THE USE OF STAINLESS STEELS IN TRANSPORT VEHICLES

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PREFACE

The report summarises the results obtained in the Finnish contribution of the Internordic R&D project "Stainless for Transport" (Oct. 1994 - Sept. 1997) financed by the Nordic Industrial Fund (NI), Technology Development Centre of Finland (TEKES) and Finnish industry (see Appendix).

The Finnish subproject was performed in collaboration between VTT Manufacturing Technology and Laboratory of Engineering Materials at Helsinki University of Technology. The authors wish to express their gratitude to the all financing organisations and co-operation partners involved in the project.

Espoo, 30 October, 1997

Authors

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1 INTRODUCTION

The use of stainless steels has been constantly increasing as a construction material of transportation vehicles such as buses, trains and trucks. In these applications the use of stainless steels has led to advantages in terms of longer operating life while maintaining the load carrying capacity. As a result, the life cycle costs of vehicle structures can often be remarkably reduced with stainless steels.

Vehicle structures are manufactured and assembled mainly by welding. Quality assurance and especially matching the mechanical and corrosion properties of welds to those of base materials becomes important. Unsuitable welding procedures may easily lead to inadequate strength, toughness, and fatigue properties as well as corrosion resistance in the welded structures. Technical developments to overcome difficulties in joining are of great importance. The main objective is to optimise the application of stainless steel structures in the transport industry [1-4].

To support the use and to solve the welding problems of high strength stainless steels in the transport industry, a 4-year Inter-Nordic project "Stainless for Transport" was established in 1993 - 1997 under the NordList R&D programme "Resursbesparande lätta konstruktioner" of the Nordic Industrial Fund. The project was composed of a number of subprojects in Sweden, Norway and Finland. The final results of the Finnish contribution are summarised in the present report.

2 OBJECTIVES

The main objective of the Finnish subproject was to optimise the application of high strength stainless steels in the welded structures of road transportation vehicles. By performing welding tests and by evaluating the mechanical and corrosion properties of the joints, the project aimed at improving the quality and fabrication of load carrying, corrosion resistant vehicle structures. The potential economic and environmental benefits available by the use of stainless steels in vehicles were also evaluated by life cycle cost (LCC) and life cycle assessment (LCA) analyses.

To obtain the goals the project was divided into following six subtasks:

- Investigation of impact and fracture toughness properties of 12%Cr stainless steels.
- Evaluation of the fatigue properties of welded, rectangular hollow sections (RHS) used in vehicles.
- Measurement of metallurgical and mechanical behaviour of dissimilar joints between stainless steel frames and structural steel parts.
- Study of the effects of post-weld treatments on corrosion behaviour of stainless steel welds through laboratory tests and field tests.
- Life cycle cost (LCC) and life cycle assessment (LCA) analyses of bus frames.
- Evaluation of the applicability of stainless steels in vehicles through case studies.

3 EXPERIMENTAL PROCEDURE

3.1 Test materials and welding processes

The test materials were 12%Cr alloyed ferritic/martensitic and 17%Cr-7%Ni alloyed austenitic stainless steels which are typically applied in the transportation industry. The 12%Cr steels were of type EN 1.4003 (Polarit 850), AISI 409 (Polarit 853) and AISI 409mod (Polarit 854 corresponding to 3CR12). AISI 409 and AISI 409mod steels were used as reference materials. The austenitic stainless steel was of type AISI 301 LN (Polarit 710). Both steel plates and rectangular hollow section (RHS) beams were investigated. The analyses and mechanical properties of the steels are given in Table 1.

Table 1. Typical properties of the test materials.

Steel			Composition (wt.-%)				Mechanical properties		
AISI/DIN	Polarit	Type	C max	Cr	Ni	Other	$R_{p0.2}$ (MPa) min	R_m (MPa) min	A_5 (%) min
301	710	A	0.15	16-18	6-8	-	205	620	40
409	853	F	0.08	10.5-11.75	max 0.50	Ti	205	380	20
1.4003	850*	M	0.03	10.5-12.5	0.3-1.0	-	320	450	20
409mod (3Cr12)	854*	F-M	0.03	10.5-12.0	max 1.50	Ti	280	460	20

A = austenitic, F = ferritic, F-M = ferritic-martensitic, M = martensitic, * = development grade

The welding procedure tests were carried out with gas metal arc, flux cored wire and laser welding as specified in references [5-7]. Austenitic wires of type AWS 307 (18%Cr-8%Ni-7%Mn) and AWS 309L (24%Cr-13%Ni) were used as welding consumables. The welds were produced manually with nominal heat input ranging from 3.5 to 13 kJ/cm. The laser welds were performed without filler material using heat input of 3 kJ/cm.

3.2 Mechanical testing

The impact toughness of the HAZ, weld metal and base metal was determined using Charpy-V testing method. Due to the plate thickness of 6 mm, subsize specimens of size 5 × 10 × 55 mm were used according to the standard SFS-EN 10 045-1. The 12%Cr steels were tested over a temperature range from -100 to +150°C using three specimens per each test temperature. Ductile-to-brittle transition temperatures (DBTT) were determined from the results. The austenitic materials were tested only at -60°C. The fracture surfaces of the impact toughness specimens were examined with scanning electron microscope (SEM) and EDS-analyser. The procedures are described in more detail elsewhere [8-12].

The elastic-plastic fracture toughness of the coarse-grained HAZ's of the 12%Cr steels was determined for the GMAW joints welded with a low heat input, about 6.5 kJ/cm. The fracture toughness tests were carried out as three-point bending tests (CTOD) according to the standard BS 7448 with testing temperatures ranging from -110°C to +50°C [3-6]. The fracture toughness values (K_{JC}) were evaluated by measuring the J-integral values from the CTOD-tests. The K_{JC}-values were calculated from the J-values (ESIS P2-92) according to a

