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Jukka Joutsenvaara • Raimo Vierelä

Future Materials in Agricultural Construction

Technical report

Publications of Kemi-Tornio University of Applied Sciences
Serie B. Reports 14/2013

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Kemi-Tornio University of Applied Sciences
Kemi 2013

ISBN 978-952-5897-78-4 (pdf)
ISSN 1799-831X (electronic publication)

Publications of Kemi-Tornio University of Applied Sciences
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Financier: European Union European Regional Development Fund, Leverage from the EU, Centre for Economic Development, Transport and the Environment, TEKES

Authors: Jukka Joutsenvaara & Raimo Vlerälä

Cover images: : AGCO Corporation, Rautaruukki Oyj, LotusHead (http://www.sxc.hu/

Kemi-TornioUniversity of Applied Sciences
Tietokatu 1
FI-94600 Kemi, Finland
Tel. 010 353 50

www.tokem.fi/julkaisut

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Preface

When planning the usage of materials in different constructions it is important to take into account, for instance, strength-to-weight ratio, harshness of the environment and so on. These factors determine or limit the range of materials usable for that particular purpose. Agricultural environments typically contain acidic substances, such as fertilizers, feed or silage acids or plant protection products. These examples limit the amount of useful materials in various agricultural machinery and constructions. In addition, the ever tightening safety requirements can have a future impact on guiding the selection of materials used in various applications.

Depending on the choice of used steel, the corrosion resistance properties are achieved either naturally or through a variety of coatings. Inherently stainless steels have good corrosion resistance properties without any extra coatings. Depending on composition, stainless steels can have for example austenitic, ferritic and martensitic grain structures. On carbon steels added corrosion resistance can be achieved with different coatings. Traditional process for adding corrosion resistance to carbon steels is galvanizing. Use of coatings increases the total production costs in carbon steel products. The change of materials from carbon steels to certain stainless steel grades does not necessarily mean automatic increase in total production costs due to lack of finishing process.

Some points to take into account:

- Real and comprehensive evaluation of environmental impact and its scope effect the calculations of CO_2 emission values greatly: for instance recyclability after usage is much higher in metal based products than in composite products.

- In some operating conditions metallic choices are better inherently, on the other hand, safety requirements and legislation can guide to specific material choices (for instance, in snow mobiles the fuel tank material is to be metallic by legislation).

- Metals do not react as strongly to, for example, moisture or sunlight, such as composites made with bio-based fibers would.

- Corrosive and oxidizing conditions can be difficult to manage if the corrosive material gets into the fibers of composite materials.

- Less environmentally friendly glass / carbon fiber composites are extensively researched, but bio-based composites are a rather new invention so, for instance, long-term durability is not so well known.

Future trends in the development and usage of metals:

- Increase in yield strength.

- Evaluation and valuation of the carbon footprint in production of metals can be affecting factor in the future for selection of production materials.

- Challenges in cold forming due to increase of strength of materials, effects equipment and tooling requirements.

- Hot forming of high-strength steels is widely used in automotive industry and it will be spreading to other branches as well. Hot forming is achieved by controlling the cooling of the product between the tools. Tooling complexity increases, which affects adversely to productions costs. Hot forming enables forming of products with very high strengths and tight dimensional tolerances in the finished state.

- Use of aluminum and titanium could be plausible, if manufacturing costs remain at reasonable levels or the price of primary energy remains low enough for the energy intensive production of base material.

