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Structural Applications of Ferritic Stainless Steels (SAFSS)
WP7: Corrosion resistance

Comparative study of the service life of building components

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Summary

The aim of this report is to quantify the advantages of using ferritic stainless steels in building applications compared to galvanised steel and austenitic stainless steels in different climate conditions. The report introduces service life assessment building applications and comparison of predicted service life times. The study covers ventilated façade, roof and frame structures.

The service life method used here is so called factor method and it is based on ISO 15686. Material quality, structural design, quality of work execution, indoor and outdoor environment and also maintenance level are taken into account by special factors. Estimated service life is obtained by multiplying the reference service life by these impact factors.

The factor for steel materials and the applications are based on VTT previous work (2001-2006) and collaborative work with TRY (Finnish Steel Construction Association), and involved companies (Rautaruukki, Outokumpu Stainless steel Oy, Boliden, Teknos Oy, Finnmap consulting Oy). This collaborative work resulted to the creation of the tool (Ennus™-Steel) for service life assessment of steel structures. ENNUS™-Steel tool gives an easy approach and quick result for the service life estimation taking into account interaction and combined effect of different impact factors. Making this comparison available Ennus™-Steel tool was complemented by new ferritic stainless steel grades and the impact factors were set for them used in the façade, roof and frame applications. According to the results ferritic stainless steels are applicable for façade, roof and frame applications.

Confidentiality	Confidential until May 2014

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1. Introduction

The aim of this study is to evaluate the advantages of using ferritic stainless steels in building applications compared to galvanised steel and austenitic stainless steels in different climate conditions. The study quantifies the service life advantages of using ferritic stainless steels instead of galvanised steel or austenitic stainless steels in building applications in different environmental conditions in the Baltic Sea region (C2, C3 and C4).

ENNUS™-program has been previously developed at VTT for the service life assessment of concrete, steel and wooden building structures which are in compliance with ISO 15686-1. The program helps designers to determine parameters that affect the service life of the structure under scrutiny. These parameters include materials quality, structural design, work execution, outdoor and indoor exposure condition, user phase, and care and maintenance level. The method is known as the factor method, and service life is obtained by multiplying the reference service life by the factors given for these parameters.

The comparative study is based on the ENNUS™-Steel tool (http://www.fcsa.fi/) with existing pre-assumptions built into the tool. During this study ENNUS™-Steel tool was complemented by relevant ferritic stainless steel grades and their service life factors. Expertize of VTT and Outokumpu Stainless Oy was used for defining service life factors for ferritic materials but also corrosion results from the project of SAFSS (Structural Application of Ferritic Stainless Steels) and other available empirical data have been utilized.

Service life estimation was performed as a comparative study for ferritic applications used in ventilated facade, roof and steel frame.

1.1 Method for Service life estimation

Standard ISO 15686 defines main phases and principles for the building service life assessment:

- The target setting establishes the building design life and performance criteria; and specifies the building components, which need to be maintained, repaired and replaced.
- In detailed building design phase the designer chooses the exact material types and components.
- Finally the designer makes the check that all chosen materials and components are compatible with the performance criteria. In this check the assessment takes into account material type, environmental conditions, work execution, coatings, care and maintenance measures and other parameters related to the durability and life time.

Service life is the time after installation during which the facility or its component parts (products, components, materials, or assemblies) meets or exceeds the performance requirements (ISO 6707-1 & ISO 15686-1 & ISO/CD 15392).

ISO differentiates also the design life and estimated service life:

- Design life is the target for the service life, set by the owners or their representative.
- Estimated service life is the estimated life time for the structure or building in the destination use.

ISO 15686-1 suggests for the service life assessment to take use of empirical data, field or accelerated test data, but also recommends so called factor method. For the estimation of service life by the factor method the parameters, impact factors and their magnitudes should be first set. The life time estimation is then performed by multiplying the reference service life by these factors.

Parameters for service life estimation which should be taken into account are:

- Type of materials and components (A),
- design quality (B),
- quality of execution work (C),
- indoor conditions (D),
- outdoor conditions (E),
- conditions in use (F) and also
- care and maintenance level (G).

Estimated service life = A * B * C * D* E * F * G * Reference service life

Reference service life is the expected service life of a product under a specified reference set of in-use conditions, which may form the basis for estimating the service life for other in-use conditions. In this context the product could also be a building which has a reference service life under specified conditions.

1.2 Provision of service life with ENNUS™ Steel tool

ENNUS™-Steel is a knowledge-based program (Visual basic + Excel), which estimates the service life of steel components used in buildings (Figure 1). It is made by VTT (latest version is from 2008) and the program was commissioned by Finnish Constructional Steelwork Association (TRY) and some industrial companies (Rautaruukki, Outokumpu Stainless steel Oy, Boliden, Teknos Oy, Finnmap consulting Oy). The tool is made for designer's use and contains estimation for climatic conditions in the surroundings of Baltic Sea (C2, C3 and C4). The language of the user interface available is so far only Finnish. The latest available version also does not cover the ferritic stainless grades.