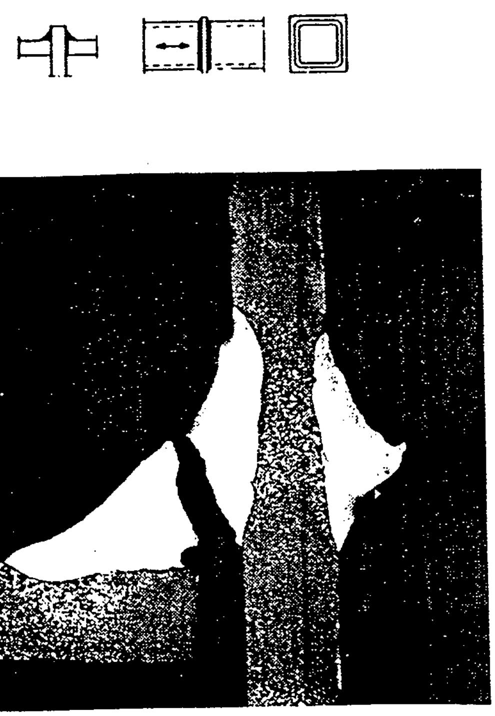
ASTM standard draft.[1] The values were size-corrected to correspond plate thickness of 25 mm using a statistical model proposed by Wallin (1985)[2]. The results were expressed as size-corrected fracture toughness values and as lowest allowable operating temperatures (T_0) using a fracture toughness criterion of 100 MPa$\sqrt{m}$.

The fatigue tests were carried out with a fillet welded RHS-beam detail described in Eurocode 3, see Fig. 1. The results were compared with the design curves of Eurocode 3, where the fatigue class of FAT 36, or design stress range of 36 MPa for $N = 2 \cdot 10^6$ cycles, is specified for the structural detail studied. The tests were carried out in constant amplitude loading with a stress ratio of $R = 0.1$ using axial and three-point bending loading modes. After testing the fracture surfaces were studied, e.g., to find the crack initiation sites. The testing procedure is described in more detail in references [13-17].

3.3 Properties of dissimilar joints

The microstructures and mechanical properties of dissimilar joints between the stainless steels and structural steel S355 were investigated with test welds shown in Table 2 and specified in reference [18]. The steels were welded with GMAW and FCAW processes using overalloyed, AWS 309 type consumables. The weld metal composition was varied by changing the filling sequence from two-pass to three-pass technique. The test welds were inspected by radiography and tested with tensile, bending and Charpy-V impact tests. In addition, the weld composition was analysed and compared to DeLong-, WRC- and Schaeffler-prediction diagrams.

a)



b)

Fig. 1. Structural details used in the fatigue tests of RHS beam joints (a) and a typical cross section of a RHS-joint after fatigue testing (b) (magnification 8x).

[1] ASTM standard draft: Determination of reference temperature To for ferritic steels in the transition temperature.

[2] Wallin et al. (1994). VTT Manufacturing Technology, Report VALB-21. 22 p.

Table 2. Welding procedure tests of dissimilar joints.

Process	Base materials	Consumable (AWS)	Shielding gas	Passes	Heat input/pass (kJ/mm)
GMAW	AISI 301LN / S355	ER 309 Si	Ar + 2%O_2	2	0.25 - 0.56
GMAW	AISI 301LN / S355	ER 309 Si	Ar + 2%O_2	3	0.21 - 0.40
GMAW	AISI 301LN / EN 1.4003	ER 309 Si	Ar + 2%O_2	2	0.25 - 0.56
GMAW	AISI 301LN / EN 1.4003	ER 309 Si	Ar + 2%O_2	3	0.21 - 0.40
GMAW	EN 1.4003 / S355	ER 309 Si	Ar + 2%O_2	2	0.25 - 0.56
GMAW	EN 1.4003 / S355	ER 309 Si	Ar + 2%O_2	3	0.21 - 0.40
FCAW	AISI 301LN / S355	E 309 LT-1	Ar + 25%CO_2	2	0.38 - 0.50
FCAW	AISI 304L / S355	E 309 LT-1	Ar + 25%CO_2	3	0.25 - 0.43
FCAW	AISI 304L / EN 1.4003	E 309 LT-1	Ar + 25%CO_2	2	0.38 - 0.50
FCAW	AISI 304L / EN 1.4003	E 309 LT-1	Ar + 25%CO_2	3	0.25 - 0.43
FCAW	EN 1.4003 / S355	E 309 LT-1	Ar + 25%CO_2	2	0.38 - 0.50
FCAW	EN 1.4003 / S355	E 309 LT-1	Ar + 25%CO_2	3	0.25 - 0.43

3.4 Corrosion testing

The corrosion properties of the test materials and welds were investigated with salt spray chamber tests and field tests [19-22]. In the salt spray chamber tests the corrosive environment simulated the effect of salt which is used for deicing roads. This was achieved by spraying 5% $CaCl_2$ solution periodically in the chamber. The test temperature varied from the room temperature to +45°C. The operating tests were carried out in the actual environment by using a test frame attached under an urban bus. The test started in autumn 1994 and was run until summer 1997 with the total amount of 296 000 test kilometers. Visual inspections and weight loss measurements were carried out annually to study corrosion behaviour of the samples.

3.5 Life cycle cost and life cycle assessment analyses

Life cycle costs of a stainless steel bus frame and an aluminium sandwich frame were calculated as present values with a desired life cycle of 20 years. The cost of capital and inflation rate were estimated as 4% and 2%, respectively, and hence the real interest rate was 1.96%. The value of lost profit was estimated as 1000 FIM per day.

The objective of the life cycle assessment study was to compare environmental impacts of two different bus frames during their entire life cycle. The studied frames are made by welding from EN 1.4003 stainless steel RHS beams or from 5000 and 6000 series aluminium sandwich panels, which contain PVC-foam. The life cycle included in this study the production of materials, manufacturing of frames and operation phase. The environmental impacts resulting from the manufacturing of the frames were considered negligible. The bus alternatives studied had almost the same total weight, outer dimensions and load carrying capacities but different frame weights. Thus, environmental loadings generated during the operation phase were allocated based on the frame weights. The environmental impacts were weighed with three generally used methods: Effect Category-, EPS- and SimaPro3-method.