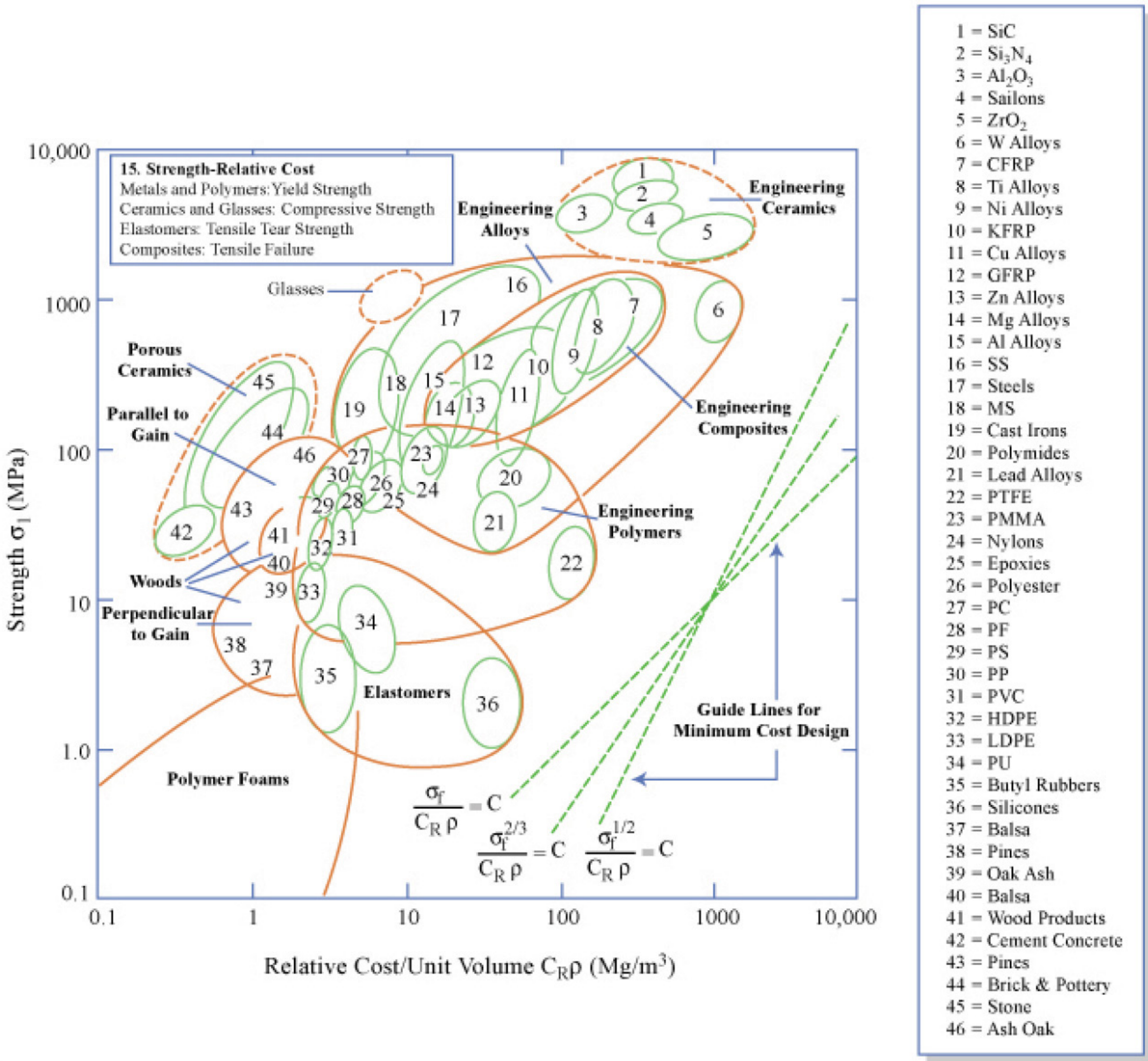
- Use and improvement of casting technologies could provide some valuable methods for manufacturing very complex parts from different steel and metal grades.

- Increase in the quality of design, in order to make the most of the potential of the developed materials. Production methods used for the specific products should be carefully evaluated and designed, especially forming and joining related issues should be thoroughly investigated. Weight-to-Strength optimization is not linear due to arise of stability issues when slenderness in construction reaches a certain point, for example, buckling issues.

- Increase of the quality of fabrication methods to better suit the handling requirements and guidelines of the new materials.

In Figure 1 Ashby diagram of strengths of different materials compared with unit costs is shown. This diagram could be used in evaluation of different materials in product design phase.