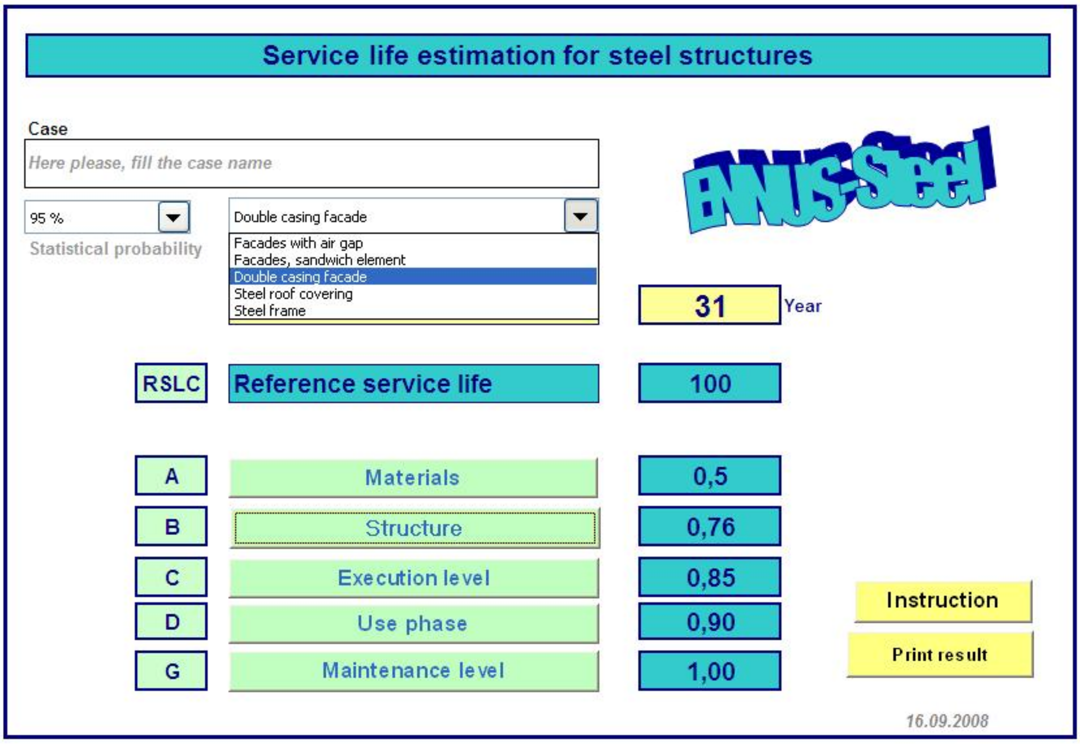

Figure 1. Ennus™-Steel tool, front-page.

The service life assessment is based on the factor method presented in ISO 15686-1:2011[1]. Main deterioration criterion is the existing environmental condition. ISO 12944 describes environmental atmospheric conditions which cause different environmental loads to the structures:

- C1 is very mild condition (heated indoor environment),
- C2 is mild conditions, countryside (low impurity content in outdoor air, unheated indoor environment),
- C3 is moderate conditions, urban, rural and coastal with low salt (sulphur dioxide content is low or moderate, coastal areas with low salt, production are with high moisture content),
- C4 is harsh conditions, rural, coastal areas (with moderate salt)
- C5-I: very harsh conditions, industrial areas (with high salt and aggressive environment)
- C5-M: very harsh conditions, coastal and outside areas (with high salt).

With the help of the current ENNUS™-Steel it is possible to assess service life for steel facades (ventilated structure, sandwich element), double casing facade (glass facade, steel facade with ventilation space), roofing sheets and steel frames, in which the design criterion is aesthetic service life (Figure 2) and environmental conditions in the Baltic Sea region (C2 – C4).

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[1] ISO 15686-1:2011 Buildings and constructed assets - Service life planning - Part 1: General principles and framework

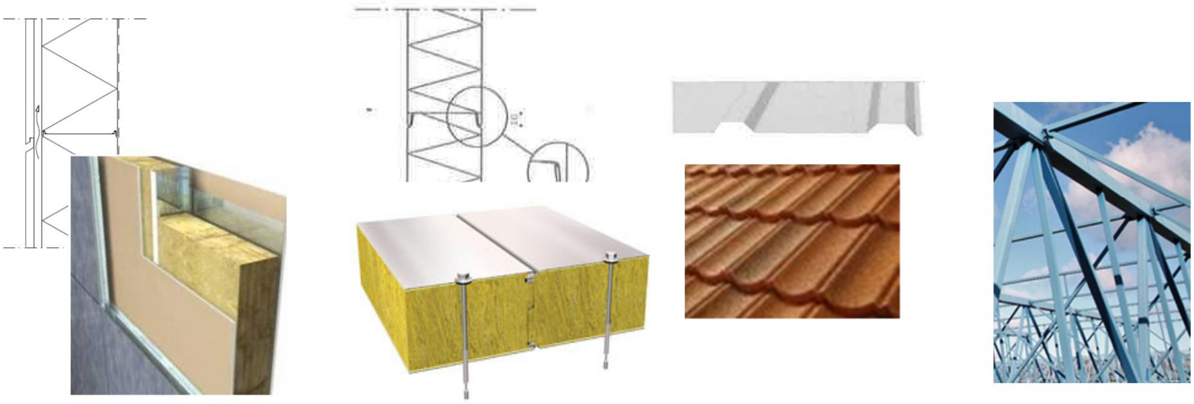


Figure 2. Structures under study (from internet).

The current tool considers many steel types

- carbon steel,
- ferritic stainless steel (17CR) EN 1.4016,
- conventional austenitic stainless steels EN 1.4301/1.4307 and 1.4401/1,4404,
- duplex stainless steel EN 1.4162,
- CorTen steel,
- painted carbon steels (Zinc coated and painted with various paints) and
- Al-zinc roof

In this work the tool is completed by ferritic stainless grades 1.4509, 1.4521, 1.4621, 1.4509 and 1.4003.

<u>Main service life criteria's for the building structures are:</u>

- All visible surfaces (façade, roofs) should maintain at least fair appearance,
- Properly designed building physics of wall structures, so that the water accumulation into the structure is prevented
- Waterproofness of walls and roofs
- Preservation the load-bearing capacity of the frames.

The factors are chosen so that these criteria will be always met. In most cases the service life criterion is the conservation of moderate appearance of visible surfaces. However the tool can also take into account the coatings and their renewals when these are relevant, but this is not utilized in the case of stainless steels. Service life is limited to the one hundred year and lifetime over it is not shown. For the applications, or material and environment combinations, which are not recommended by producers, the factors are set very low which correspondingly results also in very low service life.

Service life design means that the specification of materials and measures so that the intended service life a structure will be achieved with required probability. The more certainty in the assessment is required, the less will be the assessed service life.

2. Service life factors for steel grades and different applications

Service life parameter A related to material consists of the factors for different component types. Main impacts which have an effect to the service life in certain atmospheric conditions are corrosion category and type of surface finishing.

Service life $_{material}$ = RCLC * Corrosion category * surface type (finishing),

where RCLC is the reference service life

For service life assessment of facades and roofs, three corrosion categories - low, medium (moderate), high - and five surface finishes - 2R, 2B, 2K, 2J, 2G (EN 10088-2), were defined and the corresponding impact factors are specified. In the case of service life assessment of frames, three types of surface finishes - pickled, grounded, and as manufactured - are defined and the corresponding impact factors are specified.

