BENEFITS OF MOLYBDENUM USE:

The Myllysilta Bridge, Finland

Myllysilta Bridge, Turku, Finland

Use of molybdenum in external structures and façades

Molybdenum is used extensively as an alloying element in the production of construction and stainless steels. It enhances strength, hardenability, weldability, toughness, elevated temperature strength, and corrosion resistance.

While chromium content determines whether or not a grade of steel is considered to be ‘stainless’, molybdenum improves the corrosion resistance of all stainless steels. It has a particularly strong positive effect on pitting and crevice corrosion resistance, for example in harsh coastal environments and where chlorides and de-icing salts are present.

Federal Center South, Seattle. Photo: Kovach

Stainless steel is used in all aspects of architecture, building and construction. While it has been used in these industries since the 1920s and is not a new material, stainless steel’s use and range of applications has been growing.

The number of different stainless steel alloys used in building and construction has also expanded. The more highly alloyed molybdenum-containing stainless steels are preferred by leading architectural, landscape design and structural engineering firms for more corrosive locations because of their enhanced corrosion resistance.

Air pollution, salt exposure, weather patterns, design and cleaning frequency must be considered when selecting stainless steel and other construction materials if good long-term performance is desired.

In applications subjected to coastal or de-icing salt, industrial pollution, volcanic or other corrosive environment exposure, a molybdenum-containing stainless steel with a smooth surface finish is needed unless frequent cleaning is acceptable.

Designing the Myllysilta Bridge

The Myllysilta (literally meaning; ‘Mill Bridge’) is a road crossing of the Aurajoki River in the coastal city of Turku in Finland. Following the structural failure of a previous bridge in 2010, a design competition was held for its replacement and the bridge was completed in November 2011.

The new bridge, designed by WSP, is a slender composite steel girder construction and a key feature is the choice of stainless steel cladding for the underside. This material was specified for a combination of life-cycle cost savings, aesthetics and practical reasons.

The polished reflective surface provides a beautiful visual effect, especially at night-time when LED light projections onto the water are reflected back onto the cladding.

In addition, the outstanding practical features of molybdenum-containing stainless steel were key to its selection. Being a brackish river and with extensive use of de-icing salts on the road above throughout the long winter months, it was essential that the cladding was highly corrosion resistant. It was also essential that the cladding would require the absolute minimum of ongoing maintenance, since this would be complex, expensive and would present serious health, safety and environmental concerns.

Duplex stainless steel grade 2205 (EN1.4462), containing 3.1% molybdenum, was the clear material choice for the cladding as it is readily available, cost effective and highly durable in such an aggressive environment.

Molybdenum-containing stainless steel (grade 2205) cladding of the Myllysilta Bridge

Assessing the benefit

A Life Cycle Assessment (LCA) has been conducted of the relative environmental impacts of the choice of stainless steel grade 2205 compared to a standard alternative material for the cladding of the Myllysilta Bridge: mild steel with an anti-corrosion paint treatment.

The LCA was conducted following the principles of the ISO 14040 standard which defines LCA as “the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.”

As a comparative assessment, this LCA focused on aspects of the life cycle of the cladding that differ according to the choice of material. This includes the environmental impacts associated with the manufacturing of the cladding material (including extraction of the raw materials, steel making and processing into 4mm-thick sheet) and the required surface treatment. It also included the impacts of any maintenance and replacement that would be required within the 100-year design life of the bridge. Finally, it included the impacts (and benefits) associated with recycling the cladding material at the end of its lifetime. Stainless steel containing molybdenum is a highly recyclable and economically valuable material.

An LCA allows for a comparison of the impacts of the two materials and also any potential trade-offs between lifecycle phases. It also allows the consideration of different categories of environmental impact. This assessment has focused on the following relevant metrics:

Global warming potential

This measures the impact in terms of contribution to climate change and includes the emissions of any greenhouse gasses (GHGs), expressed in terms of carbon dioxide equivalents. This is a critical performance measure of interest to the construction industry and other stakeholders. Many companies are required (or voluntarily choose) to report upon their ‘carbon emissions’.

Acidification potential

This measures the impacts of atmospheric emissions of sulphur and nitrogen oxides which lead to acid rain. These emissions are largely associated with the combustion of fossil fuels either directly or in the generation of required electricity. Acidification potential is expressed in terms of emissions of sulphur dioxide equivalents.

