

Fabricating Railcars with Resistance Welding



Bombardier Transportation's facility in La Pocatière, Québec, Canada, produced carshells of the Eurotunnel shuttle cars, the largest stainless steel cars ever made. The locomotive is of the standard size. (Photo courtesy of the Nickel Institute.)

An overview is provided on the history, base materials, equipment, and standards regarding the use of resistance welding in creating stainless steel passenger railcars

BY WŁADYSŁAW JAXA-ROŻEN

The application of resistance welding in the production of transportation vehicles has traditionally been associated with automobiles. However, there is a lesser known area where the process has been used with success and to its full potential since the 1930s — fabrication of stainless steel passenger railcars.

History

The use of resistance welding for stainless steel railcar fabrication was a fascinating feat of engineering linked to the creativity and vision of Edward Gowan Budd (1870–1946), founder of the Edward G. Budd Manufacturing Co., Philadelphia, Pa. — Fig. 1. His company was the first to produce all-steel automobile bodies and also one of the first to use resistance spot welding.

During his visit to Europe in 1930, Ed-

ward Budd became fascinated with stainless steel. At the same time, Ralph Budd (no relation), president of Burlington Railway, had the idea of applying stainless steel in railway car design and fabrication. Two important developments followed: the mastery of producing 18-8 cold-worked, high-strength austenitic stainless steel by the Allegheny Steel Co., and the growing experience and competence of the Budd Co. regarding formability of the material and spot welding technology.

Stainless steel used by the Budd Co. had tensile strengths up to 160 ksi (1100 MPa) and yield strength of 120 ksi (830 MPa). Its weldability with both fusion and resistance processes was impaired by a relatively high carbon content that caused chromium carbide precipitation in the heat-affected zone (HAZ). Budd's chief engineer, Col. Earl J. W. Ragsdale, found the remedy. His 'shotweld' spot welding

process featured a welding time that was shorter than the dwell time causing the development of chromium carbides.

The Creation of Zephyr Trains

As a result, a new kind of passenger rail vehicle was manufactured and put into service in 1934. This was the birth of the Burlington Zephyr trains — Fig. 2. The conjunction of stainless steel, resistance welding, creative minds, and bold management brought a major paradigm shift. Compared with existing railcars, the stainless steel train was much lighter, which in turn made the first application of a diesel-electric propulsion unit practical.

In a display of its speed, the first Zephyr made a 1015-mile nonstop run from Denver to Chicago at the record average of 77 miles/h. Soon after, the first disc brakes were introduced. The sleek sil-

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very train was a forerunner in streamlined industrial design.

The Zephyrs changed railway travel, due to their speed, comfort, and amenities such as attractive interior design, air-conditioning, and an audio system broadcasting radio, public addresses, and music from wire recorders. A popular feature was the domed observation lounge.

Progress

Budd's example was followed by the St. Louis Car Co. and Pullman-Standard in the United States. Together, they produced thousands of stainless steel passenger railcars.

The next important development occurred in Japan, where stainless steel passenger railcars, mostly for subway and commuter trains, have been mass produced since the end of the 1950s. In Asia, stainless steel railcars are also produced in India and South Korea.

In North America, Bombardier Transportation entered the rail transit industry in the mid-1970s and has grown to be a global producer of subway, commuter, and intercity railcars. Its La Pocatière, Québec, facility in Canada has specialized in stainless steel since the beginning of the 1980s. This plant also produced carshells of the Eurotunnel shuttle cars, the largest stainless steel cars ever made — see lead photo. In Europe, for reasons associated with a traditional requirement for car bodies to be entirely painted, stainless steel cars gained only limited popularity. This is not the case in Australia, where stainless steel cars are produced and used.

Materials Used for Railcars Construction

Chemistry

The first stainless steel railcars were made from an austenitic alloy produced by Allegheny and classified by Budd as 18-8 steel consisting of 18% chromium and 8% nickel. Relatively high carbon content made this steel susceptible to chromium carbide precipitation in the HAZ of welds and to subsequent intergranular corrosion. The need to limit dwell time in the critical temperature range inspired the motivation for Budd's experts to invent the short-time spot welding process ('shotweld').

