Exploring graphene and related nanomaterials as multifunctional additives

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May 2024

Agenda

- Introduction to Universal Matter & Polyhedral Graphitized Carbon
- Enhancing Topcoat Resins – Experimental Overview
- Enhancing Topcoat Resins – Results
  - ✓ Abrasion resistance
  - ✓ Impact resistance
  - ✓ Impact on Colour and Gloss
  - ✓ UV resistance
- Discussion & Conclusions

Universal Matter – International Presence

Universal Matter facilities in Canada, United States and United Kingdom

Corporate HQ : UMI Burlington, ON, Canada

- New application development lab
- Polyhedral Graphitized Carbon and dispersion production facility
- Operational by Q2 2024
- 12 staff

USA Subsidiary : UML Houston, TX

- USA Subsidiary: UML Houston, TX
- Process, product & application development lab
- Pilot production
- 9 staff

UK Subsidiary: UMUK, Redcar, England

- Process, product & application development lab
- Graphene production plant
- Dispersion Plant for liquid graphene additive production
- 20 staff

Universal Matter – Our Vision

Produce high quality and economical graphene and hydrogen from simple carbon feedstocks that dramatically reduce our carbon footprint

Universal Matter is leading the transition toward the crucial circular economy by using biomass and plastic waste to create stronger, lighter, and more resilient products with graphene

"Using carbon to decarbonize"

CIRCULAR ECONOMY Inspired

CO_2 Net-Zero Emissions 2050

cradletocradle

Introduction to Polyhedral Graphitised Carbon

- Nanomaterials, such as graphene, exhibit remarkable barrier, mechanical, thermal, and electrical properties and have the potential to impart ***multifunctional improvements*** in protective coatings
- Universal Matter manufactures two particular forms of carbon-based nanomaterials, graphene nanoplatelets (GNPs) and ***polyhedral graphitized carbons*** (PCGs)
- Our previous work has shown significant performance enhancements in ***barrier*** and ***anticorrosion*** properties of epoxy coatings
- In this particular study, we take this exploration further, carrying out a comparative analysis, focusing on the use of PGCs to improve performance of topcoat resins

How Flash Joule Heating Process Works

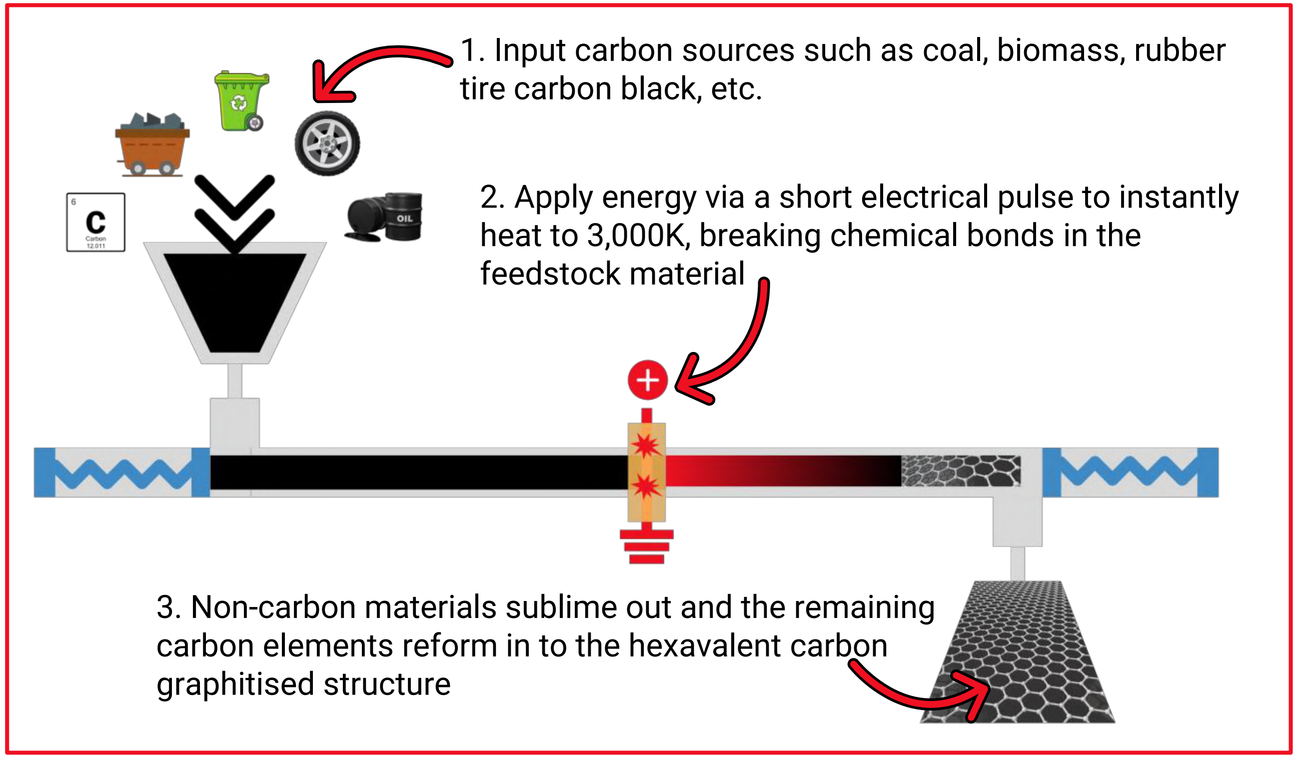
- PGCs are a new class of nanomaterial, manufactured using the Flash Joule Heating process (Rice University)

- The process is a patented high energy process where the temperature of the carbon feedstock is raised to approximately 3000K, through rapid heating steps

- This induces morphological changes in the feedstocks, resulting in the restructuring of molecules and formation of ordered domains

- The feedstocks include natural and synthetic carbons or waste, recycled or upcycled carbon based materials

- The flashing of carbon feedstocks, produces a primary PGC nanoparticle that is considered to be made of a graphitic skin–core structure, with a hollow or amorphous core



- The PGC primary particles form an interconnected network that can re-enforce the polymer matrix, potentially improving properties such as abrasion resistance

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The Solution: Flash Joule Heating Process

HIGH QUALITY: Few layer, defect free graphene

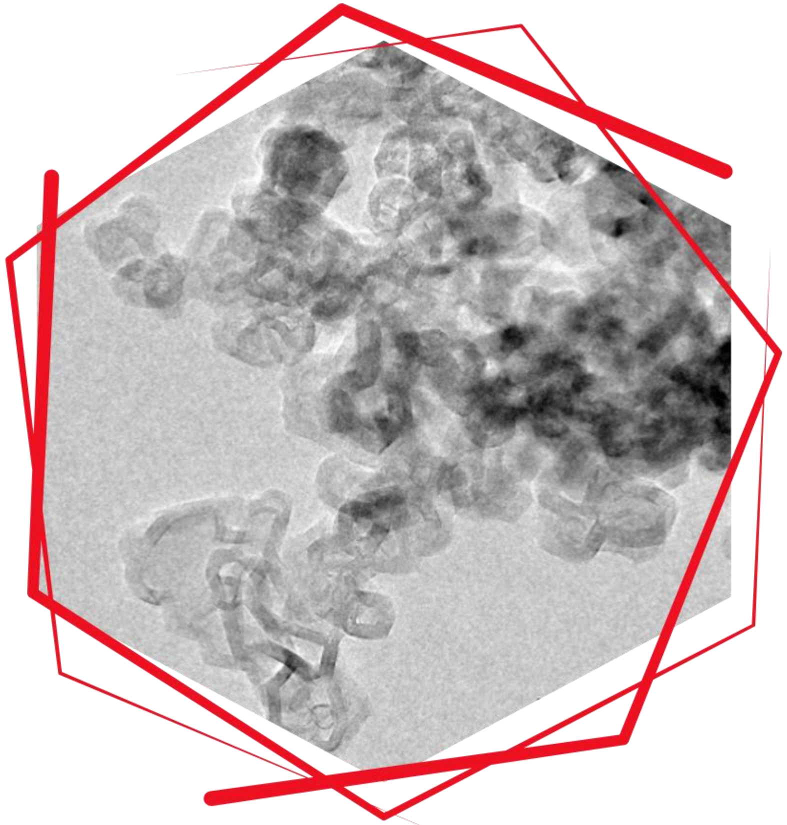
NEW MORPHOLOGIES: Turbostratic flake & Polyhedral

