

Repurposing eggshell waste as functional coating fillers

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Entering the era of circular calcium carbonate

Calcium carbonate is one of the most widely used mineral fillers in paints and coatings, enabling everything from cost optimisation to mechanical reinforcement and surface tuning. Yet, its conventional sourcing through limestone mining raises increasing concerns around carbon emissions, environmental impact and resource depletion.

At the same time, millions of tonnes of eggshell waste, naturally composed of CaCO? are generated every year and largely underutilised. Bridging this gap, innovations such as those developed by EGGXPERT transform eggshells from 100% EU-based sourcing into a high-performance renewable material.



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From waste to resource: producing renewable CaCO? from eggshells

Eggshell waste represents a significant but underutilised resource stream. Globally, around 30 million tonnes of eggshell waste are generated annually, primarily from egg processing industries. In Europe alone, countries such as the Netherlands and France each generate tens of kilotonnes per year. Within the European regulatory framework, eggshells are classified as animal by-products, which introduces handling and disposal requirements. For medium-sized processing facilities, disposal costs can reach up to €100,000 per year, creating both an environmental and economic burden.

At the same time, the minerals sector faces its own sustainability challenges. Limestone extraction, the primary source of calcium carbonate, requires energy-intensive mining, transport, and processing. Global limestone production exceeds 5 billion tonnes annually and is expected to grow further. The sector thus contributes significantly to carbon emissions (estimated at 4-7% globally) and landscape degradation.

This dual challenge, including organic waste management and mineral resource dependency, creates a clear opportunity for circular innovation. Bridging these two realities, innovative initiatives as developed by EGGXPERT demonstrate how eggshells can be transformed into a high-quality, renewable source of calcium carbonate. This unlocks new opportunities for circular materials and sustainable manufacturing. Eggshells are naturally composed of 95-98% calcium carbonate in the form of calcite. This makes them intrinsically suitable as a mineral feedstock. Unlike mined limestone, eggshell-derived CaCO? already exists in a refined biogenic structure. Therefore, it requires less intensive processing to reach functional grades.

The untapped potential of eggshell waste

From a materials science perspective, eggshell CaCO? shares many similarities with conventional Ground Calcium Carbonate (GCC), while it also exhibits unique microstructural features. The recovered eggshells have comparable content of CaCO? (99.5%) and same calcite crystalline structure as conventional sources of high-grade limestone.

However, a key differentiator lies in particle morphology. The eggshell particles exhibit a more irregular, porous and heterogeneous structure compared to synthetic or mined CaCO? (Figure 1).

The unique structure has been created by nature, where hierarchical structures of biominerals typically contribute to the optimisation of strength versus lightweight properties. The nanopores and rough features particularly lead to specific properties offering increased specific surface area for adhesion, enhanced mechanical interlocking within matrices, better filler-matrix interaction and potentially improved dispersion at certain particle sizes.

These characteristics offer good potential for local energy dissipation and improved crack resistance, which can directly influence material performance of coatings and composite systems. Yet, technical compatibility with a wide range of innovative applications has been proven and new applications are under development.

