Assessing the environmental advantages of high strength steel

Lisa Hallberg[1,*], **Jan-Olof Sperle**[2]

[1]IVL Swedish Environmental Research Institute, Gothenburg, Sweden

[2]Sperle Consulting AB, Stockholm, Sweden

[*]Lisa.Hallberg@ivl.se

Abstract High strength steel grades often have a larger environmental impact compared to ordinary steels when just considering the "cradle-to-gate" results per tonne steel. This is generally due to larger alloy content and/or more complex process routes. On the other hand, less material might be required to fulfil a specific function and the life-span of the steel product might increase. This often means that the environmental impacts of high strength steel used in an application, is lower than if ordinary steels were used. It is therefore important not to compare different steel grades based on the cradle-to-gate results per tonne steel. Using less material in a product reduces the quantity of materials produced, and also affects the use phase of the product life cycle for active applications such as vehicles. There is a huge potential for savings in fuel consumption due to weight reduction in vehicles upgraded to high strength steel.

1 The project

The results discussed in this paper are based on the project *"The environmental value of high strength steel"* a part of the research programme *"Towards a Closed Steel Eco-cycle"*, funded by MISTRA and run by the Swedish Steel Producers' Association. For further information about the project a scientific report [1] is published as a part of the summary report [2] for the whole research programme.

High strength steel grades often have a larger environmental impact compared to ordinary steels when just considering the "cradle-to-gate" results per tonne steel. This is generally due to larger alloy content and/or more complex process routes. On the other hand, less material is often required to fulfil a specific function. In addition, the life-span of the steel product can increase.

The **goal** in this project is to investigate and quantify the environmental consequences obtained by replacing ordinary steel with high strength steel. This is an important assignment since sometimes conclusions are drawn based on the cradle-to-gate LCI-results i.e. that the steel grade with the lowest impact per tonne steel is the best.

An **LCI database** for a large number of steel grades (both carbon and stainless steels) have been compiled, based on inventories among the Swedish steel producers. Both ordinary steel and high strength steel are included to facilitate the calculation of the effect on the environmental performance obtained when upgrading an application from ordinary to high strength steel.

A number of comparative **case studies** have been performed both on passive and active applications e.g. a storage tank (passive application in stainless steel), a semitrailer tipper (active application in carbon steel).

A **software tool** for design engineers is also developed in this project. This tool is intended for assessments of the life cycle environmental savings obtained when high strength steel replaces ordinary steel. The tool allows for the assessment of both passive and active structures, with focus on the latter (e.g., trucks, cars, buses, trains, and ships).

2 Comparing cradle-to-gate results of two stainless steel grades

From above it can be concluded that comparing cradle-to-gate results (per tonne steel) is not appropriate since high strength steels often require less material to fulfil a specific function.

For *stainless* steel, the fact that these steels are *scrap based* makes things even more complex, with respect to comparing steel grades.

Since the scrap input is modelled without environmental burden in the cradle-to-gate stage (which is recommended by Eurofer [3]), a stainless steel grade using a large share of scrap comes out better than a stainless steel grade with a large share of virgin raw materials, even though its content of alloys is higher for the former. This will encumber new steel grades when just comparing cradle to gate results. The use of scrap in a new steel grade is typically small, since there is not yet much scrap on the market. This means that the cradle-to-gate results will not reflect the future potential for such a steel grade.

The example presented in Table 1 will illustrate this.

Tab. 1: Example of two stainless steel grades, which because of different shares of alloys from virgin raw materials and from scrap will show unexpected cradle-to-gate results.

Steel grade according to EN definition	Steel grade description	Cr content	Ni content	Share of Cr from virgin raw materials	Share of Ni from virgin raw materials
Steel (EN 1.4301)	Ordinary steel	18.1 %	8.3 %	32 %	22 %
Steel (EN 1.4162)	High strength steel (Duplex)	21.5 %	1.5 %	56 %	27 %

In the example, the burden for scrap inputs as well as the credit from scrap outputs have been considered in the analysis. This has been performed according to the Eurofer method [3] by applying "the value of scrap". In the Eurofer study [4], the value of scrap for four stainless steel grades are reported. To obtain such values for the steel grades used in our study, a multiple regression analysis was made based on the Eurofer data, resulting in a correlation between the value of scrap and the content of alloys of nickel, chromium and molybdenum.

The cradle-to-gate results for the steel grades in Table 1 are presented in Fig. 1.