Figure 1. Ashby diagram of material strengths vs costs. /1/



1 Carbon steel Grades

1. 1 High-strength formable steels and extra high strength class 500-700 MPa

Nowadays high-strength formable steels are the biggest group in production. Steels can be divided in different groups based on the development process and its focus. Some grades are developed for excellent formability others for laser cutting and so on. For instance, practical benefit is obtained when optimal steel is used with laser cutting due to the quality of cut edges. With proper selection of material for specific production method, the number of production phases could be minimized as edge finishing phase is eliminated. The production methods which contains stretch forming of the material are better controlled and reproducible with especially tailor-made materials. In order to reduce waste, it is important to be able to decrease number of production stages and increase the quality of the remaining production stages. Reducing the waste streams directly affects the environmental impact of the product. High-strength formable steels do not require special fabrication measures as such. Normal, high-quality engineering and fabrication methods are good basis for the usage of high strength steels. /16/

The quality of manufacturing process and the quality of the whole supply chain are playing more and more important role when meeting the ever tightening requirements for environmental impacts. High-quality, cost-effective and environmentally friendly fabrication methods will be the trend of the future of steel construction industry. Appropriate and evaluated methods of fabrication are the basis for these goals to be achieved. In addition developing the traditional engineering functions at shop level, but also the development of the manufacturing processes, affect the total quality of products. In traditional fabrication complicated forms usually require assembly operations such as welding. In-depth knowledge of other fabrication or forming methods such as deep drawing could also provide good results and reduce the fabrication stages at the same time.

By changing the construction material from lower strength class to a higher it is possible to gain direct and indirect economical savings. Immediate savings are obtained due to the reduction of material needed for the product at production stage. Indirect savings could be accumulated when considering the whole life-cycle of the product. This concerns especially transportation equipment when their payload is increased due to the decrease of self-weight. /14/

Products with complex forms usually require some novel forming method. Combined forming methods include also heat treatment, or more typically, quenching phase during the forming stage. In automotive industry hot stamping is one of the most modern methods of making ultra-high strength steel components with complex forms. The increase in strength of the steels increases also the required forces to form products. Hot stamping is one method how to lower the needed forces for the forming process. With hot stamping, it is possible to get products with high tolerance accuracy and strength due to quenching in the tool. Hot stamping is best done with specially designed steel grades for added hardening features, namely Boron- steels.

Boron steels have somewhat higher yield strength in delivery state than regular construction steels. Cold formability of these steels are close to regular construction steels with same yield strength. Added value is gained by using boron steels in hot stamping. The final products dimensional accuracy and strength is achieved by quenching the blank in the tools during forming process. This fabrication method saves tooling due to the decrease of the forming forces, as well as enables high accuracy and high strength of the final product. Usefulness of this fabrication method in different products is limited due to relatively high tooling costs, due to their complexity, compared to traditional tools. Therefore, this method is best suited for large productions amounts that also require products with high accuracy of dimensions and high strength.

The development of materials by alloying allows them to have different behaviors, for example in terms of hardenability. Steels used for hot stamping, typically boron steels, are one of the fastest growing group of steels, which is already widely used in the automotive industry. Volume of usage is expected to continue to grow in the future, so it is one of the most interesting steel grade groups in the future. One of the recent developments of this fabrication method enables different strengths in different parts of the finished product. An Example of controlled cooling is shown in figure 2. /15/

When using thin, hot stamped and quenched products it is necessary to ensure corrosion resistance characteristics after manufacturing. The issue is a result of heating and cooling processes of the blank along with forming induced strains. For example, the properties of the zinc layer change significantly during these kinds of manufacturing processes. /7/

In figure 3 the range of strength of materials in a modern car is presented. In transport and work machines the range of materials might not be as wide as in cars, so there could be vast potential for optimization in material wise.