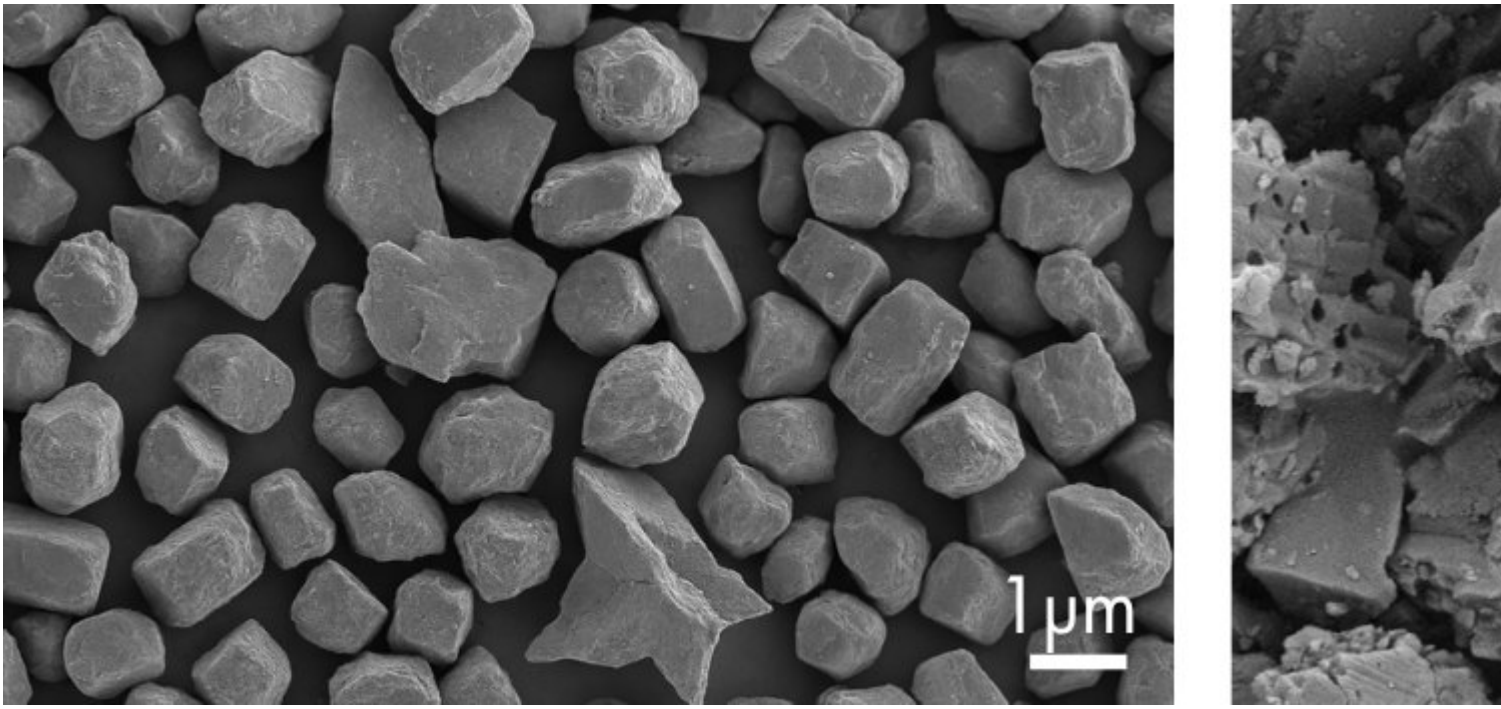


***Figure 1**. Microscopic observation of calcium carbonate sources, (left) regular ground calcium carbonate (Source: © Sirris), (right) circular calcium carbonate from eggshell (Source: © EGGXPERT).*

Performance in coatings: a promising bio-based alternative

Within the COOCK+ project AddBIO, Sirris is monitoring the use of bio-based additives as a replacement for functional fossil-based fillers in coating applications. In coatings engineering, CaCO? is far more than a low-cost extender. It plays a multifunctional role, influencing both processing and performance:

1. Rheology and processability

Calcium carbonate particles contribute to viscosity control and flow behaviour during formulation and application. By tuning particle size and loading, formulators can adjust shear thinning behaviour, sag resistance or levelling during drying. The interaction between filler particles and binder determines how the coating spreads and stabilises before curing.

2. Mechanical reinforcement

CaCO? improves the mechanical integrity of coatings through increased hardness, improved stiffness, enhanced resistance to deformation. The filler acts as a rigid phase within the polymer matrix, redistributing stress and limiting crack propagation.

3. Wear resistance and durability

One of the key roles of CaCO? is to improve abrasion resistance. The particles exposed to the surface bear part of the applied load, reduce matrix wear, and modify the frictional behaviour at the surface. The effectiveness depends strongly on particle size, dispersion, and interfacial adhesion.

4. Surface finish and optical properties

The CaCO? strongly affects surface aesthetics, including gloss and matting behaviour, surface smoothness, light scattering, and opacity. Fine particles typically improve smoothness and gloss, while coarser particles contribute to matting.