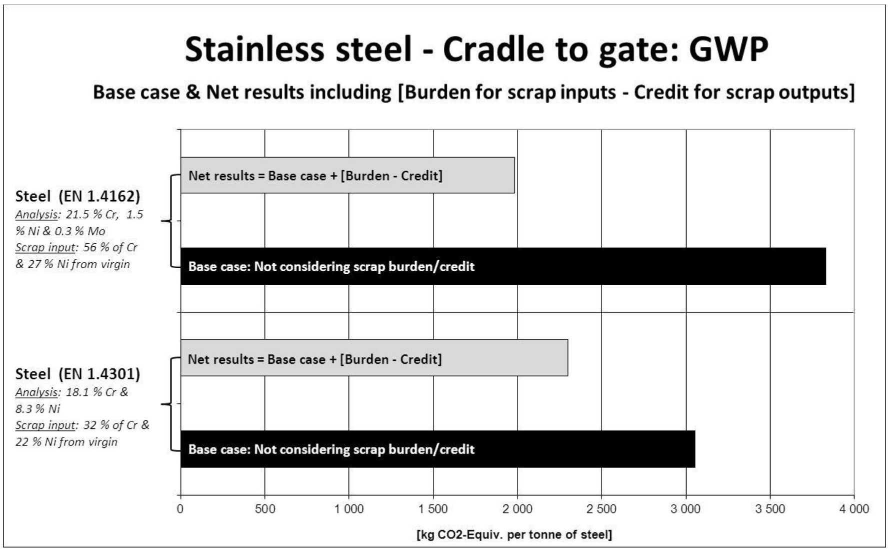

Fig.1: Cradle-to-gate results of two stainless steel grades.

The base case corresponds to the cradle-to-gate scenario, where the burden of the stainless scrap input is not included. The Eurofer study [4] publish the cradle-to-gate results in the same way. Eurofer then recommends to add the burden for the stainless steel scrap in the end of life phase when performing an LCA on a steel application and at the same time include the credit for the scrap generated at recycling of the steel application. In this project we have used the Eurofer methodology as well, but in the example above we want to illustrate the influence of the scrap together with the "cradle-to-gate-results" (base case). This is illustrated as "Net results" in Fig. 1.

The net results are obtained when considering the burden for inputs of scrap as well as the credit for scrap generated when a steel product is recycled i.e. the Net results = Base case + Burden for scrap inputs - Credit for scrap outputs. In this example, a recycling rate of 90 % for the scrap output has been assumed.

The duplex high strength steel (1.4162) has a **26 % larger** impact even though the Ni content is much lower and the Cr content is only slightly higher than in the ordinary steel grade (1.4301). This is explained by the fact that the "1.4162" steel has a larger share of Cr & Ni from virgin raw materials (56 % & 25 % compared to 32 % & 22 % for steel "1.4301"). This is due to the fact that less scrap is available on the market compared to the much more common steel grade

"1.4301". Stainless steel scrap is a scars resource and the scrap is used where it is most efficient. This means that established steel grades usually have a higher scrap input than new grades.

On the other hand when considering the burden for the scrap inputs as well as the credit for scrap generated when a steel product is recycled (assuming a recycling rate of 90 %), the high strength steel (1.4162) instead becomes **14 % better**. In a "real life" situation this steel will turn out even better since less steel will be required in an application due to higher strength. This will be illustrated in the case study of a storage tank produced in these steel grades (see Section 3, incl. Fig. 2).

The results in Fig.1 show that it is easy to interpret LCI/LCA data in the wrong way depending on what is included or not. Experienced LCA practioners will not make this mistake, but since LCA are now widely used there is a risk that wrong conclusions are drawn.

3 Case study: Storage tank

A storage tank for storing marble slurry and similar liquids was analysed in a cradle to grave perspective [1]. Before upgraded to the high strength steel "1.4162" it was made from the ordinary steel "1.4301" (see Tab. 2). The results from the LCA of the storage tank are presented in Fig. 2.

Tab. 2: Definition of the storage tank case study.

	Steel grade according to EN definition	Cr content	Ni content	Steel consumption [tonne per tank]	Recycling rate for the end of life of the tank
Before upgrading	Steel (EN 1.4301)	18.1 %	8.3 %	58.2	90 %
After upgrading	Steel (EN 1.4162)	21.5 %	1.5 %	38.7	90 %

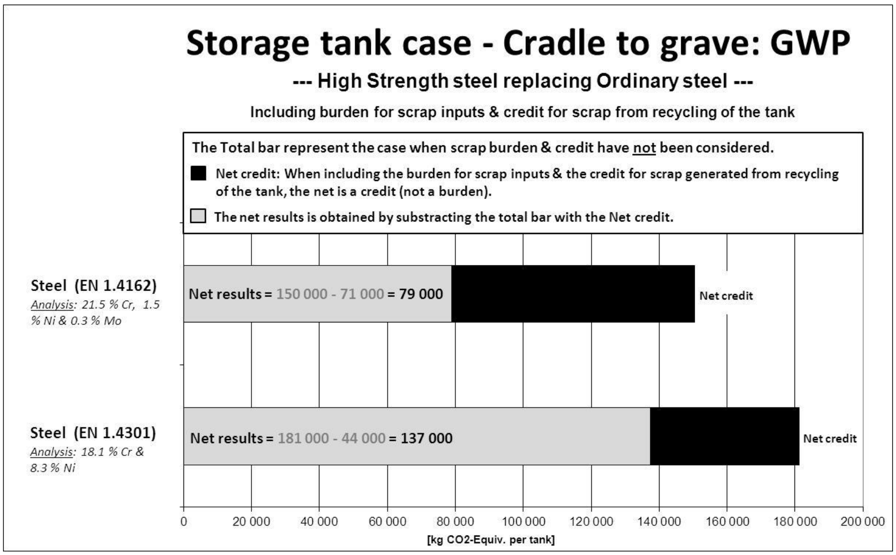

Fig. 2: Cradle-to-grave LCA results for the storage tank. The results include the burden for scrap input as well as the credit for the scrap generated from the recycling of the tank (assuming a recycling rate for the tank of 90 %).

