JMEPEG (2000) 9:669–677

Use of Stainless Steels in Bus Coach Structures

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(Submitted 12 October 1999; in revised form 10 August 1999)

This study focuses on weld integrity of stainless steels in bus coach applications. Safety aspects have been studied based on fracture mechanics and impact toughness testing. Fatigue resistance of welded rectangular hollow section (RHS) profiles was evaluated according to the Eurocode 3 (1992) fatigue standard. Corrosion resistance was studied by salt-spray chamber tests in a deicing salt atmosphere and by field testing for 3 years under an urban bus. The mechanical tests show that austenitic stainless steel EN 1.4310 (AISI 301) is a superior material, and a low-C 12% Cr alloyed stainless steel EN 1.4003 is also a competitive material in bus coach applications. According to the life cycle cost (LCC) calculations, stainless steels are competitive compared with carbon steels or aluminum.

Keywords AISI 301, AISI 430, corrosion, welding

1. Introduction

This paper deals with the results of the development work done for the bus coach frame shown in Fig. 1. The bus frame is made of stainless steel which forms a load-bearing detail of the structure. The coach frame is made by metal active gas (MAG) welding of welded rectangular hollow section (RHS) profiles. The selection of a material for bus coach structures is a complicated optimization problem between mechanical and corrosion properties required in the operation of the vehicle and manufacturing as well as their cost. The transportation business of today demands a longer lifetime and reliable service without interruptions. This requires more durable structures assembled from tough, corrosion-, fatigue-, and impact-resistant materials using reliable joining methods. At the same time, the manufacturing and operation costs of a bus have to be optimized.

Limited corrosion resistance is one of the main factors determining the lifetime of a bus. The corrosion resistance of steels is mainly influenced by their chromium content. The corrosion rate is markedly decreased by adding 12% or more chromium to steel. Twelve percent is the chromium content of the “low-alloyed” ferritic stainless steels. By increasing the chromium content up to 16 to 18%, the corrosion rate can still be significantly decreased. This chromium content is typical of the most usual austenitic EN 1.4301 (AISI 304, 18Cr-10Ni) and ferritic EN 1.4016 (AISI 430, 17Cr) stainless steels.

The mechanical properties of vehicle materials are another important factor when choosing materials for bus applications. The strength and toughness values of stainless steels are sufficient for most applications. From the impact toughness point of view, austenitic and ferritic stainless steels behave quite differently in impact loading (Fig. 2). Ferritic stainless steels traditionally have low toughness at low temperatures. The temperature at which the toughness drops is called the “ductile-to-brittle transition temperature” (DBTT). Ferrite grain growth or martensite formation caused by the thermal cycle of welding can

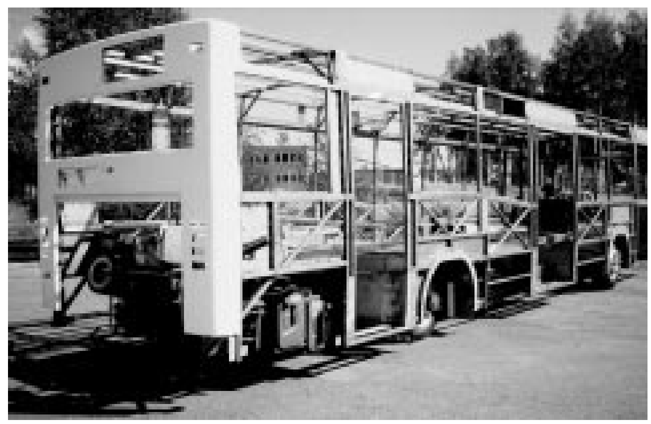

Fig. 1 Structure of the stainless steel bus frame

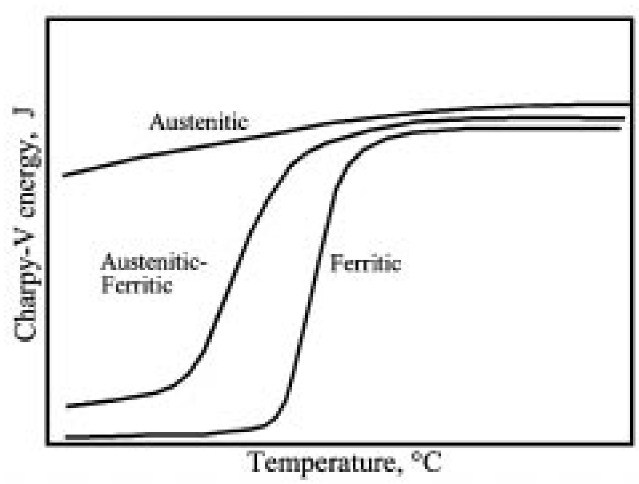

Fig. 2 Impact toughness behavior of various stainless steels (schematic)

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Table 1 Composition and mechanical properties of austenitic and ferritic stainless steels used in transportation vehicles

Steel EN	AISI	Polarit(a)	Type(b)	C (max)	Cr	Ni	Others	Strength (MPa) $R_{p0.2}$ (min)	R_m (min)	Elong. (%) A_5 (min)
	Composition (wt. %)									
1.4310	301	710	A	0.15	16–18	6–8	···	205	620	40
1.4301	304	725	A	0.08	18–20	8–10.5	···	205	515	40
1.4311	304LN	721	A	0.03	18–20	8–12	N: 0.10–0.16	240	550	40
1.4436	316	757	A	0.08	16–18	10–14	Mo: 2–3	205	515	40
1.4512	409	853(c)	F	0.08	10.5–11.75		max 0.50 Ti	205	380	20
1.4512	409_{mod}	854(c)	F-M	0.03	10.5–12	max 1.50	Ti, Mn max 1.5	280	460	20
1.4003	···	850(c)	F-M	0.03	10.5–12.5	0.3–1	···	320	450	20
1.4016	430	810(c)	F	0.12	16–18	max 0.75	···	205	450	22

(a) Polarit is a tradename for the steels of Outokumpu Polarit Oy

(b) A = austenitic, F = ferritic, and F-M = ferritic-martensitic (low carbon)

(c) Experimental Polarit steel

enhance embrittlement of ferritic stainless steels. In contrast, the impact toughness of austenitic stainless steels remains very high also at low temperatures and it is not dependent on, *e.g.*, grain size.