An LCA considers a range of environmental impact metrics

Eutrophication potential

Some products and processes result in airborne or waterborne emission of pollutants which increase nutrient levels in water bodies. This can cause algal blooms which lead to deoxygenation and death of aquatic life. Eutrophication potential is expressed in terms of emissions of phosphate equivalents.

Photochemical ozone creation potential

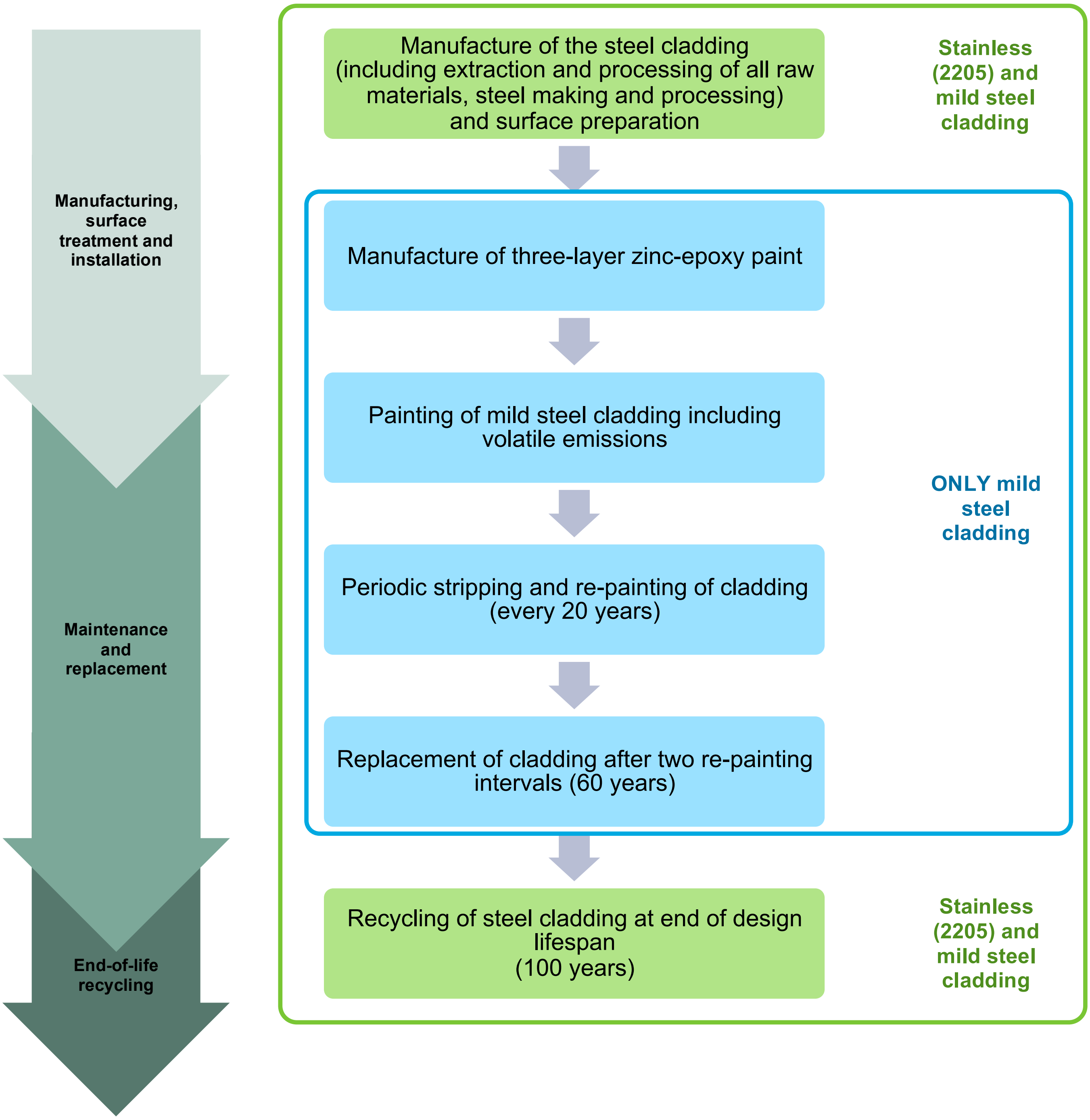
The formation of 'summer smog' in the atmosphere of large cities results from a reaction of sunlight with airborne pollutants such as nitrogen oxides and volatile organic compounds. Ozone is a highly dangerous substance at ground-level, leading to breathing difficulties, respiratory illness and premature death. Photochemical ozone creation potential (POCP) is expressed in terms of emissions of ethylene equivalents.