3.6 Case studies

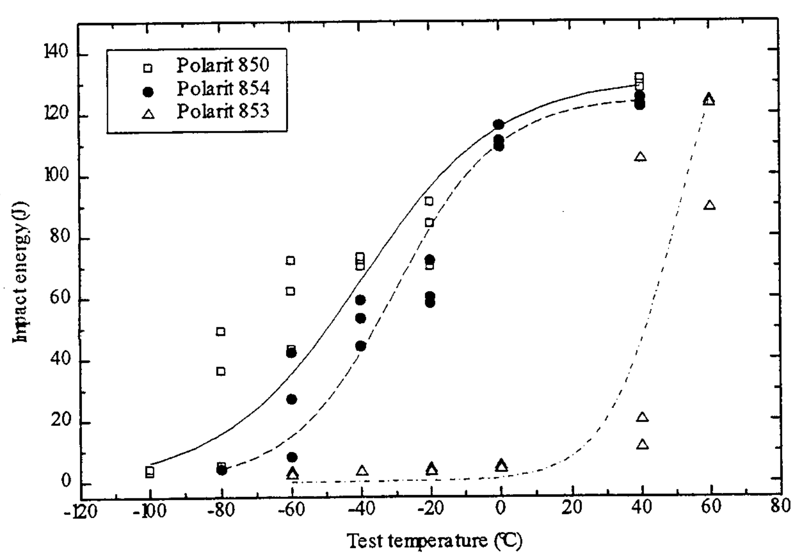
The applicability of the stainless steels studied was evaluated also through several case studies in co-operation with industry participants. The cases investigated during the project were:

- stainless steel bus frame
- stainless steel substructural parts in aluminium bus frame
- trailer made of 12%Cr stainless steel
- safety wall of a log truck.

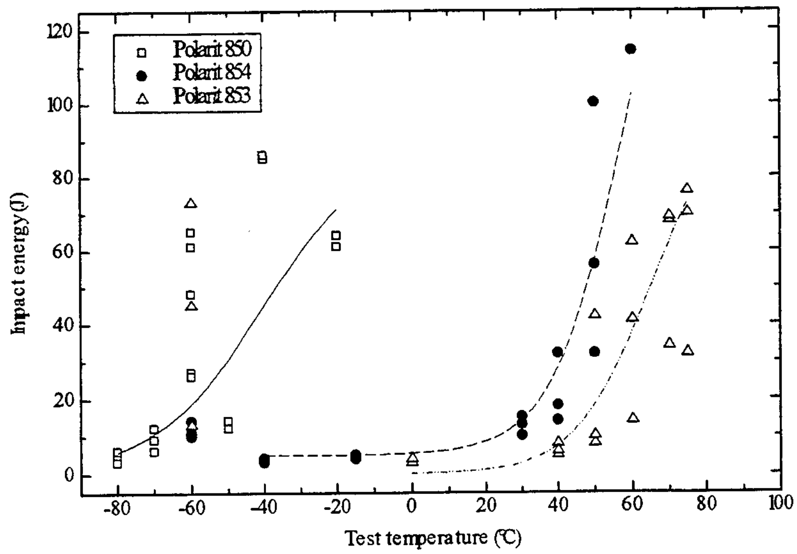
4 RESULTS AND DISCUSSION

4.1 Impact and fracture toughness of 12%Cr stainless steel welds

The results of the Charpy-V impact tests are summarised in Fig. 2. The results show that the impact toughness of the coarse-grained HAZ in the gas metal arc welds is strongly dependent on steel composition and heat input. The unstabilised steel EN 1.4003 with the lowest ferrite factor, FF = 8.7, produced fully martensitic microstructure in the HAZ resulting in the most favourable impact toughness behaviour. In this case the ductile-to-brittle transition temperatures (DBTT) were between -45°C and -25°C. The stabilised steels, AISI 409 (FF = 10.4) with ferritic-martensitic HAZ and AISI 409mod (FF = 14.0) with fully ferritic HAZ, showed DBTT's well above the room temperature. The impact toughness of austenitic weld metal was good with all three steels.



a)



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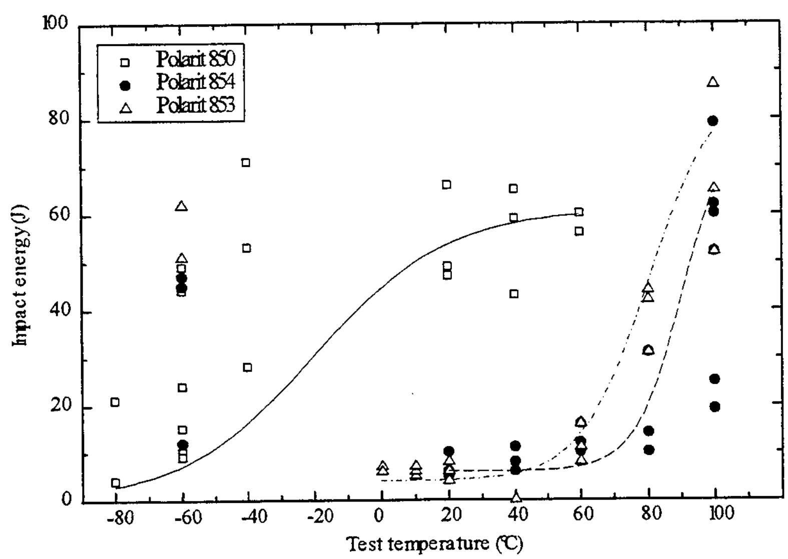
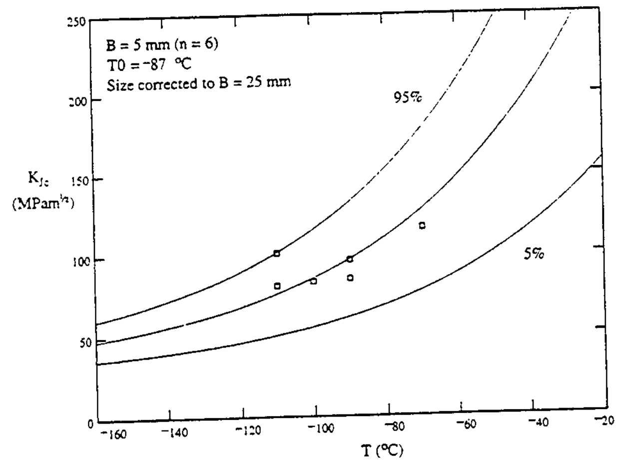


c)

Fig. 2. Charpy-V impact toughness of 12%Cr steels and their heat affected zones. Base metals (a), HAZ's of GMAW welds produced with 6.5 kJ/cm (b) and HAZ's of GMAW welds produced with 12 kJ/cm (c).