2. Steel Grades

There is a large selection of stainless steel grades with varying levels of corrosion resistance. Table 1 shows the most popular stainless steels used in the structures of transportation vehicles. Twelve percent chromium steels are an interesting possibility with low alloying costs and moderate corrosion resistance. The austenitic 18Cr-10Ni and 17Cr-7Ni steels have excellent corrosion resistance and toughness. The yield-strength values of traditional austenitic and ferritic stainless steels in annealed conditions are quite low ($R_{p0.2}$ = 205 MPa). For the ferritic-martensitic steel EN 1.4003, the yield-strength values are, however, considerably higher, usually a minimum of 320 MPa. The strength level of austenitic stainless steels can be increased by alloying with nitrogen (EN 1.4311, AISI 304LN). Austenitic stainless steels can also be used in cold-worked conditions, which significantly increases their strength level and makes them more competitive as a construction material (Table 2).

3. Applications

Stainless steels are widely used in transportation vehicles in applications such as containers, exhaust tubes, and catalytic converters.[1,2,3] In load-carrying structural components of trains, stainless steels are widely used in Japan, the United States, and Europe.[4,5] In bus manufacturing, stainless steels are making their breakthrough.[6–10]

The use of stainless steels in bus manufacturing is based on their excellent corrosion properties. Longer lifetime with longer guarantee of corrosion protection is possible and this gives an economic benefit for bus end users. The economic benefits of using stainless steels in bus structures have also been shown by life cycle cost (LCC) calculations.[11]

Due to their excellent corrosion properties and toughness, the austenitic stainless steels especially have shown their benefits in case of accidents and crashes. To improve safety, the ECE rule 66, which includes a full-scale roll-over test of a bus frame, will be required in the near future in Europe. Stainless steels are expected to be safe materials in this test when properly designed and manufactured.

Stainless steels are nearly 100% recycled. This fact, along with the longer lifetime of the stainless steel products, permits

Table 2 Cold-worked austenitic stainless steels, ASTM designation: A 666 - 88

Strength	Steel grade AISI	Strength $R_{p0.2}$ (N/mm^2)	R_m (N/mm^2)	Elongation A_5 (%)
1/16-Hard	301	310	620	40
	304	310	550	35
	304LN	310	620	40
	316	310	686	35
1/8-Hard	301	380	690	40
	304	380	690	35
	304LN	380	690	33
	316	380	690	30
1/4-Hard	301	515	860	25
	304	515	860	12
	304LN	515	860	12
	316	515	860	8
1/2-Hard	301	760	1035	18
	304	760	1035	7
	304LN	760	1035	7
	316	760	1035	7
3/4-Hard	301	930	1205	12
Full-hard	301	965	1275	9

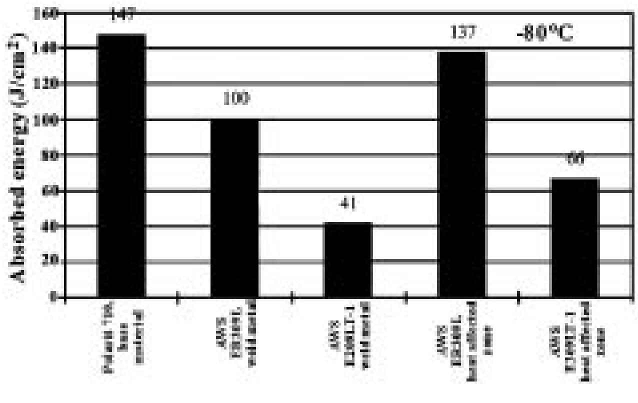


Fig. 3 Impact toughness values of EN 1.4310 (AISI 301, Polarit 710) GMA, and FCA welds at −80 °C. KLST specimens (3 × 3 × 27 mm) (Polarit is a trademark of Outokumpu Polarit Oy)[23]

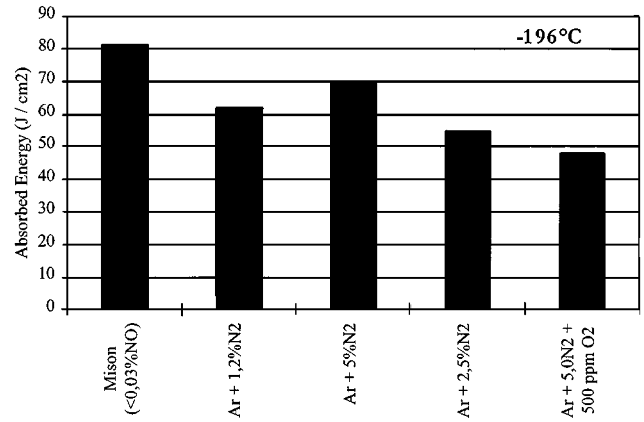


Fig. 4 Charpy-V impact toughness of EN 1.4310 (AISI 301) GTA welds welded with different shielding gas nitrogen contents. Specimen size 5 × 10 × 55 mm[23]

Table 3 Transition temperatures (°C) for the HAZ of three different 12% Cr steels (GMA welding, heat input 6.5 kJ/cm).[19]

