

# Opportunities and challenges for galvanized steel sheets in Europe

K.-P. Imlau, K.-J. Peters, B. Schuhmacher

*There is increasing social and political focus on a global solution to reduce CO<sub>2</sub> vehicle emissions and to conserve diminishing raw material resources. This is leading to ever stricter environmental regulations and consequently new challenges for steel users in Europe. These challenges must be supported by the steel producers, who can also look to find new opportunities through innovative solutions to increase the competitiveness of steel against other materials such as aluminum.*

*This paper presents answers for many of the challenges being faced by the steel industry. These are demonstrated with reference to the continual development of the galvanizing process, the coating of ultra high strength steels, new coatings for hot forming products and highly corrosion resistant zinc magnesium based alloy coatings.*

## Keywords:

galvanizing, light weight design, saving of resources, CO<sub>2</sub> reduction for vehicles, process innovation

## CHALLENGES FOR THE STEEL INDUSTRY IN EUROPE

Around the world, increasing attention is being focused on climate change due to human-caused emissions of so-called greenhouse gases (above all CO<sub>2</sub>). This will also have ever stronger effects on the steel industry - channeled through its customers. This global trend can be illustrated by reference to the European auto industry. The EU Regulation setting emission performance standards for new passenger cars entered into force in April 2009 /1/. This requires all car manufacturers in Europe to reduce the CO<sub>2</sub> emissions of their new fleets to an average 130 grams per kilometer. Driven by this increasingly strict legislation, the auto industry has been reducing the weight of its vehicles systematically over recent years /2/. It is for this reason that the use of aluminum and more recently also magnesium has steadily increased. Whereas aluminum has been used on a large scale in premium-segment vehicles since 1994, the use of magnesium has so far been limited to a few individual castings. In the current debate on reducing CO<sub>2</sub> emissions, a great deal of thought is being given to increasing the use of aluminum in mid-size cars, thus supplanting steel in some of its conventional applications. As well as these light metals, the use of plastics and in particular carbon fiber composites (CFC) is also increasing strongly /3/. The introduction of electric vehicles is expected to reinforce these development trends in lightweight vehicle manufacturing still further.

Another global trend is the increasing scarcity of resources against the background of a growing world population. Fossil fuels, above all oil, and certain materials, such as indium, lithium, etc. are of strategic importance and place particular responsibility on the countries in which they occur. Although the same is not yet true of coating metals such as zinc and

magnesium, here too there is an increasing need to conserve resources in order to save costs, either by way of reducing the quantity of coating metals used or by improving the processing of coated products.

## THE RESPONSE OF THE STEEL INDUSTRY

The steel industry is responding to these challenges with different strategies. Customized products such as tailored blanks (combining different steel grades and sheet thicknesses in one blank) and tubular sections have been used successfully to reduce weight with steel for a long time. Various concept studies /4, 5/ demonstrate that significant weight reduction potential still exists here. Efforts are also continuing to develop ever stronger steels allowing reductions in sheet thickness and therefore weight. Above all, hot stamping has increased in significance recently, a process that enables structural parts to be produced with very high strength, with further increases expected soon /6/. Another trend is directed at the development of steel-based, stiffness-optimized composite materials to achieve further weight savings. In all these development approaches, surface engineering is a very important aspect. The steel industry also has answers for the issue of resource scarcity. For example, metallic anticorrosion coatings are becoming ever thinner thanks to improved zinc alloy concepts, but with no loss of corrosion protection. A major factor in this has been continuing intensive basic research into the corrosion protection mechanisms of steel. Based on this knowledge, protection systems can be tailored to particular requirements, using as many resources as necessary but as few as possible.