In the 1950s, 201 and 202 steels were also applied. In their chemistries, a substantial part of the nickel is replaced with manganese. Later, 17-7 Type 301 steel was introduced. In the 1980s, the advent of argon-oxygen decarburization allowed the fabrication of low-carbon stainless steels containing less than 0.03% C. This carbon level prevents sensitization of stainless

Table 1 — Chemical Composition of Selected Austenitic Stainless Steels

Element	Stainless Steel Grades			
	Allegheny 18-8	304	301L	201L
C	0.12	0.08	0.03	0.03
Cr	17.0, min	18.0 – 20.0	16.0 – 18.0	16.0 – 18.0
Ni	7.0, min	8.0 – 10.5	6.0 – 8.0	3.5 – 5.5
Mn	0.2 – 2.5	2.0	2.0	5.5 – 7.5
Si	0.2–1.5	0.75	1.0	0.75
Cu	0.5	—	—	—
N	—	0.10	0.20	0.25

Contents: wt-%, maximum values unless otherwise specified.

steels caused by welding, either with resistance or fusion processes. Because of recent increases in the price of nickel, the 200 series of stainless steels is currently (2008–2010) regaining interest.

The chemical compositions of selected austenitic stainless steels are presented in Table 1.

With regard to other groups of stainless steels, duplex steels have the potential for application, especially because of their high strength in larger thicknesses. However, they probably will not become popular in the production of railcars. They are more expensive than austenitic steels, and in lower thicknesses (up to about 5 mm), cold-worked austenitics are stronger than duplex steels. Where larger thicknesses are required, high-strength, low-alloy (HSLA) steels with yield strengths up to 700 MPa are commonly used. The use of martensitic and ferritic steels is limited to nonstructural applications.

In the remaining part of this article, only austenitic steels are considered.

Mechanical Properties

In typical descriptions of austenitic stainless steels, their mechanical properties are those in the annealed condition. However, the strength of these materials may be significantly increased by cold deformation, such as thickness reduction in cold rolling, forming, or bending.

Deformation strengthening of austenitic steels results from partial transformation of austenite into martensite. Strength levels of cold-worked stainless steels are covered by ASTM International's A666, *Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar*, and British Standard EN 10088-2, *Stainless Steels: Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes*.



Fig. 1 — Edward Gowan Budd. (Photo courtesy of the Hagley Museum and Library.)



Fig. 2 — The Burlington Zephyr train came into service in 1934. It was a forerunner in streamlined industrial design.

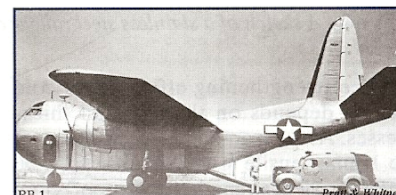


Fig. 3 — Only 20 of the RB-1 Conestoga cargo planes were produced. (Photo courtesy of Wikipedia.)

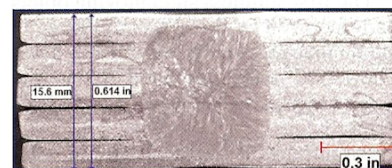


Fig. 4 — A spot weld in a thick assembly, totaling 15.6 mm, is shown. (Photo courtesy of Bombardier.)