5. Barrier properties and moisture interaction

Fillers influence water uptake, permeability and wetting behaviour by increasing tortuosity of diffusion pathways, modifying surface energy, and contact angle, affecting porosity and microstructure. These properties are essential for protective coatings on wood, metal and construction materials.

Benchmark study confirms eggshell’s replacement potential

Together with EGGXPERT, Sirris conducted a benchmark study on the unique potential of the regenerated CaCO3 particles in a model coating on wood substrates. To assess its practical applicability, the eggshell CaCO? (20 µm) was tested in a bio-based epoxy coating. In a formulation approach, filler loadings of 2 to 10 wt% were incorporated and compared with conventional Ground Calcium Carbonate (GCC) (see Figure 2). Some key takeaways to be mentioned are:

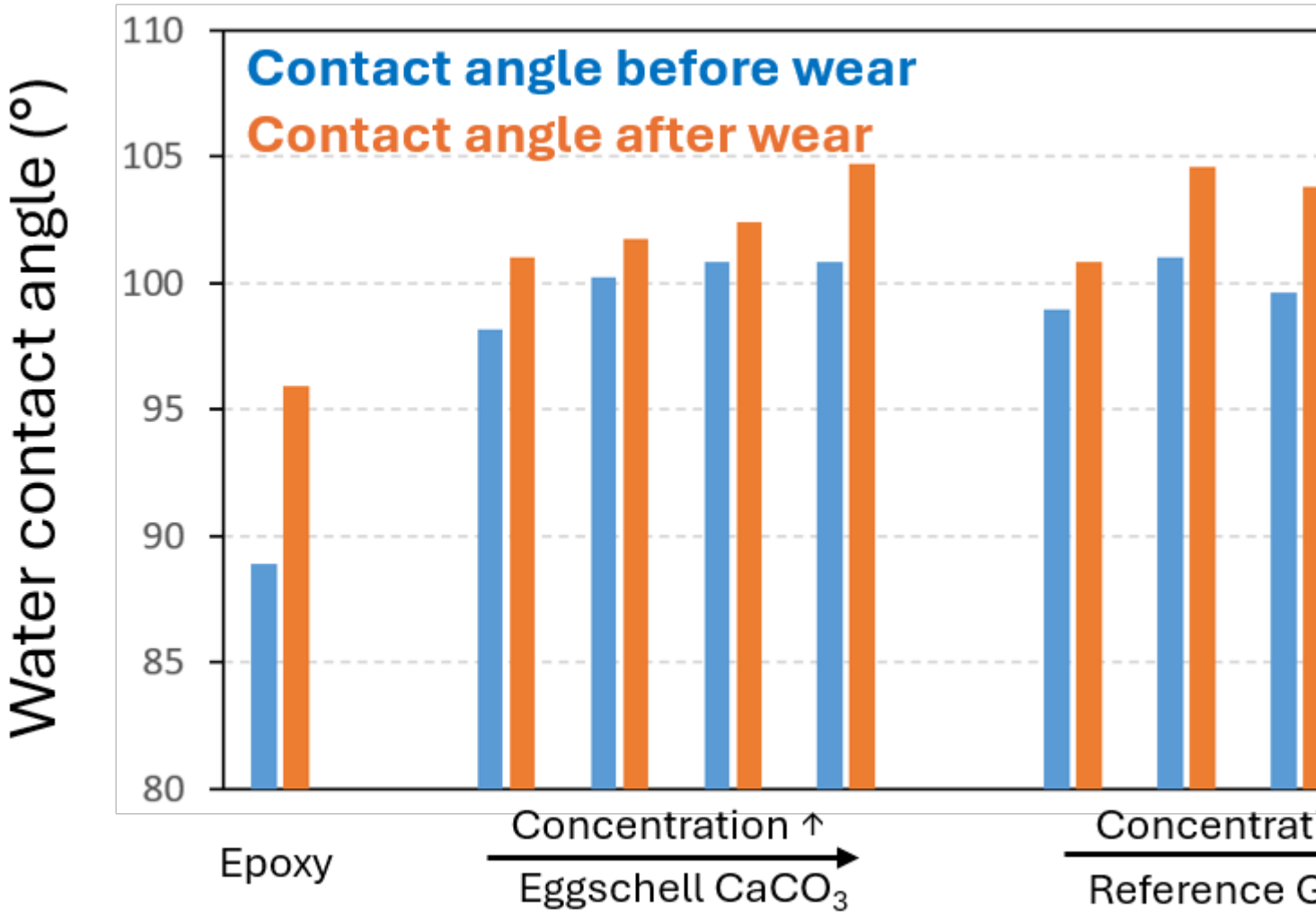
- The irregular particle morphology influences **lower viscosity and provides a better dispersion**, with reduced tendency for agglomeration at higher loadings and more homogeneous distribution in the matrix. This leads to stable processing conditions and supports higher filler incorporation, increasing bio-based content without compromising on coating integrity.