Figure 3 shows an example from ENNUS™-Steel tool where all selected factors related to the ferritic steel grades and to the service life are shown. Figure 4 shows the factors for the ferritic steel grades used in ventilated facades - according to corrosion category and environmental conditions - and Figure 5 correspondingly for the roofs. Figure 6 shows the impact factors for the ferritic steel grades used in steel frames according to the corrosion category and environmental condition. Figure 7 shows the size of ferritic steel grade factors according to the surface finishes and for the case of façades and roofs and Figure 8 correspondingly for the frame.

The impact factors for stainless steels are based on the expertise of VTT and Outokumpu Stainless Oy, on corrosion results from SAFSS project and on some other available empirical data.

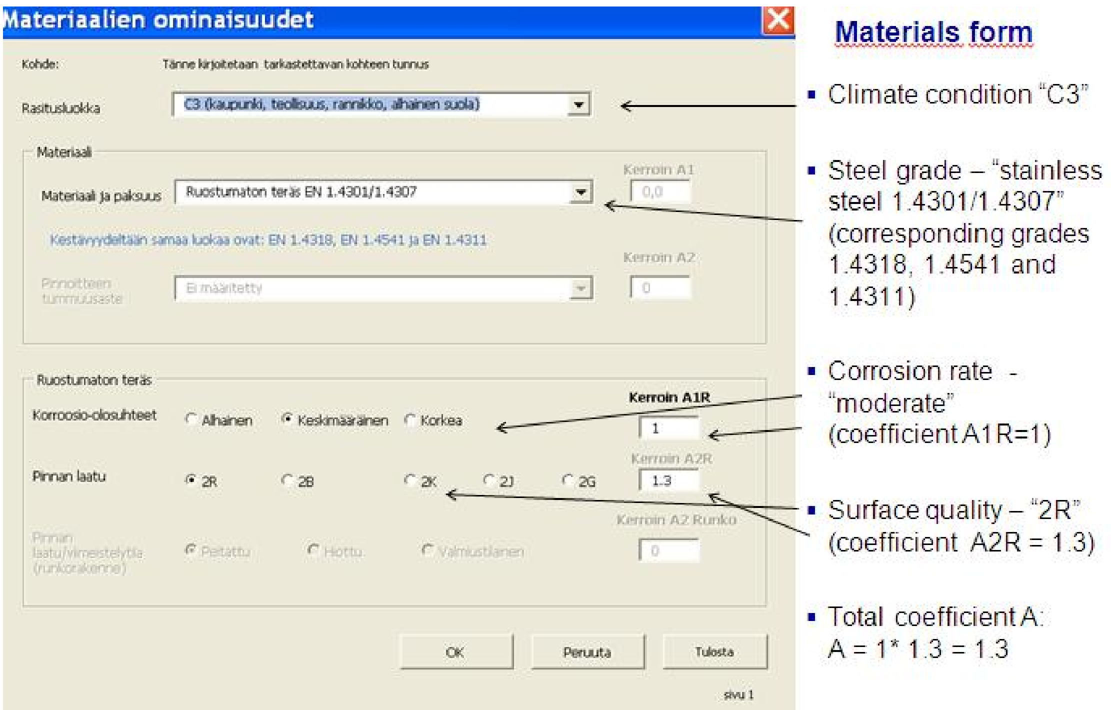


Figure 3. Service life assessment in Ennus Steel tool. The screen introduces the selection of environmental parameter, steel grade, corrosion rate and surface quality. The selection result in the total impact factor of 1.3 which will then be multiplied by reference service life and other relevant factors.