Primary energy demand (non-renewable)

This is a measure of the consumption of non-renewable primary energy resources such as coal, natural gas and oil and is therefore associated with global warming potential. The metric is expressed in terms of megajoules (MJ) of energy demand.

Data and assumptions

An LCA inventory was developed to include the significant comparative stages of the lifecycle of stainless steel (grade 2205) and painted mild steel cladding, as shown in the following diagram.



The study did not consider aspects of the lifecycle inventory which are not significantly different for the two options, for example:

- Cutting and shaping of cladding.
- Initial delivery and installation of cladding in year 1 (delivery and installation of replacement mild steel cladding after 60 years was included)
- Removal of cladding at end-of-life: estimated 100 years (removal of original mild steel cladding when replaced after 60 years was included).

A number of industry sources were used to assess the impacts of each stage of the lifecycle for the two cladding options.

Impacts of manufacturing steel

Data for the impacts of manufacturing the required 82 tonnes of cold-rolled stainless sheet (grade 2205; with 3.1% molybdenum) was provided by Outokumpu; the source of the stainless steel for cladding the Myllysilta Bridge. This was based on raw materials and steel making across their European plants (Germany, Sweden, Finland), which use electric arc furnaces and an average 61% scrap stainless steel content.

Data for the impacts of steel making for the same quantity of cold-rolled mild steel sheet was provided by the World Steel Association, based on average production across the European Union. This included the use of blast furnaces fed by an average of 0.11kg of ferrous scrap and 1.36kg of iron ore for each 1kg of steel produced (i.e. 11% scrap content).

Impacts of manufacturing anti-corrosion paint

For the mild steel cladding option, it was assumed that a three-layer zinc-epoxy paint system (Tiel 4.20) would be required to provide appropriate corrosion resistance; in line with the standards for bridges in Finland. The lifecycle impacts of manufacturing such paint were assessed on the basis of specifications for typical composition.

Impacts of surface treatment

For the stainless steel cladding option, the impacts of energy consumption were included for achieving the brushed surface finish. For the mild steel option, the impacts of preparing and painting the steel sheet were assessed. This included impacts in relation to energy consumption for shot-blasting to prepare the surface and high-pressure airless spray-painting. This was based upon the published specifications for the anti-corrosion paint.

Impact factors for all energy consumption were based on grid electricity and fuels used in Finland.

Impacts of maintenance

For the mild steel option, it was assumed that the anti-corrosion paint would have to be removed and re-applied to the outer surface of the cladding every 20 years. This frequency was a conservative assumption based upon the paint specification and industry experience. The environmental impacts were therefore assessed in relation to the whole process of shot-blasting and airless spray-painting. In this instance, the calculations were based on conducting the work in situ with a scaffold mounted on the bridge. An allowance was included for delivery and lighting of the scaffold as well as the impacts of disposal of hazardous painting waste by incineration.

Impacts of replacement of cladding

Stripping and re-painting the outer surface of the mild steel cladding would still result in gradual deterioration, leading to an unsatisfactory appearance due to edge corrosion and pitting. It was therefore assumed that after two re-painting intervals (60 years) it would be necessary to remove and replace the cladding. The lifecycle impacts of replacement cladding (and the required paint) were also therefore included.

Impacts of end-of-life recycling

The environmental impacts of the end-of-life recycling of stainless steel (grade 2205) and mild steel were provided along with the data for manufacturing impacts. On average, 95% of each type of steel in Europe is recycled at end-of-life, following its use in the construction industry. Since recycling offsets the need for virgin resources, the environmental impact at end-of-life is in fact negative (i.e. a benefit in terms of environmental impacts avoided).

In the case of the recycling of the stainless steel used at Myllysilta, this 'recycling credit' is highly significant; approaching (and for one of the metrics even exceeding) the original manufacturing impact. This is because stainless steel manufactured by the supplier has relatively low environmental impacts (relatively 'clean' grid electricity and mining practices) in comparison to the recycling credit, which is based upon European average stainless steel production – since it cannot be known where the recycling will take place.

End-of-life recycling of mild steel also provides a 'recycling credit', as provided by the World Steel Association, although this is not as significant as that for stainless steel. The end-of-life recycling benefit of the replacement mild steel cladding was added to that for the original cladding.