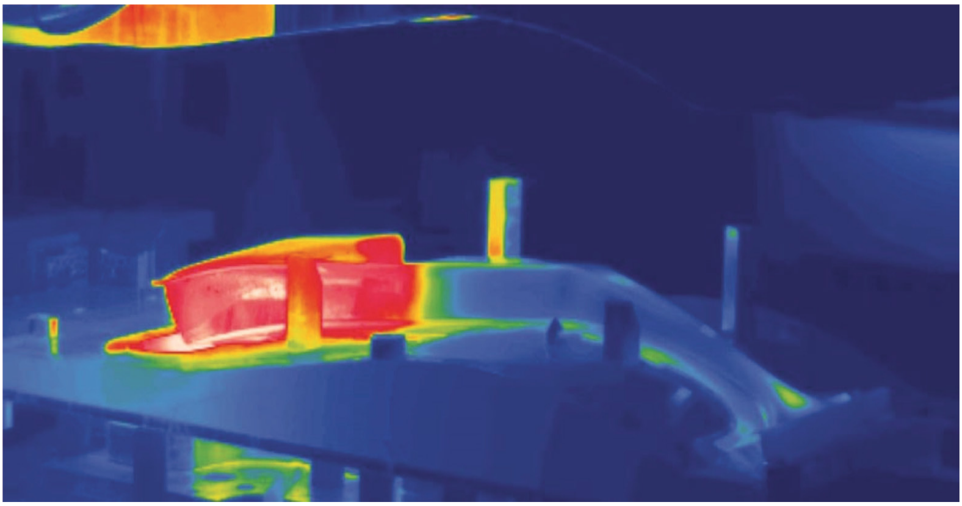


Figure 2. Tailored tempering of the product. /3/

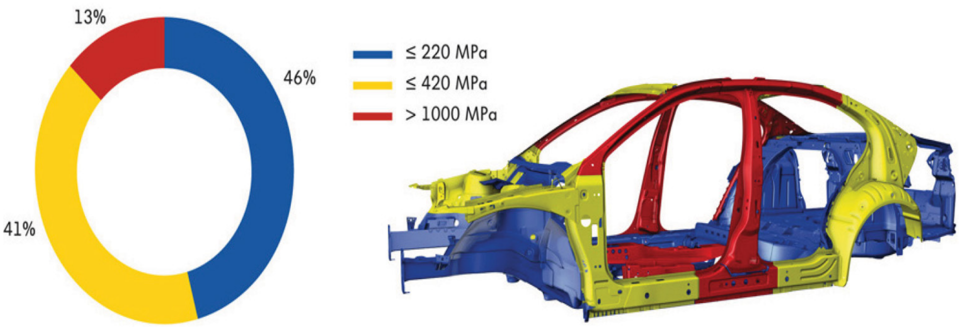


Figure 3. Usage of high strength steels in modern cars. /2/

1.2 Ultra high strength and wear-resistant steels

The use of ultra-high strength steels in modern and future products is based on a higher strength-to-weight ratio. For example Ruukki's complete selection of steels is a good example of continuous product development that can be benefitted by the end user. Increase in strength decrease the forming potential of the material but with good design the higher strengths of these steels could be fully utilized. The design principles are getting more and more important along with the strength increase in materials. Higher strengths of the materials also affect the fabrication processes. For example, the springback in bending of ultra-high strength steel is higher than in regular construction steel.

From energy efficiency point of view, increasing the strength of the structures is one way to achieve these objectives. In the current ultra-high-strength structural steels the yield strength reaches up to 1100MPa. Therefore, wear-resistant and ultra-high-strength structural steels yield strengths are very close to each other. Despite the close proximity of yield strengths, some properties are different and that can affect the rationality of usage of certain steel grades. /12/

Wear-resistant steels are typically used in applications that require specifically hard surface. Typically these applications are found in transportation and work machines that are under heavy wear and tear, especially where abrasive conditions are present. In agricultural machinery and equipment the strength of the materials and hardness will rise even further, as by utilizing these properties it is possible to increase the payload and service life as well as reduce the maintenance costs during service life. An interesting point of view is to widen the use of wear-resistant steels instead of regular construction steel. The change of material requires the design and fabrication quality to be up to date and follow the instructions of the manufacturer. An example of combined use of ultra-high strength and wear-resistant steel is shown in figure 4.