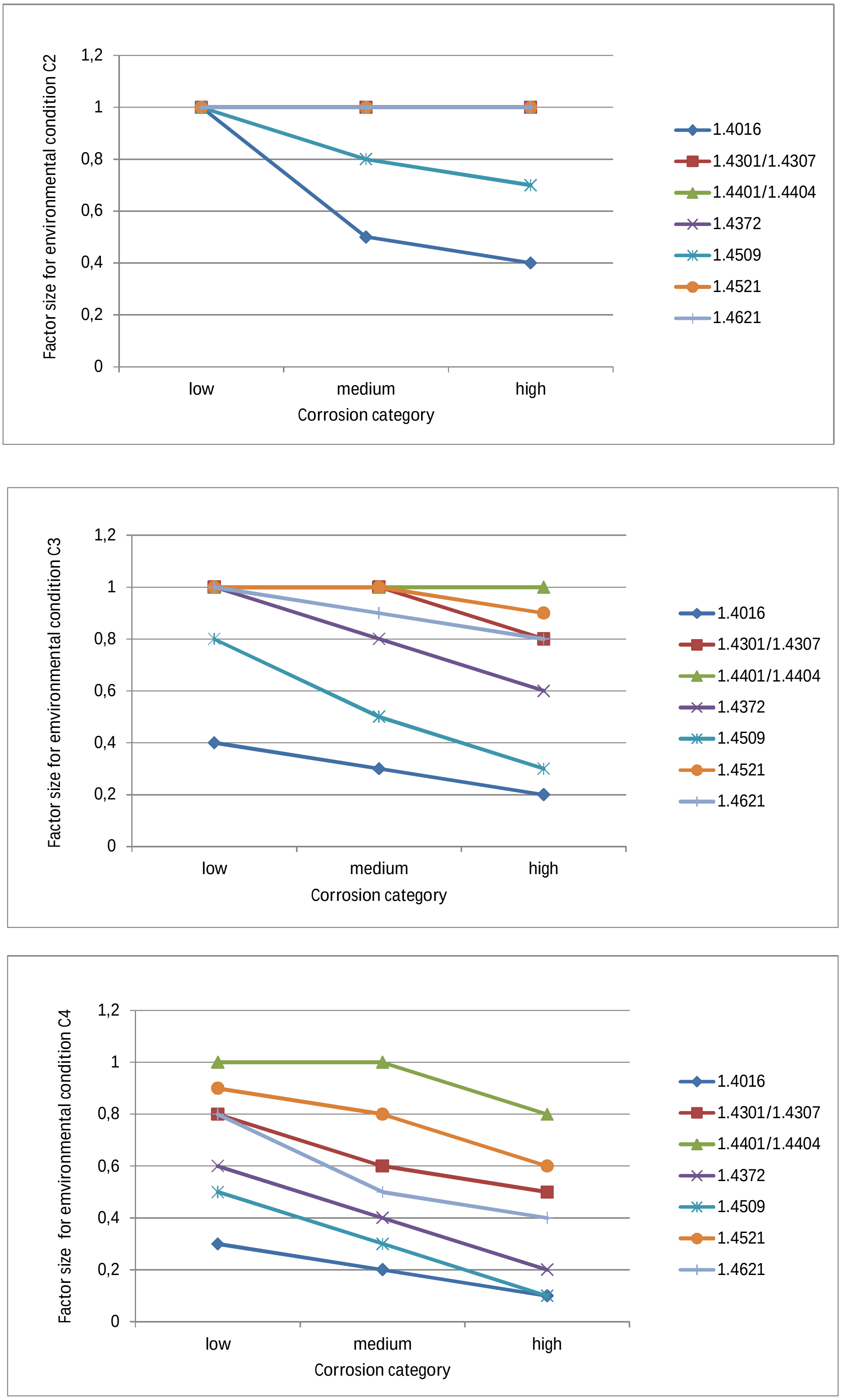
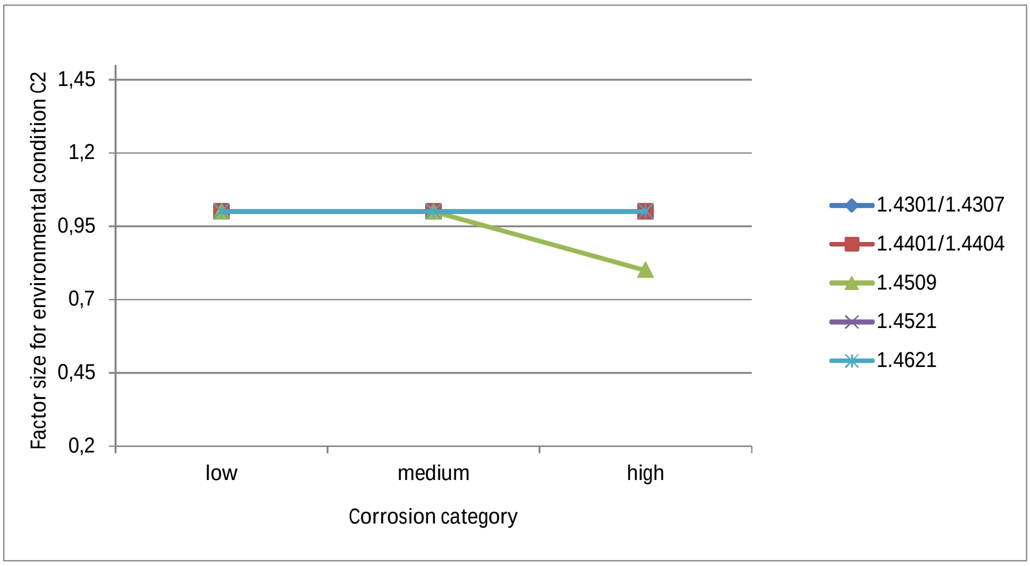
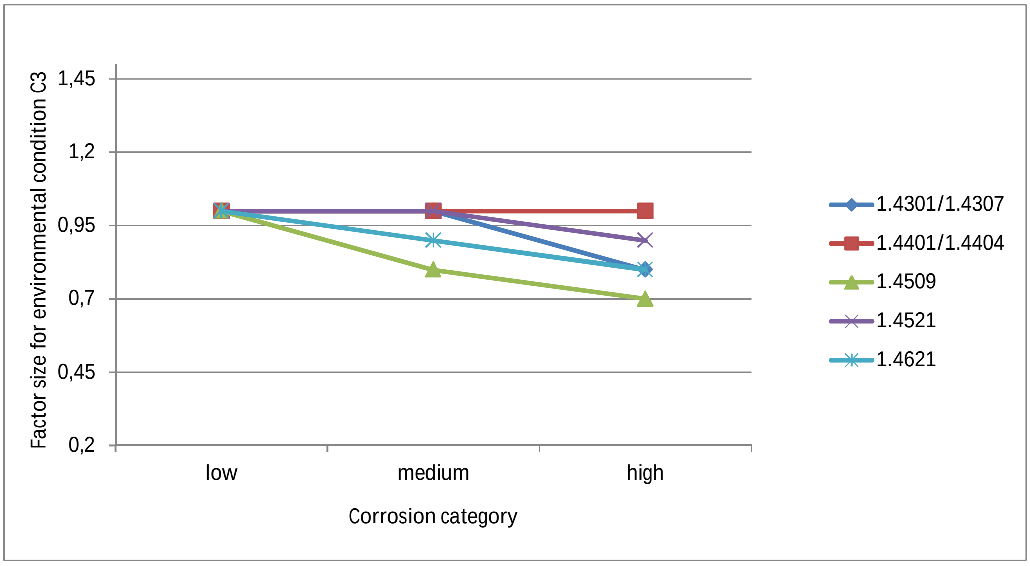


Figure 4. Service life factors for ferritic and austenitic stainless steel grades according to corrosion category and environmental condition, the case structure is a ventilated facade.





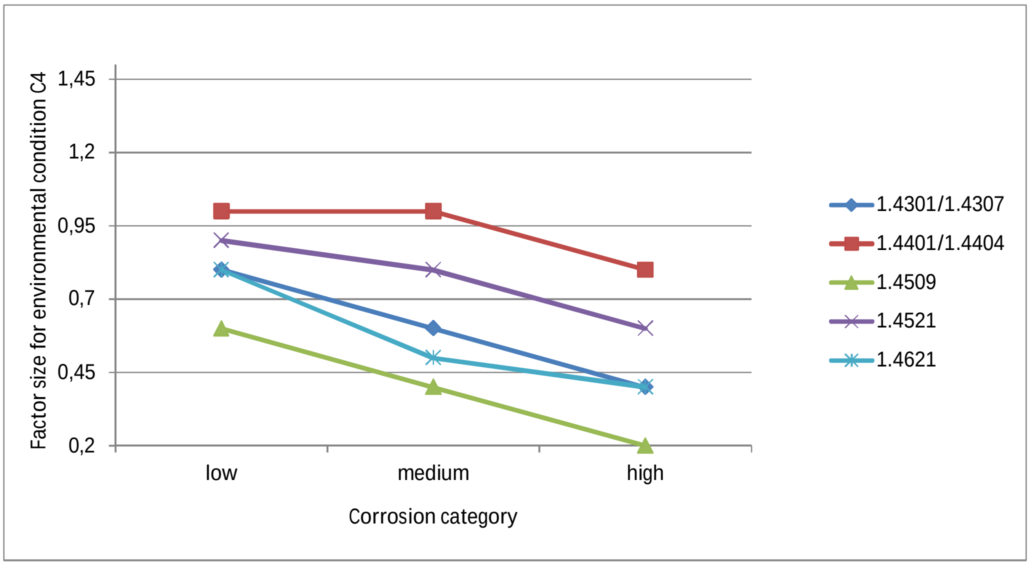


Figure 5. Service life factors for ferritic and austenitic stainless steel grades according to corrosion category and environmental condition, the case structure is a roof.