Steel	Charpy-V T_{28J}	K_{Jc} $T_{100MPa/m}$
EN 1.4003	−45	−87
EN 1.4512 (AISI 409)	+50	+89
AISI 409_{mod}	+70	+71

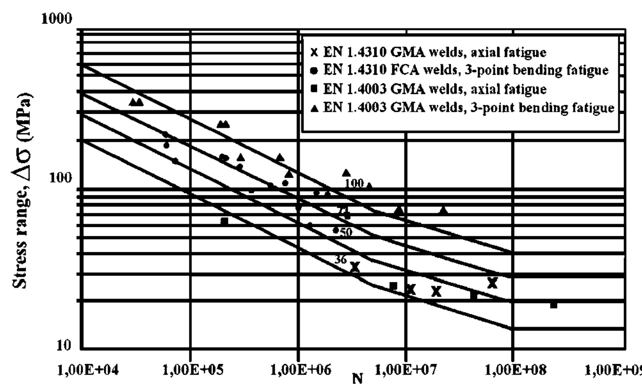


Fig. 5 Fatigue strength values of austenitic EN 1.4310 (AISI 301) and ferritic-martensitic EN 1.4003 stainless steel RHS beam welded joints in axial and three-point bending fatigue loading. Stress ratio in both cases is 0.1. Stresses are calculated for the cross-sectional area of the fracture surface. Lines (36/50/71/100) correspond to Eurocode 3[21]

stainless steel to be used in bus manufacturing also according to life cycle assessment analysis (LCA), to be called a material of sustainable development.[11]

Different stainless steel grades have been used for coach frames, side panels, mudguards, floor structures, and even for the load-carrying chassis structures in bus manufacturing. The excellent corrosion properties of stainless steels have been the main criterion of the materials' selection. Traditional austenitic (EN 1.4301, AISI 304 and EN 1.4310, AISI 301) and ferritic (EN 1.4016, AISI 430) steels have been used for bus applications. During the last few years "12% Cr-steels," such as EN 1.4003 type steel, have increasingly been used in bus coach structures.[12,13] The RHS-tubes are typically used in non-heat-treated conditions and the sheet material is heat treated. However, additional strength caused by cold forming is not systematically taken into account in the design. The other major competitive materials in bus manufacturing are aluminum alloys, plastics, and composites.

The design and manufacturing methods of steel structures of buses are traditional.[14] However, differentiation in the use of the buses (*e.g.*, city bus, tourist bus, *etc.*) is providing a market for new design concepts.[15] In this connection, new materials have also presented advantages in bus manufacturing and end use.[16] New demands for passenger safety and environmental emissions have an additional influence on the design concepts and, thus, the materials to be used.

4. Experimental

4.1 Materials

In the present investigation, 12% Cr alloyed ferritic/martensitic and 17% Cr-7% Ni alloyed austenitic stainless steels were studied. These steels are typically used in the transportation industry. The 12% Cr steels were of type EN 1.4003, EN 1.4512 (AISI 409), and AISI 409_{mod}. The EN 1.4512 and AISI 409_{mod} steels were used as reference materials. The austenitic stainless steel was of type EN 1.4310 (AISI 301). Both steel plates and RHS beams were investigated. The compositions of the steels and their mechanical properties are given in Table 1.

4.2 Fatigue

Fatigue strength was studied with a detail chosen from Eurocode 3 (1992). This consists of RHS beams, which are fillet welded to an intermittent plate between the beams. The fatigue tests were performed as axial and three-point bending tests with

Table 4 Effect of finishing, temperature, and time on the corrosion in salt-spray chamber test

(a) Welded rectangular tube T-samples, temperature 23 °C

		5 h		5 + 48 h	
Sample	**Finishing**	**w**	**bm**	**w**	**bm**
EN 1.4003	W	5	2	5	3
	G	2	1	3	3
	G + P	1	1	2	2
AISI 301	W	3	1	4	1
	G	1	0	2	1
	G + P	1	0	1	1

(b) Welded rectangular tube T-samples, temperature 45 °C

		5 h		5 + 48 h	
Sample	**Finishing**	**w**	**bm**	**w**	**bm**
EN 1.4003	W	5	4	5	5
	G	2	3	4	4
	G + P	1	2	3	4
AISI 301	W	3	1	5	2
	G	2	1	3	2
	G + P	1	1	2	1

(c) Welded plate samples, temperature 23 °C

		5 h		5 + 48 h	
Sample	**Finishing**	**w**	**bm**	**w**	**bm**
EN 1.4003/1, 3 mm	W	4	2	5	3
	G	2	2	2	2
	G + P	1	1	2	2
EN 1.4003/2, 3 mm	W	5	2	5	3
	G	2	2	2	2
	G + P	1	1	1	2
EN 1.4003, 6 mm	W	4	2	4	2
	G	2	1	3	1
	G + P	1	1	2	2
AISI 301, 3.1 mm	W	3	1	5	1
	G	1	1	1	1
	G + P	0	0	0	0
AISI 301, 6.5 mm	W	3	1	4	1
	G	2	0	2	0
	G + P	0	0	0	0

(d) Welded plate samples, temperature 45 °C

		5 h		5 + 48 h	
Sample	**Finishing**	**w**	**bm**	**w**	**bm**
EN 1.4003/1, 3 mm	W	4	3	5	5
	G	3	4	4	5
	G + P	2	4	3	5
EN 1.4003/2, 3 mm	W	5	4	5	5
	G	3	3	4	5
	G + P	2	5	3	5
EN 1.4003, 6 mm	W	4	3	4	4
	G	3	5	4	5
	G + P	1	3	3	5
AISI 301, 3.1 mm	W	5	1	5	2
	G	1	2	3	3
	G + P	0	0	2	1
AISI 301, 6.5 mm	W	4	1	4	2
	G	2	1	3	2
	G + P	0	0	1	1

W = as welded, G = ground, P = pickled, w = weld, and bm = base metal

a stress ratio of $R = 0.1$ in both cases. Eurocode 3 gives a classification of FAT class 36 for the studied detail. This means that the fatigue life of such a detail in constant amplitude loading in a stress range of 36 MPa is 2 million cycles. One objective of the study was to determine nominal stress range *S-N* curves for welded materials and to see their compatibility with the design curves of Eurocode 3.

