearance during their entire lifetime.

6.0 SUITABILITY OF STAINLESS STEEL RAILCARS FOR DELHI METRO, MUMBAI SUBURBAN RAILWAY SYSTEM AND OTHER CITIES

6.1 Delhi Metro Rail System

Delhi's Mass Rapid Transit System (MRTS) or Delhi Metro is at present under construction and has a total length of 62.5 km in Phase I consisting of 3 Lines. Phase I is scheduled for completion by September 2005. It will have two corridors, an 'Underground Metro' corridor of 12.5 km length and a combined 'At Surface & Elevated' corridor of 50 km length. Both corridors will operate lightweight train sets of Stainless Steel railcars or coaches, with modern features such as AC Drive for Propulsion (with regenerative braking capability), Automatic Train Protection, Integrated Train Management System, air conditioning and an automatic door closing system.

A total of 240 coaches have been ordered for Phase I of the Delhi Metro and the last 100 coaches will be fully manufactured in India. The first train set of 4 Stainless Steel coaches (22 metres long and 3.2 metres wide) will be manufactured jointly by Mitsubishi Corporation, Japan and Rotem Company, Korea did a trial run of 20 km in September 2002 and further Safety and System integration tests are scheduled until November 2002.

The civil works on first section of Line 1 ('At Surface & Elevated' corridor) from *Shahdara* to *Tis Hazari*, a distance of 8.3 km, was started on October 1, 1998. *Shahdara-Tis Hazari* section is planned for passenger traffic operation in December 2002.

6.2 Mumbai Suburban Rail System

Mumbai today has the largest Suburban Rail System in India, which started modestly in 1925. It carries more than 6 million people every day on combined Central and Western Railway suburban railway systems. The system today is heavy loaded with passenger density exceeding 10 persons per square metre in coaches during peak hours. It operates EMU (Electric Multiple Unit) trains with extra wide coaches of 3.6 metre width, to maximize passenger carrying capacity. (For comparison sake, the normal width is 3.0 metres for passenger coaches and locomotives on Broad Gauge lines of Indian Railways)

These suburban trains pass over seawater or creeks at number of places in Mumbai everyday. The heavily loaded coaches working in Mumbai's saline environment suffer the effects of corrosion quickly. This requires heavy repair on coach bodies below window level, on floors and on longitudinal structural members of the underframe (side sills). These coaches are supposed to undergo a midlife rehabilitation after 12 years but due to heavy corrosion, this period is reduced to 6 to 8 years.

A study of these coaches was made by PAI in 1999 and based on this study during formal and informal communications with Indian Railways engineers, it was suggested that stainless steel coaches would be the best option for Mumbai. RDSO (Research Design and Standards Organization) of Indian Railways, while preparing specification for procurement of new EMU train sets by Mumbai Rail Vikas Corporation (MRVC), have specified stainless steel coaches. The new EMU train sets having stainless steel coaches are under procurement by MRVC.

6.3 Mass Rapid Transit/Light Rail Systems for Other Cities

There are many large cities in India having a population between 3 to 5 million that do not have any Rail based Mass Rapid Transit System. The roads are becoming saturated and all these cities are potential candidates for a suitable MRTS. Once Delhi Metro starts operating, more cities are likely to follow suit. It is expected that other large cities like Navi Mumbai, Hyderabad, Ahmedabad, Nagpur, Kanpur, and Pune, which are considering MRTS, would adopt modern lightweight trains with stainless steel coaches and AC Drive propulsion system. The suitability of stainless steel coaches for Indian conditions is without any doubt.

It is worthy of note that the Light Rail Transit (LRT) system proposed for Bangalore has specified stainless steel for Light Rail vehicles.

7.0 RECOMMENDATIONS

Any new MRTS shall be modern, safe, energy efficient and low on maintenance. Lightweight trains with stainless steel coaches, AC Drive propulsion, Automatic Train Protection and Operation system are recommended to meet the above mentioned requirements.

Parker and Associates Inc. with a broad range of experience with many Transit Systems operating world wide, recommend that Stainless Steel railcars provide the lowest overall Life Cycle Cost (LCC) for operation in large Indian cities due to large ridership, large fleets, heavy loading, climatic and environmental conditions.

In passing it is also recommended that the Indian Government attempt to create a standard LRV design for its cities. Given that these will all be new, there are substantial savings to be realized in terms of first capital costs of both the vehicles and related infrastructure because of economies of scale.

8.0 CONCLUSIONS

The long-standing dispute among supporters of different materials for the construction of transit vehicles has not yet been brought to a conclusion and, quite likely, never will. All three of the discussed materials have known advantages and shortcomings, and each of them will be appropriate in certain specific circumstances.

At the introduction to this paper, the question was posed, “Why is the world moving to stainless steel for carbodies?” The answers provided include:

- There are considerable savings to be realised in terms of significant reductions in Life Cycle Costs (LCC);
- Appreciable cost benefits arise from increased life expectancy of the stainless steel carbodies;
- Increased material strength provides an inherently higher level of passenger safety; and
- Since stainless steel retains its mechanical properties better at high temperatures, it has superior fire resistance capabilities.

The selection of Stainless Steel railcars/coaches by Delhi Metro is a well founded conclusion that is particular to their local conditions, but these same conditions are applicable to many other Indian cities and therefore represents a genuine indication to other authorities, of the merits of stainless steel as a carbody material.

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