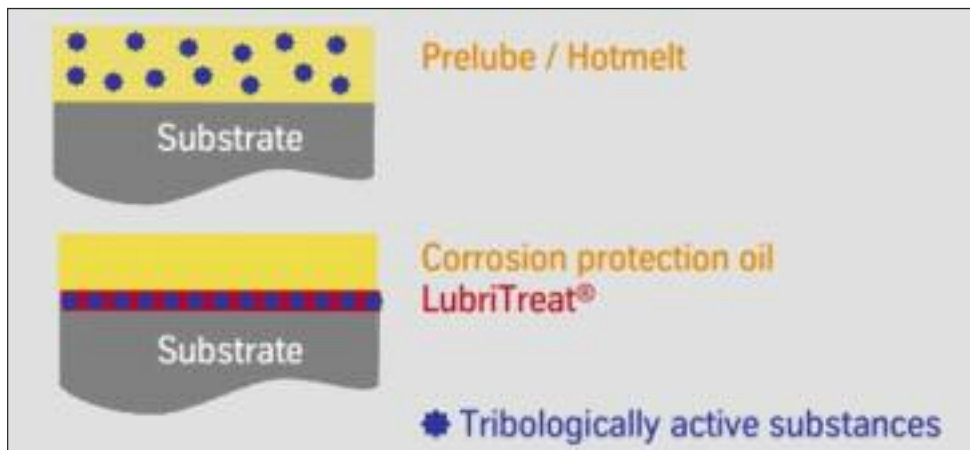
## Solutions for steel-based light-weight structures

### *a) Galvanizing and processing of advanced high-strength steels*

Advanced high-strength steels (AHSS) offer great potential for the further development of automobile bodies-in-white due to their combined mechanical properties of high formability and strength. New types of grades - multi-phase steels, superductile steels and density-reduced steels - with tensile strength levels of up to 1000 MPa in combination with excellent forma-

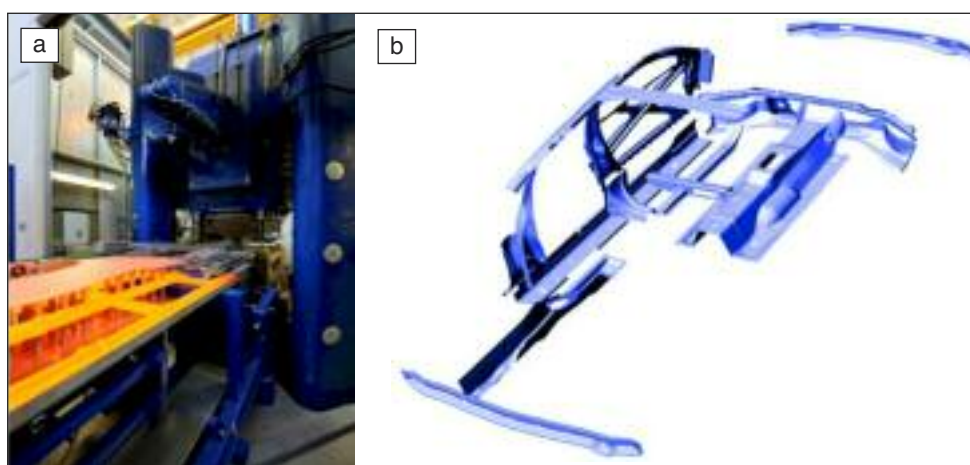
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**FIG. 1**  
**Schematic sketch of the Lubritreat® post treatment of steel sheet.**

*Schema del post-trattamento Lubritreat® delle lamiere di acciaio.*



**FIG. 2**  
**Press shop for hot forming (a) and typical hot-pressed structural parts (b).**

*Pressa per la formatura a caldo (a) e tipici componenti strutturali formati a caldo (b).*

