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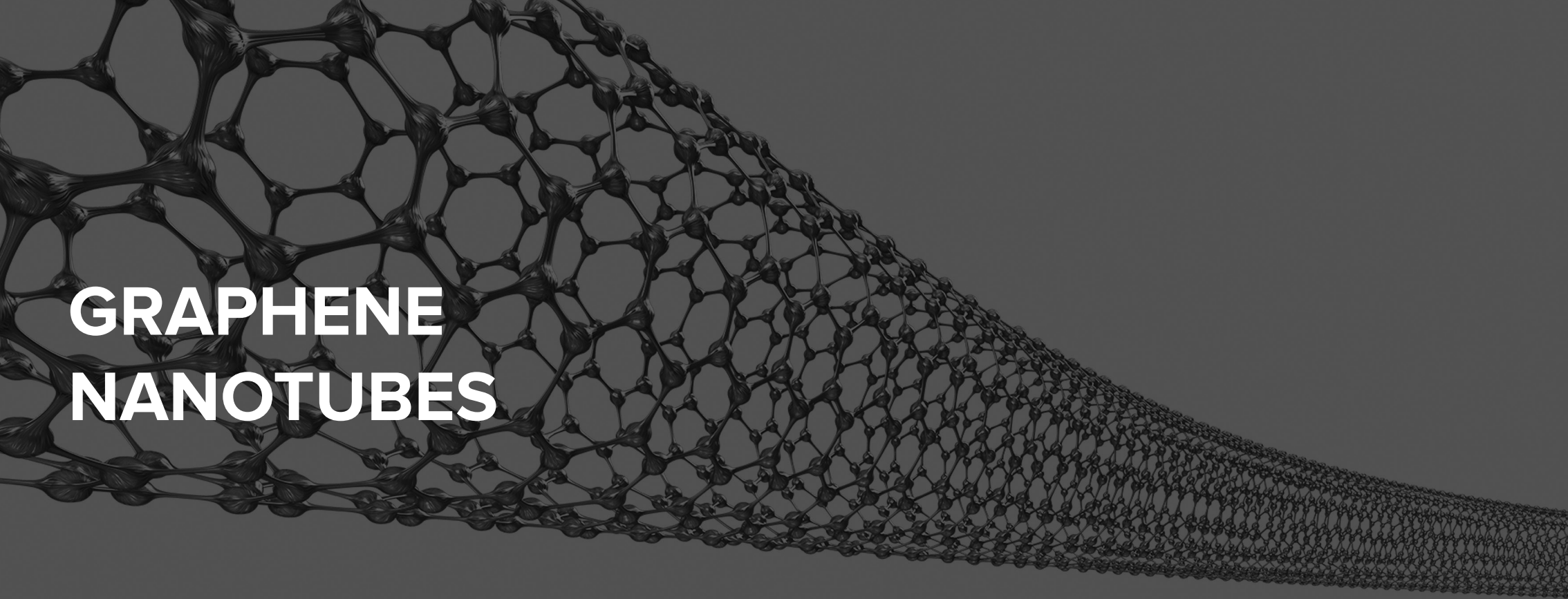
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PRODUCT CATALOG

OCTOBER 2020

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GRAPHENE NANOTUBES

**TUBALL™**

Diameter

 1.6 ± 0.4 nm

Length

 >5 μm

GRAPHENE NANOTUBES

Human existence is shaped by the materials we use. More than 70% of all basic materials can be improved by introducing a universal additive – single wall carbon nanotubes. These tiny tubes provide us with a rare opportunity to create nanoaugmented materials that have extraordinary properties.



Single wall carbon nanotubes (SWCNTs) should be referred to as graphene nanotubes (GNTs) because each nanotube is an extremely thin rolled-up sheet of graphene. The superiority of graphene nanotubes is due to their exceptional properties, such as superior conductivity, high temperature resistance, strength and flexibility.

TUBALL™

While the huge potential of SWCNTs has been recognised for many years, until recently their wide application in industry was not possible because of an absence of technology for their mass production, their high price, and a lack of methods for introducing them into materials.

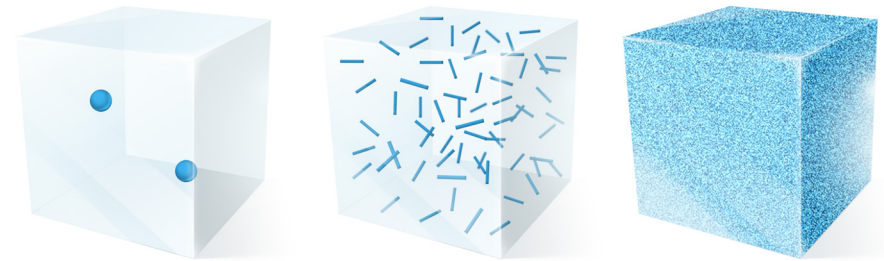
TUBALL™ nanotubes are the first GNTs to be available for commercial applications in a wide range of industries. OCSiAl's breakthrough yet low-cost mass-production technology has made the widespread use of nanotubes economically viable while still preserving their high quality.

FEATURES

- Best price to performance ratio compared with similar products
- Maintains color, elasticity, durability and other key properties
- Versatile for an extremely wide range of applications
- High-quality nanotubes (G/D ratio >90)
- Gains traction starting from ultra-low concentrations
- Adds uniform, permanent and stable electrical conductivity
- Enhances mechanical properties of materials

HOW IT WORKS

TUBALL™ provides significant improvements in material properties upon the addition of ultra-low loadings – starting from only 0.01%.



Microparticles

Nanofibers

GNTs

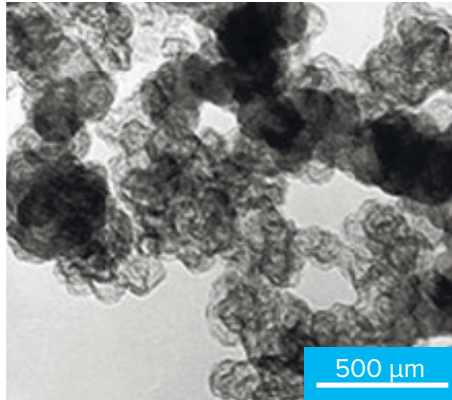
The same concentration of particles (~0.1%) in the same volume.

Unlike conventional additives such as multi wall carbon nanotubes, carbon fibers and most types of carbon black that unevenly disperse in a material's matrix, GNTs create a 3D uniform reinforced and conductive network.*

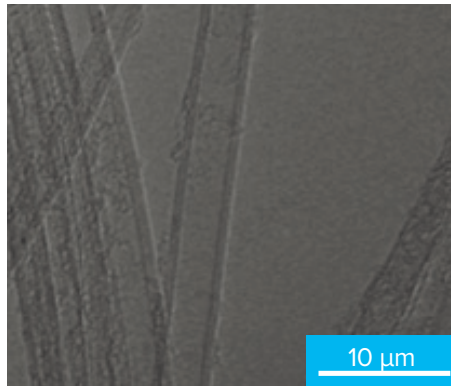
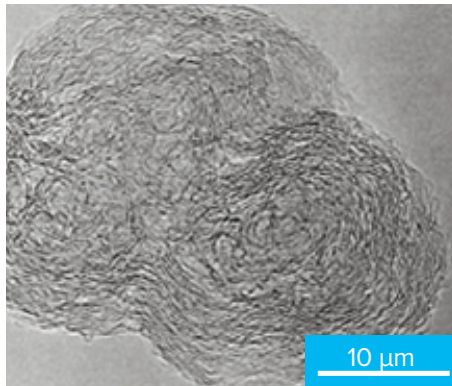
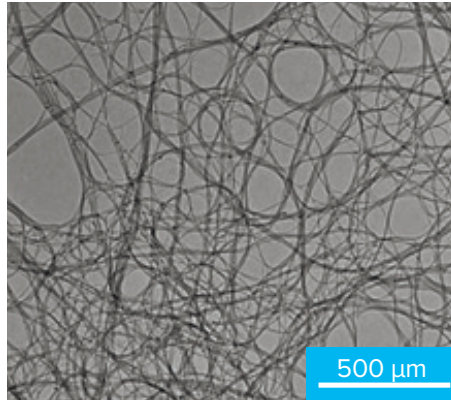
* Ma, P. C., Siddiqui, N. A., Marom, G., & Kim, J. K. (2010). Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: a review. *Composites Part A: Applied Science and Manufacturing*, 41 (10), 1345-1367.