The results of the fracture toughness tests performed with the low heat input welds (6.5 kJ/cm) are presented as K_{JC}-values in Fig. 3. The results confirm the dominating effect of steel composition on fracture toughness behaviour. The HAZ of EN 1.4003 steel showed excellent fracture toughness due to low carbon, lath-type martensite in the HAZ. The fracture toughness values of two other 12%Cr steels were significantly lower.



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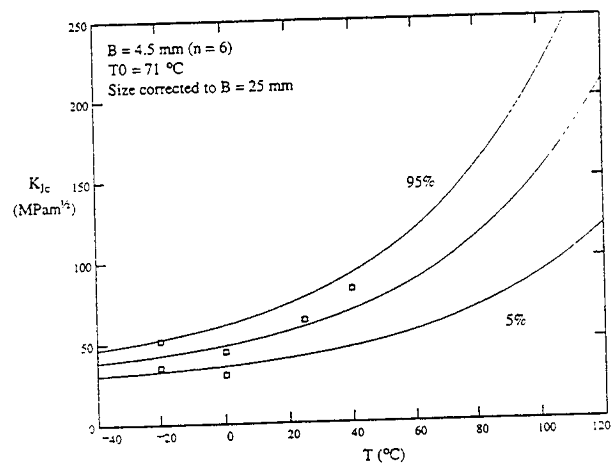

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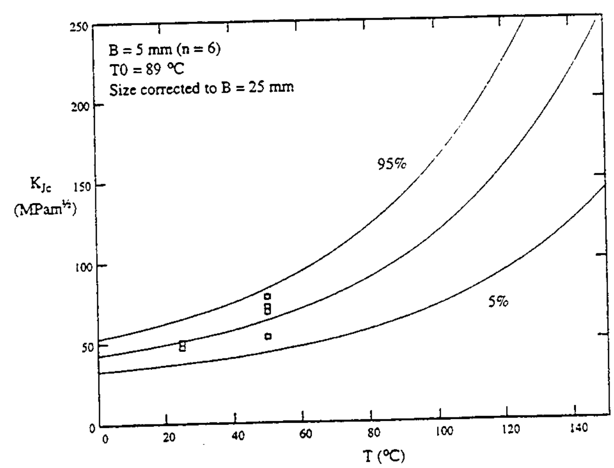


c)

Fig. 3. HAZ fracture toughness values of 12%Cr steels. Heat input 6.5 kJ/cm. EN 1.4003 (a), AISI 409 (b) and AISI 409mod (c).

The SEM/EDS investigation of the fracture surfaces showed that in the fully martensitic HAZ of EN 1.4003 steel fracture propagated predominantly through martensite lath packets, the effective grain size being smaller than the prior austenite grain size. In AISI 409 and AISI 409mod steels the facet size of the fracture surface was markedly larger corresponding to the grain size of the coarse-grained HAZ. In these Ti-stabilised steels there was also evidence that the crack initiation is related to Ti(C,N) particles present in the microstructure [7].

4.2 Fatigue properties of welded RHS-profiles

The results of the fatigue tests are summarised in Fig. 4. The results show good agreement with the design curves given in Eurocode 3. The required fatigue class for the structural detail studied is FAT 36. In the majority of cases the results are well above this level. This is the case especially with three-point bending tests where the maximum stress range is induced only to one side of the beam. On the contrary, in axial loading the entire cross-section of weld is uniformly loaded and pre-existing defects can initiate more easily fatigue fracture. In addition, the misfit usually present in welded samples causes additional stresses which change the loading mode and decrease fatigue resistance. These factors explain why the stress ranges measured in axial loading were lower compared to three-point bending loading.

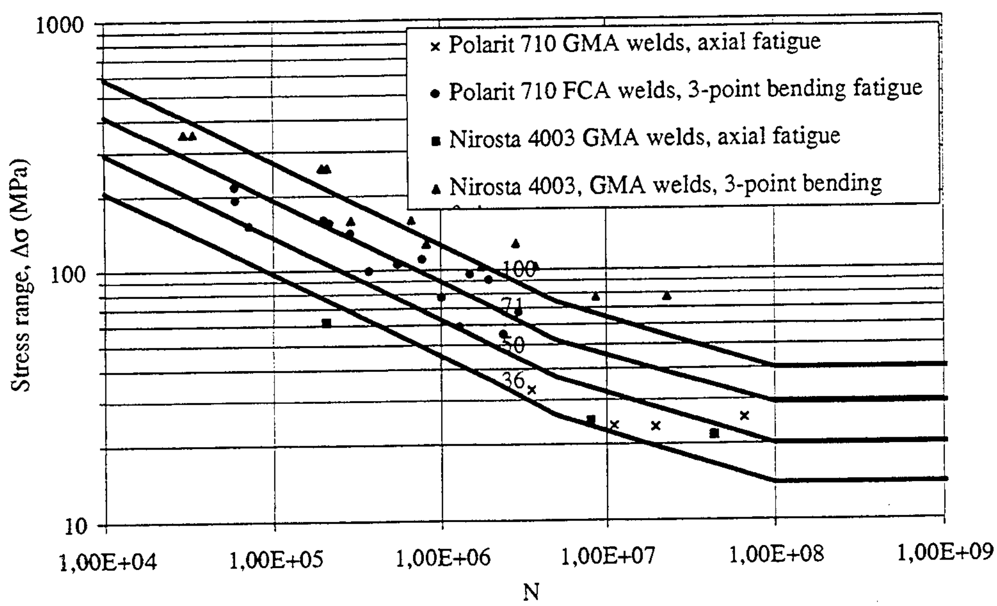


Fig. 4. Fatigue strength of AISI 301 and EN 1.4003 steel RHS-beam welds. Axial loading and three-point bending loading with a stress ratio of R = 0.1. Stresses are calculated for the cross-section of the fracture surfaces.