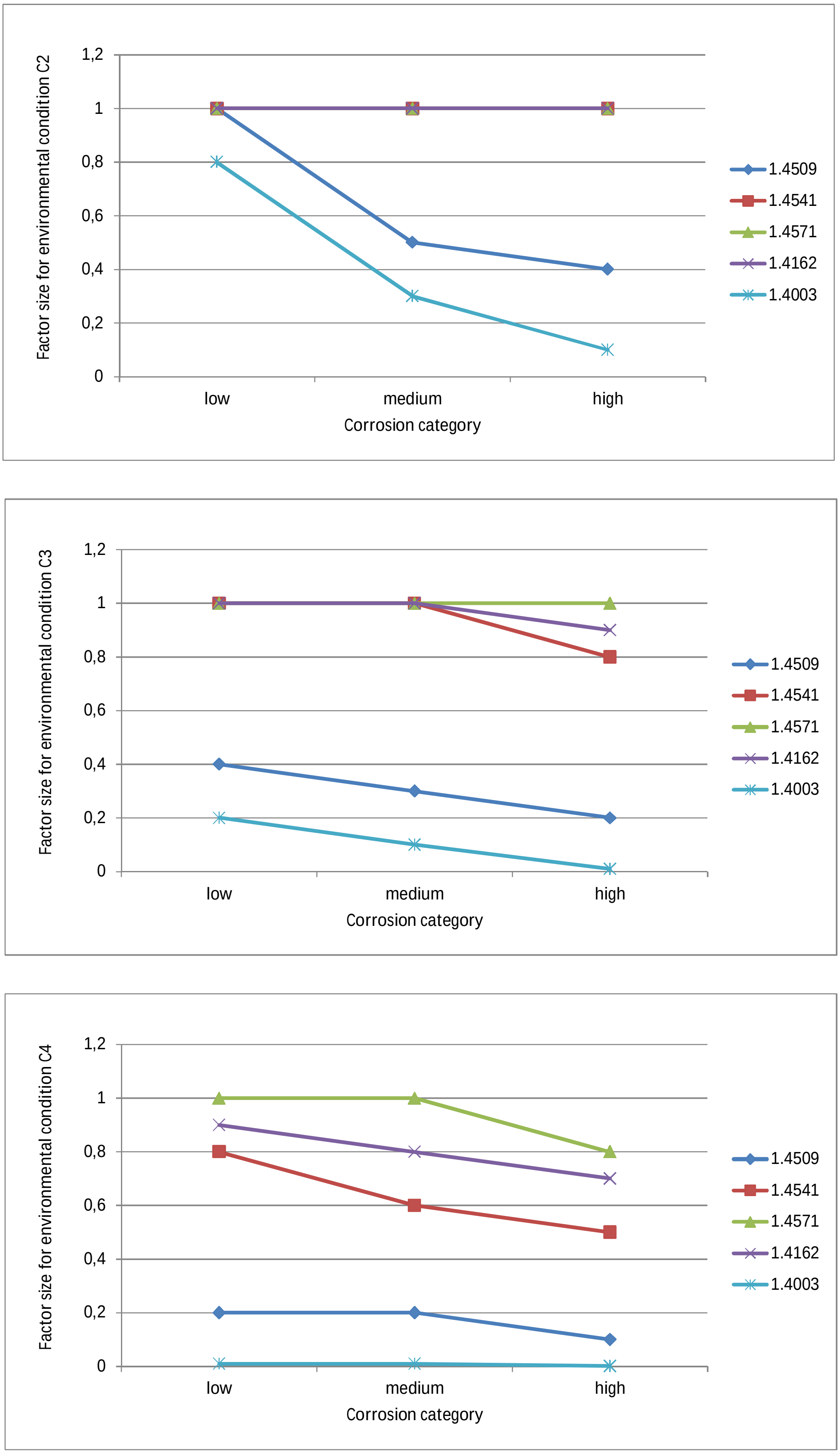


Figure 6. Service life factors for ferritic, austenitic and duplex stainless steel grades according to corrosion category and environmental condition, the case structure is a steel frame.

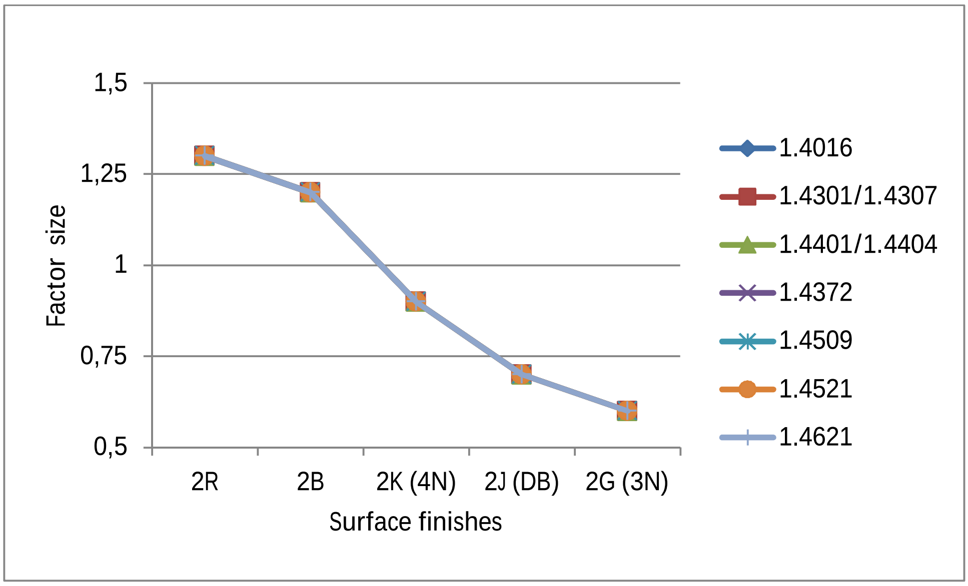


Figure 7. Service life factors for ferritic, austenitic and duplex stainless steel grades according the surface finishes, the cases are facades and roofs.