NANOTUBES: THE ULTIMATE CARBON ADDITIVE

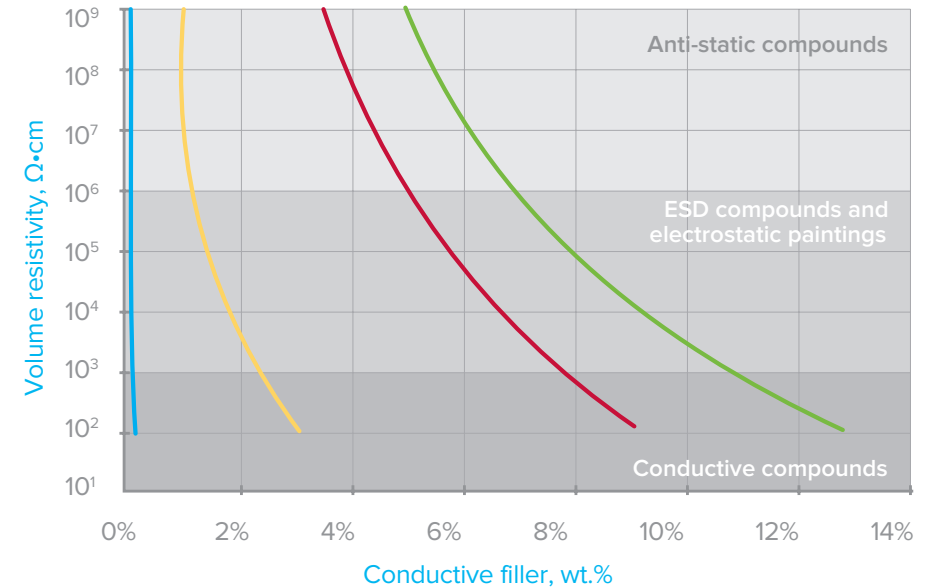
Conductive carbon black



TUBALL™ graphene nanotubes



THERMOSETS WITH TUBALL™ SHOW A SIGNIFICANT INCREASE IN CONDUCTIVITY



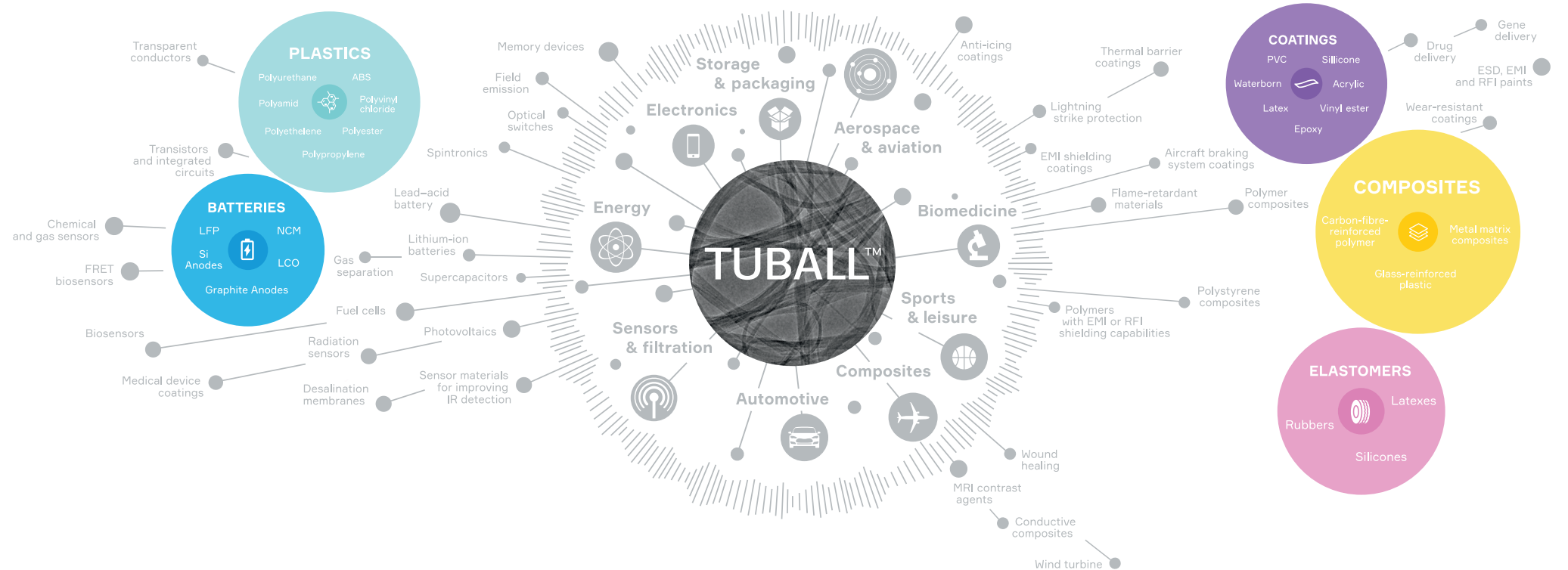
- TUBALL™ graphene nanotubes
- Multi wall CNT
- Premium carbon black
- Conductive carbon black

Results for unfilled polyester resin. ASTM D257.

PROCESSING GUIDELINES

To easily and properly incorporate TUBALL™ into materials, OCSiAl has developed and successfully brought to market a line of pre-dispersed concentrates, masterbatches and suspensions that are compatible with various industry-standard formulations.

For more information on TUBALL™ application in a specific matrix, refer to the product listing in the catalogue or contact the nearest OCSiAl office for assistance in selecting the right solution.



A blurred, grayscale background image showing an electric car parked at a charging station. The car is positioned horizontally across the frame, and a charging cable is visible on the right side, connected to the vehicle. The overall image has a soft, out-of-focus quality.

PRODUCTS FOR ENERGY STORAGE

TUBALL™ BATT

TUBALL™ BATT is a ready-to-use dispersion designed to easily incorporate TUBALL™ into electrode formulations during the battery manufacturing process.

TUBALL™ BATT provides a complete or partial substitute for carbon black in battery electrodes and can replace several percent of carbon black with 0.03–0.1% of TUBALL™.

TUBALL™ forms conductive 3D networks between active material particles at very low concentrations. The nanotubes reinforce the electrode structure and improve its mechanical stability during cycling. TUBALL™ improves adhesion by establishing strong ties between the particles, reducing the amount of binder required.





E-NABLE ENERGY

300
Wh/kg

TUBALL™ SWCNTs

for high-energy lithium-ion batteries

GREAT CHALLENGE:
BEST TECHNOLOGY WINS

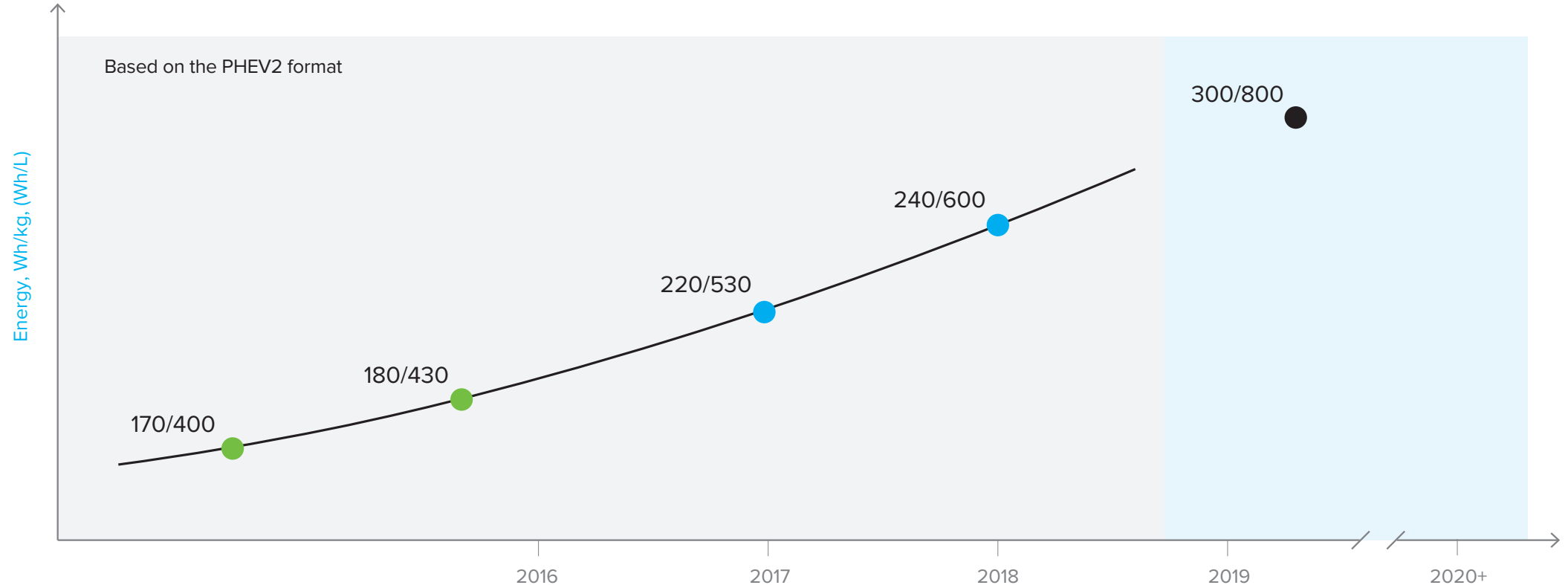
In order for electric vehicles to have a range and cost that is competitive with cars powered by internal combustion engines, the energy density of lithium-ion batteries (LIBs) needs to be dramatically improved.

The 2020 energy density goal, which is shared by the majority of LIB manufacturers, is 300 Wh/kg.

This is a major technological challenge, and solving it will require the most advanced materials and technologies to be implemented in the design of LIBs.