bility for the high demands of cold formed structural automobile components are under development. Accordingly, AHSS still set high demands on hot dip galvanizing process technology. The influence of the annealing dew point as well as pre-oxidation on the surface chemistry of AHSS and its impact on the hot dip galvanizing process is well known. In recent years, many investigations have been performed to gain a deeper understanding of the interaction between gas atmospheres and the steel surface /7/. Based on this scientific knowledge the industrial galvanizing process can be adapted to each particular steel grade in such a way that satisfactory galvanized coatings free of bare spots and other defects are obtained. Overall it can be concluded that the combination of pre-oxidation with dew point control is a very effective tool to control the surface reactivity of AHSS. Another way to gain a deeper understanding of the galvanizing process and to point out routes for improving the process is provided by numerical simulations. In case of a variation of process parameters beyond the known ok-area the risk in the production line is often too high so that simulations are the best choice to investigate and optimize new process parameter settings such as flow characteristics within the snout and at the air knife or the particle distribution and their separation within the zinc pot. In order to facilitate the forming of complex parts from galvanized AHSS some notable efforts are being made to develop novel lubrication treatments. One basic idea is to apply the tribologically effective substance directly on the surface directly after the zinc-coating e.g. by chem-coating technology or spraying/squeezing. The improved product properties can then be achieved by simple corrosion protective oils (Fig.1). By

means of such treatments, in particular Lubritreat®, a recent development of ThyssenKrupp Steel Europe /8/ the friction coefficient can be clearly reduced and kept constant over the complete measurement range.

The working range for deep-drawing is expanded significantly, depending on the substrate by up to some 100%. Furthermore, the undesired slip-stick effect is avoided in a large parameter field of normal forces and drawing rates. These developments again demonstrate how product design of nano-scale layers based on scientific knowledge may lead to significant improvements which will make it possible to exploit the whole forming potential which lies in modern high strength steels.

#### *b) Coatings for hot press forming*

Due to the excellent crash performance and the potential for weight reduction the use of hot press forming has gained great importance in car body manufacturing. Representative estimations reveal a still increasing share of hot-formed parts in the car body-in-white /6/. The technique of hot press forming is used mainly for the production of structural parts with high crash relevance, e.g. bumpers or B-pillars (Fig.2).

With regard to coatings for hot press formed components currently hot dip aluminizing is state of the art. This coating provides excellent scale protection and is preferentially applied in the direct hot stamping process. However, corrosion protection of hot dip aluminized parts after the hot forming process is limited to a barrier effect only. Cathodic protection as known from conventional zinc or zinc alloy coatings cannot be provided. Already in series use is the PHS Ultraform process /9/, which provides cathodic protection; however, it can only be applied to the indirect, i.e. two-step forming process. Re-

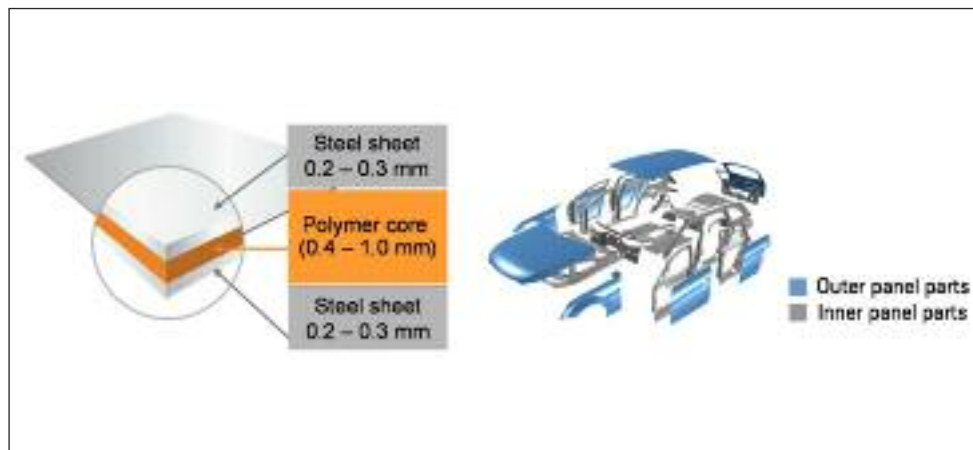


FIG. 3

**Schematic structure of a stiffness and weight optimized steel /polymer sandwich sheet material and application potential in the car body.**

*Struttura schematica di una lamiera sandwich in acciaio /polimero con rigidità e peso ottimizzati e potenziale impiego nelle autovetture.*

cently, among car manufacturers there has been an increasing demand for universal coatings for hot press forming. These coatings should be applicable for both the one- and two-step-process and should additionally provide not only good scale protection but also cathodic corrosion protection for the use of press formed parts in highly corrosive environments. For these reasons steel manufacturers spend much effort to develop zinc-based coatings which can be applied for the one-step process. Some examples are coatings based on the alloy systems Zn-Ni /10/, Zn-Fe /6/ and others. Since zinc-bearing coatings are the only way to provide cathodic protection the main problem to be overcome is to avoid the formation of cracking induced by liquid metal penetration into the grain boundaries of the base material.