Main stainless steel carbody materials

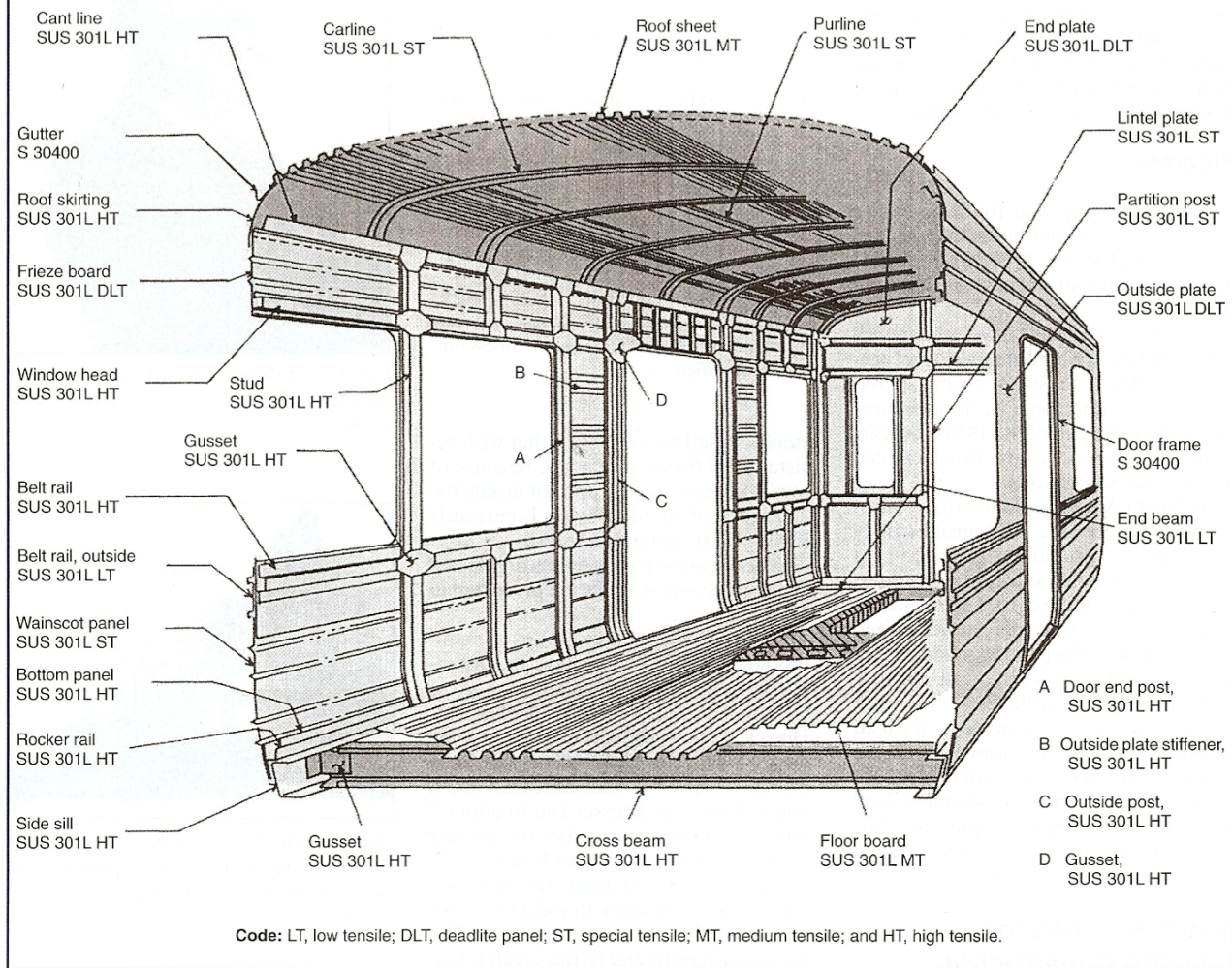


Fig. 5 — A sketch of a stainless steel railcar detailing its key components. (Photo courtesy of the Nickel Institute.)

The strengthening efficiency of cold rolling depends on the material thicknesses. As an example, in thicknesses up to 1 mm, tensile strength close to 1300 MPa and yield strength (0.2% proof) close to 1000 MPa may be achieved. For 5-mm-thick materials, the achievable values are 1000 and 750 MPa, respectively. The high strength-to-weight ratio allows for considering cold-worked stainless steel as light-weight material.

The first stainless steel moving object manufactured by Budd was the Pioneer amphibious plane launched in 1931. It was followed 12 years later by the RB-1 Conestoga cargo plane, 20 of which were built — Fig. 3.

An important characteristic of cold-worked austenitic steels is the absence of yield point in tensile deformation. In design, 0.2% proof stress is typically used as the reference value.

Technological Properties

Austenitic stainless steels can be bent with ease. Even in the cold-worked condition, material may be safely bent with a radius equal to twice its thickness.

Formability of austenitic steels is strongly dependent on the initial condition of the material. Annealed material can be formed without difficulty, while the forming potential of cold-worked materials is limited. If material is to be formed, its final properties resulting from deformation may be considered for design.

Physical Properties

Three properties of austenitic steels are important for resistance welding — electrical resistivity, thermal conductivity, and coefficient of thermal expansion. In comparison with the properties for car-

bon steels, austenitic steels have a resistivity five times higher, thermal conductivity three times lower, and coefficient of thermal expansion one-third higher.

Weldability

Austenitic stainless steels do not undergo the γ - α transformation, which ensures their good metallurgical weldability. A limited recrystallization occurs in the HAZ, leading to some softening. However, this has practically no consequence on the strength of resistance welds. The HAZ remains ductile in all cases. In either a peel or chisel test of spot welds, a well-defined button is always obtained.