**IN ORDER TO ACHIEVE THE HIGH ENERGY
DENSITY GOALS SET BY THE AUTOMOTIVE INDUSTRY,
ANODES MUST CONTAIN SILICON**

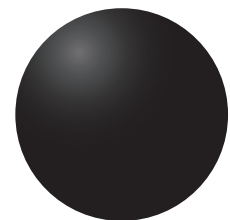
>240 Wh/kg: addition of SiO or Si/C to anodes is a necessity
300 Wh/kg: >20% SiO should be used inside the anodes



THE PULVERISATION OF Si ANODES

However, the more Si in the anode, the worse the swelling and pulverisation problem

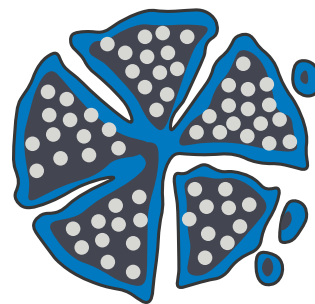
Si nanoparticles



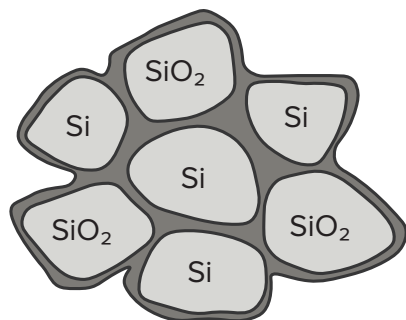
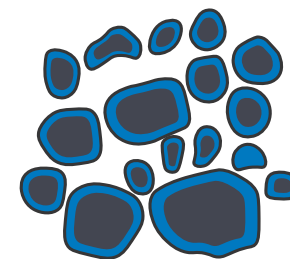
Lithiation
Cracking



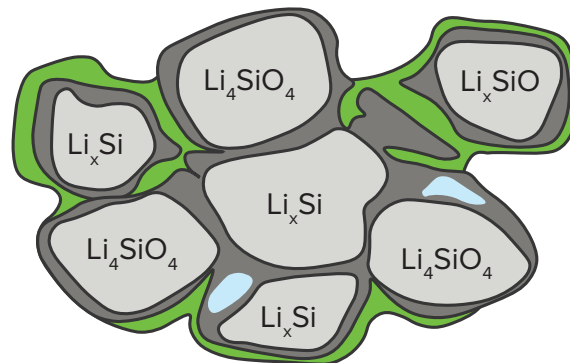
Delithiation
Pulverisation



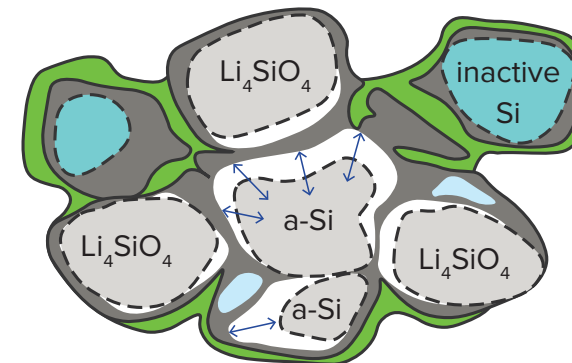
Cycles
Pulverisation



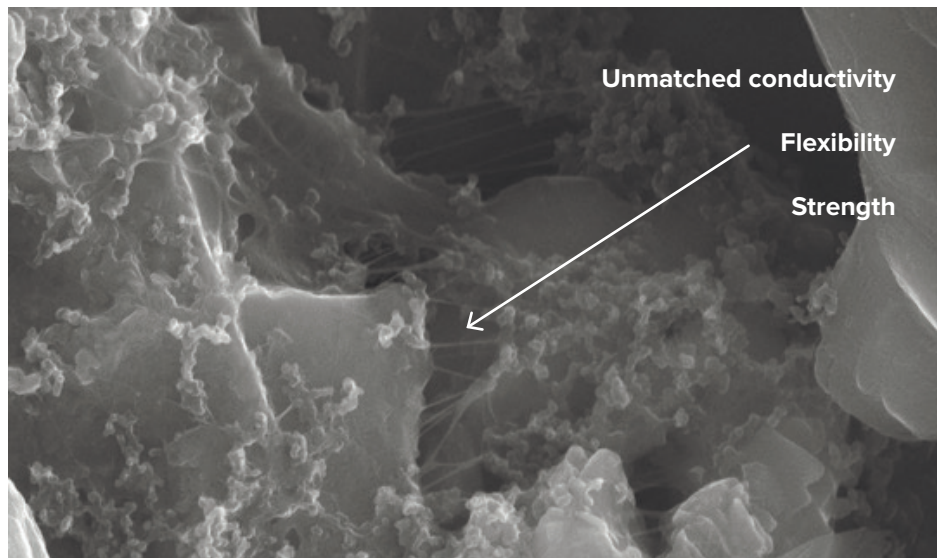
Li insertion



Li extraction



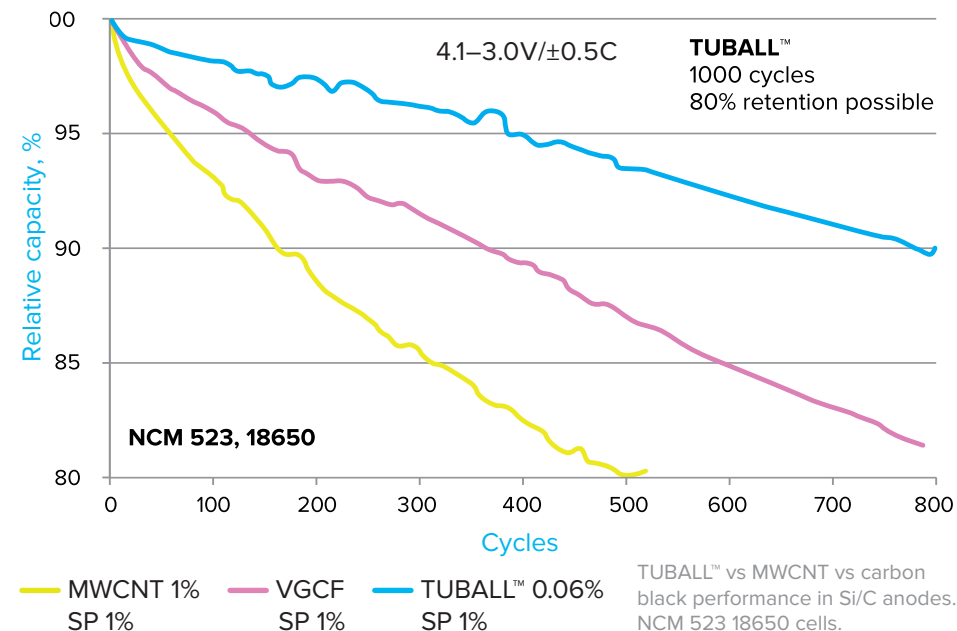
SOLVING THE SWELLING PROBLEM OF Si/C ANODES BY REINFORCING THEM WITH TUBALL™ SWCNTs



OCSiAl has developed the first ready-to-use TUBALL™ nanotube-based solution, TUBALL™ BATT H₂O, that efficiently solves the key problem of Si/C anodes – poor cycle life.

The ultra-fine and stable TUBALL™ SWCNTs dispersion in TUBALL™ BATT H₂O, when introduced into Si/C anodes at the stage of slurry manufacturing (by simple mixing), fully covers and electrically connects Si/C anode particles during the charge–discharge process of LIBs, even during the most harsh cycling conditions required by EV manufacturers.

E-NABLING THE INDUSTRIAL ADOPTION OF Si/C ANODES IN HIGH-ENERGY LIBs



TUBALL™ e-enables the opportunity for LIB manufacturers to use high-energy Si/C anodes in their commercial LIB formulations for the EV market, while having good cycle life that can meet the industry standards.

>240 Wh/kg – THE BENEFITS START

The more that high-energy-density anodes are used, the more essential is the application of TUBALL™ SWCNTs.

TUBALL™ BATT H₂O

ULTRA-FINE TUBALL™ DISPERSION IN H₂O

FOR HIGH-ENERGY Si/C ANODES

FEATURES:

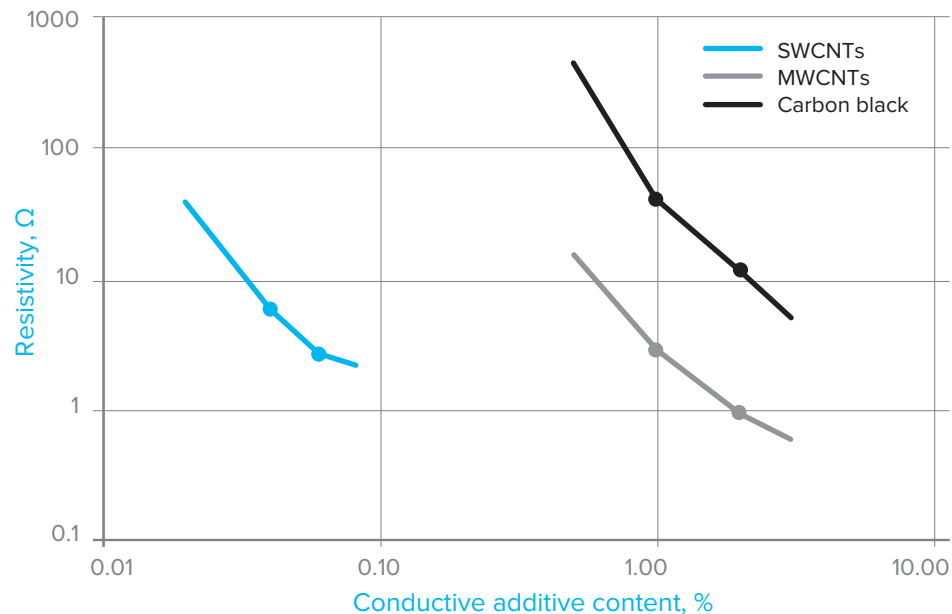
- 0.4% TUBALL™, CMC or other binders available
- Compatible with the majority of state-of-the-art Si/C recipes
- Ready and easy to use

IMPROVES THE CYCLE LIFE OF Si/C ANODES

E-nabling their industrial use in high-energy cells.