MORE ECONOMICAL: High-volume, efficient production process

HIGHLY SUSTAINABLE: Energy efficient process, using waste, upcycled and recycled carbon as raw materials

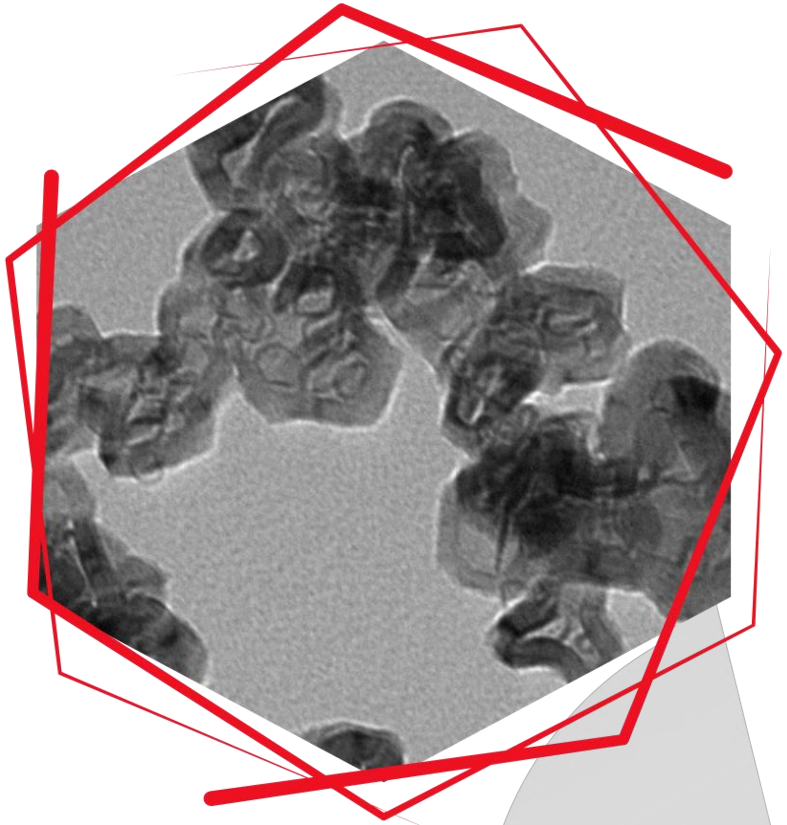
Introduction to Polyhedral Graphitised Carbon

PGC-06.08



- PGC06.08 has the larger primary particle size

PGC06.18



- PGC06.18 is a smaller primary particle with a higher structure

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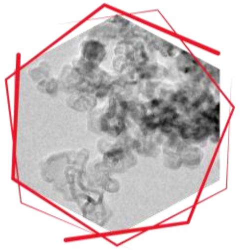
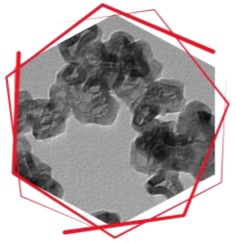
Introduction to Polyhedral Graphitised Carbon





	PGC-06.08	PGC-06.18
Particle Size (D90, Laser Diffraction)	1.0 - 2.0 microns	0.9 - 1.0 microns
Surface Area (BET)	40	65
Bulk Density (kg/m^3)	229	165
Typical PGC Loading in Dispersion (by Weight %)	10%	10%

Enhancing Topcoat Resins – Experimental Overview

Enhancing Topcoat Resins – Project Objective

Having previously demonstrated enhancements in anticorrosion performance of epoxy primers, the authors set out to:

1. Investigate potential multifunctional performance benefits of Polyhedral Graphitized Carbons in a polyurethane resin
2. Investigate whether these benefits can be realized in new isocyanate free topcoat chemistries, such as acrylic functionalized epoxy

Polyurethane Formulation

- PGCs were dispersed in Cyrene™ at 10% loading by weight
- This dispersion was used to introduce the graphene into the topcoat resins

Material	Control	0.1% UM-06.08	0.5% UM-06.08	0.1% UM-06.18	0.5% UM-06.18
Polyol Resin	90.70%	89.90%	86.10%	89.90%	86.10%
Isocyanate	9.30%	9.20%	8.90%	9.20%	8.90%
10% PGC Dispersion in Cyrene	---	1.00%	5.00%	1.00%	5.00%
Total PGC Loading	---	0.10%	0.5%	0.10%	0.5%

Epoxy-Acrylic Resin Formulation

- PGC was initially dispersed in Cyrene™ or butyl acetate at 10% loading by weight
- This dispersion was used to introduce the graphene into the topcoat resins

Material	Control	0.1% UM-06.08	0.5% UM-06.08	0.1% UM-06.18	0.5% UM-06.18
Epoxy-Acrylic Resin	55.30%	54.70%	52.50%	54.70%	52.50%
Amine-Acrylic Resin	44.70%	44.30%	42.50%	44.30%	42.50%
10% PGC Dispersion in Cyrene or Butyl Acetate	---	1.00%	5.00%	1.00%	5.00%
Total PGC Loading	---	0.10%	0.5%	0.10%	0.5%

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Experimental Overview

Panel Preparation

- All samples applied using 200-micron drawdown bar, achieving a dry film thickness of 65 ± 10 microns
- Films were cured at 25 °C for 7 days

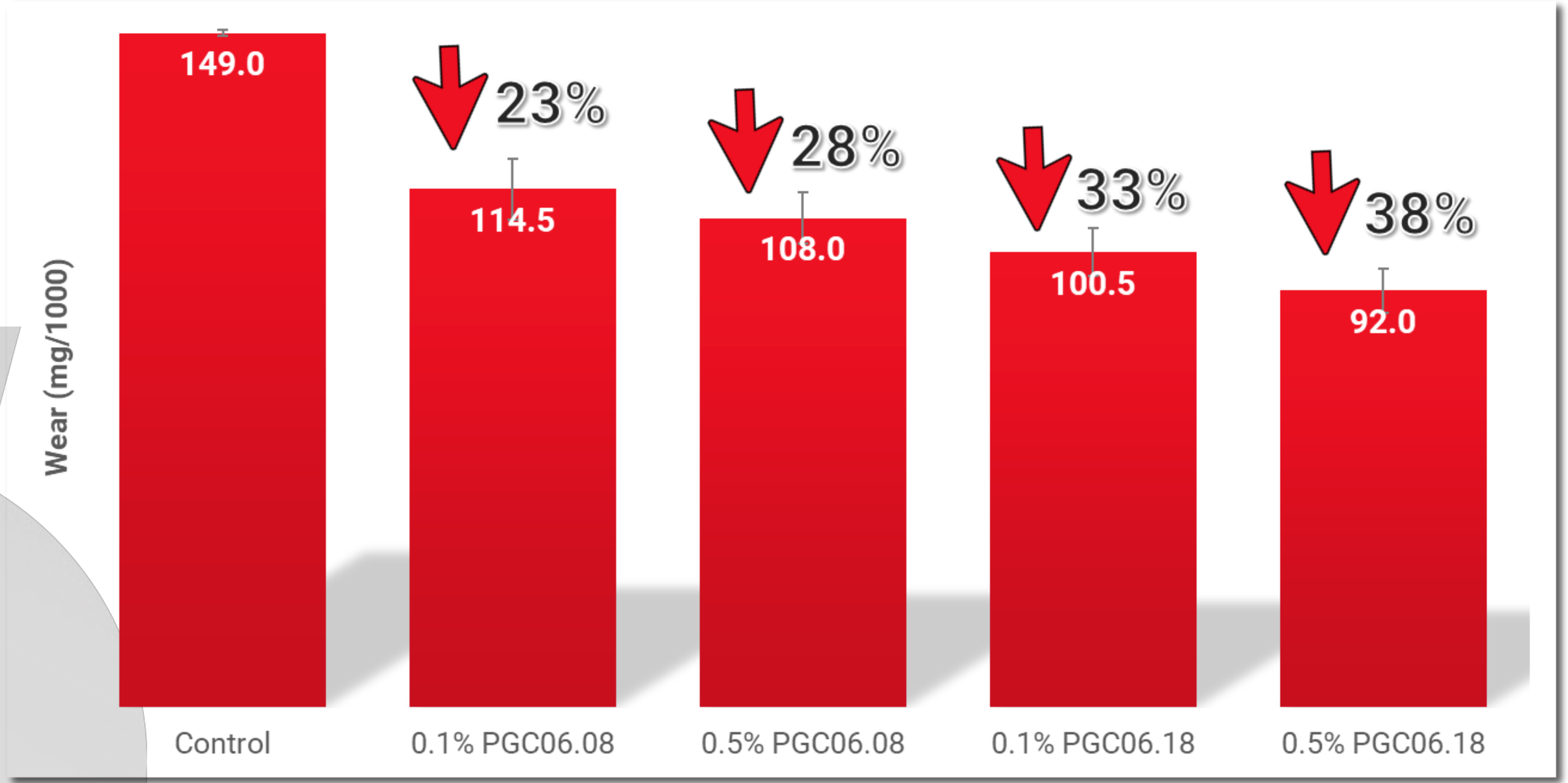
Test Program

- Abrasion resistance
- Impact resistance
- Impact on colour and gloss
- UV resistance
  - Colour retention
  - Gloss retention

