The term resource efficiency is used widely in the paints and coatings market. The aim is to offer customers the products they need in order to produce resource-efficient paints and coatings. The term resource efficiency here characterizes the bundling of the environmental and economic pillars of sustainability. [1]

More than any other sector, the corrosion protection market is showing the impact that the use of perfectly tailored pigments and binder systems can have on the function of the coating as a whole and also on the protection/durability of valuable objects.

Silicone-epoxy hybrid resin for corrosion protection applications
Silicone-epoxy hybrid resins (one such product is SILIKOPON® EF offered by Evonik Resource Efficiency GmbH) can be used in corrosion protection applications. [2] In these applications, the coating must meet different requirements to fulfill the needed corrosion resistance. The coating must protect the underlying steel by adhering well while simultaneously preventing harmful substances from coming into contact with the substrate. The coating must, itself, be weather resistant. This means not only resistant to rain, snow and ice but also to the high energy UV component of sunlight. However, additional active protection of the steel, with for example a zinc primer, cannot be avoided.

Conventional coating systems for heavy corrosion protection are based on a 3 layer application system built to reach the above mentioned requirements, specified in ISO 12944 (C5-I/M, high protection). The market standard is based on an epoxy zinc rich primer, an epoxy intermediate layer and a PU top coat. [3]

Silicone-epoxy hybrid resins can be used as solvent-free, ultra high solids binders for resource-conserving in many different industrial top coat applications. This technology allows formulation of coating systems with significantly less than 250
g/L (sometimes even less than 100 g/L) VOC as well as permitting isocyanate-free crosslinking. [3] The silicone-epoxy hybrid resin technology combines the positive effects of an aliphatic epoxy resin like corrosion protection and chemical resistance with the UV resistance and low yellowing characteristics of an alkoxy silicone resin. Together with an amino alkoxy silane hardener the abilities of the intermediate epoxy layer and the PU top coat can be combined (Fig. 1). Thus, new two layer corrosion protection systems with lower film thicknesses and the same corrosion protection abilities can be achieved. By reducing the film thickness, less coating material is needed. This led to the assumption that the two layer systems are more resource efficient than the market standard three layer systems. To prove that silicone-epoxy hybrid resins support resource efficient coating systems, the entire life cycle of a coating based on a silicone-epoxy hybrid resin was analyzed in an ISO certified life cycle assessment.

Concept of the life cycle assessment of a silicone-epoxy hybrid resin in a corrosion protection application

A life cycle assessment (LCA) is an evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. The life cycle depends on the boundaries of the study. A Cradle-to-Gate LCA investigates all environmental impacts from feedstock over production until a product leaves the “gate” of

Ciclo di vita di una resina epossi-siliconica ibrida in un sistema applicativo contro la corrosione

La valutazione del ciclo di vita di un prodotto (LCA) è uno studio volto ad analizzare i potenziali impatti ambientali di un prodotto nel corso del suo intero ciclo di vita, dalle origini allo smaltimento dello stesso. I confini dello studio dipendono dal ciclo di vita del prodotto. Una valutazione LCA Cradle-to-Gate analizza tutti gli impatti ambientali a partire dalle materie prime utilizzate fino all’uscita dallo
a manufacturing site. The system boundary of a Cradle-to-Gate LCA defines which “gate” of multiple steps within a supply chain is meant. The Cradle-to-Grave approach, on the other hand, additionally investigates the application (Use-phase) and the End-of-Life of a product so that it covers the entire life cycle from raw material acquisition or generation from natural resources to the final disposal.

The LCA study of the silicone-epoxy hybrid resin was conducted in accordance with ISO 14040 and 14044 and approved by an external review panel. It investigates the environmental impacts of corrosion protection coatings over their whole life cycle, from the raw material production, through coating formulation and production, as well as their application, and the end-of-life (Cradle-to-Grave). The system boundaries are displayed in Figure 2. The results are analyzed in a stepwise approach. First the preliminary Cradle-to-Gate results of each coating layer are discussed. Afterwards, application and end-of-life are added to get the final results over the entire life cycle (Cradle-to-Grave).

The study gives a comprehensive overview on the environmental impacts of the different coating systems. Nonetheless, special attention is drawn on the Global Warming Potential (GWP, also known as Carbon Footprint), Primary Energy Demand (PED) and Photochemical Ozone Stabilization Potential.
Creation Potential (POCP). The POCP (also called summer smog) describes the change of the ozone concentration near ground level. VOC emissions from the drying process of coatings have a major impact on the POCP; hence this impact category is of special interest in this application. GWP and PED are the most common impact categories and will therefore generate a good understanding of the overall results. Other categories are not as closely analyzed even though qualitative and quantitative results are also given in the study.

Two different coating systems are compared regarding their environmental performance.

Reference System
The reference system has three different layers and represents the market standard for a heavy duty corrosion protection coating. Each layer is applied in a different thickness. The NDFT (nominal dry film thickness) of epoxy zinc-rich primer is 80 μm, which is the same in both coating systems. The intermediate layer of this reference system is an epoxy based layer with the average coating thickness of 170 μm.