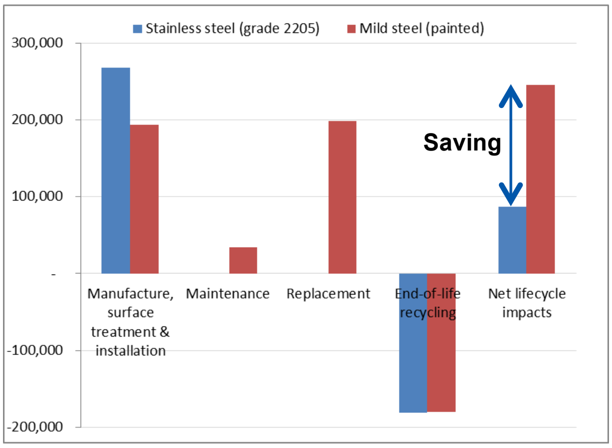
Life cycle assessment results

The LCA of cladding materials for the case of the Myllysilta Bridge indicates that stainless steel (grade 2205; 3.1% molybdenum) presents significant net benefits across all major impact categories, in comparison to painted mild steel.

Global warming potential

Although manufacturing of stainless steel (grade 2205) cladding causes greater impacts than mild steel in terms of global warming potential, this is more than offset by the relatively high end-of-life recycling credit and the impacts of the need for painting and replacement of the mild steel cladding.

Overall, for this bridge, stainless steel cladding has only around 38% of the net lifecycle global warming potential of the mild-steel option. The scale of the lifecycle saving in global warming potential is indicated on the chart below.

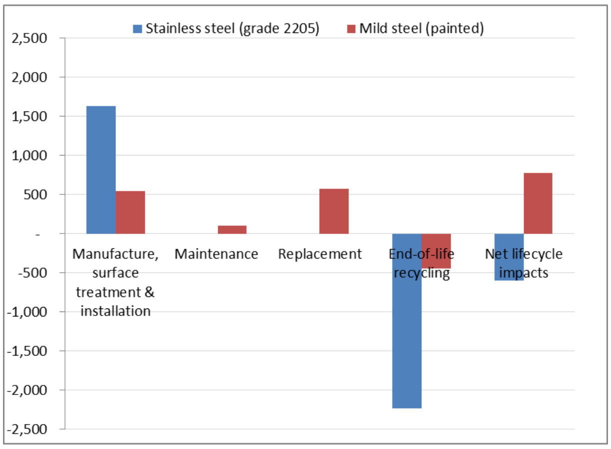


Global warming potential (kg CO_2 eq)

Acidification potential

As a result of the highly significant end-of-life recycling credit, the net lifecycle acidification potential of stainless steel cladding is actually negative[1]. This is due to the relatively low environmental impact of the manufacture of stainless steel used at Myllysilta in comparison to the European average (see previous section on end-of-life recycling).

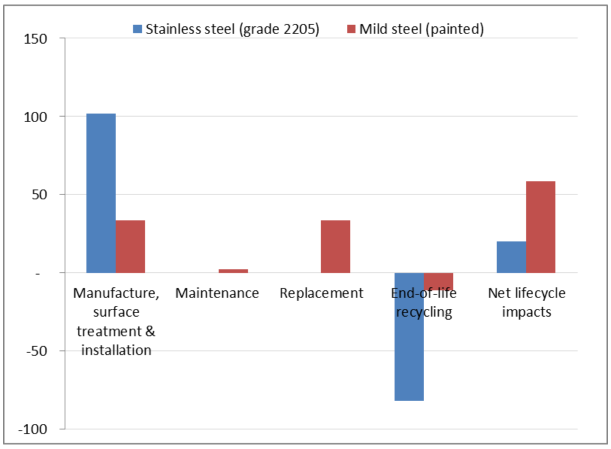
The recycling credit for mild steel cladding is also included but there is a (positive) net lifecycle impact in terms of acidification potential.



Acidification potential (kg SO_2 eq)

Eutrophication potential

Stainless steel cladding has only around 33% of the net lifecycle eutrophication potential of the mild steel option.



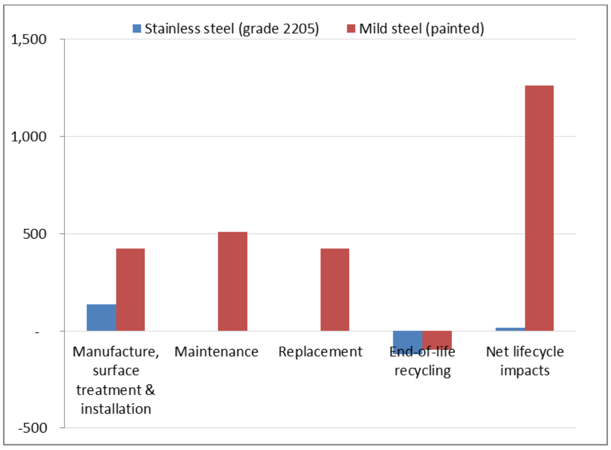
Eutrophication potential (kg PO_4^{3-} eq)