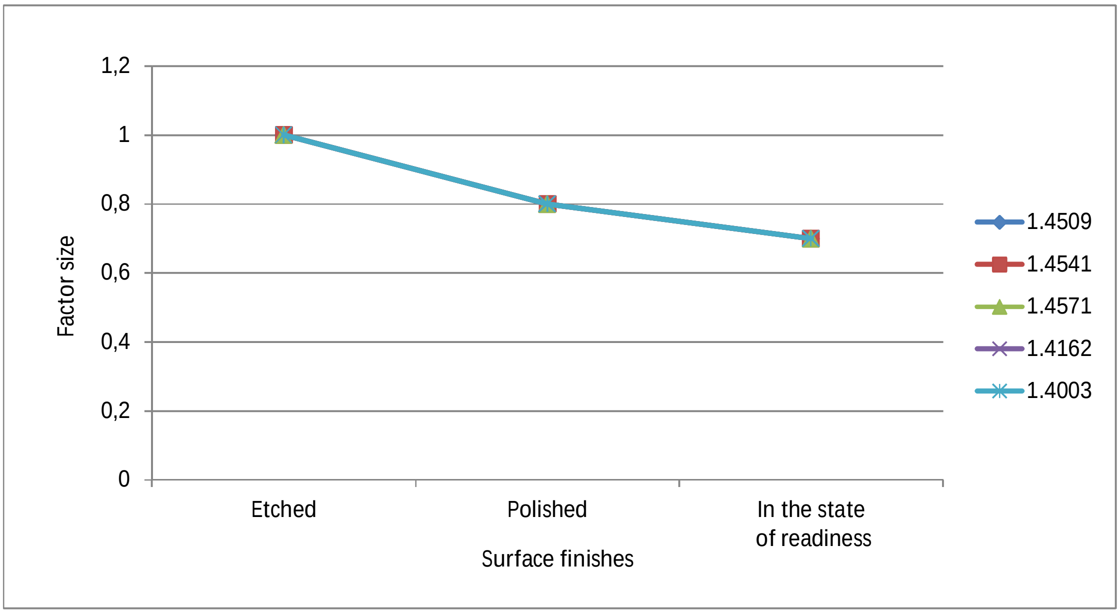


Figure 8. Service life factors for ferritic, austenitic and duplex stainless steel grades according to the surface finishes, the case structure is a steel frame.

2.1 Other parameters related to the service life

Other main parameters which have an impact on the service life are structural parameters (factor B), execution level (factor C), use phase (factor D), care- and maintenance level (factor G). All of them have many sub-parameters and their pattern of influence.

- Structural parameters which are taken into account in service life assessment are ventilation rate (factor B1) of the structure, protection rate against rain- and condensed water (factor B2), materials of fasteners and also their connection structure (factor B3).

- Parameters which related to the execution quality are transportation and storage level (factor C1), storage temperature and atmospheric humidity (factor C2), steel cutting method (factor C3), protection of edges (factor C4), and surface cleaning after cutting (factor C5).

- Façade deterioration parameters which are determined by the use phase are exposure to de-icing salt used in the streets (factor D1), façade protection level from the traffic load (factor D2), and strains from indoor air quality (factor D3).

- Parameters which are related to the maintenance level and which can cause loss in service life are omission of inspections (factor G1) and re-painting options (considered for those steel grades in which the painting is relevant) (factor G2).

It is assumed that all the parameters described above are most favourable for the assessed structure and they are chosen in this comparison so that they do not have an effect on the results (the factors for all those parameters is 1).

3. Estimation of service life for building components

The service life estimation for ferritic stainless steel grade applications and their comparison with carbon steel and austenitic stainless steel grades are made with the aid of ENNUS™-Steel tool for typical environmental conditions in the Baltic Sea region conditions (C2, C3 and C4). The corrosion category "high" is used for all climate conditions in the comparison (coefficient A1R=1 in Figure 3). The results are calculated by the probability level of 95% for the façade, roof and frame. The comparison of service lives of façades and roofs are shown in Figure 9 and *Figure 10*, and the comparison of steel frames are shown in *Figure 11*.

In the case of facades, the ferritic stainless grades 1.4016, 1.4509, 1.4521, 1.4509 and 1.4621 are compared with conventional austenitic stainless steel grades and zinc coated carbon steel grade. In the case of roofings, only grades 1.4521 and 1.4621 have been thought to have potential use there. Figure 9 and *Figure 10* show the results of these comparisons:

– Molybdenum alloyed ferritic stainless steel grade1.4521 is a little weaker than molybdenum containing austenitic 1.4401/1.4404, and 1.4621 is a little weaker than austenitic 1.4301/1.4307, but both of them can reach service life of 50 years even in the corrosion category C4.

– Grade 1.4509 is somewhat better than 1.4016 and somewhat weaker than austenitic 1.4372; and it is usually quite equal to and zinc coated carbon steel, but with good surface finishes the service life can be 50 years when the corrosion category is not more than C3 in the case roofs and not more than C2 of in the case of facades.

In the case of frames, only grades 1.4509 and 1.4003 are compared in *Figure 11*, because only they have today been thought to have potential use in this kind of applications. The comparison shows that the ferritic stainless steel grades are not competitive with the austenitic and duplex grades in outdoor applications, when 50 years surface life is required without any paintings and when the service life criterion is fair appearance. However, 30-year service life can be reached in the case of grade 1.4509.