MAXIMISING THE ENERGY DENSITY OF CATHODES BY UTILISING THE UNMATCHED CONDUCTIVITY OF TUBALL™ SWCNTs

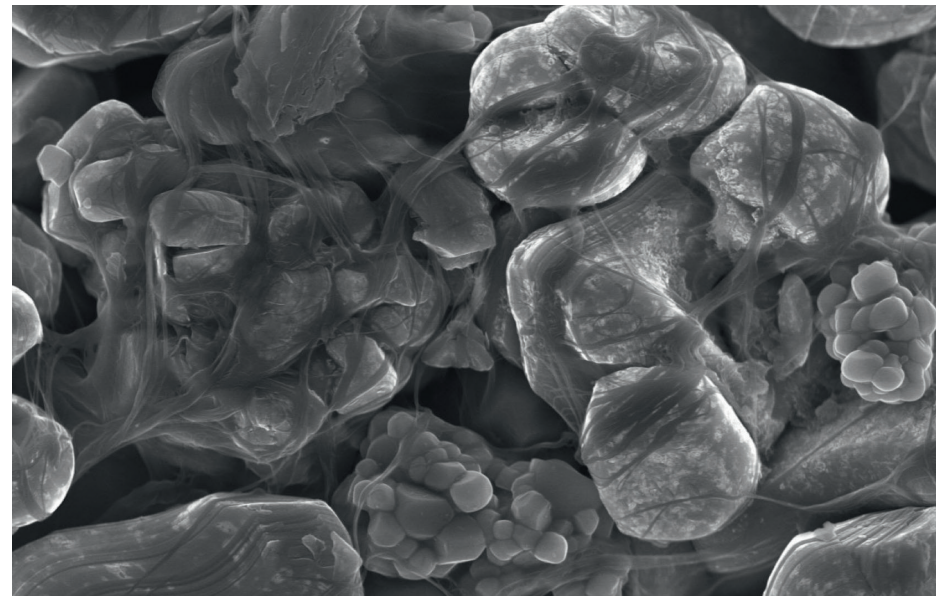


The exceptional conductive properties of TUBALL™ SWCNTs allow them to offer the required conductivity, adhesion, safety, rate and cycle performance in cathodes **starting from a loading of just 0.03%.**

This is a best-in-class result — the typical effective concentration required of industrially used MWCNTs or conductive carbon black is 10–50 times higher!

The ultra-low loading level of TUBALL™ SWCNTs allows LIB manufacturers to maximise the energy density of the cathodes by using a higher amount of active material: **up to 99% in modern high-energy NCM and other cathode materials.**

3–4 kg of conductive carbon black in EV batteries can be replaced with just **100 g** of TUBALL™.



Electrode sample with 0.06% of TUBALL™ shows good coverage of the particle's surface.

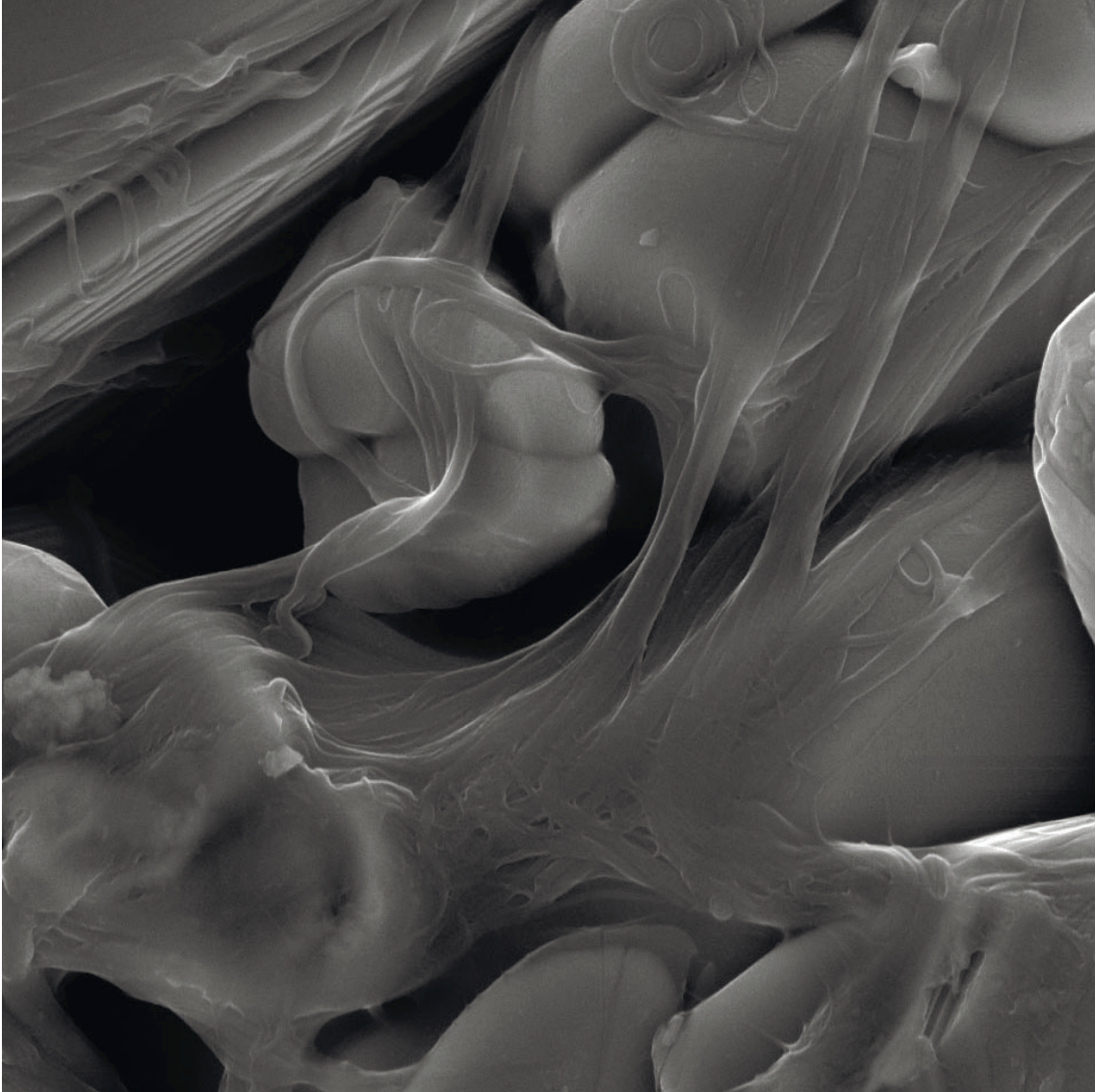
**BOOSTING C-RATE, REDUCING DCR
BY UTILISING THE UNMATCHED CONDUCTIVITY
OF TUBALL™ SWCNTs**

16 Ah, NCM 523 cells. Having normalised the capacities to the capacities under 0.2 C:

| Group / Rate | 0.2 C | 0.5 C | 1 C | 2 C | 3 C | 4 C | 5 C |
|---------------------------|-------|--------|--------|--------|--------|--------|--------|
| 2.81% SP + 0.47% KS6 | 100% | 98.10% | 96.90% | 90.70% | 90.60% | 82.00% | 63.40% |
| 0.1% TUBALL™ + 0.4% SP | 100% | 98.60% | 98.50% | 96.50% | 92.70% | 89.40% | 80.90% |
| Improved C-rate | | | | | | | |

TUBALL™ SWCNTs have a synergistic effect when used with other conductive additives starting from just TUBALL™ dosage.

The unparalleled conductivity of TUBALL™ SWCNTs makes it possible to achieve the highest possible energy densities in modern cathode materials, but to boost the C-rate and reduce the DCR of LIBs, especially when combined with other conductive additives.



TUBALL™ BATT NMP

ULTRA-FINE TUBALL™ DISPERSION IN NMP

FOR HIGH-ENERGY AND HIGH-POWER CATHODES

FEATURES:

- 0.4% TUBALL™, 2% PVDF, no foreign additives inside
- More than 80% solids achievable
- Low Fe content
- Choice of PVDF possible
- Ready and easy to use

MAXIMISES ENERGY DENSITY

By e-nabling the possibility to maximise the content of active material: up to 99%.

BOOSTS C-RATE, REDUCES DCR

By utilising the unmatched conductivity of TUBALL™. Starting from just 0.01%, when used together with other conductive additives.



TUBALL™ BATT READY-TO-USE PRODUCTS FOR LIBs

| | SWCNTs, % | DISPERSING AGENT, % | METAL IMPURITIES, PPM | DESCRIPTION |
|------------------------------------|-----------|---------------------|-----------------------|---|
| FOR CATHODES | | | | |
| 0.2% TUBALL™ BATT NMP | 0.2% | PVDF 2% | <20 | ULTRA-FINE TUBALL™ DISPERSION IN NMP for high-energy and high-power cathodes |
| 0.4% TUBALL™ BATT NMP | 0.4% | PVDF 2% | <40 | Maximises energy density when used as a full or partial replacement of other conductive additives Boosts C-rate, reduces impedance when used at low dosage in combination with other additives |
| FOR Si/C ANODES | | | | |
| 0.2% TUBALL™ BATT H ₂ O | 0.2% | CMC 0.3% | <300 | ULTRA-FINE TUBALL™ DISPERSION IN H₂O for high-energy Si/C anodes |
| 0.4% TUBALL™ BATT H ₂ O | 0.4% | CMC 0.6% | <40 | Improves cycle life of Si/C anodes e-nabling their industrial adoption in hi-energy cells >240 Wh/kg – benefits start. The more that high-energy-density anodes are used, the more essential is the application of TUBALL™ SWCNTs |



PRODUCTS FOR ELASTOMERS

TUBALL™ MATRIX 603

TUBALL™ MATRIX 603 is a nanotube concentrate specifically designed to enhance the physical and mechanical properties of rubbers and contribute to electrical conductivity. TUBALL™ MATRIX 603 expands rubber compound performance, providing manufacturers with the freedom to access new high performance options.