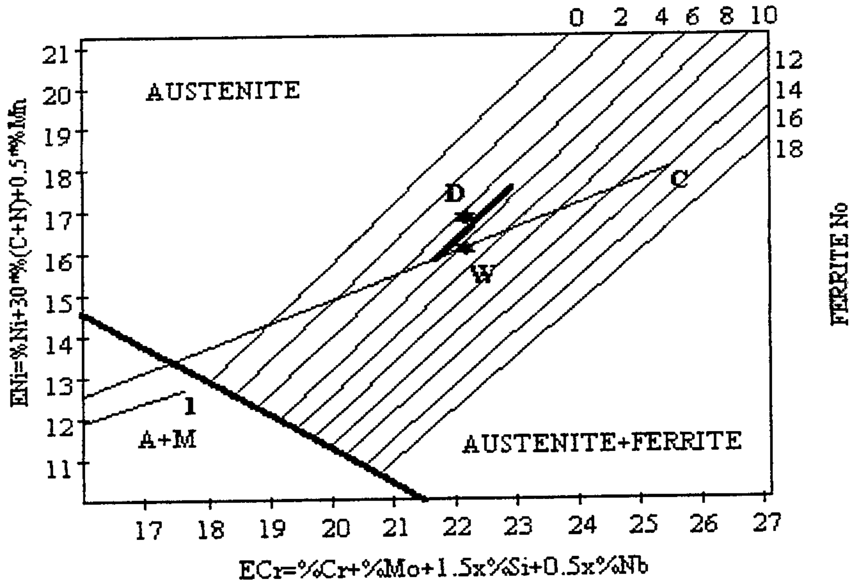
The fatigue behaviour was found to depend also from weld geometry and especially from the throat thickness used in welding. Depending on these geometrical factors, the fracture initiated and propagated either from the weld toe or from the weld root. An increase in the throat thickness resulted more often in toe fracture whereas a smaller throat thickness favoured root fracture. This indicates that the dimensions of fillet welds need to be carefully selected to avoid invisible root fractures. According to the results a throat thickness equal or greater than two times the plate thickness is recommended in order to avoid root fractures [13]. However, it should be noticed that excessive throat thickness increases residual stresses and distortions and can, thus, effect detrimentally mechanical behaviour in structural applications.

4.3 Mechanical behaviour of dissimilar joints

The mechanical properties of dissimilar joints were acceptable in the majority of test welds. All the tensile test specimens fractured in base metal indicating higher weld metal strength. The toughness properties of welds were good since the bending tests did not show any notable cracking problems. Especially the FCAW welds proved to be resistant to cracking but GMAW welds experienced some small cracks in the bending tests.

The Charpy-V impact toughness tests carried out at -60°C revealed that the coarse-grained HAZ of the 12%Cr steel is the weakest area in the dissimilar joints studied. The impact toughness of this zone is strongly dependent on the steel composition and HAZ microstructure, as described also in Chapter 4.1. The weld metals studied showed reasonably high impact toughness values. The weld metal composition and ferrite content had some effect on impact toughness, but in all cases the toughness values were well above the required level. The HAZ's of steel S355, which were tested at -20°C, demonstrated good values with respect to requirements set for this steel [18].

The measured weld metal analyses and ferrite contents were compared to DeLong- and WRC- prediction diagrams as shown in Fig. 5. There was a fairly good compatibility between the measured and calculated values. The results indicated that the best compatibility is achieved by the DeLong-diagram where the calculated and analysed weld compositions as well as the measured ferrite contents are reasonably close to each other. Also the WRC-diagram yielded reasonably good results. The third diagram applied, the Schaeffler-diagram, was less accurate since it does not include the effect of nitrogen in promoting austenite at the expense of ferrite. This was demonstrated also in the studies by Lahti [19], which focused on the weld properties of AISI 301LN steels.

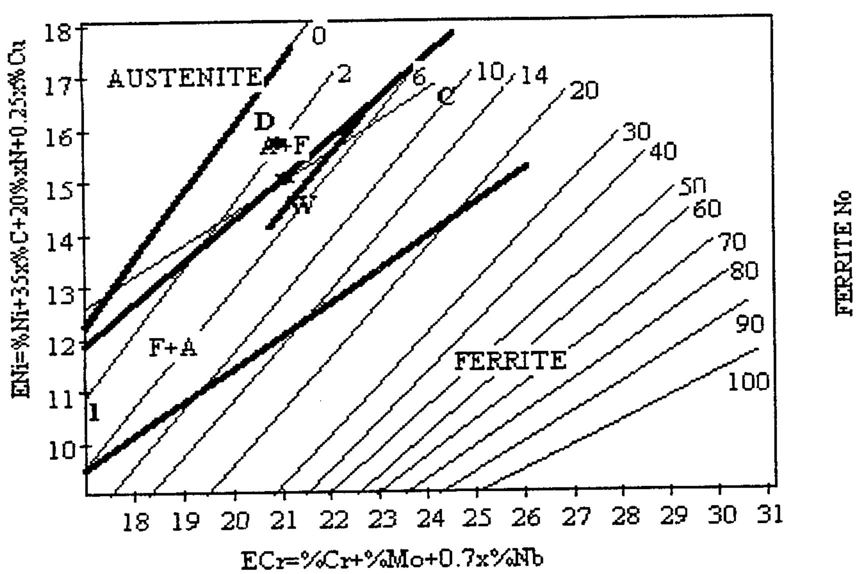


1 = AISI 301LN　　2 = S355

C = OK Autrod 16.52　　W = Analysed weld

D = Calculated weld　　___ = Measured weld

a) DeLong



1 = AISI 301LN　　2 = S355

C = OK Autrod 16.52　　W = Analysed weld

D = Calculated weld　　___ = Measured weld

b) WRC-1992

Fig. 5. DeLong (a) and WRC (b) analyses for the dissimilar welds between AISI 304L and S355 and comparisons to the measurements.

4.4 Corrosion properties of welds

The salt spray chamber tests indicated that the corrosion resistance depends on steel quality and on post-weld surface conditions. As expected, the austenitic AISI 301L steel showed the most favourable general corrosion resistance compared to 12%Cr steels. An increase in the testing temperature accelerated colouring and corrosion. With both steel types the corrosion damage was most prominent in the welds left in as-welded condition. The corrosion problems could be reduced by applying different post-weld surface treatments. Pickling was found to be the best post-weld cleaning method. With other methods, such as brushing, polymer wheel polishing and shot peening, the corrosion resistance of welds was improved only marginally. Manual grinding with silicon carbide wheel was found to be detrimental since it results in rough surfaces [20-22].