Due to the development of the rapidly growing market for hot forming steels in the automotive industry and their suppliers, steel manufacturers should enhance their capacity. An example of this is the recent revamping of the hot-dip coating line No.3 of ThyssenKrupp Steel Europe which was provided with a new second pot, mainly dedicated to the production of AS with three 500 kW inductors, a nozzle with a special heat protection and a new change snout system.

### c) Stiffness-optimized composite sheet (lightweight sheet)

Sandwich products have been used in specific applications for many years /12/. So far the focus has been on noise-reducing systems consisting of two thicker steel face sheets and a thin (0.025 - 0.05 mm) viscoelastic polymer layer. The products are made on conventional coil coating lines and are suitable for forming. Sandwich panels, used for example for roofs, walls, etc. in the building industry, are generally systems consisting of a thick insulating material (10 - 100 mm) and steel face sheets (0.5 - 0.6 mm).

A new development approach going beyond existing sandwich products involves producing steel/sandwich materials specifically for weight reduction. The aim is to make steel competitive with aluminum in terms of weight, while also significantly reducing costs. In this approach, two thin steel face sheets (approx. 0.2 - 0.3 mm) and a thicker polymer core layer (upwards of approx. 0.4mm) are combined (Fig.3).

The aim behind this new and innovative sandwich material is to close the gap between steel and aluminum. For many applications, the material is equal or only slightly higher in weight than aluminum designs, but at much more attractive costs /12/. Another potential advantage of the system is its noise-damping properties, which could make it possible to reduce or even dispense with insulation systems in the car - with positive effects on weight and CO<sub>2</sub> emissions. Because of the

non-conductive polymer interlayer and its limited thermal stability, resistance spot welding and MAG welding cannot be applied. Adhesive bonding or mechanical fastening methods should be preferred.

The main applications of this new sandwich material will be large parts such as floor panels for the car interior, as well as outer skin applications such as engine lids, doors and roofs. Using this sandwich material with the steel face sheets can avoid some of the challenges that could lead to problems with a material mix of steel with aluminum (or plastic). Challenges in terms of tolerance problems due to different thermal expansion, color matching, contact corrosion, etc. are significantly reduced, and advantages can also be achieved in manufacturing by avoiding the material mix.

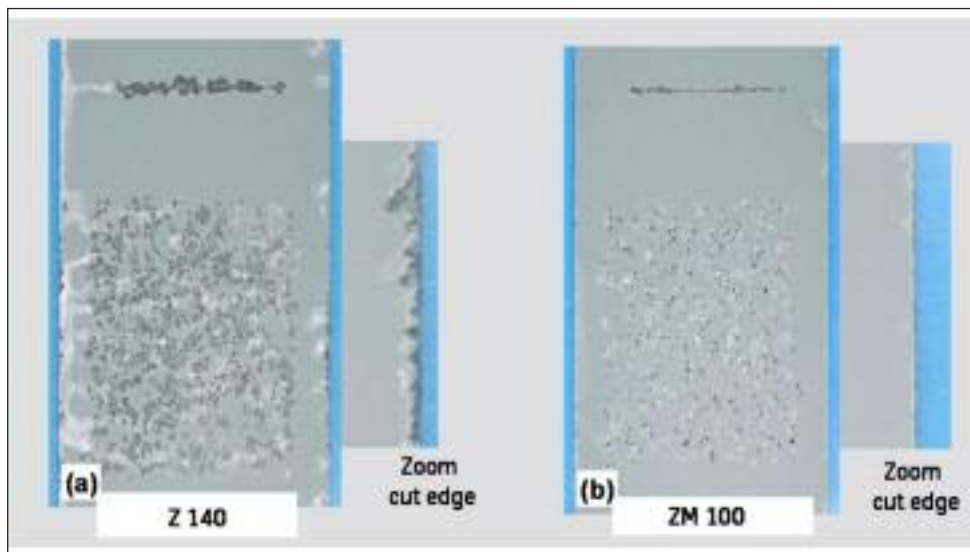
### Saving resources by means of novel corrosion resistant coatings