High resistivity of austenitic steels allows for rapid obtaining and growth of the weld nugget. This is further enhanced by the low thermal conductivity, which lim-

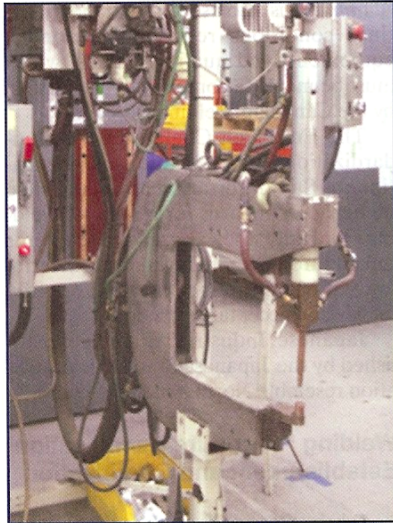


Fig. 6 — A large C-type gun. Welding guns should have a rigid structure, preferably made of a nonmagnetic material. (Photo courtesy of Bombardier.)

its heat sinking into surrounding material. As a result, relatively low amperages are required, and spot welding multiple part combinations of a large total thickness is possible — Fig. 4.

The high coefficient of thermal expansion results in a tendency to produce nugget shrinkage discontinuities as well as high residual stresses in welds and distortion of assemblies. To prevent both occurrences, high forging forces are applied.

Design

A typical car body is of monocoque design — Fig. 5. The sides and roof consist of cold-formed member frames to which skin is attached. The floor structure is composed of crossbeams, which are fixed to side sills. A center sill is rarely used.

The design strength of spot welds is defined in standards such as the AWS C1.1, *Recommended Practices for Resistance Welding*, and AWS D17.2, *Specification for Resistance Welding for Aerospace Applications*. Minimum distance between spot welds is limited by shunting current. The typical maximum center-to-center distance in North American practice is $50 \text{ mm} + 2d$, where d represents the nugget diameter. These design principles have ensured structural integrity of the cars through the decades. In addition, the strength of seam welds is comparable to that of base metal and is not a design consideration.

Fabrication

The external surfaces of stainless steel car bodies should be scratch free and flat. No thermal straightening, such as that used in the fabrication of carbon-steel

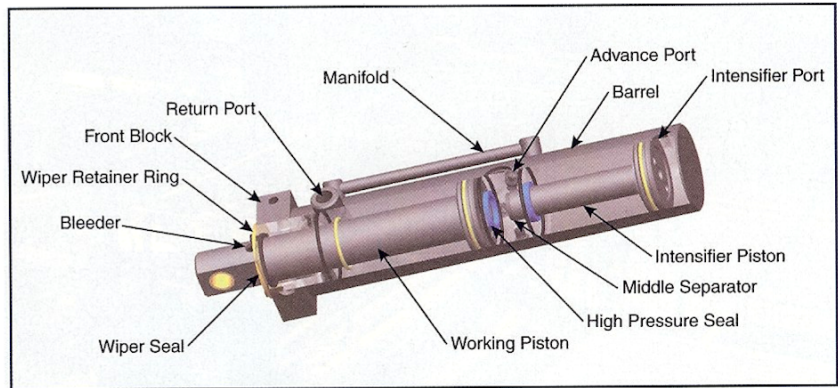


Fig. 7 — An air-over-oil intensifier cylinder is shown. (Photo courtesy of CenterLine Windsor.)

cars, is possible, and restoration of the original finish is difficult. Also, spot weld indentations should be shallow and defect free, and no discoloration on visible surfaces is permitted. The answer to these challenges is the use of protective plastic foil, which is removed just before welding; appropriate welding schedules and sequences; and the use of shielding gas. Contact surfaces of electrodes should be maintained in a perfect state, and the schedules of electrode dressing and replacement should be rigorously respected.

Equipment

General Requirements

Resistance welding equipment should have the following characteristics:

- Large length and width coverage
- High forces up to 20 kN (4500 lbf)
- Moderate amperages with an order maximum of 15 kA for spot welds and 30 kA for seam welds
- High reliability.

A description of the particular equipment elements follows.

Stationary Machines and Mobile Guns

Stationary machines and C-type mobile welding guns should have rigid structures — Fig. 6. Rectilinear movement of electrodes is preferable to rotational movement. For gun structures, nonmagnetic stainless steel is the material of choice.

Cylinders

Cylinders should ensure rapid advance movement, high forces, and soft contact with welded assembly. They should also have a limited size. Hydraulic and pneumatic cylinders only partially meet these

requirements. An optimal solution is represented by a cylinder using both media with an internal intensifier. The device makes a quick “soft touch” approach using compressed air. Upon the contact between electrodes and the assembly, the air pressure is converted into a high hydraulic force — Fig. 7. Electric servo-guns represent an interesting application potential, especially when their squeezing force reaches the required level.