4.3 Toughness

The toughness properties of the test joints were studied with Charpy-V subsize (5 × 10 × 55 mm) impact and fracture mechanics tests. From the Charpy-V tests, the DBTT's for the heat-affected zone (HAZ) were determined. The fracture toughness (K_{Jc}) values and the transition temperatures (T_0) were calculated from the measured J-values (ESIS P2-92)[17] according to ASTM standard E1921-97.[18] The values were size corrected to correspond to the specimen thickness of 25 mm and evaluated by using a statistical model. The T_0 defined by K_{Jc} = 100 MPa/m was used for comparison of the different steels.

4.4 Corrosion

The corrosion properties of sheets and welded rectangular tubes were studied with salt-spray chamber and actual field tests. In the salt-spray chamber tests, the corrosive environment was created by spraying intermittently 5% $CaCl_2$ solution into the test chamber. The test temperature was +20 and +45 °C and the time was 5 and 53 h (=5 + 48 h). The solution simulated conditions caused by deicing salt on the road. In the evaluation of the tested samples, the following classification criteria were used:

Class	Criterion
0	No coloring or pitting
1	Occasional coloring or pitting
2	5% of the area colored or pitted
3	5–25% of the area colored or pitted
4	25–75% of the area colored or pitted
5	75–100% of the area colored or pitted

The operating tests were carried out using a test frame attached under an urban bus. The tests started in autumn 1994, and have been running since then. By the inspection in 1998, the total test endurance was 372,000 km. Visual inspection and weight-loss measurements of welded samples were used.

5. Results

5.1 Joint Toughness

5.1.1 Ferritic Stainless Steels. The results of both Charpy-V impact and fracture toughness tests showed clearly that the DBTT of HAZ depends strongly on steel composition and HAZ microstructure.[19] The EN 1.4003 steel, having lath-martensitic microstructure in the HAZ, showed very low transition temperature (Table 3). Titanium addition of EN 1.4512 (AISI 409) and AISI 409_{mod} steels was found to have a negative effect on the toughness values. Titanium-containing particles, which had initiated brittle fracture, were found on the fracture surfaces of

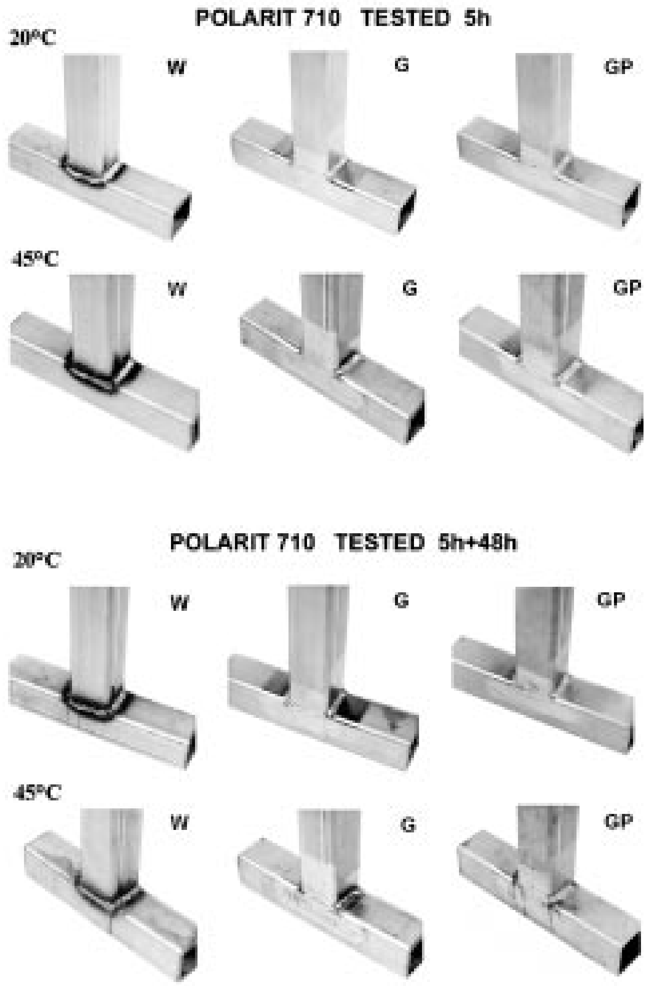


Fig. 6 Appearance of the steel EN 1.4310 (AISI 301, Polarit 710, and RHS profiles 40 × 40 × 2.5 mm) after salt-spray test