The modern wear-resistant steels have hardness range roughly from 300 HBW up to 550 HBW, which is nearly 3 times harder than in regular construction steel. Also when comparing service life, certain wear-resistant steels last up to 5 times longer than regular construction steel in similar conditions. As mentioned previously, fabrication parameters supplied by the manufacturer are to be used in order to get best results. /16/

Some manufacturers aim at developing wear-resistant steels to increase their ductility and formability. At the same time the development of ultra-high strength steels increases the yield strength, which also increases the hardness of the material. So perhaps, in the future, we might have only one type of ultra-high strength wear-resistant steel the hardness of which is enough for multitude of environments and conditions.

As mentioned before, it is most likely that a combination of usage of higher-strength steel grades with quality engineering services provides the most cost effective solutions for the manufacturing of products. In practice, this means that novel forming methods with new materials are not the easiest way for economical savings. The small steps required to improve the cost effectiveness are most likely the ones to succeed. Development of fabrication processes in order to facilitate the usage higher strength steels is a good way to start. All these improvements in the design and production stages aim at more environmentally friendly and cost effective production and products. In order to evaluate operating and maintenance cost throughout the life cycle of the product it is imperative to have the best available technology and knowledge at disposal.

Figure 4. Example of usage of ultra-high strength and wear-resistant steel. / 13/

2 Stainless steel grades

Traditionally, the use of stainless steel has focused on two steel grades: austenitic stainless steels 1.4301, and 1.4404. The usages of these two steel grades are historically high compared to other stainless steels grades. The use of these steels in the future can be justified by very good corrosion resistance properties and formability. Ferritic stainless steels have again emerged along with the austenitic grades primarily for their stable price due to the lack of nickel. Developed dual phase austenitic-ferritic steel grades, also referred as Duplex- stainless steels, have higher yield strength as austenitic and ferritic stainless steel grades. That provides the possibility for cost saving through material selection. In addition of these three mentioned types above, there are a lot of different grades for general and specific applications. Comprehensive methods for evaluating life cycle costs and carbon footprints favor stainless steel grades when the scope is wide enough and includes, for instance, previous recycling rounds.

2.1 Austenitic stainless steel grades

When regarding the economic aspects of the material selection phase, it could prove valuable to also take account into other grades than traditionally selected ones. The properties of stainless steels can be influenced by a variety of alloying elements and their relations during the manufacturing process. The properties can be enhanced by adding, for example chromium, nickel, molybdenum, nitrogen and others. Steel grade customization for a particular purpose or property can be achieved in this way.

In products, the environmental impact and the cost-effectiveness of the selected steel grade is based on material selection in the design or development phase of the product. Similarly the material selection affects the fabrication phase, for example increase in yield strength effects springback phenomenon. This is particularly true for products that experience large deformations during the manufacturing process. As with the high strength steels, the proper selection of the material based on the required properties is of outmost importance. /9/

The development of austenitic stainless steel grades trend seems to be heading toward customized solutions for demanding applications. With this trend, the manufacturers are able to provide the best solutions for specific applications for the customers. This also provides the customers to have a better way to assess the cost effectiveness of product selection. From Outokumpu's product range good examples of tailor-made grades are 724L and 725LN, which have good resistance particularly to urea which is common substance in agricultural environment. /9/

2.2 Ferritic stainless steel grades

When considering material selection for the product, the material cost plays a big part. In order to maintain reasonable variance of material costs, the stability of the price plays an important role. One of the reasons for selecting ferritic stainless steel grades is the stability of the price. The stability is due to lack of nickel. Some ferritic grades could be used in similar conditions as certain austenitic grades and that would provide cost savings rather easily. The figure 5 shows a few austenitic and ferritic grades in terms of corrosion resistance properties.

When considering the cost effectiveness of the whole production, manufacturing issues tend to affect the calculations. The welding is typically somewhat different from austenitic stainless steels compared to carbon steels due to the difference in thermal expansion coefficient. Ferritic grades, on the other hand, typically have similar coefficient than carbon steels, so the behavior in welding is better known and manageable at shop level. Machining and other cutting related processes require lower forces than with austenitic grades, so fabrication is quite close to normal carbon steels. When considering alternative materials for coated carbon steels in a product, the ferritic grades provide a good starting point to increase the properties of the product in question. Fabrication costs typically remain the same when changing the material from carbon steel to ferritic stainless steel grades.