The results show that the tank in high strength steel (1.4162) is **17 % better** than the ordinary steel (1.4301) even when the burden/credit of scrap is not considered. This is due to the lower weight of the application in high strength steel. When including the scrap burden/credit, the tank in high strength steel turns out to be **43 % better**.

4 Environmental savings in the use phase

Using less material in a product not only reduces the quantity of materials produced. It can also affect the use phase of the product life cycle, especially for active applications such as vehicles. There is a huge potential for **savings in fuel** consumption due to weight reduction in vehicles upgraded to high strength steel.

4.1 Case study: Semitrailer tipper

A semitrailer tipper used for transport of steel coils and steel scrap was analysed in a cradle to grave perspective (Fig. 3) [1]. Parts in the chassis and the tipper body were upgraded from ordinary carbon steel to high strength carbon steel. Several different steel grades were involved.

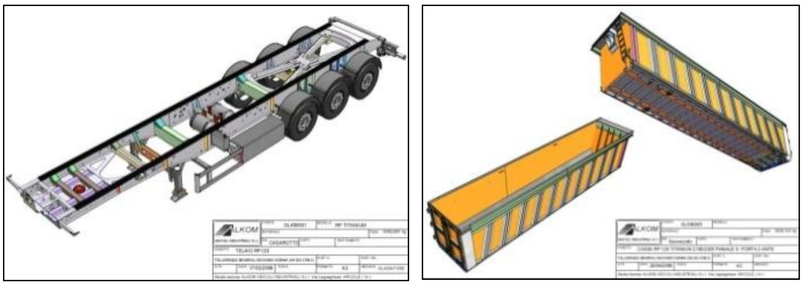

Fig. 3: In a semitrailer tipper, parts in the chassis and the tipper body were upgraded from ordinary steel to high strength steel.

The total weight of the vehicle is 44 tonnes. The total weight reduction of the upgraded parts is 1.3 tonne. This weight reduction can be used to increase the payload (from 27 to 28.3 tonnes) since transport of steel is weight critical. A life time of 6 years was assumed.

The total environmental savings in terms of Global Warming turned out to be 5 %, which corresponds to 40 tonnes of CO2 equivalents per vehicle during its life time. About 99 % of these savings is due to the use phase (the reduction in fuel consumption). An economic analysis showed a reduction in cost of 10 %, of which 90 % is caused by the fuel savings.

4.2 Case study: European road vehicle fleet

In order to facilitate the understanding of the environmental value of high strength steel, a general case study including the use phase was performed [1].

This shows that every million tonne of high strength steel that replaces conventional steel in the European road vehicle fleet results in a saving of 8 million tonne CO_2 emissions and 30 TWh non-renewable energy resources during the lifetime of the vehicles. Over 90 % of these savings are related to the use of the vehicles.

These results highlight the importance of including the use phase in order to recognize the environmental potential of advanced high strength steel.

5 Conclusions

Because of the following reasons, different steel grades should not be compared based on the cradle-to-gate results per tonne steel:

- Less material is required to fulfil a specific function when high strength steel is used.

- Since the scrap input for stainless steel is modelled without environmental impact, a stainless steel grade using a large share of scrap comes out better in the cradle-to-gate analysis than a stainless steel grade with a large share of virgin raw materials, even though its content of alloys is higher for the former.

A full cradle to grave LCA including the function of the use of steel in an application and considering the burden for scrap inputs and the credit for scrap outputs must be performed in order to obtain a fair comparison of different steel grades.

The environmental impacts of high strength steel used in an application, is often lower than if ordinary steels were used. Using less material in a product not only reduces the quantity of materials produced. It can also affect the use phase of the product life cycle, especially for active applications such as vehicles. There is a huge potential for savings in fuel consumption due to weight reduction in vehicles upgraded to high strength steel.

6 References

[1] Jan-Olof Sperle, Lisa Hallberg, Jonas Larsson, Hans Groth, The environmental value of high-strength steel structures II (88044), The Steel Eco-Cycle, Environmental Research Programme for the Swedish Steel Industry, 2004 – 2012.

[2] The summary report for the whole Steel Eco-Cycle research programme can be downloaded at www.steelecocycle.com <http://www.stalkretsloppet.se/english/index.php>.

[3] Eurofer and PE International, Methodology report: Life Cycle Inventory on Stainless Steel Production in the EU, March 2011.

[4] Eurofer and PE International, Life Cycle Inventory Study on Stainless Steel Production in the EU, November 2009. The report is not public.