Enhancing Topcoat Resins – Results

Abrasion Resistance – Polyurethane System

- Testing was carried to ASTM D4060
- Samples were tested for 100 cycles under a 1Kg load and a 60 RPM speed, then extrapolated to 1000 cycles



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Abrasion Resistance – Epoxy-Acrylic System

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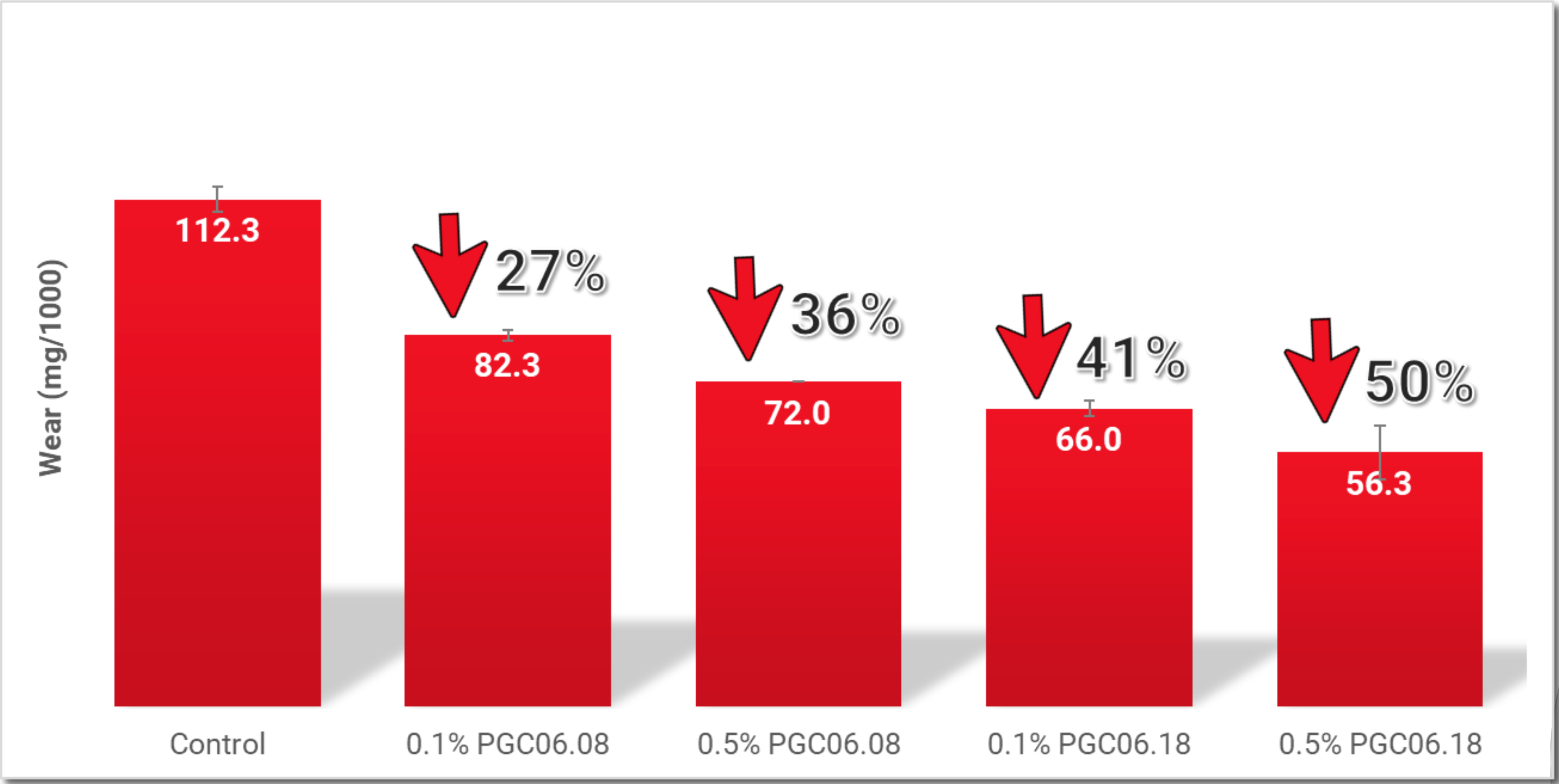


Abrasion Resistance – Results

Polyurethane Performance:

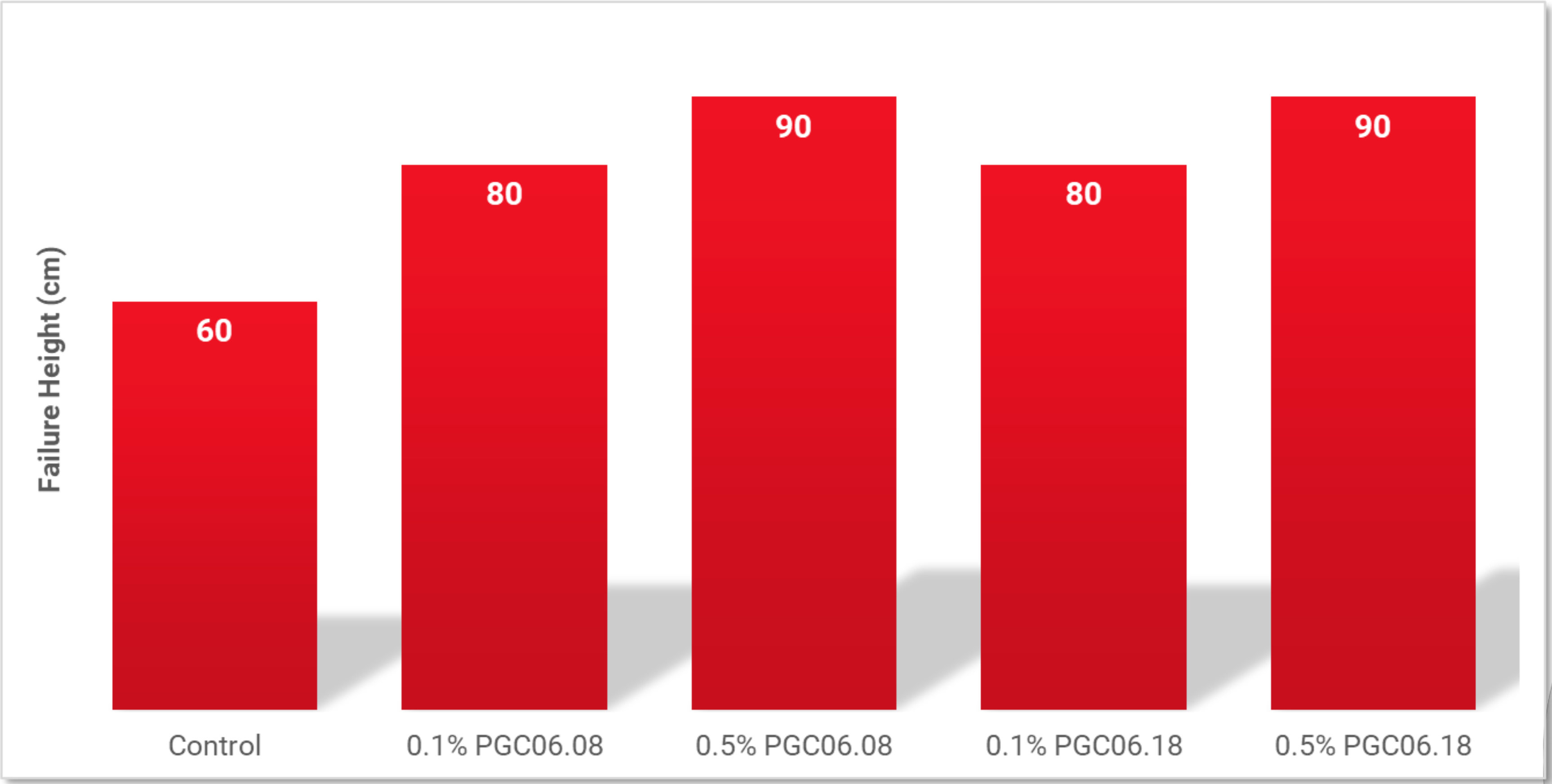
- In all cases, the addition of the PGCs improved abrasion resistance, with the higher loadings giving the better performance
- Best performance was achieved with the 06.18, giving nearly **40% reduction** in wear