Future prospects are relatively difficult to evaluate, but in practice however it is likely that there are a lots of applications where the change from austenitic grades to ferritic grades would provide savings in materials costs yet keeping the corrosion resistance properties at an adequate level. When changing to ferritic stainless steel from uncoated carbon steel, the corrosion resistance properties of the product will improve while manufacturing methods and costs typically remains almost the same.

2.3 Austenitic-ferritic steels, aka Duplex-steels

In duplex stainless steel grades, which have an austenitic-ferrite grain structure, have been combined excellent corrosion resistance and high yield strength. Cost-effectiveness of the duplex steels is based on the utilization of its high yield strength in corrosive conditions. Fabrication and other workshop processes of duplex grades are similar to austenitic grades with the exception of thermal expansion coefficient, which is closer to carbon steel. /8/

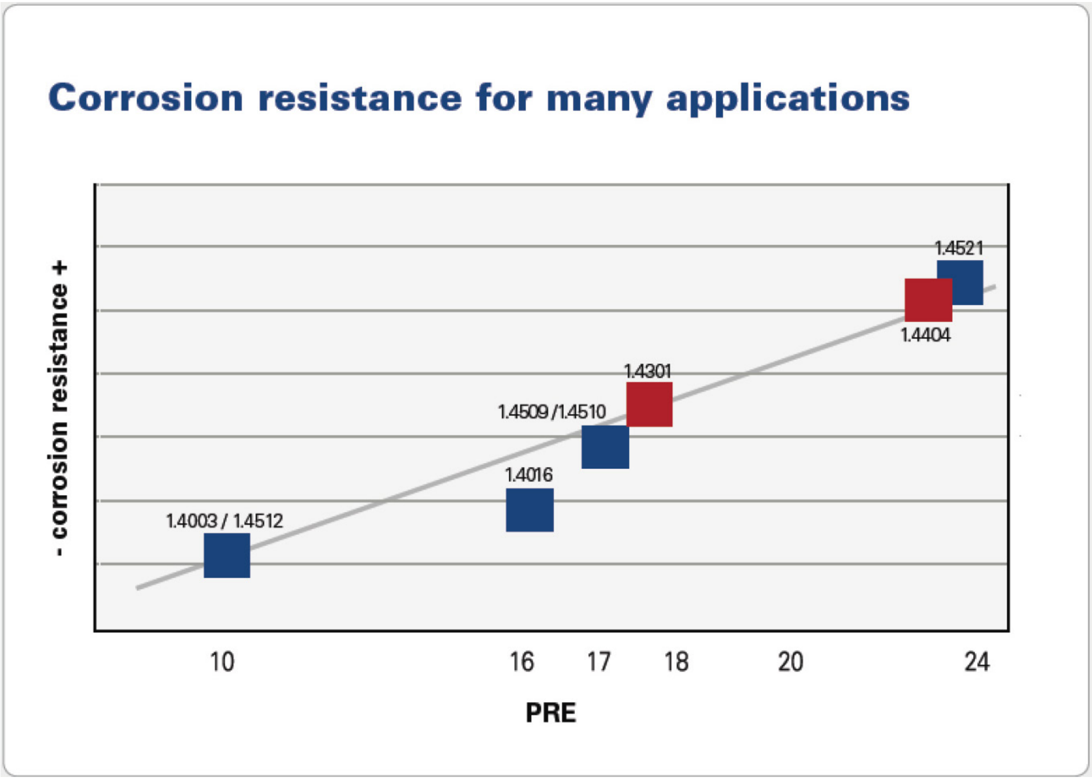


Figure 5. Corrosion resistance of some ferritic grades compared to austenitic grades. /11/