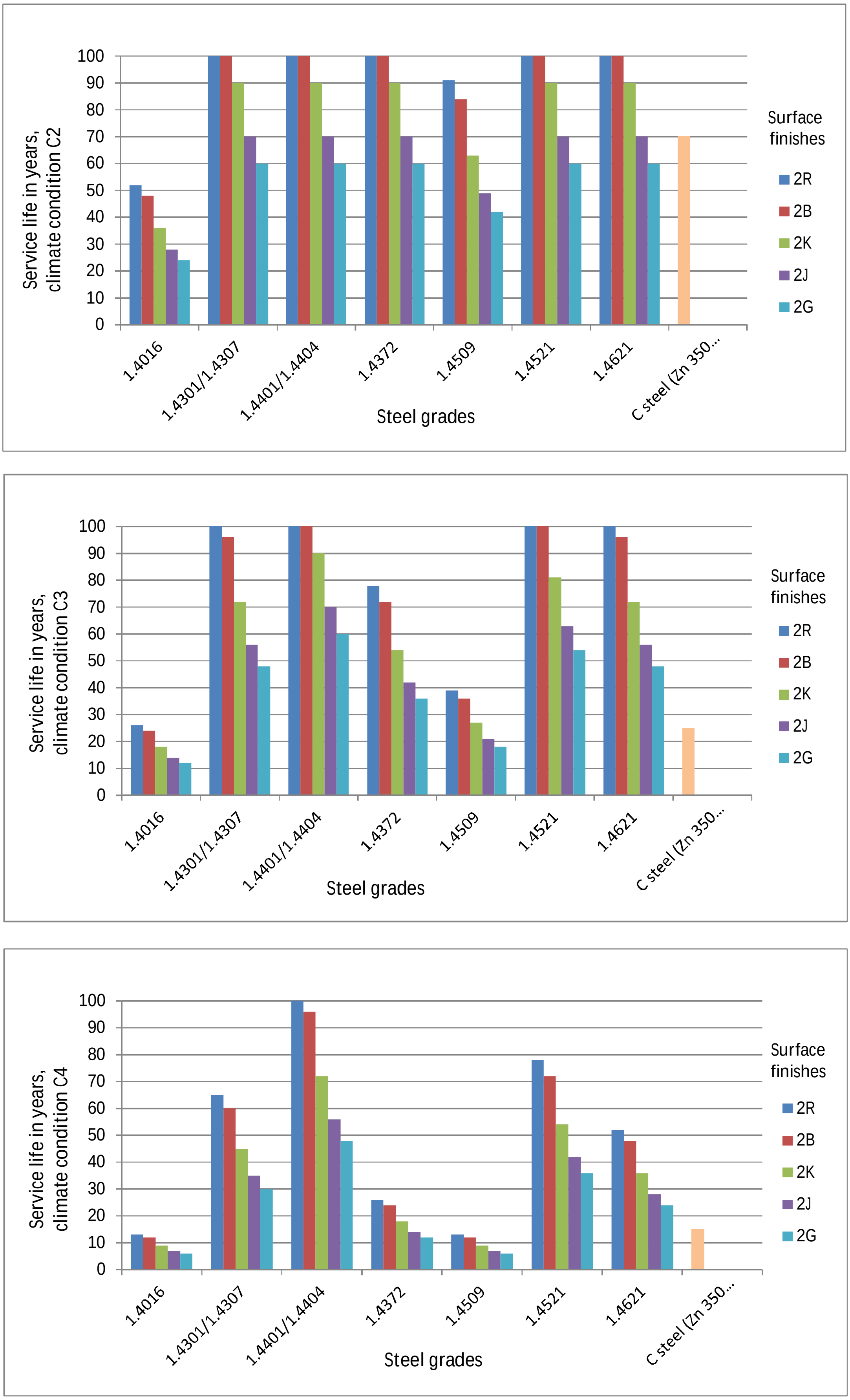


Figure 9. Service life for ventilated façade structure according to steel grade, climate condition, surface finishes and corrosion category high.

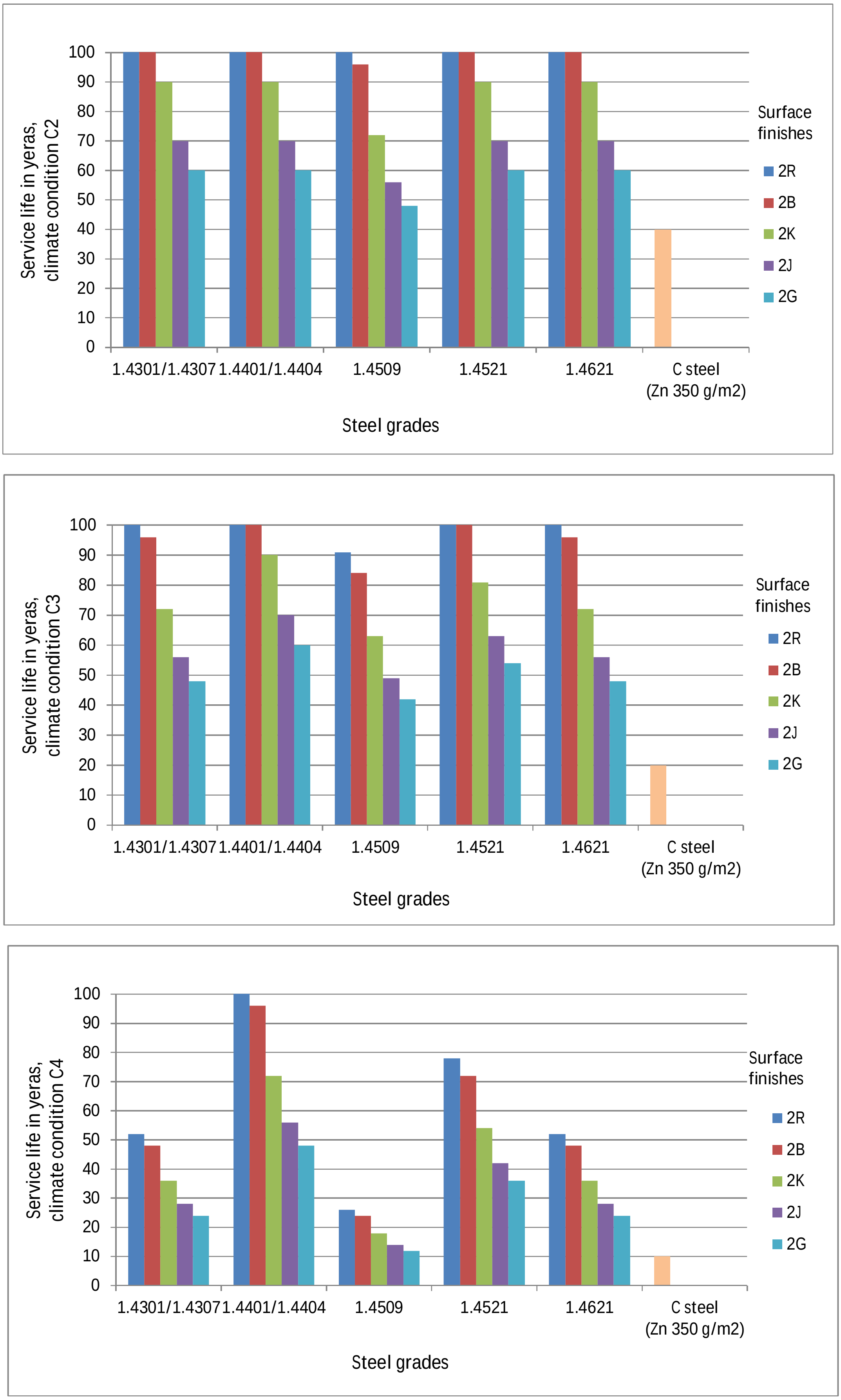


Figure 10. Service life for the roof structure according to steel grade, climate condition, surface finishes and corrosion category high.