Epoxy-Acrylic Performance:

- Higher loading of each PGC gave better wear resistance
- Best performance was achieved with 0.5% 06.18, which showed a **50% reduction in wear**
- Various literature sources suggest lower particle size, higher structure materials perform better under abrasion, which can be seen here with PGC06.18 performing better in both chemistries

Impact Resistance – Polyurethane System

- The impact resistance of each coating was tested using an Elcometer 1615 Variable Impact Tester, dropping a 1kg weight under direct impact



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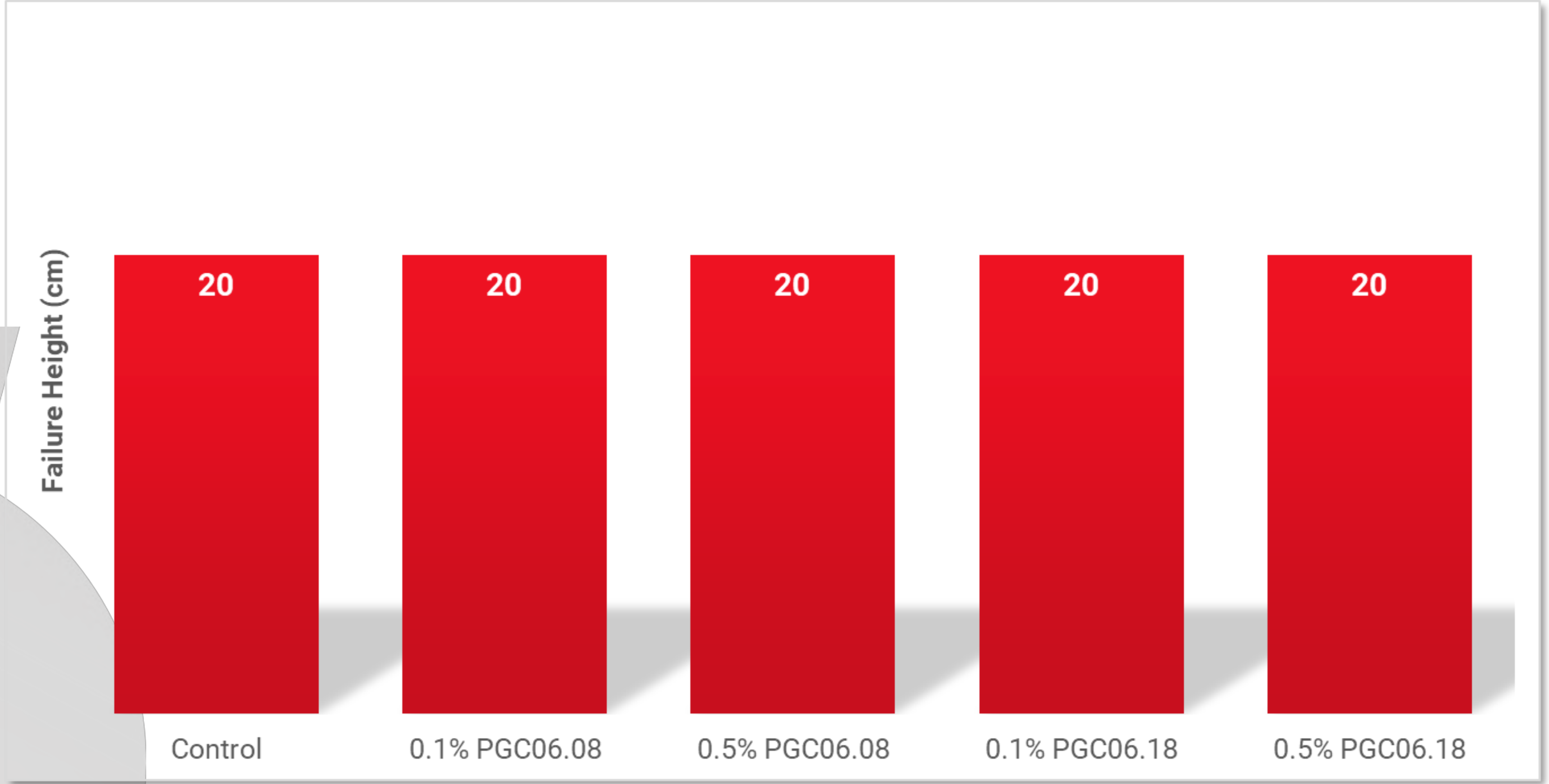

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Impact Resistance – Results

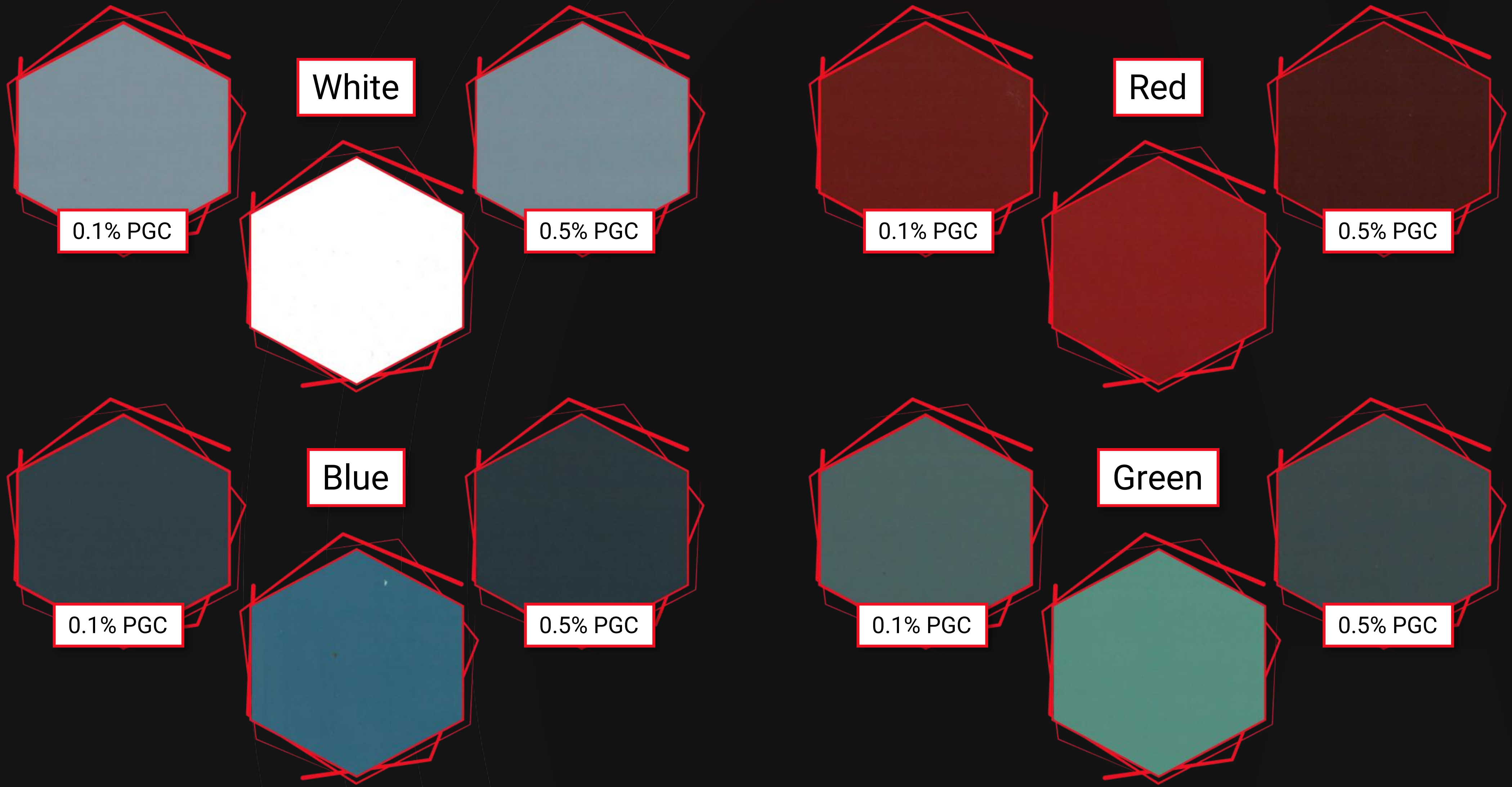
Polyurethane Performance using Cyrene™-based dispersions:

- Increasing PGC loading increased the maximum impact that the coatings could withstand
- Up to **50% improvement** was achieved at the highest loading of PGC

Epoxy-Acrylic Performance:

- Loading had seemingly no effect on impact resistance
- The performance of the resin was very low in this case and could not be improved with use of the PGCs

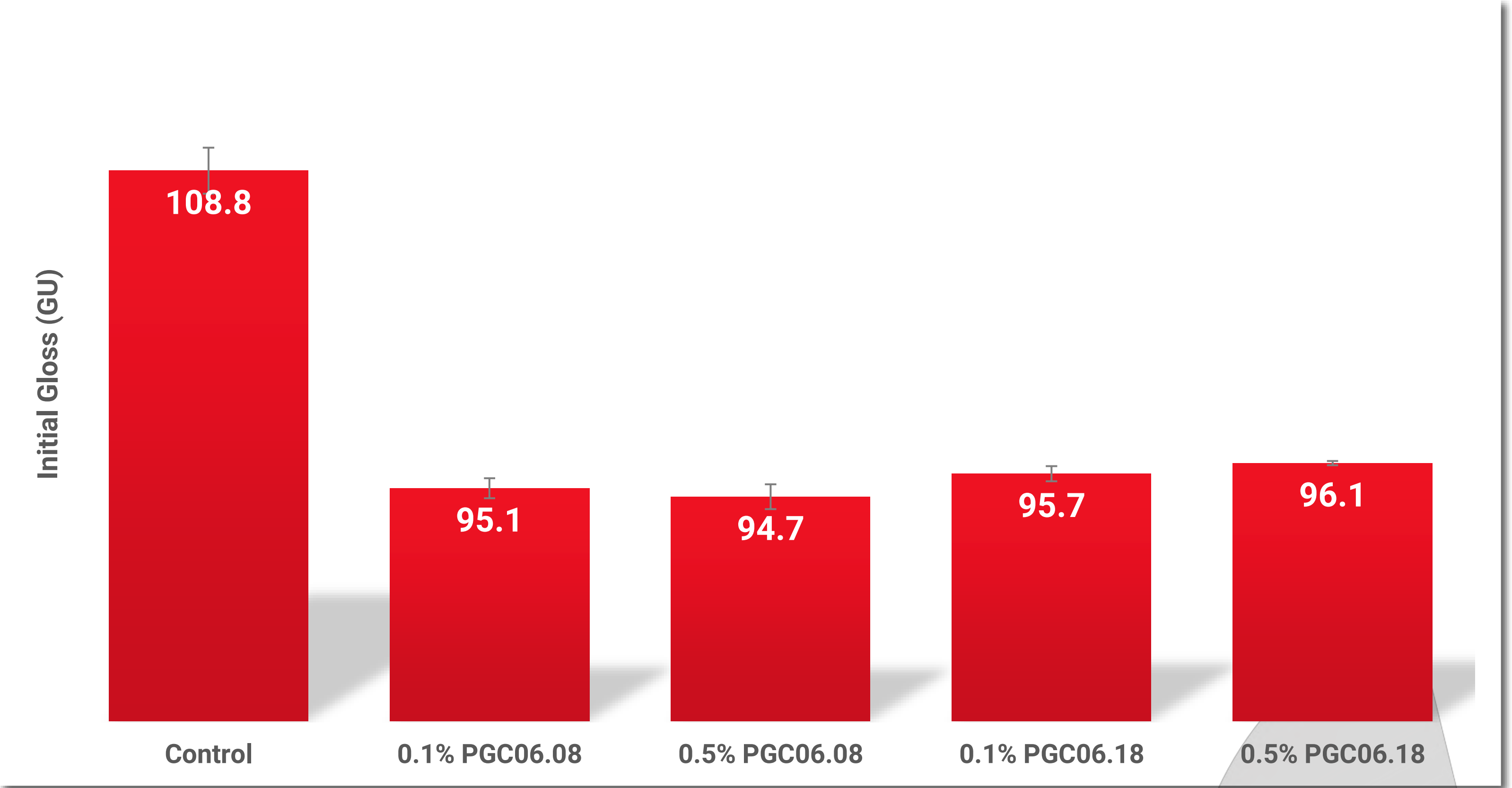
Effect on Colour



Impact on Gloss– Polyurethane System

➢ Initial gloss of all coatings was tested at a 60-degree incidence angle prior to any exposure

Paint Type	Gloss Level
Ultra Flat	<1
Flat	1 - 2
Matt	3 - 10
Low Sheen	10 - 20
Satin	20 - 30
Gloss	40 - 80
High Gloss	> 80



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Impact on Gloss – Epoxy-Acrylic System

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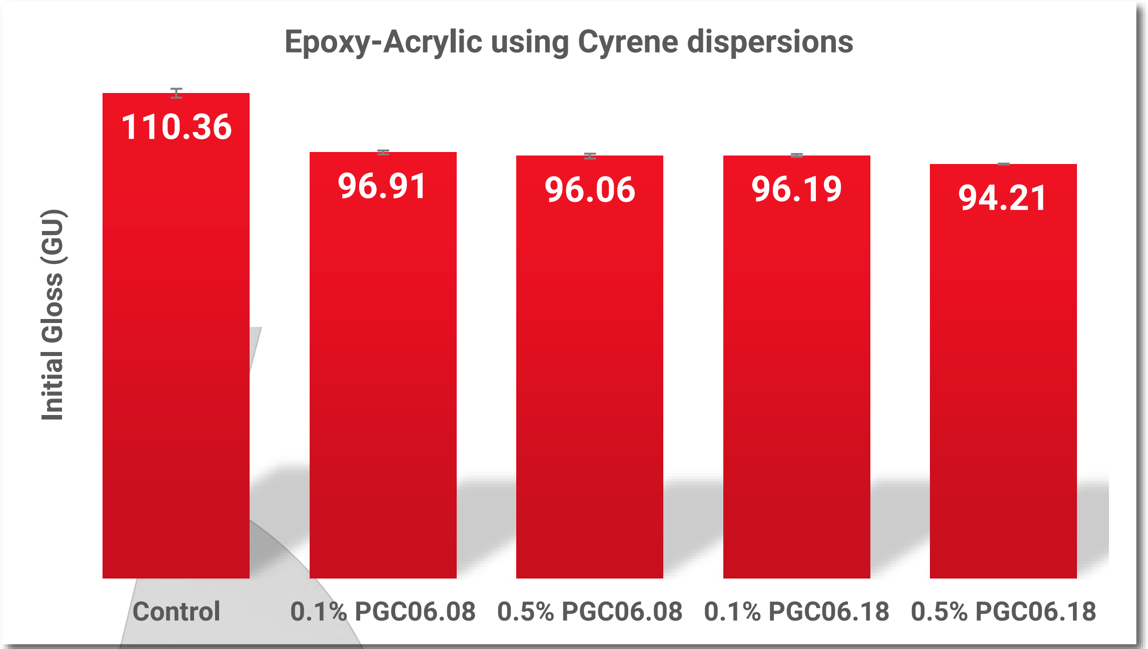
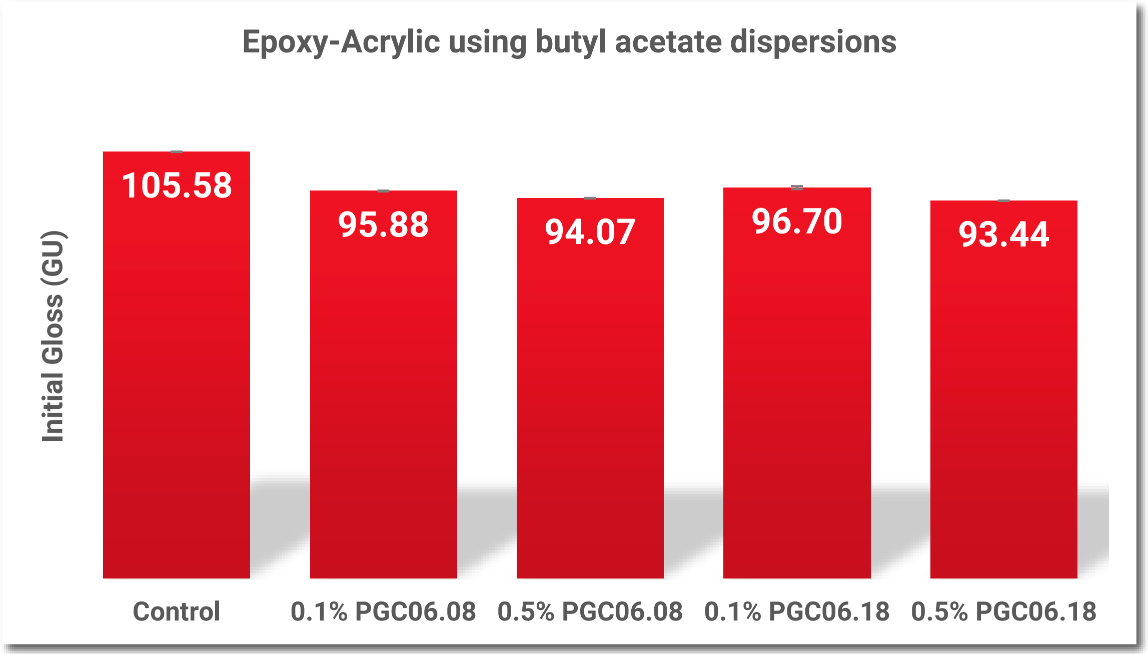