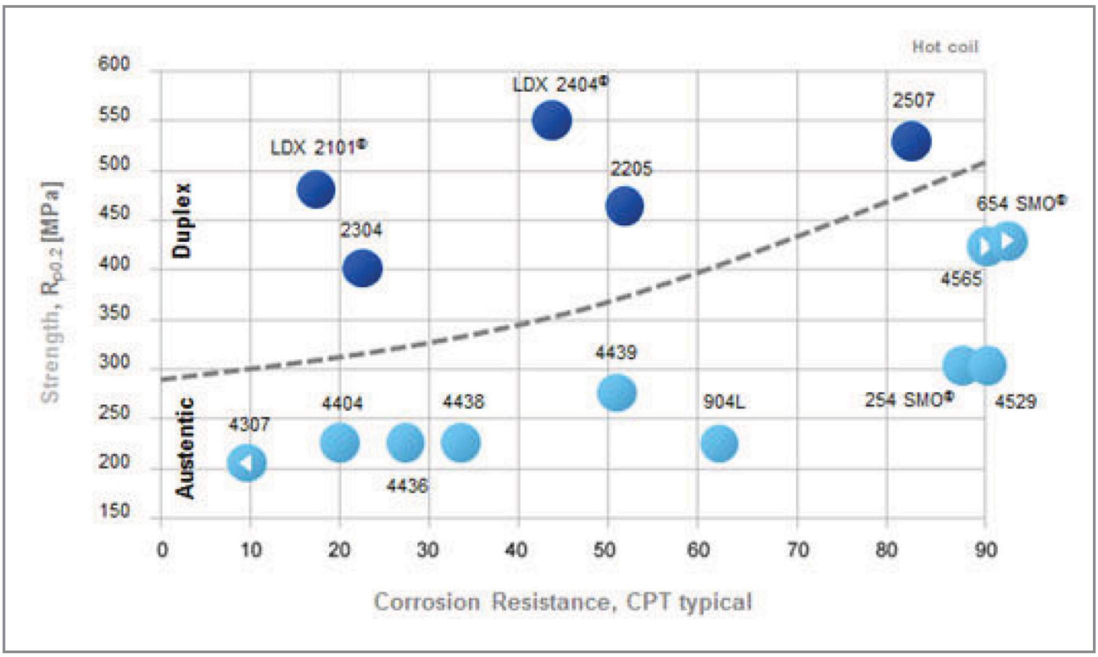


Figure 6. Properties of duplex-steel grades in relation to austenitic grades. /8/

Figure 6 shows the different types of duplex steel properties compared to the austenitic steel grades. From this figure is readily seen that the key to the cost efficiency is selection of proper material for particular application.

The forming operations of duplex steels are primarily similar to austenitic steel. The forming forces are affected by the higher yield strength of duplex steels and that should be taken into account when using this grade instead of austenitic stainless grades. Hot stamping of duplex steels is a similar process as with the previously mentioned boron steels. High precision is retained in the product after quenching process as with boron steels. / 7/

In figure 7 an example of material savings realized by substituting material in construction is shown. In this case the change is made from traditional austenitic stainless steel grade to duplex steel grade.