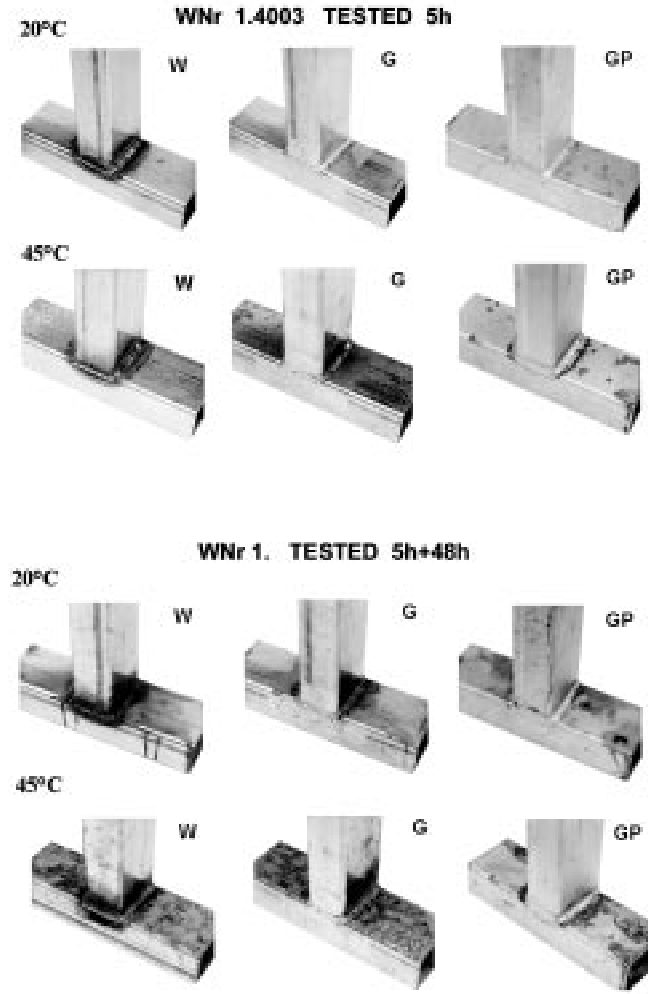


Fig. 7 Appearance of the steel EN 1.4003 (RHS profiles 40 × 60 × 2 mm) after salt-spray test

these reference steels. The fracture mechanics test results showed a reasonably good agreement with the probability curves developed by Wallin[20] based on a statistical analysis for ferritic steels (Table 3).

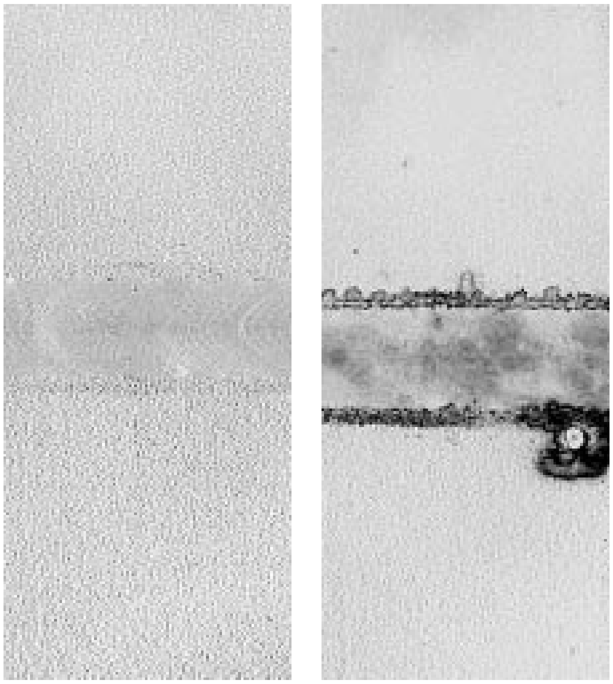
The weld metals deposited by austenitic consumable of type AWS E309 showed excellent impact toughness values in the test temperature range used for HAZ.

5.1.2 Austenitic Stainless Steels. The impact toughness properties of work-hardened austenitic stainless steel welds using austenitic consumables were measured with KLST specimens for the weld metal and the HAZ (Fig. 3). It can be clearly seen that, with both consumables used, good impact toughness is still obtained at a low temperature of −80 °C. The flux cored arc (FCA) wire AWS 309L T-1 results in lower toughness values than the solid wires, which most probably is due to a higher oxygen content of the FCA weld metal. Autogeneous gas tungsten arc (GTA) welds with nitrogen addition through shielding gas had excellent toughness values still at low liquid nitrogen temperature (−196 °C) (Fig. 4).

5.2 Fatigue

Both axial and three-point bending fatigue tests for welded RHS-beam joints yielded better results than expected based on the design curves of Eurocode 3. The requirement for fatigue class (FAT) class 36 was fulfilled in both loading cases and with both austenitic and ferritic-martensitic materials (Fig. 5).[21] Depending on the throat thickness and the geometry of the weld, fatigue crack initiated and grew either from the weld toe or from the weld root. As the throat thickness increased, cracking took place more constantly at the weld toe. In each case, the stress range was determined using the cross-sectional area of the fracture surface, which was determined either based on the weld gauge or was measured from the actual fracture surface.

Figure 5 shows that the fatigue strength tested in three-point bending is more favorable than that with axial loading. This arises from differences in loading characteristics. In three-point bending, maximum tensile stress is induced only to one side of the RHS beam opposite to the applied force. In axial loading, the whole weld cross section is under more or less uniform



(a) **(b)**

Fig. 8 Glass-particle-blasted samples (**a**) before and (**b**) after salt-spray corrosion test. Blasting was not able to remove the Cr-depleted zone under the thick oxide layer from the HAZ. In order to recover the corrosion resistance of the HAZ, pickling is recommended

tensile stress state, which increases the probability of fatigue crack initiation and growth at the weld root as was also noticed in the axial loading tests.

5.3 Corrosion Resistance

5.3.1 Salt Spray Chamber Tests. Differences in the corrosion resistance of the studied steel grades were mainly caused by the Cr content of the steel, finishing practice, and test temperature used, *i.e.*, 17% Cr austenitic EN 1.4310 (AISI 301) steel showed clearly better corrosion resistance compared to 12% Cr ferritic-martensitic EN 1.4003 steel in the entire temperature range studied (Table 4).[22] An increase in the test temperature from 20 to 45 °C significantly accelerated corrosion of EN 1.4003 steel. The 12% Cr steels cannot be considered to be corrosion resistant at 45 °C. Finishing increases corrosion resistance considerably. Figures 6 and 7 show the appearance of corrosion in the welded EN 1.4310 (AISI 301) and EN 1.4003 steel samples at different temperatures and times. Strong coloring happens on the steel EN 1.4003 surface at 45 °C.