Impact on Gloss– Results

Polyurethane Performance using Cyrene™-based dispersions:

- Slightly lower initial gloss - to be expected with adding filler/pigment to a neat resin, albeit at low addition levels
- All values remain in the "High Gloss" region
- Loading level/concentration did not appear to have a big impact on the gloss level

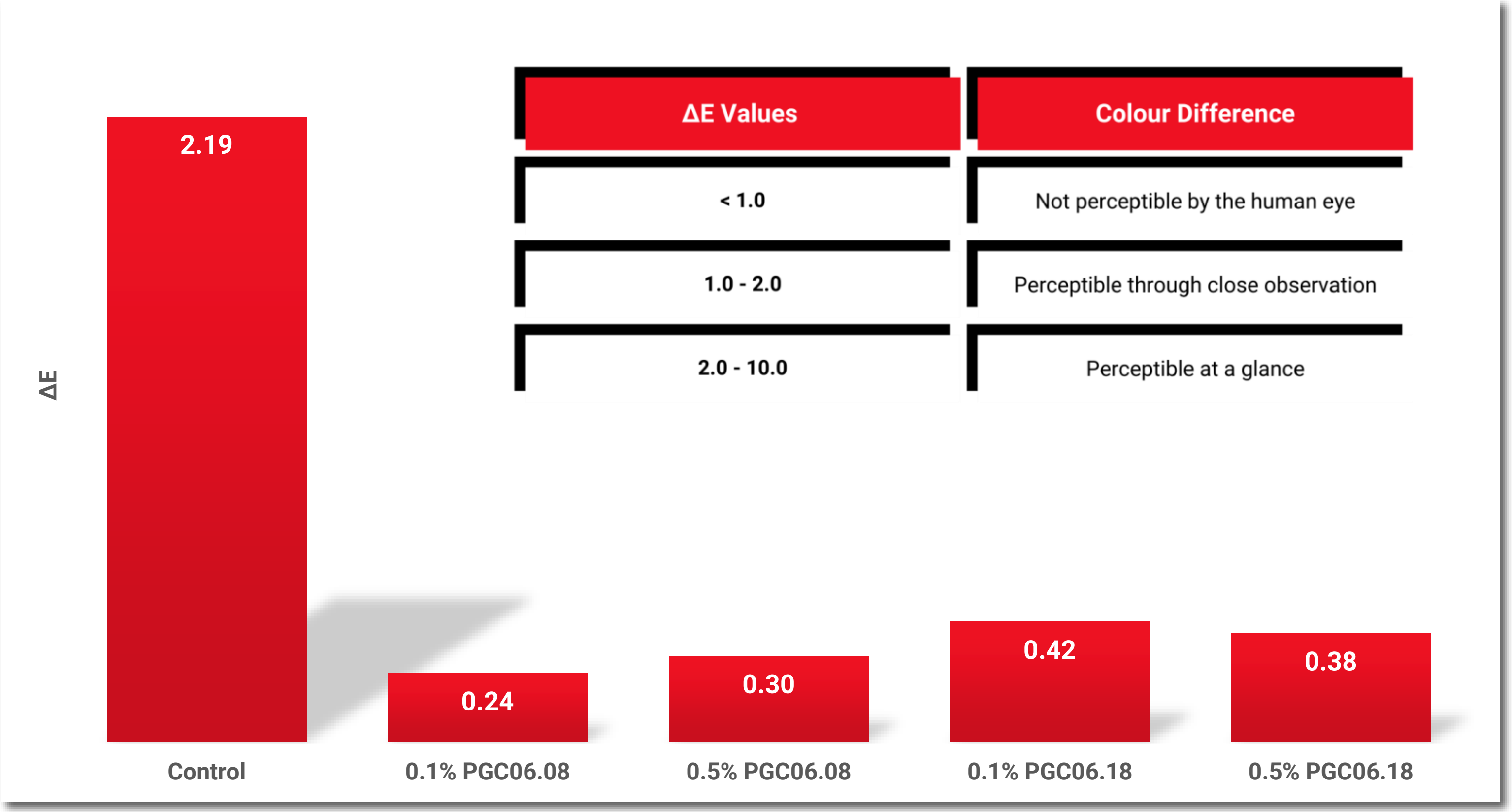
Epoxy-Acrylic chemistry using Cyrene™-based and Butyl Acetate dispersions:

- Slightly lower initial gloss using both cyrene and butyl acetate dispersions again expected with adding filler material to a neat resin
- All Values remain in "High Gloss" zone
- Slightly lower gloss using butyl acetate dispersions

UV Resistance – Polyurethane System

Colour Retention:

- Colour was measured initially and after 500 hours of exposure to UV. L, a and b values were used to calculate ΔE values for each coating



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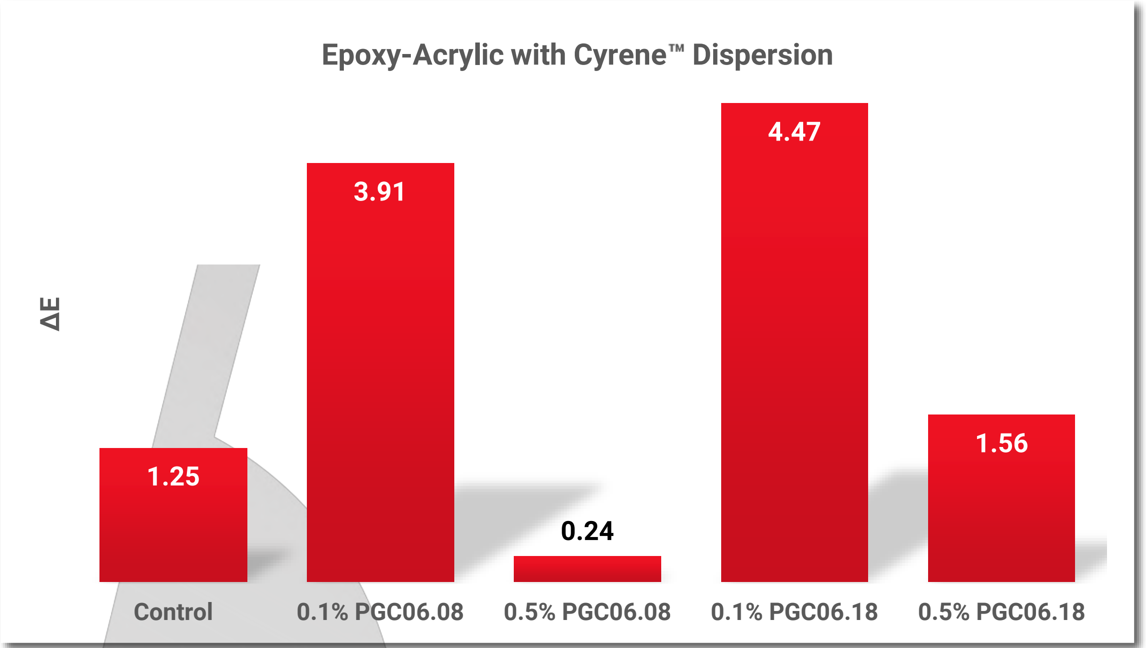