Electrodes

Resistance Welding Manufacturing Alliance (RWMA) Class 3 electrodes are used. This class primarily includes UNS C17510 beryllium copper and UNS C18000 nickel-silicon copper, the latter commonly referred to as beryllium-free Class 3. Beryllium copper provides remarkable performance; however, use of this alloy for electrodes has become complicated because of restrictions related to beryllium toxicity. As a result, C18000 is now the preferred alloy for electrodes. A spherical contact surface of a 75 mm (3 in.) radius, recommended by the AWS C1.1 standard, represents an optimal shape. Large electrode diameters around 20 mm (0.750 or 0.875 in.) are preferred.

Gun Positioning

Guns for welding large structures are displaced by gantry systems, the level of mechanization of which varies from manual to fully automatic. In manual mode, spot welds are positioned with the help of templates.

The opposite side of the spectrum is represented by robotic gantry systems, which are typically used for welding side and roof frames. For better flexibility, the welding head is equipped with a gun exchanger.

Welding the roof and side skins to their structures represents a special challenge.



Fig. 8 — Specialized gantry machines with separate but synchronized mechanical systems for top and bottom electrodes are the solution for welding roof and side skin to their structures. (Photo courtesy of Bombardier.)

Up to a certain width, mobile C-type guns may be used. In some cases, guns may be introduced through window and door openings. However, this solution is laborious, and not always possible. In the case of roofs, the situation is further complicated by their curvature. A possible solution consists of using specialized gantry machines with separate but synchronized mechanical systems for top and bottom electrodes — Fig. 8.

Power Sources

All kinds of systems may be used to provide welding current. For large spot welding machines, direct current is the preferred logical choice. As in the whole resistance welding industry, medium frequency inverters have made their entrance.

Seam Welding Machines

Seam welding is used to assemble the roof and sometimes the side skin panels. The considerable size of both assemblies requires large installations. Fixed-machine stations have a length that is twice that of a railcar. This is not the case of stations using mobile machines. However, while sparing a lot of floor surface, this solution represents considerable challenges, not least of which is the accurate movement of heavy cantilevered equipment. Weld discoloration is prevented or limited by water jets from the top and bottom sides. The current used is direct with polarity changing from one pulsation to another.

Resistance Welding Controls

Because of the required quality of the welds, as well as of the multitude and complexity of schedules, the most advanced resistance welding controls are sought. Monitoring capability of the controls is used for a signature verification of each weld.

Quality

General Requirements

The requirements for weld integrity and appearance necessitate stringent weld quality criteria. There can be no nugget expulsion. Indentation must be shallow and uniform. Discoloration at surfaces exposed to users is not permitted. There are precise limits of nugget strength, diameter, penetration, and discontinuities.

Standards

The two basic standards used in North America are AWS D17.2, *Specification for Resistance Welding for Aerospace Applications*, which replaced the military specification MIL-W-6858D, *Welding, Resistance: Spot and Seam*, and AWS C1.1, *Recommended Practices for Resistance Welding*. AWS C1.1 covers a larger range of thicknesses, while AWS D17.2 has requirements for multiple thicknesses.

In Canada, the Canadian Standards Association's W55.3, *Certification of Companies for Resistance Welding of Steel and*

Aluminum, is also used. This standard defines conditions regarding personnel, equipment, and quality systems, which must be met by a company to be certified by the Canadian Welding Bureau.

The European Committee for Standardization and International Organization for Standardization have published numerous standards for resistance welding. Typically, they are short documents linked through cross references, describing test procedures, rather than specifying precise acceptance criteria.

Japanese Industrial Standards published by the Japanese Standards Association resemble North American codes.

Welding Procedure Specification Establishment and Qualification

Fabricating car bodies requires a large number of spot welded thickness combinations. Combinations may include three, four, and even five thicknesses of varying gauges. In large stations, dozens of different combinations must be welded, and their number is by far larger than that of available schedules. This represents a challenge for resistance welding technicians. Another difficulty is a need to verify the shear strength qualification assemblies totalling up to four faying surfaces.

Production Control

Every weld is important to the structural integrity of the car. Consequently, rigorous quality control is necessary during fabrication. Monitoring parameters combined with application of threshold values for essential variables allows for real-time verification of the process. On automatic equipment, position and signature records for each weld are used for traceability. Also, frequent testing is performed on samples, namely chisel tests and periodic verification of weld characteristics, which were determined in procedure qualification. The equipment operators' involvement and constant vigilance represent equally important factors in ensuring quality of production welds.

Conclusion

In the fabrication of stainless steel rail cars, resistance welding ensures high-productivity, structural integrity, and aesthetic quality, while taking advantage of the characteristics for austenitic steels.

More than 75 years after introducing resistance welding in passenger railcar fabrication, the legacy of Edward G. Budd and his companions is still alive and well. ♦

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