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Cold-worked austenitic stainless steels in passenger railcars and in other applications

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ABSTRACT

The structural applications of cold-worked austenitic stainless steels are reviewed in a historical perspective, with an emphasis on passenger railcars. The base materials are described, including their mechanical and technological properties. Some notions of car body design are presented, together with the challenges related to design practices involving the discussed materials. The fabrication processes are described. Information on resistance and arc welding processes is provided, including their specific aspects concerning the discussed materials, a description of the equipment, procedures qualification, reference standards, and production control. Challenges relative to the wider application of cold-worked austenitic stainless steels are discussed.

1. Introduction

Cold-worked austenitic stainless steels (CWASS) represent a remarkable structural material. They possess a unique assembly of advantages, namely high to ultra-high strength, high ductility, ease of metalworking and welding operations, and corrosion resistance.

The first CWASS structures were railway passenger cars made in the mid 1930s. It was a beginning of a great success story which continues to this day. CWASS also found applications in areas such as tubular structures, road transportation (buses, trailers, and tank cars), lightning (masts and poles), storage tanks, and others.

The first part of this paper is devoted to passenger railcars. Other applications are discussed in the second part of the paper. The last part is devoted to the challenges and opportunities relative to CWASS applications.

The overall goal of this paper is to increase awareness of CWASS properties and their advantages among the scientific community, and, first of all, among potential users. To this effect, the successful application of CWASS in passenger railcars should act as an encouragement for its successful extension to other areas.

2. Passenger railcars

2.1. History

2.1.1. Beginning

The beginning of stainless steel application in passenger railcar fabrication represents a fascinating feat of engineering. It is linked to the creativity and vision of Edward Gowan Budd (1870–1946), founder of the Edward G. Budd Manufacturing Company of Philadelphia, Pennsylvania. His company was the first to produce all-steel automobile bodies and all-steel wheels made out of sheet, as well as one of the first to use resistance spot welding (Fig. 1).

During his visit to Europe in 1930, Edward Budd became fascinated with stainless steel. At the same time, Ralph Budd, president of Burlington Railway, had the idea of applying stainless steel in railway car design and fabrication. Two important developments made this possible: the mastery of production of 18-8 cold-worked high strength austenitic stainless steel by the US mills and the growing experience and competence of the Budd Co. regarding formability and resistance spot welding of the material. As a final result, a new kind of passenger rail vehicle was created and put into service in 1934. This was the birth of the Zephyr trains (Fig. 2), which represented a major paradigm shift in passenger railcar design. In comparison with existing railcars, the weight of the train was significantly reduced, which in turn made possible the very first application of a diesel–electric propulsion unit. In a display of its speed, the first Zephyr made a 1632 km non-stop drive from Denver to Chicago at the record average of 125 km per hour [1,2]. The sleek silvery train was one of the forerunners of the “Streamline” tendency in industrial design. The Zephyr trains changed railway travel, due to their speed, comfort, and amenities such as careful interior design, air conditioning, and an audio system broadcasting radio, public addresses and music from wire recorders.

2.1.2. Progress

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

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Fig. 1. Edward Gowan Budd (courtesy of Hagley Museum & Library)..

Fig. 2. Burlington Zephyr (courtesy of Burlington Route Historical Society).

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

In North America, Bombardier Transportation has been fabricating stainless steel cars since the beginning of the 1980s in its plants in La Pocatière, Québec, Canada, and in Plattsburgh, NY, USA. These cars include shuttle cars for the Eurotunnel, the largest railcars of any kind ever produced (Fig. 3). Some Japanese companies also produce stainless steel cars at satellite plants in the United States.

In Australia there are over 2000 stainless steel cars in service. They represent above 80% of all passenger cars in the continent.

In Europe, for reasons which are associated with a traditional requirement for car bodies to be entirely painted, stainless steel cars gained only limited popularity. A notable exception was the X2000 Swedish train, made in the 1990s. The important DOLTRAC project [3] and the INSAPTRANS dissemination initiative [4] on CWASS application in passenger railcars were also undertaken by the European stainless steel producers and research organisations.

2.2. Materials

2.2.1. Chemistry

The first stainless steel railcars were made from an austenitic “18-8” alloy with a chemical composition close to 301 (1.4310) steel [2]. Relatively high carbon content made this steel susceptible to chromium carbide precipitation in heat-affected zones (HAZ) of welds, and to subsequent intergranular corrosion. The need to limit dwell time in the critical temperature range led Budd's experts to invent the 'Shotweld' short-time spot welding process [2,5].

In the 1950s and 1960s, 201 and 202 Cr–Mn–Ni steels were also applied. Since the late 1970s, argon–oxygen decarburization has allowed the fabrication of low-carbon stainless steels containing less than 0.03% C. This carbon level prevents chromium carbide precipitation in the HAZ of welds.

A significant nickel price increase in the beginning of the 21st Century has favoured a comeback of the Cr–Mn–Ni steels [6].

The chemical compositions of the CWASS most used in passenger railcars fabrication are shown in Table 1. The reference used for the 18-8 alloy is a paper published in 1940 [7]. Chemistry of other grades is defined in ASTM A 666 *Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar* [8] and in EN 10088-4 *Stainless steels. Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for construction purposes.* [9]. All these steels have a relatively limited content of alloying elements, which has a double beneficial effect on response to cold working of the materials and on their price. Grades currently most applied in railcars are 301 L/LN and 201 L/LN, close respectively to 1.4318 and 1.4371.

With regard to other groups of stainless steels, duplex (austenitic–ferritic) steels have potential for application, especially because of their high strength in larger thicknesses. However, where larger thicknesses are required in the car body structures, high-strength low-alloy (HSLA) steels with yield strength up to 700 MPa are commonly used.

2.2.2. Mechanical properties

Stainless steel car bodies are produced almost exclusively from CWASS. Their strength levels are defined in ASTM A 666 [8], see Table 2, and in EN 10088-4 [9], see Table 3. According to [9], the process route describing CWASS is designated 2H.

The strengthening potential of cold rolling depends on the material thickness. As an example, in thicknesses up to 1 mm, tensile strength close to 1300 MPa and 0.2% proof strength close to 1000 MPa may be achieved. For 5 mm thick materials, the achievable values are respectively 1000 MPa and 750 MPa. The very high strength-to-weight ratio allows for considering cold-worked stainless steel as a lightweight material. Actually, the first stainless steel moving object manufactured by the Budd Co. was the Pioneer amphibious plane, first flown in 1932 [2]. It was followed 11 years later by the Conestoga cargo plane, 25 of which were built [2] (Fig. 4).

Mechanical properties of CWASS differ to some extent as a function of direction. There is also an asymmetry in tensile and compressive 0.2% proof strength, especially in the longitudinal direction. For this case, The Euro Inox Design Manual for Structural Stainless Steel [10], in accordance with [11], specifies the compression/tension 0.2% proof strength ratio equal to 0.8. Higher values for 0.2% proof strength in compression, especially for profiles, may be established by testing (in transverse direction, the compression/tension 0.2% proof strength ratio is greater than 1).

2.2.3. Physical properties

Three physical properties of austenitic steels are important for their welded fabrication: electric resistivity, thermal conductivity and coefficient of thermal expansion. In comparison with carbon steels, austenitic steels have their resistivity three and half times higher, thermal conductivity three times lower, and coefficient of thermal expansion 40% higher. These properties are the same for annealed and cold-worked austenitic stainless steels.

2.2.4. Weldability

Austenitic stainless steels do not undergo the γ–α transformation, which ensures their excellent metallurgical weldability in any resistance or fusion welding process. A limited recrystallisation