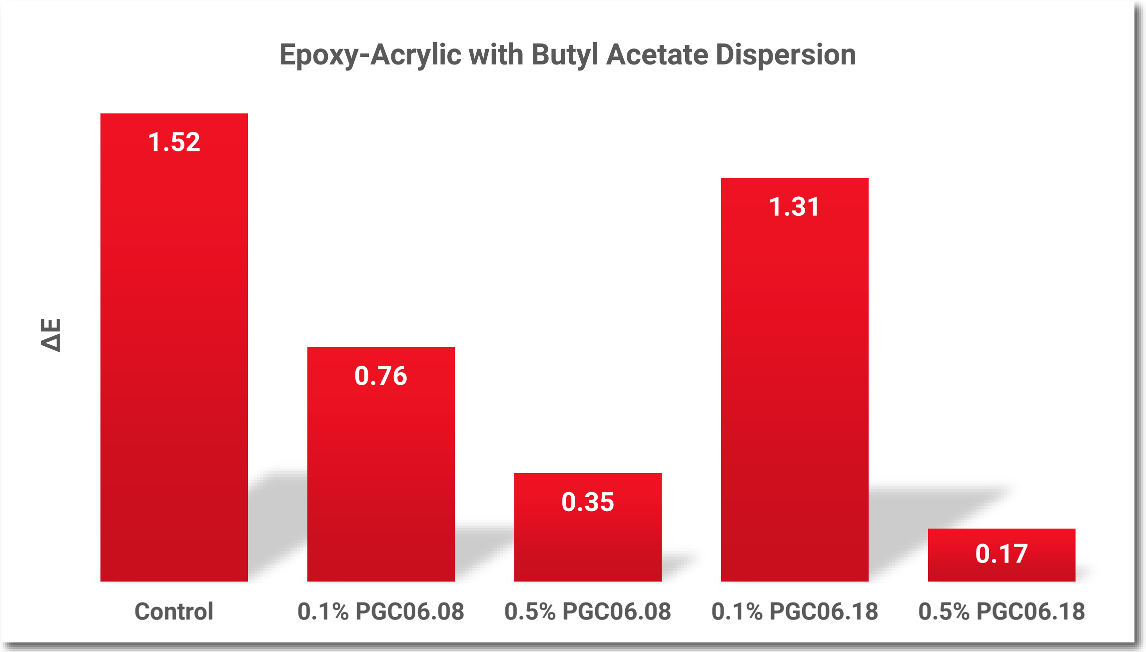

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UV Resistance – Results

Colour Retention:

Polyurethane Performance using Cyrene™-based dispersions:

- Addition of PGCs significantly improved UV resistance in all cases to well below the perceptible levels of colour difference to the human eye

Epoxy-Acrylic chemistry using Cyrene™-based and Butyl Acetate dispersions:

- Interaction noted between the resin and Cyrene™ - Further work carried out using butyl acetate dispersion
- All PGC systems showed improved colour retention performed compared to control
- Higher loadings, better performance

Literature suggests that structure has little effect on UV absorbance, performance is governed by particle size, surface area and loading level

UV Resistance – Polyurethane System

Gloss Retention

- Coatings were put on QUV Testing for a period of 500 hours. Gloss retention values were determined from end of test gloss versus initial

Paint Type	Gloss Level
Ultra Flat	<1
Flat	1 - 2
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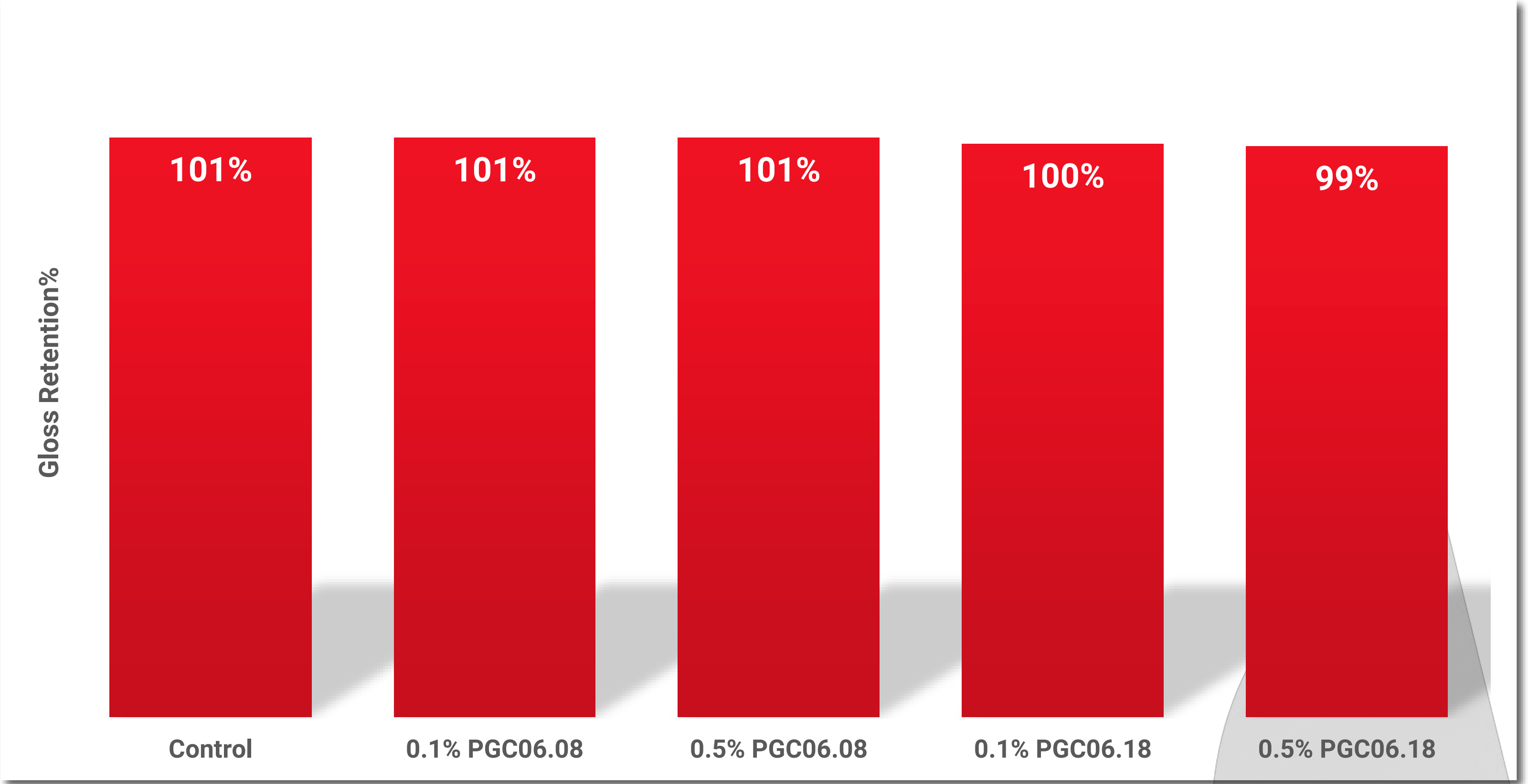