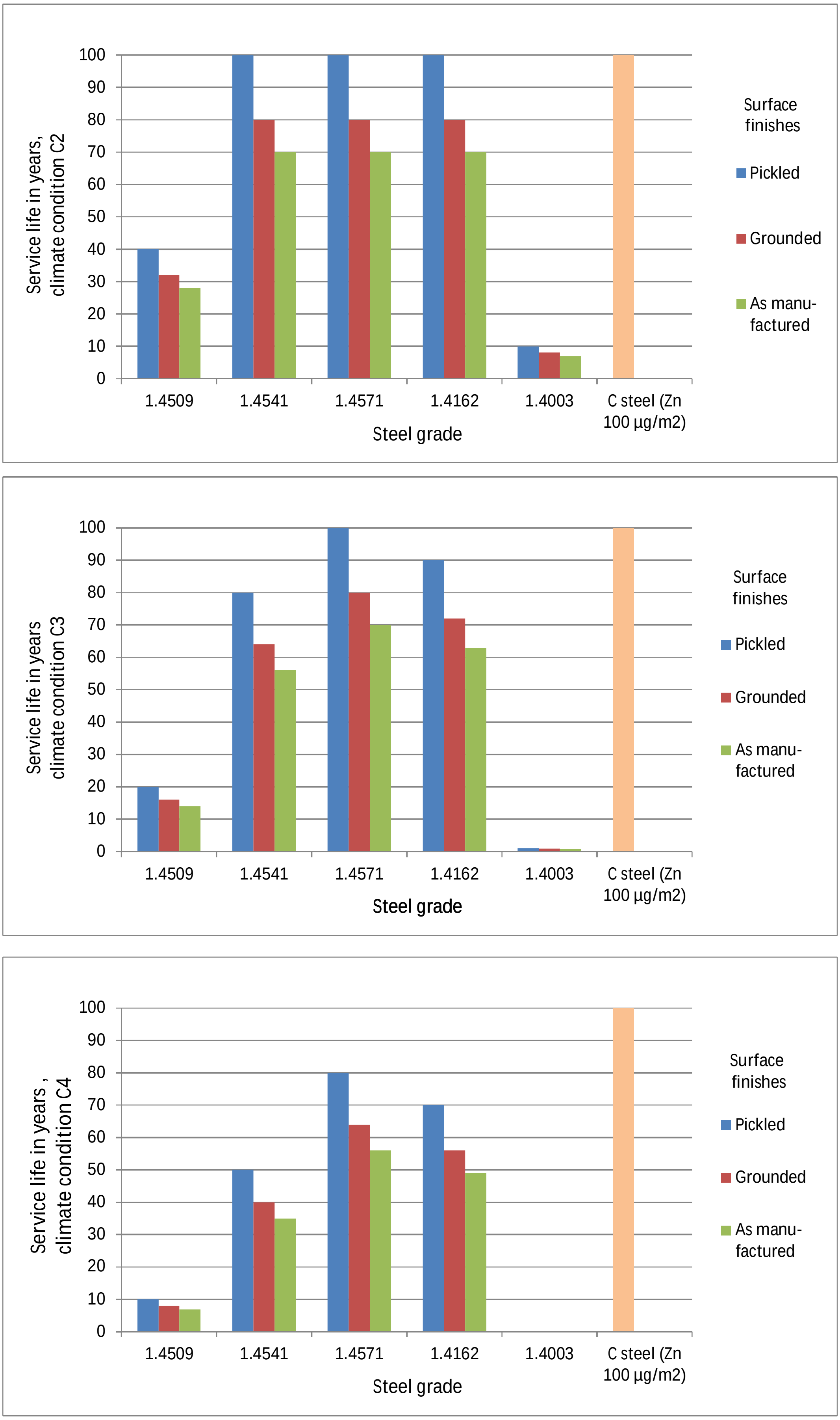


Figure 11. Service life for the frame structure according to steel grade, climate condition, surface finishes and corrosion category high.

4. Summary

In the design phase the designer should take care that the estimated service life is always longer than design life for the structure or building in question. Factor based method gives a good understanding how selection of steel grade, environmental condition and other design parameters effect on the service life and which are the real risks that set design life is not reached.

ENNUS™-Steel tool gives an easy approach and quick result for the service life estimation taking into account interaction and combined effect of different parameters like, atmospheric conditions, execution, use phase and maintenance quality. Main importance is the selection of appropriate grade for the application so that the designed life will be always achieved or exceeded.

Reference service life is determined as the typical lifetime for the structure in the operation. Estimated service life is calculated by multiplying the reference service life by different impact factors. Especially material type (steel grade) and atmospheric conditions have a decisive influence. The impact factors used in the comparisons of this study are based on the test results and they are defined as expert estimations in cooperation with Outokumpu Stainless Oy and VTT.

Service life, calculated by the factor method, is giving an order of magnitude for service life comparison. It is very challenging to set accurate magnitudes for the impact factors, and in addition to take into account the interaction effects of different factors. This is still an open process during which the 'right' factors and their values should be clarified. In any case the work should be continued just to take into account the final conclusions of SAFSS project, which were not available during writing this report. In addition, in the further development of the program, the more demanding corrosion categories C5-I and C5-M should also be included to it.

The comparison shows that beside the traditional carbon steel also ferritic stainless steels might as well be used for façade, roof and frame applications. The ferritic stainless steels are most competitive in facades and roofs, but they can be competitive also in steel frames if the atmospheric corrosion conditions are low or additional painting is used. The ferritic stainless steel grades can in the future substitute more and more carbon steels and austenitic stainless grades, because there are available many different steel grades with diverse mechanical and corrosion properties, and because their material prices are not depending the fluctuations of nickel price.