The improvement of the corrosion resistance of zinc based coatings by means of adding certain alloying elements has been the subject of intensive research work in Europe for many years. After the successful introduction of Zn-Al coatings in the market, the focus in recent years has been on the beneficial effects of Mg additions to the zinc coating. Much scientific insight into the effect of Mg on the corrosion protection has been gained /13/. Over the last few years, novel hot-dip zinc magnesium coatings have emerged in the market for organic coated flat products, e.g. for applications in the building industry /14/. These coatings can be produced on existing continuous hot-dip galvanizing lines without or with only minor modifications. In Europe, the first industrial implementation of zinc magnesium coatings was conducted successfully in a continuous hot-dip galvanizing line of ThyssenKrupp Steel Europe in 2006 /14/.

The excellent corrosion protection properties of zinc magnesium coatings can be enhanced even further by applying an additional organic coating and become especially evident in scratched regions and at cut edges (Fig.4). Furthermore, prolonged cathodic protection and less underpaint corrosion are achievable. Extensive investigations, partly as joint activities of the steel producers, reveal that the thickness of zinc magnesium coatings may be reduced as compared to pure zinc coatings while maintaining the same level of corrosion resistance.

Accordingly, the new coatings contribute significantly to saving resources in industrial production.

In 2008 the new organic coated steel sheets were officially approved for construction uses by the German institute for building products. In particular in the building industry and for home applications market shares of coil coated zinc magnesium



**FIG. 4**  
Corrosion protection of steel sheet by means of ZnMg coatings; EC-coated panels after 10 cycles acc. VDA 621-415; (a) Z140: conventional hdg, 70 g/m<sup>2</sup> Zn each side, (b) ZM 100: ZnMg coating, 50 g/m<sup>2</sup> each side.

*Protezione dalla corrosione di lamiere di acciaio mediante rivestimenti ZnMg; pannelli con rivestimento EC dopo 10 cicli con acc. VDA 621-415; (a) Z140: hdg convenzionale di 70 g/m<sup>2</sup> Zn su ogni lato, (b) ZM 100: rivestimento ZnMg, 50 g/m<sup>2</sup> su ogni lato.*

coatings are continuously growing.

Recent research works regarding zinc magnesium based coatings give evidence that there are still uncovered fields of applications of these coatings with high potential for further development.

Recently, other approaches of highly resistant coating systems were set into focus. Among these the zinc-chromium system is of particular interest, especially if thin zinc chromium layers are combined with thin-film organic coatings (so-called corrosion protection primers) /15/. Similarly to the zinc-magnesium system, more insight into the corrosion protection mechanisms of these coating systems has to be gained to make use of them in customer-specific product developments.

#### **InCar® - A contribution by the steel industry in the competition among materials**

The InCar® project marks a further milestone in the weight reduction efforts of the steel industry, carrying on from projects /4/ such as ULSAB, ULSAB-AVC, NSB, Atlas, ABC and ScaLight. InCar® can be understood as a “tool kit” for steel based solutions aimed and developed for use in the body, chassis and powertrain as well (Fig.5). The over 30 innovative solutions were assessed in terms of costs, weight, functionality and CO<sub>2</sub> emissions. This materials and technology benchmark is intended to support the auto industry in their efforts for developing new cost-efficient lightweight construction concepts.