- Microhardness measurements show that eggshell CaCO? delivers **comparable hardness** values to conventional CaCO?. The hardness trends are primarily governed by particle size rather than origin. This confirms that eggshell-based fillers can replace traditional fillers without negative effects on structural and mechanical performance.

- A particularly important function of CaCO? fillers is wear resistance. Mainly at higher filler loadings, it showed **equal or superior abrasion resistance** and lower material loss compared to GCC. The microscopic analysis revealed narrower and shallower wear tracks with reduced microcracking and uniform abrasion patterns. These observations indicate better stress distribution, improved energy dissipation, and enhanced filler–matrix interaction. This suggests that the morphology-driven reinforcement plays a key role in extending coating lifetime.

- Water contact angle measurements show that **hydrophobicity is maintained before and after wear** with a slightly more **neutral wetting behaviour** for eggshell CaCO?. This is important because extreme hydrophobicity can negatively impact adhesion while balanced wetting improves coating-substrate interaction. Thus, eggshell CaCO? may offer a better compromise between water resistance and adhesion.

- Optical properties indicated **higher gloss level** of eggschell CaCO3 at **low filler loading** in parallel with a better surface levelling. This behaviour is linked to good dispersion, particle size effects, and surface smoothness after curing. For coatings where aesthetics matter, this provides an additional design lever.


Water contact angle (°)
110
105
100
95
90
85
80
Contact angle before wear
Contact angle after wear
Epoxy
Concentration ↑
Eggschell CaCO3
Concentrat
Reference G