A salt-spray chamber test was also found to be an effective method to reveal quickly the differences between various postweld surface treatments of stainless steel welds. A total of six different postweld surface treatments were studied and the following conclusions can be drawn from these test results.[23,24]

- **Brushing with stainless steel brush** alone is an insufficient method for corrosion protection of stainless steel welds.
- **Pickling added to brushing** improves corrosion resistance significantly.
- **Polymer wheel polishing** does not improve the corrosion resistance. Poor results were partially affected by the low rotation speed of the wheel and the fact that the wheel material was too soft.
- **Manual grinding with a silicon carbide grinding wheel** cannot be recommended as a postweld surface treatment. Grinding leaves the weld surface very rough, which helps initiation of corrosion.
- **Shot peening with glass particles** gives a good-looking surface, but it does not improve the corrosion resistance markedly.
- **Pickling added to shot peening** results in nearly matching corrosion properties as compared to those of the base material.

In Figure 8 is an example of the effect of pickling on the coloring behavior of the weld-fusion line.

5.3.2 Field Tests. The test rig used in the field test is shown in Fig. 9. The samples were surveyed annually, about 100,000 km between each control. Of the samples attached to the operation test rig, the welded joints of austenitic EN 1.4310 (AISI 301) steel were in the best condition after testing of 372,000 km (Fig. 10). In postweld pickled condition, practically no indications of corrosion were observed on these samples. The 12% Cr EN 1.4003 steel samples exhibited some corrosion on the welded joints, and the structural steel (S355) samples were totally corroded. Weight losses after two years exposure were nonexistent for stainless steel grades, but the structural steel samples have, as expected, started to loose their weight (Fig. 10).

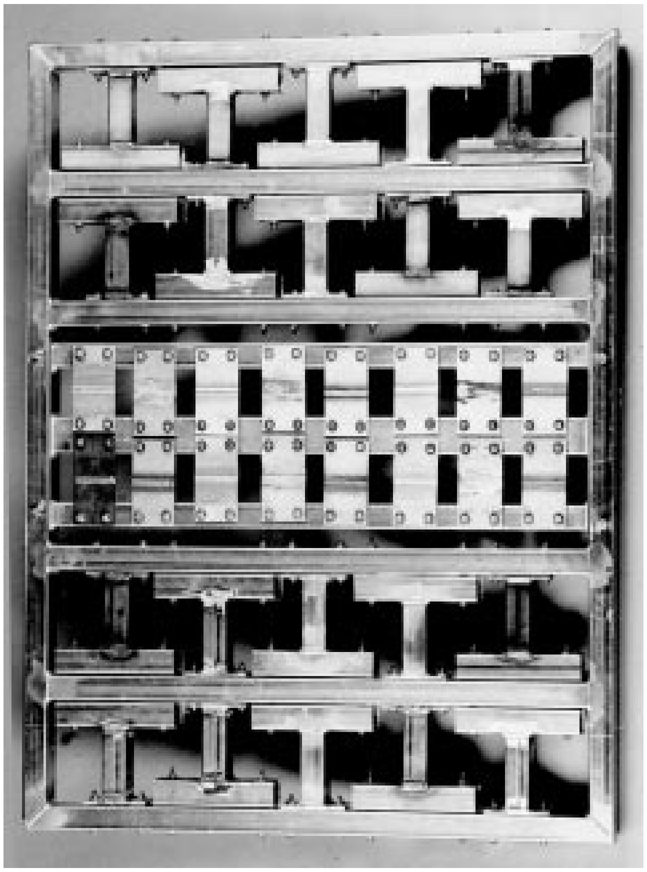
5.4 LCC/LCA

The LCC calculations have been made for stainless steel, carbon steel, and aluminum bus coach frames. The LCA was made for stainless steel and aluminum bus bodies.[11]

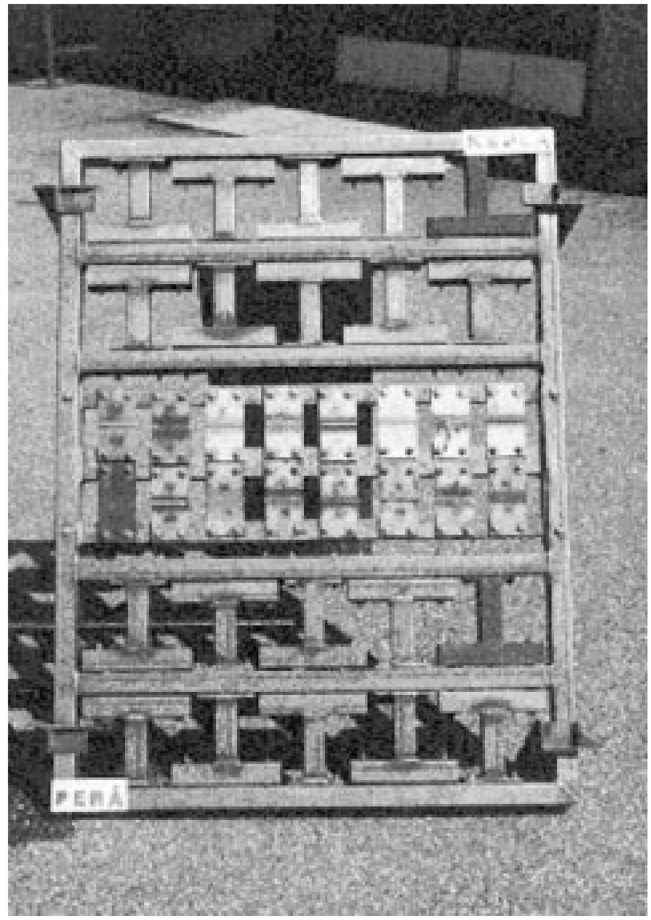
5.4.1 LCC, Stainless Steel-Carbon Steel. The construction of the stainless steel and carbon steel bus coach frame used in this calculation[11,25,26] is made of the RHS by welding, and it represents, therefore, a traditional solution. Comparison between stainless steel and carbon steel frames has been made by evaluating the differences of the costs in every phase of the life cycle. The results of these calculations are summarized in Table 5. These results show that the stainless steel frame has about 50% of the life cycle cost of the carbon steel frame during a 25 year life cycle.