Sistema di riferimento
Lo standard di mercato è rappresentato da un sistema di riferimento a tre strati utilizzato per ottenere una protezione anticrosolazione altamente resistente. Ogni strato viene applicato con differenti spessori. Lo spessore nominale del film essiccato (Nominal Dry Film Thickness – NDFT) di un primer zincante epossidico è di 80 μm, uguale per entrambi i sistemi. Lo strato intermedio di questo sistema di riferimento è una resina epossidica con uno spessore medio
The two-pack PU top coat of this system is based on a hydroxy functional acrylic resin with a film thickness of 70 μm. [4]

The international standard ISO 12944 (C5-I/M, high protection) describes not only the tests that need to be fulfilled to reach a certain level of corrosion protection, but it prescribes the film thickness that is mandatory to achieve a desired durability class at chosen corrosion category. The reference system, which was chosen here, fulfills all the specifications concerning the total NDFT according to ISO 12944 (C5-I/M, high protection). [4]

Silicone-epoxy hybrid system

The second system is a two layer system with an epoxy zinc-rich primer and a top coat that is based on the silicone-epoxy hybrid resin. The silicone-epoxy hybrid resin based top coat is applied with a nominal dry thickness of 100 μm. Since polysiloxane based paints are not included in ISO 12944 (C5-I/M, high protection) and therefore no recommendations for NDFT are available, the top coat was applied as thin as possible, while still achieving the same corrosion protection performance as the reference system. For the top coat of the silicone-epoxy hybrid system the film thickness is 170 μm. La finitura è un sistema PU a due componenti a base di una resina acrilica ossidrilata e il film applicato di 70 μm. [4]

Lo standard internazionale ISO 12944 (C5-I/M, protezione elevata) descrive non solo i test necessari per raggiungere un determinato livello di protezione dalla corrosione, ma allo stesso tempo prescrive lo spessore minimo del film per ottenere una determinata classe di durevolezza. Il sistema di riferimento preso in esame risponde a tutte le richieste inerenti lo spessore minimo del film essiccato (NDFT) in conformità alla norma ISO 12944 (C5-I/M, protezione elevata). [4]

Sistema epossi-siliconico ibrido

Il secondo sistema è a due strati e consiste in un primer zincante epossidico e una finitura a base di una resina epossi-siliconica ibrida. La finitura viene applicata con uno spessore nominale del film essiccato di 100 μm. Poiché i rivestimenti a base di polisilossani non sono contemplati nella norma ISO 12944 (C5-I/M, protezione elevata) e quindi non sono disponibili informazioni sullo spessore minimo raccomandato, la finitura viene applicata con uno strato il più sottile possibile, che garantisca le prestazioni anti-corrosione del sistema di riferimento. La formulazione utilizzata per questo tipo di finitura è quella riportata nell’articolo.
formulation from the article “Silicone-epoxy hybrid binders – a strong network against rust” was used. [3] In Figure 3, the two systems are compared regarding their film thickness. The film thickness is always the Nominal Dry Film Thickness (NDFT).

**Testing**
Both systems were tested according to ISO 12944 (C5-I/M, high protection). This includes exposure to chemicals in accordance with ISO 2812-1 for 168 h, determination of resistance to humidity (continuous condensation) according to ISO 6270 for 720 h and determination of resistance to neutral salt spray (fog) according to ISO 9227 for 1440 h. The results of the salt spray test are shown in Figure 4. Both coatings systems performed comparably in the above mentioned test methods, although they significantly differ in film thickness. Hence, these tests prove that the corrosion protection performance of both systems is similar. This is the base for the comparison of the environmental impacts in the life cycle assessment of the two coating systems. [5]

**Results of the Life Cycle Assessment**
The Cradle-to-Gate results of each layer used for the two systems are shown in Figure 5. It shows the Global Warming Potential of the four different layers up to the point where the coatings leave the site of the coating manufacturer (Cradle-to-Gate). The silicone-epoxy hybrid resin shows the highest carbon dioxide emissions per kg liquid coating formulation, which is mainly because of the complex production process and its silicone based nature. However the carbon dioxide emissions per kg layer were just the results of a Cradle-to-Gate system boundary.


**Test**
Entrambi i sistemi sono stati testati secondo la norma ISO 12944 (C5-I/M, elevata protezione). Questo test comprende l’esposizione agli agenti chimici, in conformità alla norma ISO 2812-1 per 168 ore, la determinazione della resistenza all’umidità (condensazione continua) secondo norma ISO 6270 per 720 ore e la determinazione della resistenza alla nebbia salina secondo norma ISO 9227 per 1440 ore. I risultati del test di resistenza alla nebbia salina sono illustrati nella figura 4. Nei test sopra citati, entrambi i sistemi vernicianti offrono prestazioni paragonabili, nonostante differiscano in modo sostanziale nello spessore del film. Questi test provano quindi che le prestazioni anti corrosione di entrambi i sistemi sono equivalenti e questo rappresenta la base per un accurato confronto dell’impatto ambientale all’interno dello studio sul ciclo di vita dei due sistemi vernicianti. [5]