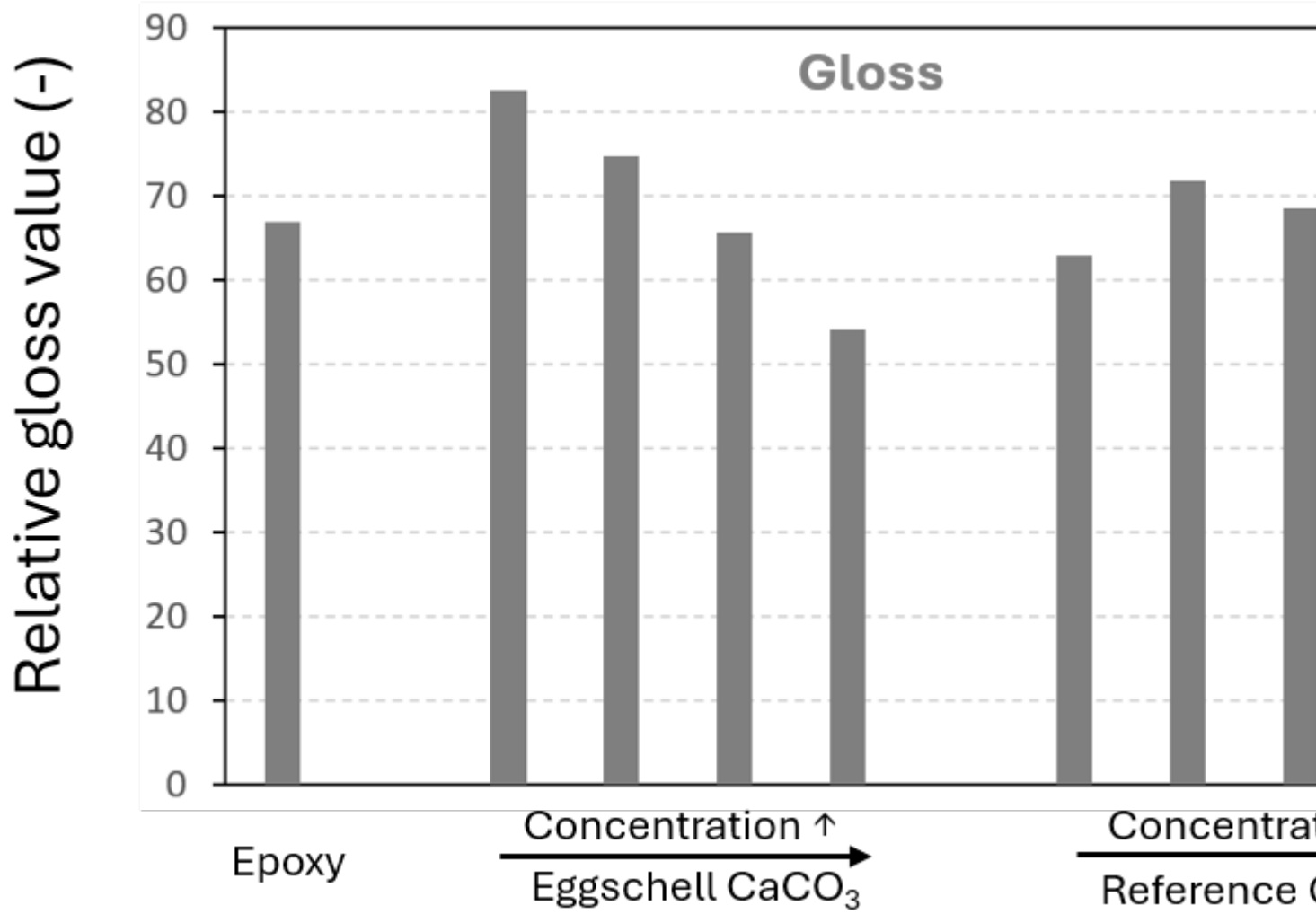

Relative gloss value (-)
90
80
70
60
50
40
30
20
10
0
Gloss
Epoxy
Concentration ↑
Eggschell CaCO3
Concentrat
Reference

***Figure 2**. Results of benchmark study on intrinsic coating properties of a bio-based epoxy coatings with different concentrations of eggshell CaCO3 and reference ground calcium carbonate (GCC), 20 µm particle sizes. © Sirris*

Beyond coatings: broader application potential

Coatings provide a clear demonstration of eggshell's potential. Yet eggshell CaCO? can be used across multiple sectors: **polymers and composites** (including 3D printing filaments), construction materials (cement blends, tiles), **consumer products and packaging**. In all cases, the same filler functions apply: reinforcement, cost reduction, and property tuning - now with a circular origin!

"Nature has already engineered an exceptional calcium carbonate structure for us. At EGGXPERT, our role is to unlock its value for different industries. We highly appreciate the support of Sirris and the AddBIO project in providing independent testing and scientific validation of our unique product in coating applications. Their expertise helps bridge the gap between innovative circular materials and industrial adoption." says Rong Wang, Founder & CEO of EGGXPERT.

Join the journey towards circular coating

If you are also interested in further testing of functional fillers that are derived from biomass waste streams, the COOCK+ AddBIO project offers access to coating testing facilities and provides comparative testing data of reference materials. Sirris is supporting companies in the valorisation of biomass residues and helping to connect actors over the entire valorisation chain ranging from biomass suppliers to convertors, coating formulators, applicators, and end-users.

Discover the potential of bio-based additives for coatings

Would you like to learn more about the AddBIO project and the processing of bio-based additives for high-performance coatings? Discover how the project supports companies with hands-on knowledge, practical tools and collaboration across the value chain.

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