SOLUTION FOR HIGH PERFORMANCE RUBBERS

TUBALL™ MATRIX 603 enables high performance NR, BR and SBR rubber compounds for tires and rubber goods with loadings starting from 1%. Mechanical and conductivity improvements at low loadings allow for the next leap in performance since silica.

FEATURES:

- Low loadings of 1 to 5 phr
- Improved mechanical properties
- Better wet grip & abrasion resistance
- Lower rolling resistance
- Reduced heat buildup
- Strong increase of electrical conductivity
- Weight reduction
- Scale of improvement depending on recipe

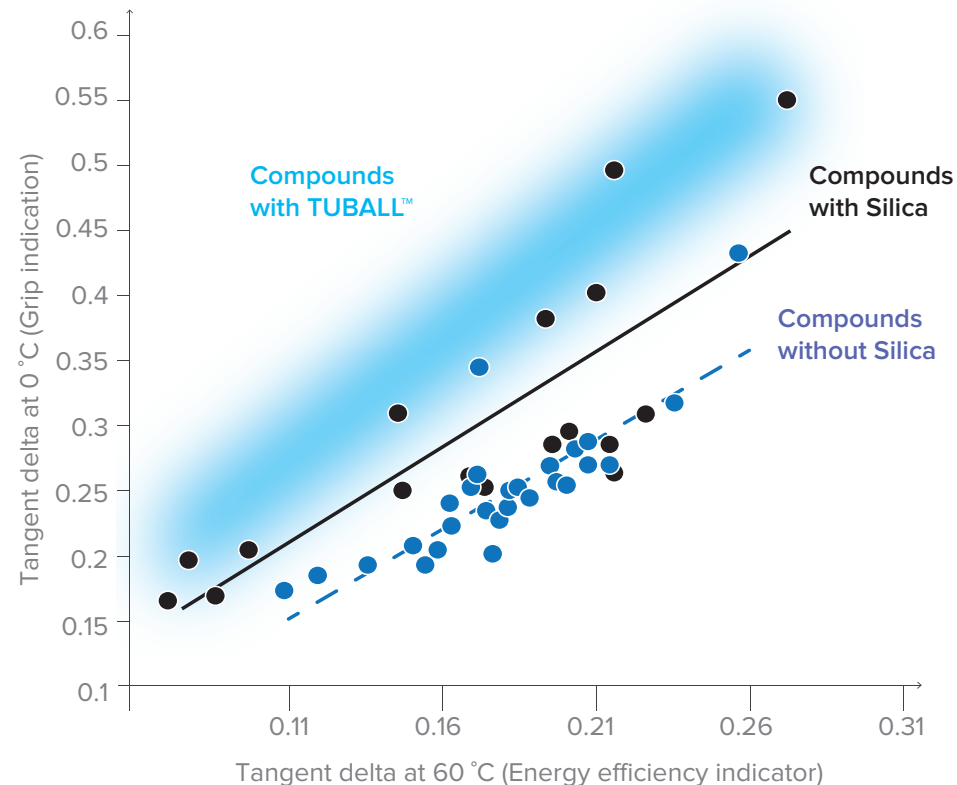
TUBALL™ MATRIX 603

Carrier: TDAE (Low aromatic oil-plasticizer)

KEY APPLICATIONS:

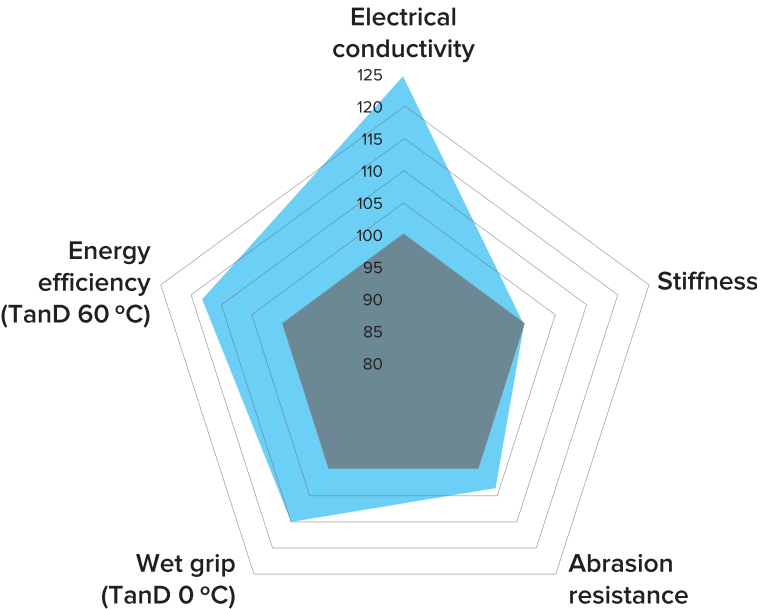
- Tires
- Conveyor belts
- Seals
- Hoses
- V-belts and others

THE NEXT LEAP IN PERFORMANCE SINCE SILICA

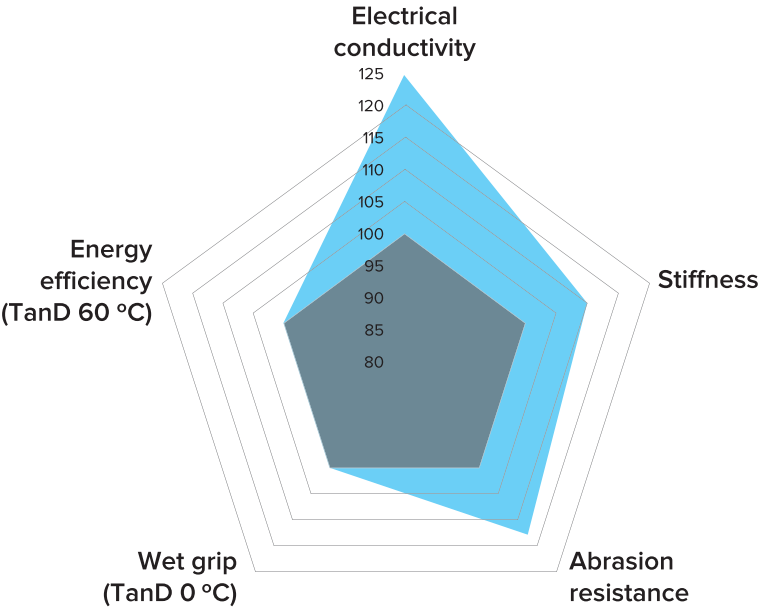


TUBALL™ data from OCSIAI customer trials. Silica data from NHTSA Feb. 2010 report Dynamic Mechanical Properties of Passenger and Light Truck Tire Treads.

TIRE PERFORMANCE: NEW SPACE



Recipe #1



Recipe #2

■ Reference compound
■ Compounds with 1 wt.% of TUBALL™ MATRIX 603

TUBALL™ MATRIX

601 / 602 / 605

TUBALL™ MATRIX 601, 602 and 605 are concentrates specifically designed to provide superior electrical conductivity to silicone compounds (LSR – liquid silicone rubber, RTV – room temperature vulcanized rubber, and HCR – high consistency rubber) while retaining mechanical properties and minimally impacting the host matrix.



TUBALL™ MATRIX 601 / 602 / 605

PROPERTY — Electrical conductivity



TUBALL™ MATRIX 601

Carrier:
polydimethylsiloxane oil

KEY APPLICATIONS

- LSR (liquid silicone rubber)
- RTV (room temperature vulcanised) silicones

TUBALL™ MATRIX 602

Carrier: vinyl-terminated
polydimethylsiloxane

KEY APPLICATIONS

- LSR (liquid silicone rubber)
- HCR (high consistency rubber)

TUBALL™ MATRIX 605

Carrier: silicone gum

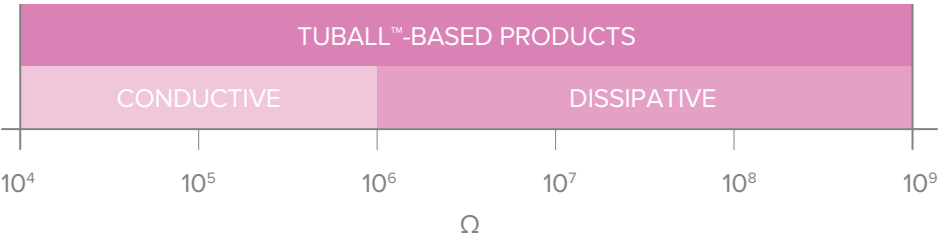
KEY APPLICATIONS

- HCR (high consistency rubber)