The results of the field tests supported the findings of the laboratory tests (Fig. 6). After 296 000 test kilometers the austenitic AISI 301L steel welds were in the best condition. Especially the welds which were pickled after welding showed practically no indication of corrosion. The 12%Cr steel exhibited some colouring and corrosion in the vicinity of welds. Also in this case post-weld pickling improved corrosion resistance. Contrary to this, the reference samples made of structural steel S355 were totally corroded. The results of the weight loss measurements showed that the degree of corrosion damage in both AISI 301L and 12%Cr steel was negligible after 3 years of field testing, see Fig. 7.

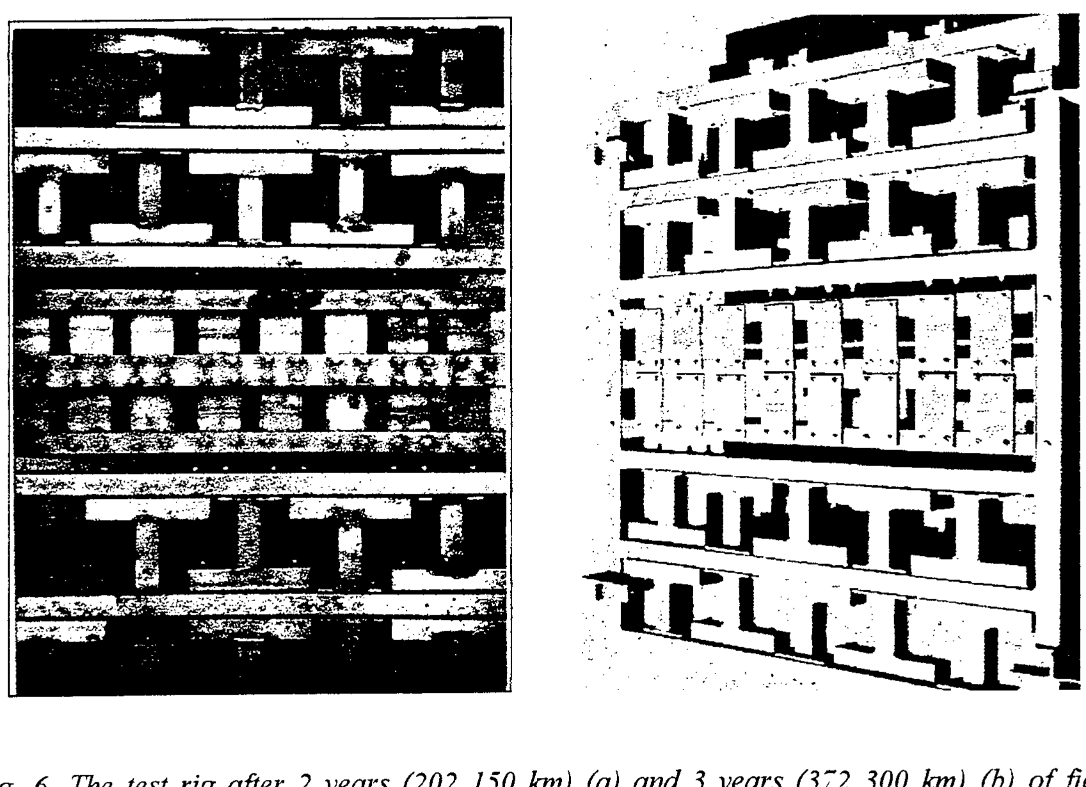


Fig. 6. The test rig after 2 years (202 150 km) (a) and 3 years (372 300 km) (b) of field testing. The samples looked brighter after 3 years due to the dry weather conditions during spring 1997 and, thus, natural "sand blasting".

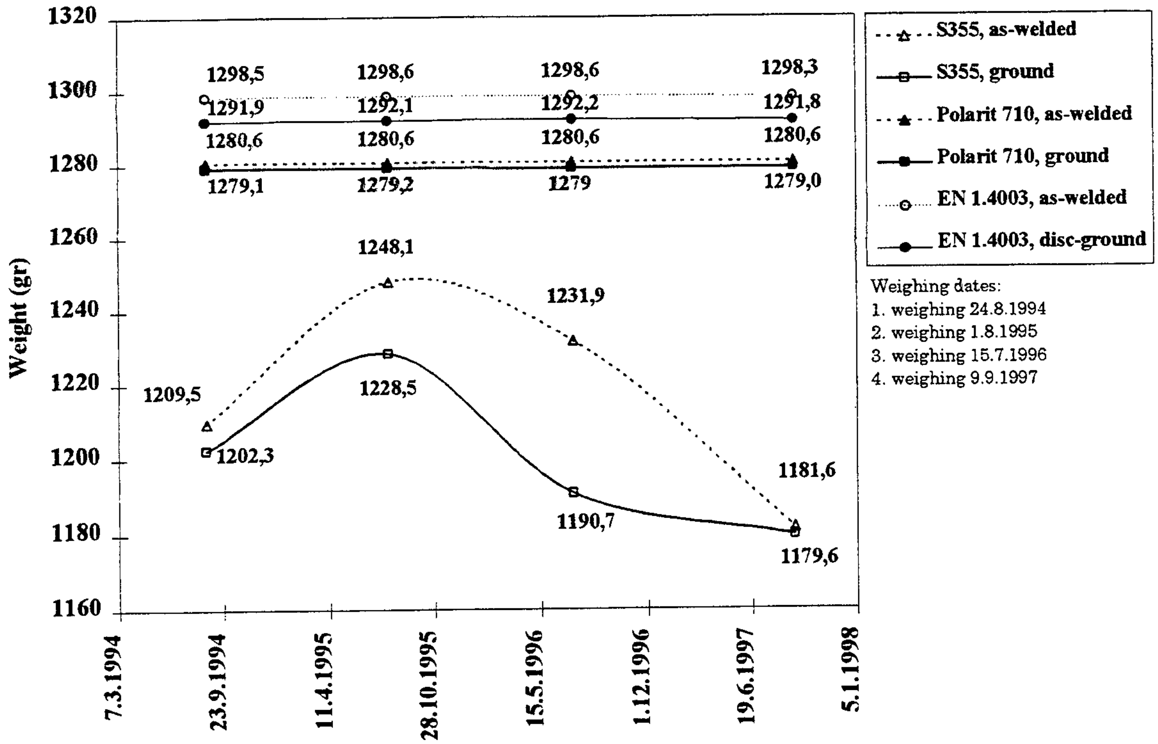


Fig. 7. Weight loss of the stainless steel and structural steel samples shown in Fig. 6.