**Risultati dello studio sul ciclo di vita**
I risultati Cradle-to-Gate di ciascuno strato impiegato nei due sistemi comparati, sono illustrati nella figura 5. L’analisi mostra il potenziale riscaldamento globale dei quattro differenti sistemi applicati fino all’uscita della vernice dallo stabilimento di produzione (Cradle-to-Gate). La resina epossi-siliconica ibrida mostra le più alte emissioni di anidride carbonica per ogni kg di rivestimento liquido, dovuto principalmente alla complessità del processo produttivo e alla sua natura siliconica. In ogni caso si tratta dell’emissione di anidride carbonica del ciclo di vita relativa alla fase Cradle-to-Gate.
More significant results can be achieved with a system boundary over the entire life cycle. In a life cycle assessment with a Cradle-to-Grave approach, the application phase and the end-of-life have to be considered as well. Also the functional unit which is investigated is not the kg of the layer but the coating of 1 m² of coated metal substrate.

The environmental impact on the Global Warming Potential of the two compared coating systems is shown in Figure 6. It shows that the CO₂ emissions of the silicone-epoxy hybrid based coating system are up to 36% lower than the market standard system. Figure 6 shows that silicone-epoxy hybrid resin based coating can also reduce the Primary Energy Demand by up to 36%. A closer look at the two impact categories shows that the majority of the emissions are raw material related. Disposal of the systems is responsible for 25% of the CO₂ emissions, and is a function of the amount of coating which must be removed and disposed of. These results prove that a reduction of film thickness reduces the environmental impact of this coating system over the entire life cycle.

The third impact category that was analyzed in detail is the Photochemical Ozone Creation Potential. It represents the VOC emissions of a coating system. Figure 6 shows that the Photochemical Ozone Creation Potential (POCP) can be reduced by 65% within the thin silicone-epoxy hybrid resin system. Almost all the emissions are created in the application phase in which the coating is applied, dries and the solvent leaves the coating film. [5]

Risultati più significativi si possono ottenere amplian- do i limiti del sistema e analizzando l’intero ciclo di vita del rivestimento. In uno studio LCA Cradle-to-Grave vengono presi in esame sia la fase applicativa, sia lo smaltimento. Anche l’unità di misura di riferimento non sarà la massa espressa in kg dello strato, ma il rivestimento di 1 m² di metallo verniciato. L’impatto ambientale sul potenziale riscaldamento globale (GWP) dei due sistemi vernicianti messi a confronto è illustrato nella figura 6. Si nota come le emissioni di CO₂ del sistema a base di una resina epossi-siliconica ibrida siano fino al 36% inferiori rispetto al sistema di riferimento. La figura 6 mostra inoltre che il rivestimento a base di resina epossi-siliconica ibrida può ridurre il consumo di energia primaria fino al 36%. Uno sguardo più attento alle due categorie di impatto ambientale rivela che la maggior parte delle emissioni provengono dalle relative materie prime. Lo smaltimento dei sistemi è responsabile del 25% delle emissioni di CO₂ e varia in funzione del quantitativo di vernice da rimuovere e quindi smaltire. Questi risultati dimostrano che una riduzione dello spessore del film riduce l’impatto ambientale del sistema verniciante lungo l’intero ciclo di vita.

La terza categoria di impatto analizzata nel dettaglio è l’inquinamento fotochimico prodotto dall’ozono. Esso rappresenta le emissioni di COV di un rivestimento protettivo. La figura 6 mostra come l’inquinamento prodotto dall’ozono (POCP) possa essere ridotto del 65% attraverso un sistema a base di un sottile strato sottile di resina epossi-siliconica ibrida. Quasi tutte le emissioni vengono prodotte durante la fase applicativa, quando la vernice asciuga e il solvente evapora. [5]
The life cycle assessment covers the environmental differences between the chosen systems. A coating system with just two layers provides several additional advantages over the conventional three layer systems, which are not covered quantitatively with the LCA results. Some examples are shorter curing times, less application time and fewer raw materials to purchase, store and carry for the professional painters.

Results at a glance
- Increasing trend towards ecologically-responsible business practices.
- It is possible to achieve the same corrosion protection performance as the current market standard systems with just two layers and a much lower overall film thickness with a top coat which is based on silicone-epoxy hybrid resin.
- Silicone-epoxy hybrid resins help reduce emissions from Cradle-to-Grave although they have higher Cradle-to-Gate emissions. The Carbon Footprint and Primary Energy Demand decrease by 36%, while the VOC emissions drop by 65%.

Literature

In sintesi
- Miglior atteggiamento eco-responsabile con innovative resine epossili-siliconiche ibride.
- Con una finitura a base di una resina epossili-siliconica ibrida, con solo due strati ed uno spessore del film più ridotto, è possibile ottenere le medesime prestazioni di protezione dalla corrosione di un sistema tradizionale.
- Le resine epossili-siliconiche ibride riducono le emissioni durante l’intero ciclo di vita (Cradle-to-Grave), nonostante risultino avere un più elevato valore di emissioni rapportato all’analisi parziale Cradle-to-Gate. Il potenziale riscaldamento globale e il consumo di energia primaria si riducono del 36%, mentre le emissioni di COV del 65%.

Bibliografia