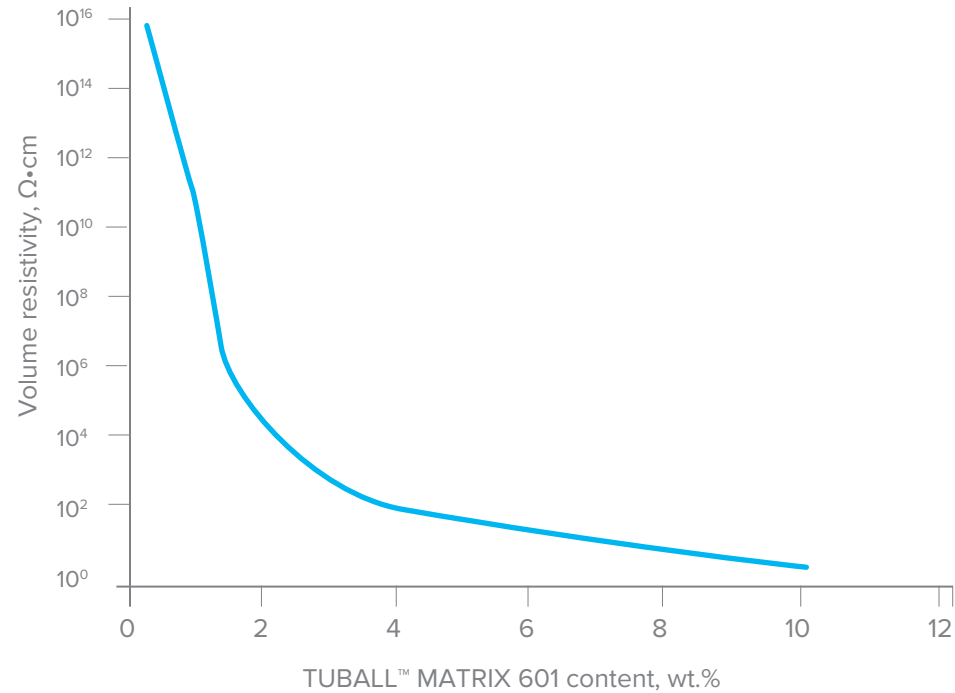
CONDUCTIVE SILICONES WITH TUBALL™ MATRIX

| | Currently available | TUBALL™ MATRIX |
|------------------------------------|---------------------------|---------------------------|
| Volume resistivity level | <100–10 ⁸ Ω•cm | <100–10 ⁸ Ω•cm |
| Concentration of conductive filler | 30–70 wt.% | 0.5–5 wt.% |
| Retain mechanical properties | No | Yes |
| Allow colouration | No | Yes |

FULL RANGE OF RESISTIVITY

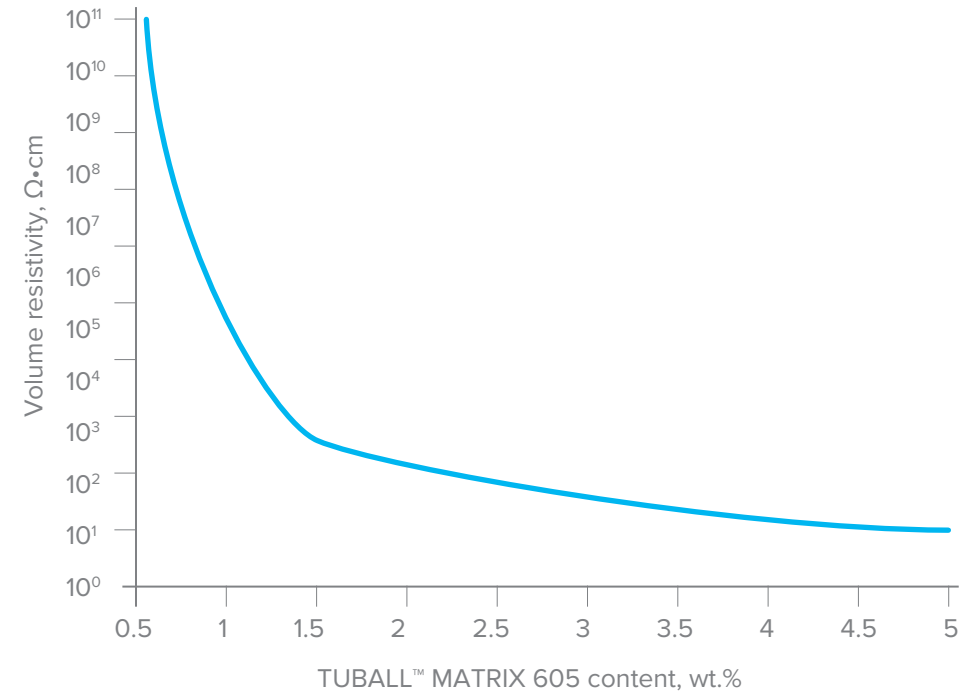


**VOLUME RESISTIVITY OF LSR SILICONE
WITH TUBALL™ MATRIX 601 IS IN THE RANGE $10\text{--}10^{15} \Omega\cdot\text{cm}^*$**



* Tested in two-component LSR (Shore 40).
Measurements conducted according to ASTM D991.

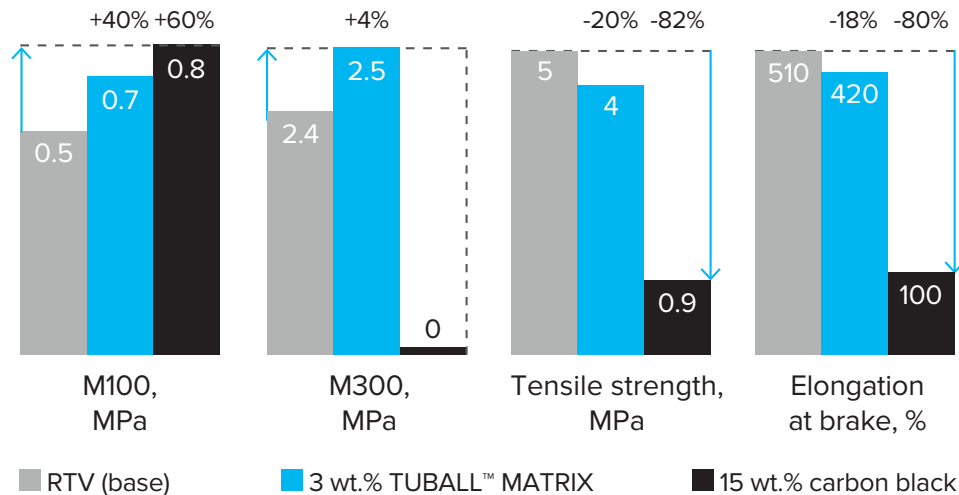
**VOLUME RESISTIVITY OF HCR SILICONE
WITH TUBALL™ MATRIX 605 IS IN THE RANGE $<10\text{--}10^{11} \Omega\cdot\text{cm}^*$**



* Tested in HCR (Shore 60).
Measurements conducted according to ASTM D991.

PHYSICAL PROPERTIES OF RTV WITH 3 wt.% TUBALL™ MATRIX 601 IN COMPARISON WITH CONDUCTIVE CARBON BLACK

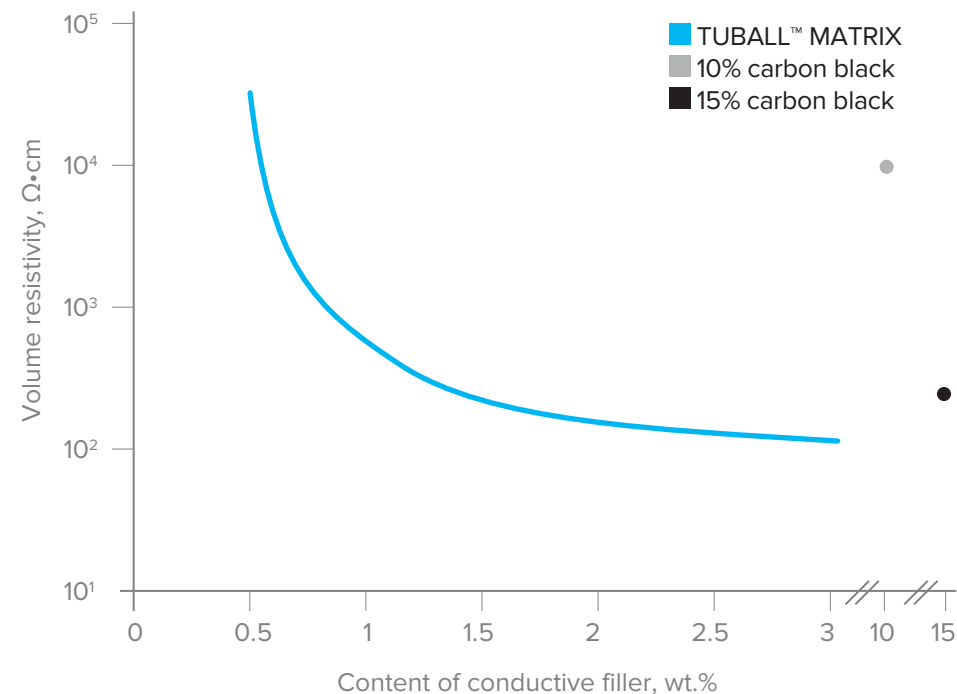
Volume resistivity 200 $\Omega \cdot \text{cm}$



TUBALL™ MATRIX makes it possible to produce conductive compounds without losing their flexibility or mechanical properties

* Measurements conducted according to ASTM D412.
Study was conducted with conductive carbon black VULCAN® XC72R.

VOLUME RESISTIVITY OF RTV SILICONE WITH TUBALL™ MATRIX 601 IN COMPARISON WITH CONDUCTIVE CARBON BLACK



* Measurements conducted according to ASTM D991.

TUBALL™ LATEX

TUBALL™ LATEX is a water-based suspension for manufacturing latex gloves and latex products with anti-static properties, while retaining mechanical properties and minimally impacting the host matrix.

TUBALL™ LATEX makes it possible to attain permanent and humidity-independent conductivity that is fully compliant with the most demanding applications, including the new European standard EN 16350:2014 (EN 1149) for anti-static properties in safety wear.