Photochemical ozone creation potential

The net photochemical ozone creation potential (POCP) of the stainless steel (2205) cladding option is a tiny fraction (around 1%) of that for the mild steel option. This is largely a result of the very high POCP for various volatile organic compounds (solvents) which are present in the anti-corrosion paint system for the mild steel cladding. Following the application of this paint, these compounds evaporate off and may contribute to photochemical smog formation.

[1] The EC ILCD Handbook *General guide for Life Cycle Assessment - Detailed guidance* (page 77) discusses how credits for recycling operations for avoided primary production can lead to negative overall environmental impacts.

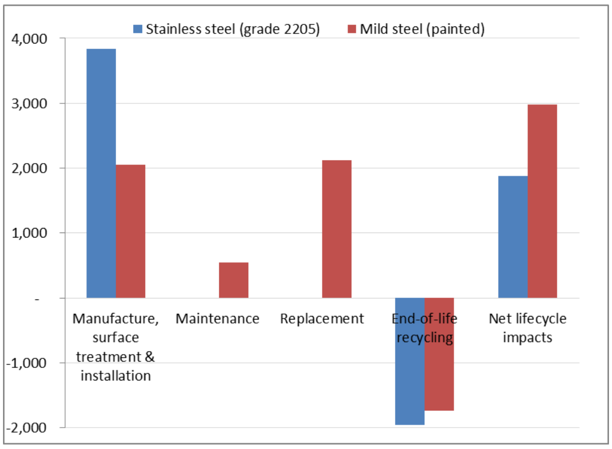
These volatile organic compounds are emitted from the paint after application to the original cladding, after each 20-year interval of re-painting and after painting the replacement cladding. There is a lesser contribution to POCP from the manufacturing of steel (stainless and mild steel).



Photochemical ozone creation potential (kg C_2H_4 eq)

Primary Energy Demand (non-renewable)

Related to the results for global warming potential; the stainless steel cladding has only around 62% of the net lifecycle primary energy demand (non-renewable) of the mild steel option.



Primary Energy Demand (non-renewable) (GJ)

Sensitivity analysis

Sensitivity testing was completed in relation to a key assumption for this LCA: the need for replacement of the mild steel cladding after two re-painting intervals (60 years). The LCA model was re-run with the assumption that replacement would not be required within the 100-year bridge design life as long as the cladding was re-painted every 20 years. Even on the basis of this assumption, stainless steel (grade 2205) presents significant net benefits across the major impact categories.

A sensitivity test was also performed using European average data for the lifecycle impacts of manufacturing stainless steel (2205) – rather than the data provided by the steelmaker that supplied the Myllysilta bridge cladding. Net life cycle impacts were still found to be lower than those for the mild steel option in the case of global warming potential, eutrophication potential, photochemical ozone potential and primary energy demand (non-renewable). Acidification potential was found to be higher using European average manufacturing data, which may be due to a lower proportion of renewable energy in the mix compared to the steelmaker's data.

Summary and conclusions

A Life Cycle Assessment (LCA) was completed for the comparative environmental impacts of the use of stainless steel (grade 2205; containing 3.1% molybdenum) and mild steel cladding for the Myllysilta Bridge in Finland. This covered the significant stages of the cladding lifecycle which differ for the options, during the following stages of the bridge's assumed 100-year design life:

- Manufacturing (including raw material extraction processing and steel making), surface treatment and installation of cladding
- Maintenance (mild steel only)
- Replacement (mild steel only)
- End-of-life recycling credit

The results indicate that stainless steel presents net benefits across all major impact categories:

- **around 38% of the global warming potential**: significantly lower carbon emissions due to the relatively high recycling credit as well as the lack of required maintenance or replacement;
- **around 33% of the eutrophication potential;**
- **a tiny fraction (1%) of the photochemical ozone creation potential:** much lower 'smog formation' potential due to the high content of volatile organic compounds in the anti-corrosion paint required to protect mild steel;
- **around 62% of the primary energy demand (non-renewable).**

Molybdenum-containing stainless steel (grade 2205) therefore offers significant environmental benefits in the case of the Myllysilta Bridge. It also avoids the cost, complexity and safety issues of lifetime maintenance in coastal or other equally harsh environments.

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