5.4.2 LCC, Stainless Steel-Aluminum. The studied cases were modern city buses. The weights of the buses were as follows: stainless steel bus, 11,850 kg; and aluminum bus, 10,530 kg. However, the stainless steel bus body was slightly lighter than the aluminum body: the stainless steel body was 1144 kg and the aluminum body was 1213 kg. The passenger capacity of the buses was practically the same (stainless steel bus, 70 passengers; and aluminum bus, 74 passengers).

The LCC calculations for stainless steel and aluminum bus bodies are summarized in Table 5. It shows that the initial cost of the aluminum bus body is almost 80% higher than the initial cost of the stainless steel bus body. This is mainly due to the high prices of modern structural parts used in the aluminum buses (Table 5). The operating costs are lower for the aluminum



(a)



(b)

Fig. 9 The test rig (**a** and **b**) before start of the field test in autumn 1994 (continued on next page)

bus than for the stainless steel bus. In the total LCC calculation, however, stainless steel is a more favorable bus body material than aluminum.

5.4.3 LCA, Stainless Steel-Aluminum. The aim of this study was to compare environmental impacts of two bus bodies during the entire life cycle. Comparison is made with the LCA methods for the same buses as in the preceding LCC comparison. The life cycle of a bus consists of

- production of the materials for the bus body,
- manufacturing of the bus body, and
- operation of the bus body.

The first phase in the LCA of a bus was to classify technical details of bus body construction and manufacturing. Also, some data about the entire bus (weight, fuel consumption, *etc.*) are needed in the LCA.

The second phase is to evaluate ecobalances for the bus bodies. This consisted of ecobalance for materials used in the bus bodies and recycling of the bus bodies. In this study, the environmental impacts of the manufacturing of the bus body are considered to be negligible.

The third phase is to calculate total environmental impacts of the bus bodies. Weighting methods used in this study were effect category, environmental priority strategies 2.1 (EPS 2.1), Ecopoint, and SimaPro3.[26]

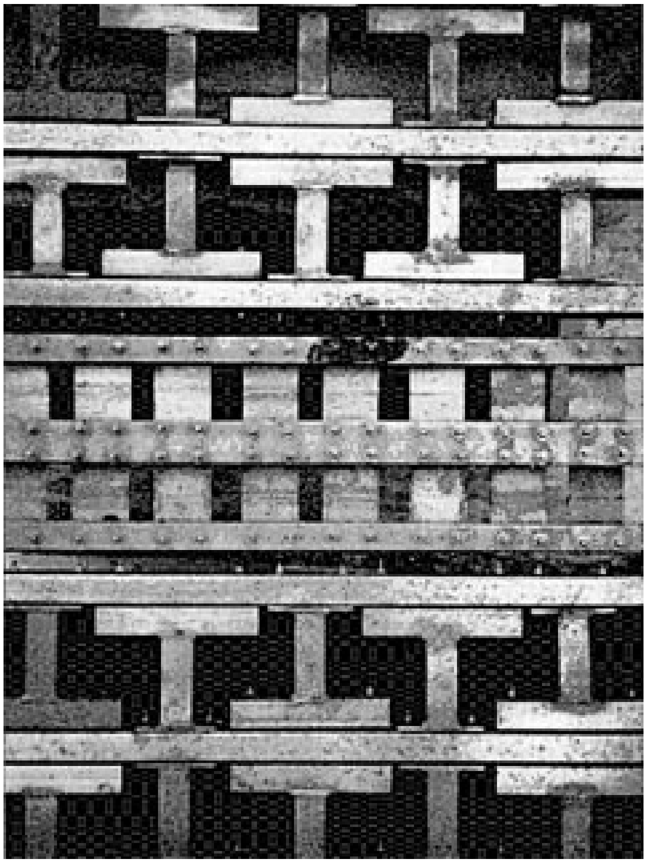
Figure 11 shows the final results of the LCA. Depending on the weighting method, large differences exist between the results. It is, however, noticeable that all the methods give better results for the stainless steel bus body than for the aluminum bus body. This difference is mainly due to the material's production phase, in which stainless steel has smaller environmental impacts than aluminum.[26]