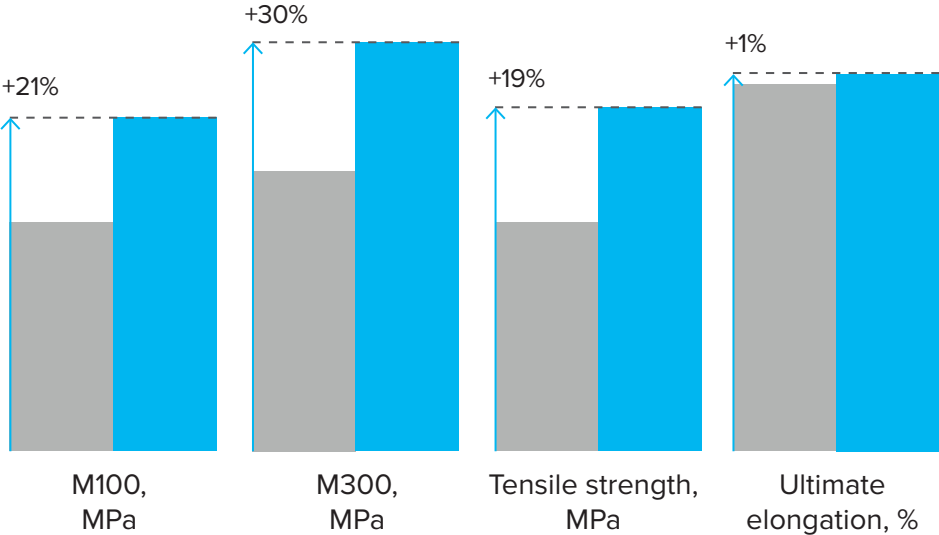


ANTI-STATIC NITRILE LATEX WITH TUBALL™

| | Current solutions | Results with TUBALL™ |
|--|--|--|
| Specific resistivity level | 10 ⁷ –10 ¹¹ Ω·cm | 10 ² –10 ¹¹ Ω·cm |
| Concentration of conductive filler | 5–25 wt.% | 0.03–0.075 wt.% |
| Negative impact on mechanical properties | Yes | No |
| Color retention | Yes | Yes |




PHYSICAL PROPERTIES OF NATURAL LATEX WITH 0.03 wt.% TUBALL™



■ No CNT added
■ 0.03 wt.% TUBALL™

CL60, medium modulus, pre-vulcanized latex.
CNT dispersion stabilized by CMC surfactant.

Adding 0.03 wt.% of TUBALL™ improved the natural latex’s mechanical properties by 20% while maintaining its elastic properties.

The background image is a dark, high-contrast photograph of an industrial interior. It features a highly reflective floor that mirrors the green structural columns and the silhouettes of workers in the distance. The lighting is dramatic, with strong highlights and deep shadows, creating a sense of depth and scale.

PRODUCTS FOR THERMOSET COATINGS & COMPOSITES

TUBALL™ MATRIX 200/300s

TUBALL™ MATRIX 200/300s are nanotube concentrates designed to provide permanent, uniform electrical conductivity to various materials: epoxy, polyurethane, polyester etc. TUBALL™ MATRIX is compatible with a variety of color shades while meeting ESD standards.



COMPOSITES



GFRP pipes



Equipment for mines, electronics, chemical plants and petrol stations



Equipment in clean rooms



Housing/packaging for sensitive electronics, and combustible powders or liquids

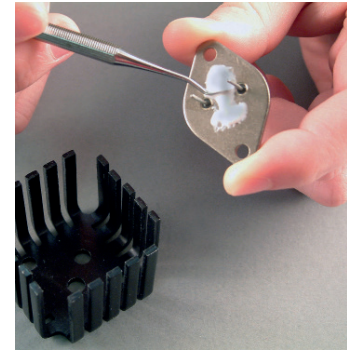
COATINGS



Epoxy and PU anti-static flooring



Gelcoats and mouldcoats

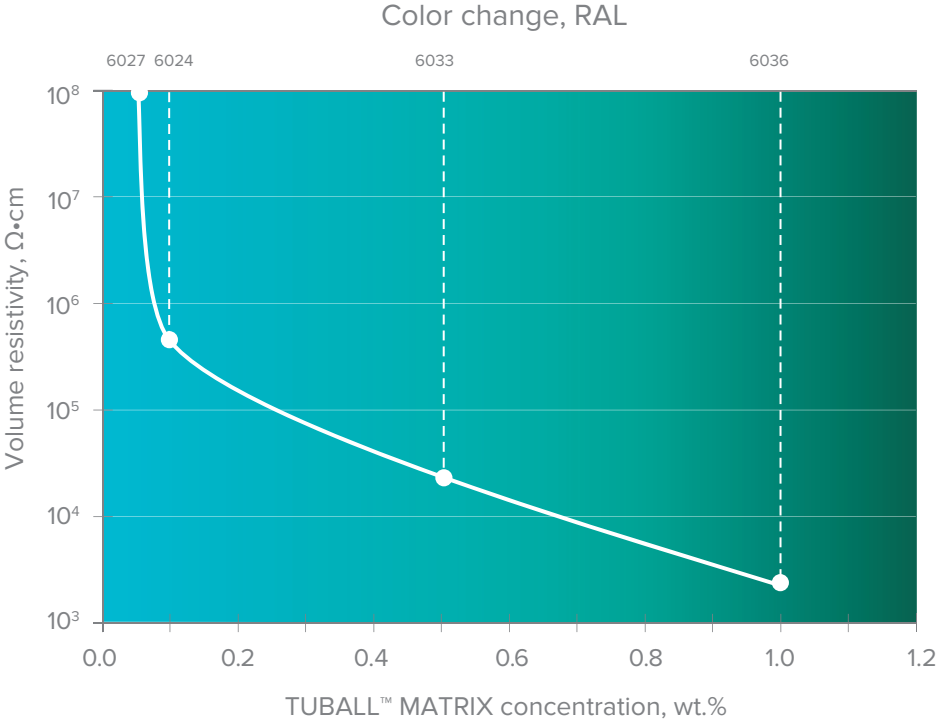


Epoxy and PU conductive adhesives



Conductive primers for plastic components

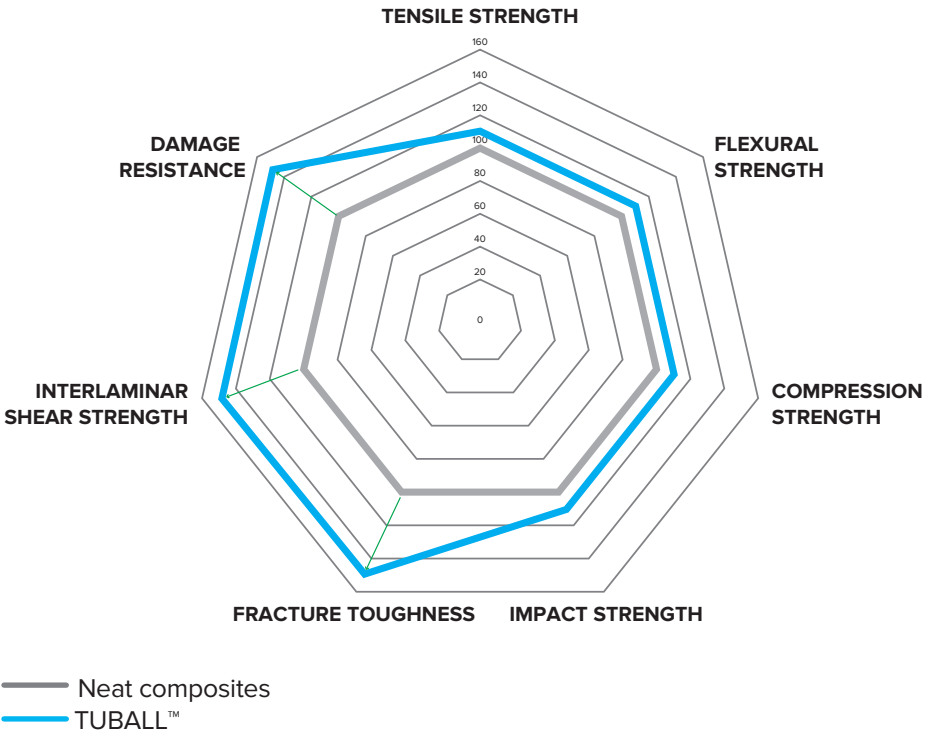
TUBALL™ MATRIX CONDUCTIVITY AND COLOR



Note: all samples include 5 wt.% of TiO₂ as a whitening agent.
Results for epoxy resin D.E.R. 351.

EXPECTATIONS: ENHANCED BY TUBALL™ MATRIX

+20–60% improvement +5–10% improvement



DECREASED CREEPING

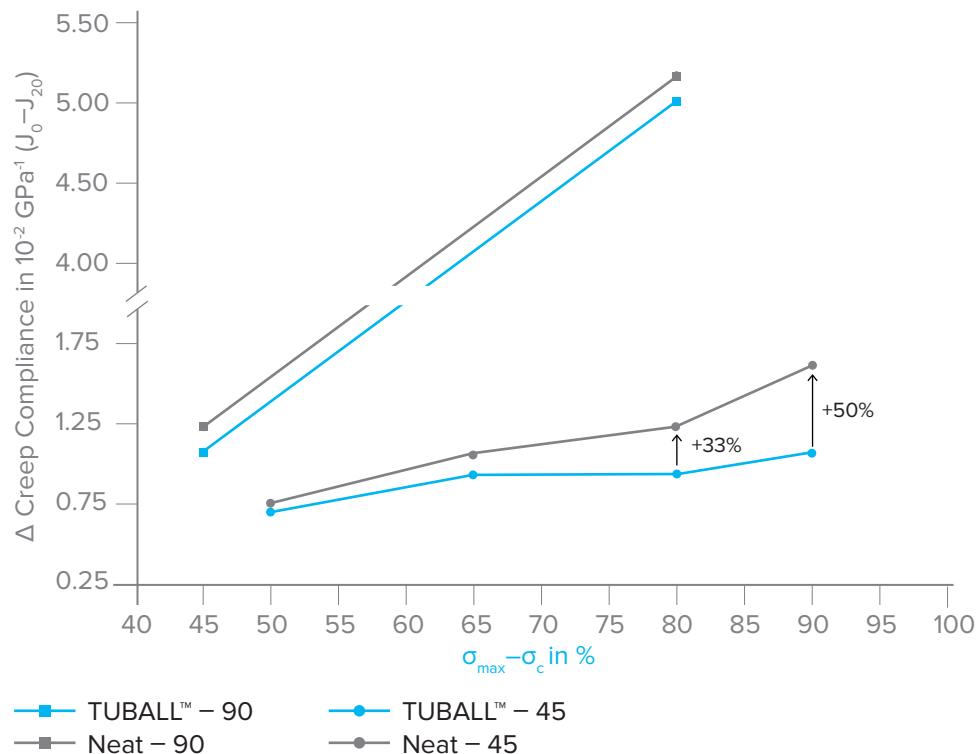
For fiber reinforced composites

NET COMPOSITES

Δ Creep Compliance in $10^{-2} \text{ GPa}^{-1} 1.5$

COMPOSITES WITH 0.05% of TUBALL™

Δ Creep Compliance in $10^{-2} \text{ GPa}^{-1} 1.0$



Maximum creep compliance achieved after 20 hours of constant loading in dependence of the applied stress level for tested configurations.