4.5 Life cycle cost and life cycle assessment analyses

The total initial costs of the stainless steel frame were about half of the total manufacturing costs of the aluminium frame, see Table 3. In the case of stainless steel frame, the raw material is cheaper, but manufacturing and surface treatment costs are higher compared to aluminium frame. Aluminium bus frame is assembled from large panels whereas stainless steel frame is manufactured from less expensive hollow sections. On the other hand, welding requires three times more manufacturing time. The stainless steel frame is also painted and treated against corrosion which is costly compared to aluminium frame that is only taped. Both treatments have to be renewed after 10 years. Overall, the life cycle costs of the stainless steel frame were about 70% of the costs of the aluminium frame.

Table 3. Life cycle cost comparison of stainless steel and aluminium bus frames (present value in FIM).

Initial costs	**Stainless steel frame**	**Aluminium frame**
Material costs	15 555	108 507
Manufacturing costs	28 490	10 010
Surface treatment costs	27 020	8500
Total initial costs	**71 065**	**127 017**
Operating costs		
- Time between maintanence operations	10 years	10 years
- Time needed for maintanence operations	7 days	4 days
Maintanence costs	22 251	7000
Value of lost profit	5765	3294
Total operating costs	**28 016**	**10 294**
LIFE CYCLE COSTS	**99 081**	**137 311**

According to Fig. 8, the total environmental harm points are lower for stainless steel frame, even though the results of Effect Category-method are almost the same for both material alternatives. Moreover, the materials production phase of the stainless steel frame is environmentally preferable to the production of aluminium one according to the three weighing methods considered. Since the environmental loadings during the operation phase are expected to be similar for both frames, the stainless steel frame seems to be environmentally less detrimental during the life cycle of the buses [23, 24]. The data collected was also used in one of the three case studies included in the NordList LCA-project [25]. The NordList LCA-project was established to develop and demonstrate new models and methods for integrating life cycle assessment into product design activities. Only the manufacturing phase of the bus frames was studied in this project. The results were similar compared to the results obtained in the present project.

4.6 Case studies

The objective of the case studies was to evaluate the use of test materials in industrial applications /26/. The bus frame made of 12%Cr steel RHS-profiles is a typical example, see Fig. 9. The most suitable steel grade for this application was chosen and verified by extensive material and corrosion tests, as described in Chapters 4.1 - 4.4. A 12%Cr steel grade producing fully martensitic HAZ was recommended based on the toughness properties of welds. Also the corrosion test results confirmed the suitability of this steel as construction material of bus frames.

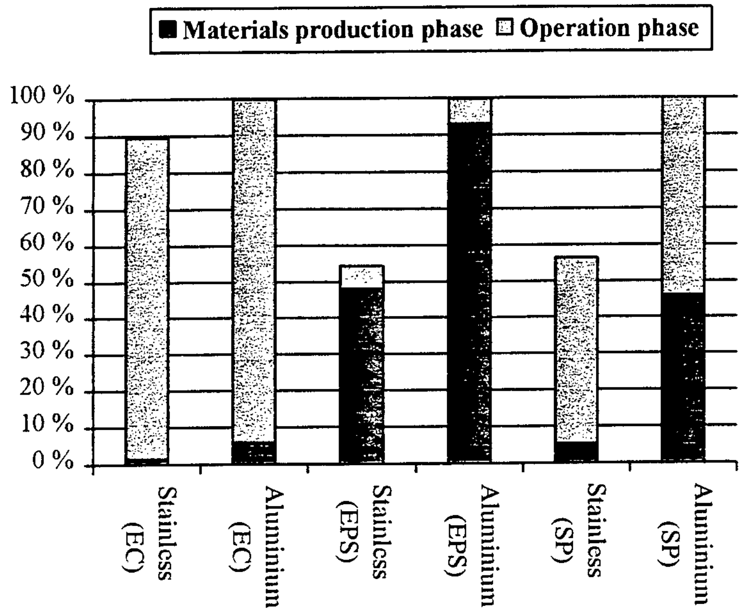


Fig. 8. Environmental loadings of the materials production and operation phase of stainless steel and aluminium bus frames. Results were summed and weighed with three different methods: Effect Category (EF), EPS and SimaPro3 (SP).

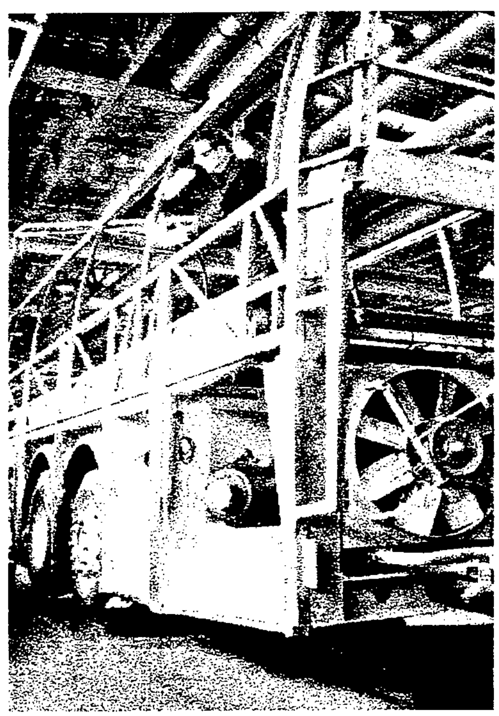


Fig. 9. Stainless steel bus frame studied in the project (Carrus Oy).

The use of stainless steels in bus structures was studied also in another application. The main aim was to reduce the bus weight as much as possible and, therefore, the bus chassis was replaced by sandwich structure made of aluminium. Substructures made of steel are needed in the most loaded parts located in the vicinity of front and rear axles and close to the engine. In order to obtain service life of 20 years or, approximately, 2 million kilometres, the substructures are manufactured from AISI 316 stainless steel. AISI 316 steel was chosen even though stress corrosion cracking may appear in this material in the structures close to the engine. Depending on the results of future tests, 12%Cr steel can also be considered for the substructures.