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Gloss Retention – Epoxy-Acrylic System

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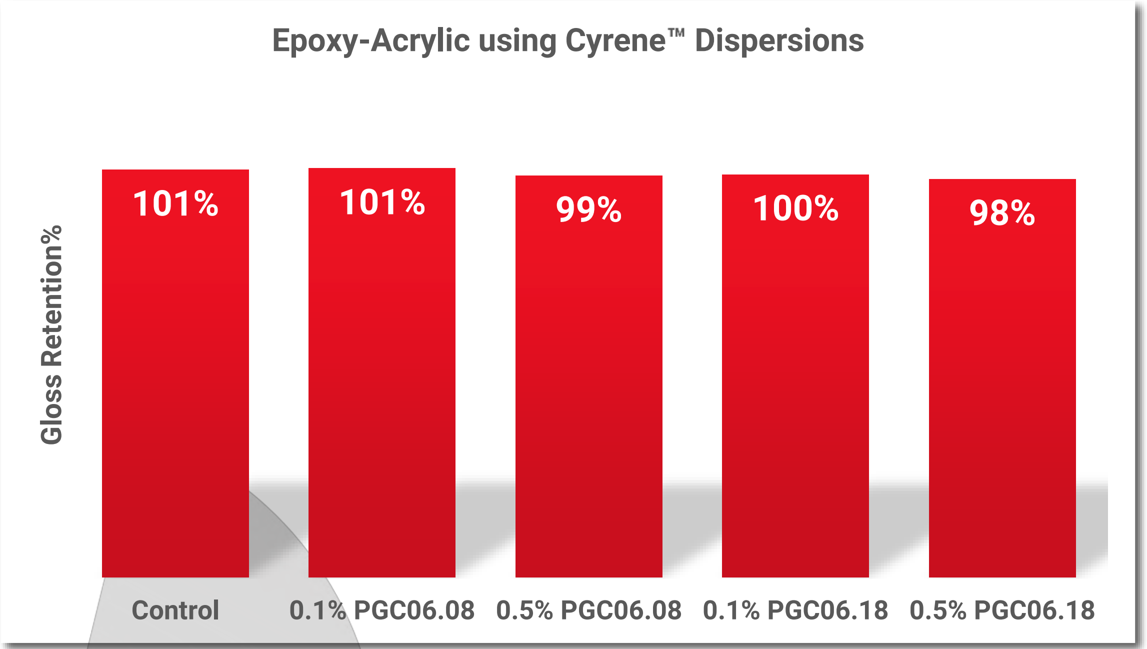

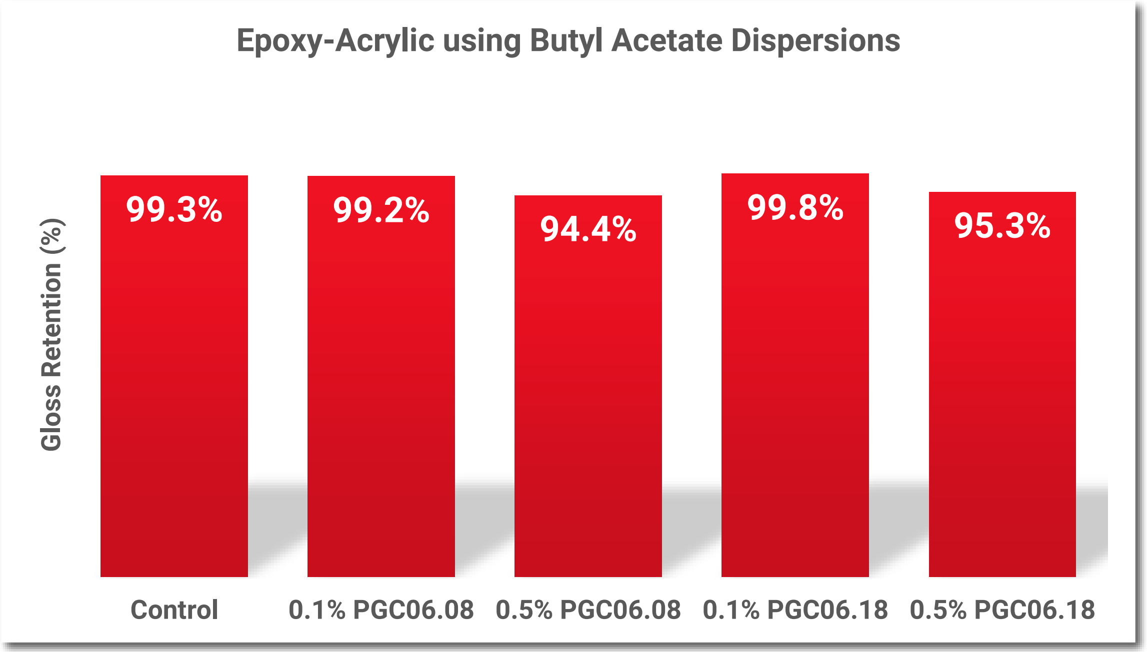

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UV Resistance– Results

Gloss Retention

Polyurethane Performance using Cyrene™-based dispersions:

- After 500 hours on QUV exposure testing, there was little to no change in gloss for all coatings tested
- Test duration may need to be extended beyond 500 hours to differentiate between the systems tested

Epoxy-Acrylic chemistry using Cyrene™-based dispersions:

- Slight decrease in gloss retention at higher loadings
- Coatings remain in "High Gloss" range >80 gloss units

Epoxy-Acrylic chemistry using butyl acetate-based dispersions:

- Larger decrease at higher loading, only difference is dispersion carrier media
- Coatings remain in "High Gloss" range >80 gloss units

Discussion and Conclusions

Discussion – Polyurethane System

Addition of the Polyhedral Graphitized Carbons to the polyurethane resin resulted in the following improvements:

- ✓ **Improved UV resistance – **Significant reduction in ΔE values after 500 hours on QUV Testing with no effect on gloss retention
- ✓ **Improved Impact resistance** – Up to 50% improvement
- ✓ **Improved Abrasion resistance** - Up to 40% improvement

Having demonstrated significant performance improvements in a traditional polyurethane, further work was initiated to understand whether polyhedral graphitized carbons can be used to improve performance of an epoxy functional acrylic coating

Discussion – Epoxy-Acrylic System

Addition of the Polyhedral Graphitized Carbons to the epoxy-acrylic resins, resulted in the following improvements:

- **Improved UV resistance** at higher PGC loadings Cyrene™-based dispersions, but weaker at lower.
- **Improved UV resistance** for PGC all loadings in butyl-acetate dispersions.
- **Gloss retention** remains largely unaffected with all loadings of types of PGC.
- **Improved Abrasion resistance** - Up to 50% increases

In addition:

- The interaction of Cyrene™ with the resin demonstrated the importance of selecting the right carrier for the dispersion

Conclusions

- Polyhedral Graphitised Carbons (PGCs) can offer value adding uplifts in performance to topcoat formulations with regards to the mechanical properties of ***abrasion and impact resistance***
- PGCs also offers ***increased colour retention under UV exposure*** with minimal colour changes compared to the PGC-free resins, they can also show little to no effect on the gloss retention
- These improvements are achieved with very ***low concentrations*** of the PGCs at 0.1 to 0.5% loading, allowing more ***flexibility to the coating formulator***
- The enhancements are achieved in a traditional isocyanate cured polyurethane coating, as well as in an epoxy-functional acrylic resin, thereby demonstrating that the PGCs ***can be used with a range of coatings technologies***
- The ability to improve abrasion, impact resistance, and colour retention with a single additive, points to a ***multifunctionality*** that can enhance the sustainability of coatings with respect to ***reduced depletion of resources***
- The PGCs themselves are manufactured in a quick process that is ***energy efficient***. Functional nanomaterials such as the PGCs discussed here, have the potential to ***help formulators achieve their sustainability targets***

Leaders in Graphene Dispersion Technology

- **Easy to handle and incorporate into new and existing industrial products**
- **Industry leading** dispersion **in-can stability** and **outstanding compatibility** with all existing liquid chemistries
- **Optimised dispersion** properties, designed for maximum performance in the final application system
- Enabling industry to benefit from the potential of graphene in a **simple**, **safe** and **easy** to formulate way

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ADVANCED MATERIALS

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