The InCar® project reveals that with advanced steel grades, semi-finished products and manufacturing techniques, weight reductions of up to 38% compared with the current state of the art are realistic at very attractive costs and in some cases even cost neutrality. In addition to the advantages of the InCar® solutions in the usage phase which is currently emphasized by legislators, significant benefits can also be achieved over the full vehicle life cycle. The comprehensive Life Cycle Assessment (LCA) approach shows clearly the ecological advantage of steel and illustrates impressively that both ecological and economic requirements can be met equally well.

#### **FUTURE PROSPECTS**

The examples mentioned above show that the steel industry is very well positioned to meet the challenges posed by the global



**FIG. 5** *InCar® - a solution kit for weight reduction, cost-efficiency and safety.*

*InCar® - un pacchetto di soluzioni per riduzione del peso, efficienza economica e sicurezza.*

trends of climate protection, CO<sub>2</sub> emissions reduction and resource conservation. Another trend that can be mentioned is the increasing functionalization of steel surfaces, the “added value” achieved by combining steel intelligently with corrosion protecting metallic coatings. The surface functions made possible by this are becoming more and more diverse. In the past these were limited to decorative effects, but today a wide range of additional functions is possible, such as scratch and wear resistance, special structural effects, and dirt-repellent or anti-microbial effects. Phosphorescent paint coatings applied to steel by the coil coating process can store energy from daylight or artificial light and release it again over a period of up to 15 hours. This can be exploited for example to illuminate emergency exit signs on steel doors. Anti-condensation paint coatings developed especially for indoor use absorb and store condensation until the ambient temperature allows it to evaporate. Various advanced coating methods are being used, e.g. sol-gel processes for scratch-resistant surfaces and nanoparticle matrix modification for scratch protection and functionalization. Scratch-resistant surfaces produced by nanotechnology are already in use or nearing readiness for the market and may have potential to be used for continuous coating of steel strip. Also under research are so-called self-healing surfaces using nano particles in the coating system matrix. These can reduce the cracking that results in destruction of the



**FIG. 6 Solabs®: (a) sketch of a facade element with solarthermic function (b) demonstration facade at EPFL Lausanne.**

*Solabs®: (a) schema di un elemento di facciata con funzione solare termica (b) facciata dimostrativa presso la EPFL di Losanna.*

coating and weakening or failure of the part. By extending life cycle, self-healing surfaces can reduce costs and increase the safety and reliability of capital equipment. Possible applications for self-healing surfaces include corrosion protection and vehicle manufacturing.

Renewable energy production also presents major opportunities for steel, particularly in the building industry. Energy-efficient buildings are sustainable, but energy-producing buildings are even more so. Solar thermal, for example, is developing into a very attractive growth market for the steel industry, e.g. steel-based solar collectors for use as facade elements in industrial steel buildings. The design of the collectors is an important point in facilitating architectural integration into the building and therefore increasing the acceptance of solar thermal systems. The challenge lies in developing unglazed and colored facade collectors based on coated steel sheet. The Solabs® concept of ThyssenKrupp Steel Europe is a multi-functional coating system with a zinc-magnesium coat for excellent corrosion protection and a special solar-selective paint coating. The latter contains special pigments that provide multiple reflections to heat the steel. The heat is transmitted to water-filled pipes installed directly beneath the face sheet to transport the energy (Fig.6)/16/.

As part of the research work, several prototype collectors have already been assembled and feasibility has been demonstrated. A demonstration facade is currently being erected in a large-scale test on a real industrial building to show the architectural integration of the facade collectors and permit systematic measurement of energy yields under real conditions. In the future, this intelligent steel product, a synergy of ZnMg alloy coatings and functional paint coatings, is to be used for the large-scale manufacture of solar collectors for use as facade elements. In contrast to conventional glazed collectors the intention is to offer the coil-coated facade collectors in various colors to support integration into building designs. Construction elements with photovoltaic power-generating properties are attractive for use in both industrial and residential buildings. For example, ThyssenKrupp Solartec® is a complete system for building-integrated photovoltaic solutions consisting of two-side galvanized and plastic-coated steel with laminated-on UNI-SOLAR® PV elements (Fig.7). This system is equally suitable for new buildings and for refurbishment projects and combines building envelope and solar power ge-



**FIG. 7 Facade with building integrated photovoltaic elements.**

*Facciata con elementi fotovoltaici integrati nella struttura.*

nerator in one construction element. It can completely replace conventional roofing. No roof-top mounting or other structural measures are required. The system can therefore be used to meet sophisticated design and structural requirements. A joint project by DyeSol and TATA-Steel is pursuing the novel approach of applying photovoltaic coating systems, in this case based on dye-sensitized solar cells, directly to steel construction elements /17/.