A third example studied in the project was a stainless steel trailer shown in Fig. 10. The frame of the trailer was constructed of 12%Cr steel RHS-profiles similar to the bus frame application. The strength of the frame was tested in full scale bending tests. The corrosion behaviour was evaluated in field tests during one winter including about 35 000 test kilometres.

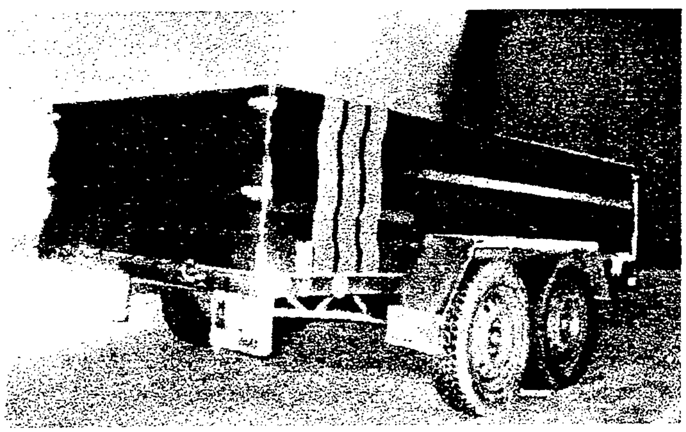


Fig. 10. Stainless steel trailer (S. Sainio Technics Ltd).

Trucks used for timber transportation are another potential application for stainless steels in the transport sector. A typical example is the safety wall between the truck cabin and the load, see Fig. 11. This application is usually manufactured from high strength steels due to structural requirements. Since steel structures are susceptible to corrosion and colouring, a safety wall made of AISI 301 and 304 stainless steels was constructed and tested in the project. The endurance of the structure was surveyed in log transportation which started in January 1996. The frame was undamaged after 101 000 test kilometres in May 1997. However, some parts of the frame had been cold worked during the loading of logs showing indications of colouring and corrosion (Fig. 11). The welds in the safety wall did not show any visible changes.

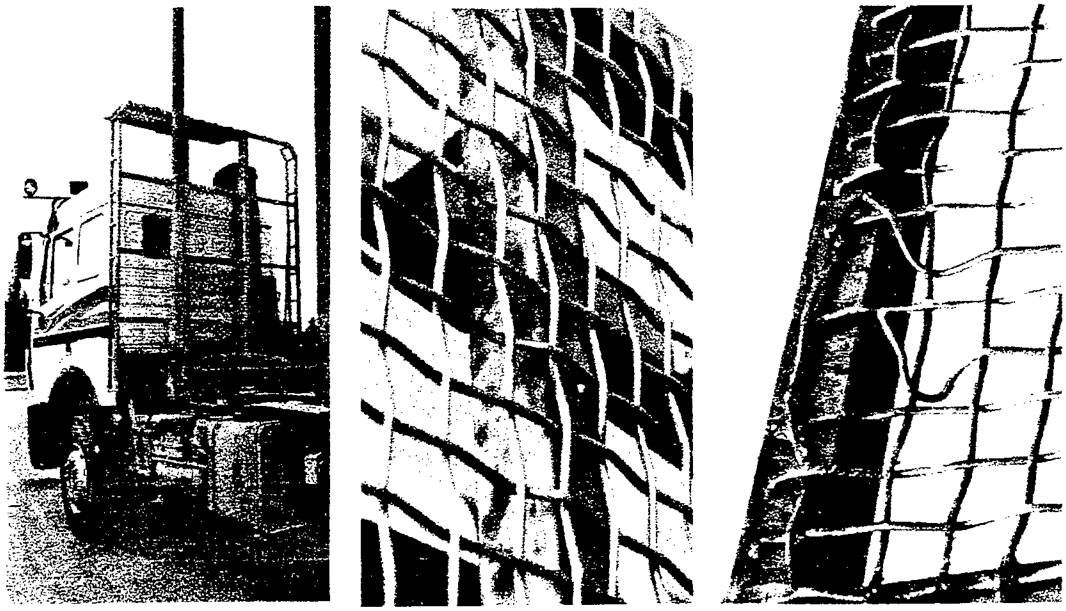


Fig. 11. Safety wall of the log truck and the structure after 101 000 test kilometers.

5 SUMMARY AND CONCLUSIONS

The results obtained in the project can be summarised as follows:

- 12%Cr stainless steels are a promising alternative to austenitic steel grades in vehicle applications. The steel composition should be adjusted in order to obtain fully martensitic HAZ during welding, which is beneficial to joint impact and fracture toughness. By using an austenitic consumable, required toughness is guaranteed also in the weld metal.

- The fatigue properties of welded RHS-profiles of 12%Cr and AISI 301 steels met the requirements specified in Eurocode 3 for structural steels. To improve fatigue resistance the throat thickness of the fillet welds studied should be equal or larger than about two times the plate thickness. This is necessary in order to avoid the initiation of fatigue cracks from the weld root.

- The dissimilar joints between the stainless steels and S355 structural steel showed acceptable mechanical behaviour. The composition of 12%Cr steel is of great importance also in this case. The ferrite contents and microstructures of the austenitic weld metals in the dissimilar joints could be reasonably well estimated by DeLong- and WRC-1992-prediction diagrams within the heat input range used in the study.

- The corrosion properties of test welds and steels were dependent on the steel composition and post-weld condition. The best corrosion resistance was achieved with austenitic steels, especially when post-weld pickling treatment was applied. The corrosion resistance of 12%Cr steels was also reasonably good, provided that post-weld pickling is applied. Other cleaning methods were less effective. The field tests did not show any weight changes in the 12%Cr and AISI 301 steel samples after 3 years, or about 300 000 test kilometers, in bus service in Helsinki area.

- According to the life cycle cost calculations, the total costs of stainless steel bus frame were about 70% of the costs of aluminium frame. The results of the life cycle assessment analyses suggested that the stainless steel bus frame is environmentally less harmful compared to the aluminium bus frame.

- The applicability of stainless steels was studied also in several industrial cases, e.g., in bus frame, support structure of bus chassis, trailer and safety wall of the log truck. In all cases the use of stainless steels was found to be an excellent alternative, by which corrosion resistance can be increased remarkably during service.

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APPENDIX

ORGANISATION OF THE FINNISH SUBPROJECT

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