A significant increase in creep resistance is shown for the 0.05 wt.% TUBALL™ modified systems especially at high stress level in transverse direction.

RESIN

Epoxy hotmelt system (R 481/H 482)

FIBER

Carbon fiber Grafil 34-700 (MITSUBISHI RAYON)

- tensile strength 4.83 GPa
- tensile modulus 234 GPa
- density 1.8 g/cm³

FABRICATION

Prepreg + autoclave

MEASUREMENT STANDARD

DIN EN ISO 527-5

VALIDATED BY

TUHH
Technische Universität Hamburg-Harburg

TUBALL™ COAT_E

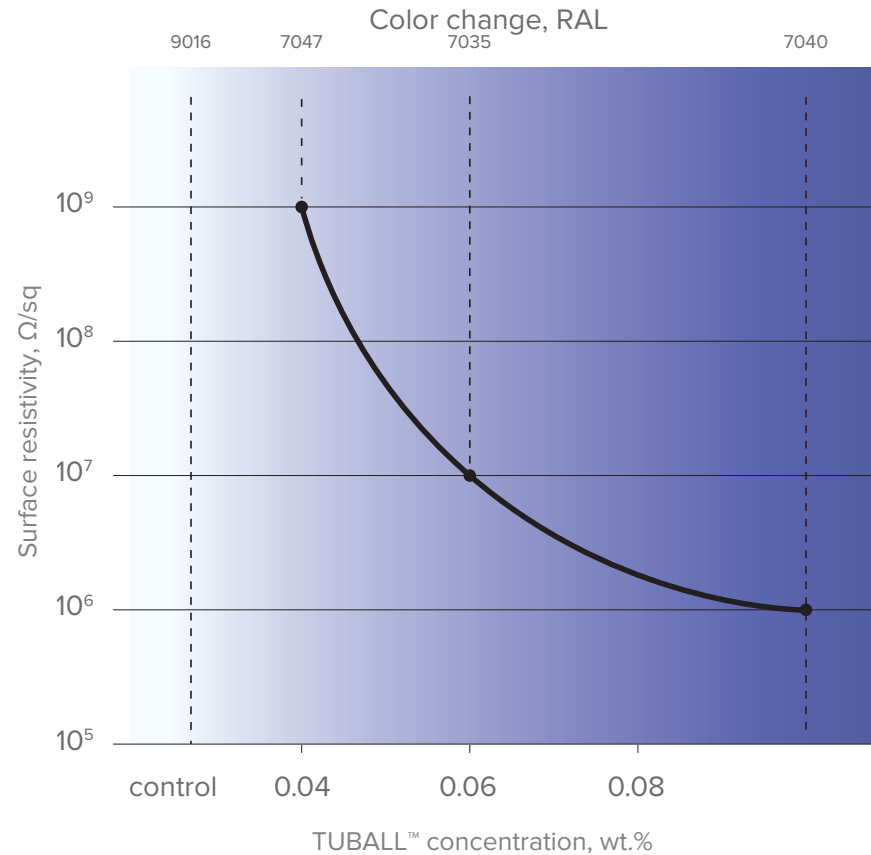
TUBALL™ COAT_E is an easy-to-use single wall carbon nanotube suspension in water, which provides permanent antistatic properties to waterborne paints and coatings with minimal impact on their color and mechanical properties.

TUBALL™ COAT_E is suitable for production of anti-static waterborne paints and coatings intended for the following applications:

- Industrial ESD flooring
- Textiles and clothing
- Walls and work surfaces in ESD protected areas
- Packaging for electronics

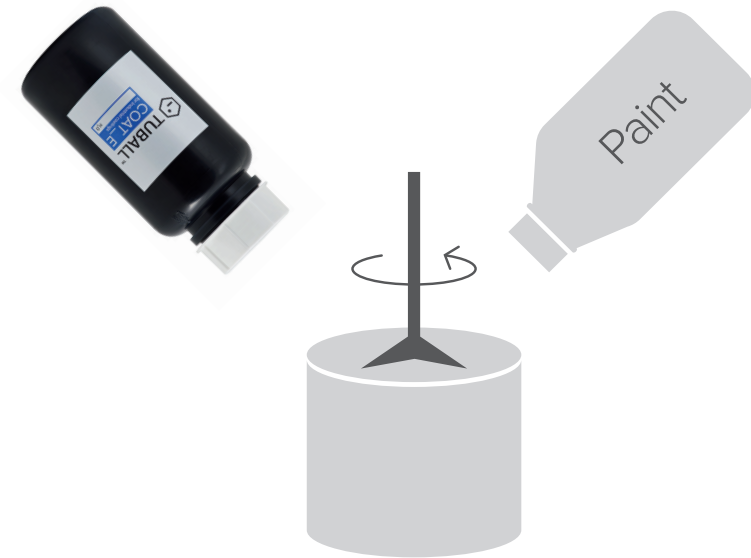


TUBALL™ COAT_E IS SUITABLE FOR COLORED AND TRANSPARENT SYSTEMS



Permanent electrostatic dissipative and conductive properties with color and/or transparency are achieved by simply mixing TUBALL™ COAT_E with the paint system.

- Easy to use
- Efficient ESD protection
- Permanent conductivity
- Suitable for colored and transparent systems



SAFETY INFORMATION

OCSiAl produces nanotube dispersions and concentrates to enable a simple and easy integration process. TUBALL™ MATRIX products and TUBALL™ suspension products were developed to minimize handling requirements and provide all manufacturers access to the superior performance of single wall carbon nanotubes.

For handling and safety information please refer to the Material Safety Data Sheet and Safe Handling guide for the corresponding product.

WARRANTIES AND DISCLAIMER

The Products correspond to the chemical composition indicated in the Technical Data Sheet and the Material Safety Data Sheet supplied with the Product. The information contained in this document (Information) is based on trials carried out by OCSiAl and may contain inaccuracies or errors that could cause injury, loss or damage.

OCSiAl gives no further warranty and makes no further representation regarding the Products and/or the accuracy of Information and/or suggestions for any particular use of the Products or Information, or that suggested use will not infringe any patent. The Products and Information are supplied on an “as is” basis. These express provisions are in place for all warranties, representations, conditions, terms, undertakings and obligations implied by statute, common law, custom, trade usage, course of dealing or otherwise (including implied undertakings of satisfactory quality, conformity with description, fitness for purpose and reasonable skill and care), all of which are hereby excluded to the maximum extent permitted by applicable law.

TUBALL CENTERS

TUBALL CENTERS are hubs for production technology development and new materials prototyping.

OCSiAl's TUBALL CENTERS are located in regions with the highest market demand for graphene nanotube solutions and the most rapid industry adoption of advanced technologies. TUBALL CENTERS develop new nanotube products and provide local customers with technical support.

TUBALL CENTER Shanghai was opened in December 2019. It covers an area of 1 260 m² and has 12 laboratories with 150 unique items of equipment for developing nanotube solutions in batteries, plastics, coatings, composites and elastomers.

THE MOST ADVANCED SWCNT RESEARCH CENTER



TUBALL CENTER Novosibirsk was the first R&D facility opened by OCSiAl, in 2015 in Akademgorodok. It performs fundamental studies and develops nanotube applications by designing intermediate formulations – currently more than 40 additives are commercially produced. The R&D team has unique equipment for developing and testing products in batteries, plastics, coatings, composites, and elastomers, forming a center for prototyping industrial materials enhanced with nanotubes.



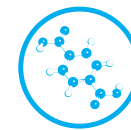
nanotube properties



coatings



energy storage



thermoplastics



elastomers



thermosets

ABOUT OCSiAl



OCSiAl is an international advanced materials company, commercializing breakthrough technologies for the synthesis of high quality industrial carbon nanomaterials.

OCSiAl was founded by a group of like-minded visionaries who identified the fundamental need for clean materials, and understood the reality that graphene nanotubes (GNTs) are the only universal additive with mechanical, thermal and electrical properties capable of improving the composition of more than two-thirds of all materials used in industrial production.

Today OCSiAl employs over 450 scientists, engineers, technologists, designers, industry vendors and managers working in 13 countries. With experts in physics, chemistry, nanomaterials and other scientific fields at the core of OCSiAl's R&D and product development, OCSiAl has one of the most experienced teams in the nanomaterials industry.

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CONTACT YOUR LOCAL DISTRIBUTOR TO ORDER A SAMPLE AND OBTAIN TECHNICAL/SAFETY DATA SHEETS

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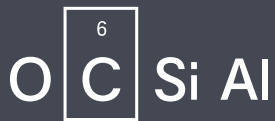
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