6. Conclusions

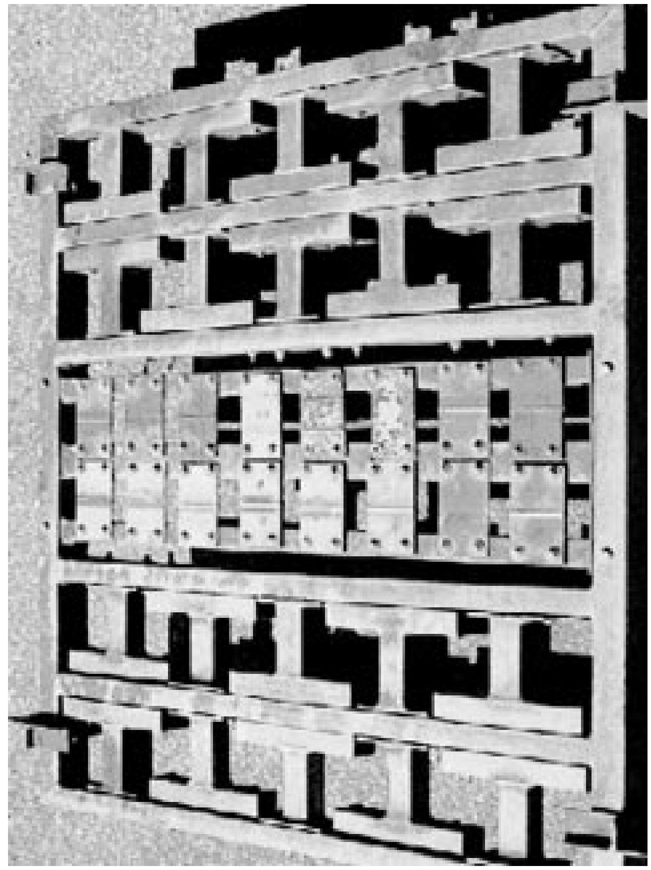
This study was concerned with the safety development of the bus frames based on three approaches:

- mechanical safety: strength, toughness, fatigue resistance;
- corrosion safety: lifetime; and
- environmental safety: LCA.

In addition to the traditional mechanical safety, the new safety concepts also take corrosion and environmental impacts and their costs into account.



(c)



(d)

Fig. 9 continued. (**c** and **d**) after the first test year (102,995 km)

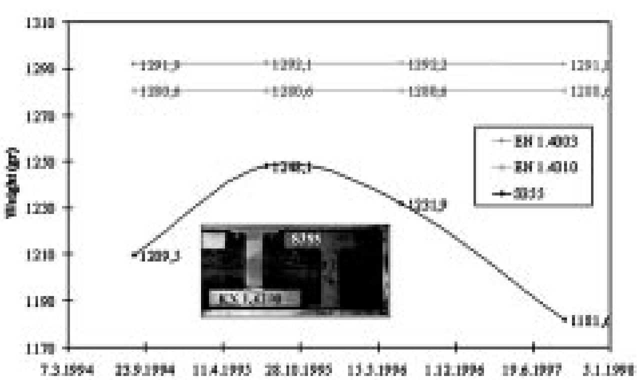


Fig. 10 Environmental loadings of the material's production and bus operation

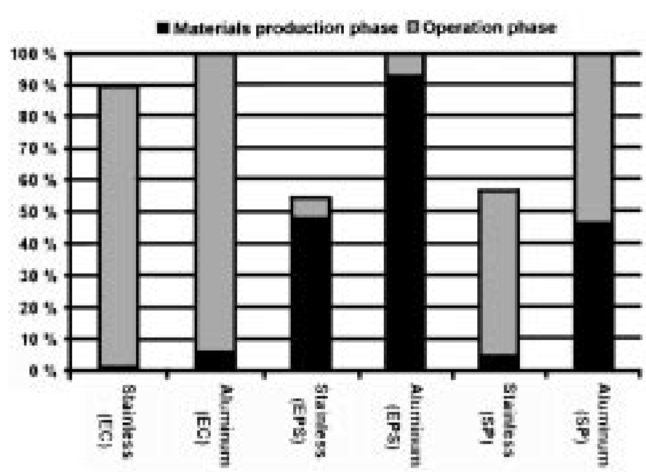


Fig. 11 Weight losses of as-welded field test samples of S355, EN 1.4310, and EN 1.4003 steels after 372,300 test kilometers under an urban bus in Helsinki city traffic

Impact toughness, fatigue, and corrosion tests show that austenitic stainless steel EN 1.4310 (AISI 301) is a superior material compared with the materials used traditionally for bus coach frames. The 12% Cr ferritic stainless steel EN 1.4003 is also competitive with other materials, such as carbon steel and aluminum in bus coach applications.

According to the LCC and LCA calculations, stainless steels are also competitive materials compared with carbon steel and aluminum as the bus coach material.

Table 5 LCC comparison of stainless steel and carbon steel bus coach frames[25]

LCC summary for a bus frame (Finnmarks, present value)		
Cost of capital (n)	9%	
Inflation rate (q)	3%	
Real interest rate (r)	5.83% [$r = (n - q)/(1 + q)$]	
Desired life cycle duration	25 years	
	Carbon steel	Stainless steel
Material costs	Fe 52	AISI 304/ 316
Bar, weight 1482/1182 kg	5187	20,094/ 28,368
or		
Bar, weight 1482/1042 kg	5187	17,714/ 25,008
Consumables	180	3510/6312
Shielding gas	434	1076
Fabrication and inspection costs	Same	Same
Surface protection costs	5700	…
Total initial costs		
Weight 1182 kg, consumable 16.32	11,501	24,680/32,954
Weight 1042 kg, consumable 16.32	11,501	22,300/29,594
(16.32 = AISI 316)		
Operating maintenance costs	Present value	
Difference in operating costs in 25 years	38,215(a)	…
	57,323(b)	…
Maintenance costs	…	…
Residual value of material	…	…
Total LCC costs		
Weight 1182 kg, consumable 16.32	49,716	24,680/ 32,954
Weight 1042 kg, consumable 16.32	68,824	22,300/ 29,594

(a) In one year: 2940, if the weight of stainless steel is 1182 kg (2% × 3.50 × 35 × 1200) × 4410, if the weight of stainless steel is 1042 kg (3% × 3.50 × 35 × 1200)

(b) The difference in fuel consumption 25 × the price of fuel 3.50 mk/L × the fuel consumption about 35 L/100 km × the total driven distance per year 120,000 km

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