In addition, the juwi group and ThyssenKrupp Steel Europe recently began offering construction elements with roof-parallel photovoltaic modules. They turn the roofs of industrial buildings into solar power plants - and an additional steady source of income. The roof-parallel photovoltaic modules are mounted on special substructures, which in turn are matched to the roof elements. The systems are suitable for both single-skin roofs and roofs made from sandwich elements. With sandwich roofs, the collaboration provides a climate- and resource-friendly combination of effective heat insulation

and renewable energy generation.

Under the motto "Steel Goes Green" this underlines the good environmental performance of steel building products. The sandwich elements in particular, with their first-rate insulating properties, are extremely energy-efficient and so make a sustainable contribution to climate protection. For example, the elements offer a simple and low-cost way to meet the requirements of the Energy Saving Ordinance (EnEV) for building heat insulation, which since 2009 have also applied to industrial buildings. The steel industry is therefore pursuing a holistic sustainability strategy that includes economic and socio-cultural as well as ecological aspects. As a consequence, ThyssenKrupp Steel Europe provides ecological product declarations (EPDs) for all flat steel products (single-skin as well as sandwich elements) that help the customer to certify his building.

#### SUMMARY AND CONCLUSION

The steel industry faces major challenges. In the auto industry, an important area of steel use, stricter legislation on emissions of pollutant gases and CO<sub>2</sub> and the emergence of electric vehicles will make weight reduction ever more important. As a result, competition between steel and other lightweight materials will increase. However, steel still offers considerable potential for further development to consolidate its position. This potential lies in the development of new ultrahigh-strength steels with good forming properties and in the targeted use of hot stamping to produce ultrahigh-strength parts, particularly for crash-relevant areas of the car body. Important contributions will also be made by technology solutions, as impressively demonstrated by the studies carried out by steel producers. The benefit of these solutions is underlined by the increasing importance of comprehensive LCAs. In all these approaches, surface technology has a key role to play in ensuring corrosion protection and enhancing the processing properties of these new steel materials and steel-based solutions. Major additional opportunities for steel will arise from the potential for multi-functionalization of materials, particularly material surfaces. One highly topical subject is renewable

energy production, which will play a key role in future energy supply. Industrial buildings with roofs and facades made from steel construction elements featuring solar thermal or photovoltaic functions can make a sustainable contribution to energy supply in the future.

Intelligent, steel-based solutions are already available on the market, and the steel producers will increase their efforts to exploit the opportunities arising in this area.

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### Abstract

## Opportunità e sfide per le lamiere zincate in Europa

**Parole chiave:** rivestimenti, acciaio, tecnologie

C'è una crescente attenzione sociale e politica relativa a una soluzione globale per ridurre le emissioni di CO<sub>2</sub> dei veicoli e di preservare le fonti di materie prime. Questo sta portando all'introduzione di normative ambientali sempre più severe e di conseguenza a nuove sfide per gli utilizzatori di acciaio in Europa. Queste sfide devono essere sostenute dai produttori di acciaio, che possono anche cercare di trovare nuove opportunità attraverso soluzioni innovative che permettano di aumentare la competitività dell'acciaio rispetto ad altri materiali come l'alluminio.

Questa memoria presenta le risposte a molte delle sfide che deve affrontare l'industria siderurgica.

Queste vengono presentate con riferimento al continuo sviluppo del processo di zincatura, al rivestimento di acciai ad ultra alta resistenza, ai nuovi rivestimenti per i prodotti formati a caldo, ai rivestimenti a base di zinco e magnesio altamente resistenti alla corrosione.