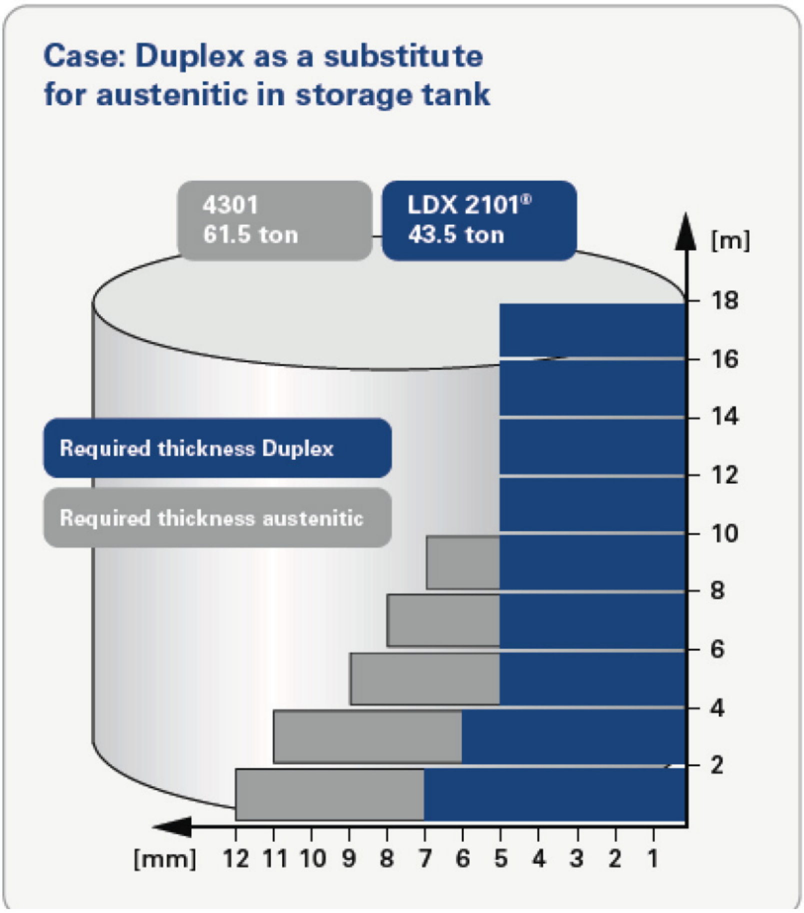


Figure 7. An example of material savings when using duplex steel grade. /10/

3 Other metal alloys

3.1 Aluminum

Based on experiences from transport equipment, the usage of aluminum is not without issues. The products exhibited some corrosion, as well as staining which were resolved with extra coatings. The extra coatings increased the production costs and maintenance costs during the service life. In highly loaded structures, the used aluminum is most likely alloyed with iron for extra rigidity. The recycling process of such material has lower yield or purity which adversely affects the environmental impact the material has in a product. In normal state aluminum has lower yield strength than traditional carbon steel, austenitic stainless or ferritic stainless steels. /4/

One example of good usage of aluminum in agricultural environment is spray booms with extreme width. Spray booms typically reach up to 50 meters and are foldable for easier transport to on-site. Aluminum structures with such long dimensions require quality engineering services in design as well as in assembly. In figure 8 an example of foldable aluminum spray boom is shown.

Figure 8. An example of aluminum spray boom in use. /17/

4 Comments on environmental evaluations

Definition of the life cycle costs plays an important role in assessing the validity and scope of the calculations. Same notion applies to more advanced evaluation of carbon footprint of product or production. The manufacturing and material costs define together the cost effectiveness of choices made for the product. Currently, there are numerous methods and evaluation processes available for life cycle costs analyses and carbon footprint evaluations, which leads to a vast variation of end results depending on the choice of method. In addition, there are efforts to construct even more comprehensive term for total environmental impact of a product or production. One addition is the acknowledgment of previous recycling loops of materials used in a product. This decreases the environmental impact due to the diminished amount of new raw material needed for the product. In the cited source text are shown more in-depth examples these of evaluation methods. The examples focus on life-cycle costs relative to the stainless steels. According to the authors, these examples are likely to be applicable also to other metals. / 5/

Summary

The precise evaluation of the development of the metals in the future is understandably difficult. What is clear is that the strength of the steels will increase along with their hardness. The growth of the strength inevitably brings more challenges to the fabrication; however with high quality engineering and fabrication practices the effect of these challenges can be reduced. Various coating techniques also pave the way for the use of carbon steels in corrosion demanding applications.

Regarding the stainless steels, the increase of yield strength in addition to improvements of corrosion resistance provides basis for much wider range of possible applications when compared to non-coated carbon steels. The use of stainless steel grades in the structures in agricultural environment and work machinery can be easily seen with the knowledge of the conditions in the agricultural environment. The needed corrosion resistance is one on the key factors when choosing the material for specific product. The material selection phase should include thorough analysis of available grades from ferritic to duplex. The actual operating costs and environmental impacts throughout the whole life cycle of the products remain as a challenge. Current methods for estimating, for instance, carbon footprint are in abundance and their usage lacks clear guidelines, which does not help the situation.

Acknowledgements

The authors would like to acknowledge the financial support of Tekes – the Finnish Funding Agency for Technology and Innovation as well as the Regional Council of Lapland (European Regional Development Fund) and the "Osaamista ajoneuvoteollisuuden kanssa – ConceptCar" -project.

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Tekes

European Union
European Regional Development Fund

Leverage from the EU 2007–2013

ISBN 978-952-5897-78-4