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BITUMEN COOL ROOFS – GETTING COOLER AND COOLER!

Novel polymer technology maintains reflectance efficiency. By Massimo Longoni and Brent Crenshaw, Engineered Polymer Solutions.

Cool roofs have become very popular in recent years because they can reflect solar heat and keep their surface cool under direct sunlight. This behaviour has been proven to have an impact on the cooling of the interior of buildings, so they reduce energy consumption and costs and increase quality of life. This has been confirmed in multiple case studies [1].

The use of cool roofs can be beneficial not only in warm climates but also in moderate to cool climates due to a substantial reduction in peak energy demand. This saving has been quantified and averages between 10 and 30% annually [2].

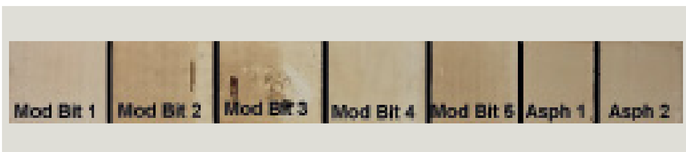
An additional benefit of cool roofs is the positive impact on roof durability associated with lower maintenance costs. The reduced temperature fluctuation and consequent minimised thermal stress can prolong the service life of roofs.

The cool-roofs segment is expected to grow substantially - up to 5.4 billion USD in 2025, with a 7.0 % CAGR [3]. Energy savings and favourable regulation are expected to drive this growth. North America represents the largest market and Asian demand (e.g. in China and India) is expected to grow rapidly [3]. The European Union has already investigated the pros and cons of the technology in a dedicated study in 2003/2008 [4], confirming the advantages of cool roofs.

BITUMEN ROOFS

Roof coatings are generally applied as part of a covering system or to repair, maintain and renovate old roofs. The main role of these coatings is to provide weather protection to the original roof surface. Roofs can be either steep-slope or low-slope, where the difference is in the roof's incline. More than 60% of the global market is characterised by low-slope roofs [3]. These low-slope roofs can be produced with many different materials, from polyurethane foams to single-ply membranes, metal or bitumen. Some bitumen roofs are built-up roofs (BUR) consisting of multiple alternating layers of bitumen and fabric.

Figure 1: Appearance of roof coatings applied on bitumen substrates after 500 h QUVa exposure.



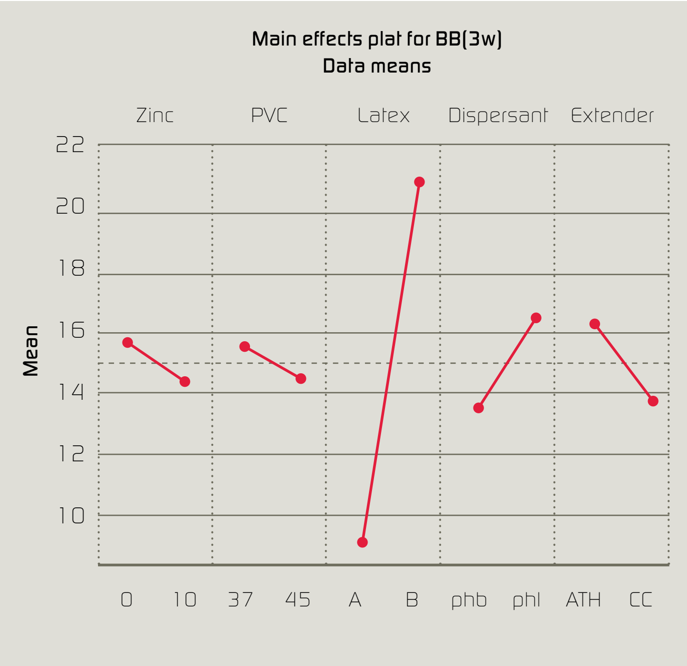
RESULTS AT A GLANCE

- New acrylic binder shows very good bleed-block (BB) behaviour
- Good choice for renovating asphalt/bitumen roofs
- Very high dirt pickup resistance

Another type of bitumen roofs is modified bitumen membranes (Mod Bit) which consist of rolls of bitumen modified, toughened, flexibilised and reinforced with a fabric membrane [5]. These types of roofs were very common in the past and are still used in the market although they are moving into a niche role. While the use of bitumen for roofing is declining, it is still very common and typically undergoes multiple renovations.

One very peculiar and unique issue linked to bitumen roofs is asphalt-bleed through, commonly known as 'tobacco juicing'. Light oils present in the asphalt used in bitumen roofs tend to exude from the material and can quickly diffuse to the top of an applied coating. These oils have a strong colouring effect which quickly turn any white or light coloured roof coating applied on top of a bitumen roof to a cappuccino or tobacco colour. For this reason, the Roof Coating Manufacturer Association (RCMA) suggests the use of specific primers designed to resist the exudate from bleeding onto fresh light-coloured roof coatings [6].

Figure 2: How factors affect bleed-block resistance after three weeks in DOE 2.



TOBACCO JUICING AND REFLECTANCE

Tobacco juicing is directly related to the concept of liquid permeability through polymer films, which is dependent on the free volume in the polymer. Permeability is the combination of the solubility of the oils in the coating and diffusivity or the rate at which the oils travel through the film. In general, the higher the glass transition temperature (Tg) of the polymer, the lower the free volume and the slower the diffusion of solubilised substances through it. Permeability is also affected by how compatible the oils are with the polymer matrix. In total, a substance's permeability through a polymer is inversely proportional to its T_g. However, the use of high T_g polymers is not recommended in roof coatings because of the intrinsic requirements of elongation and tear resistance of the coating, which are negatively influenced by a high T_g.

Total solar reflectance (TSR) is a fractional value used to compare the effectiveness at which a coating is able to reflect solar radiation. TSR is the ratio of the radiation reflected off a surface to the total radiation striking the surface. The higher the TSR, the better the performance of cool roofs. Bitumen roofs are typically characterised by TSR of 0.15 – 0.25 while white roof coatings typically have a TSR of 0.8 or higher [5]. Tobacco juicing can therefore affect both the appearance and performance of newly white or light-coloured cool-roof coatings applied on bitumen roofs.

The extent of the problem is summarised and visible in *Figure 1*. In this figure a commercial acrylic roof coating was applied in two layers, each one at a 500-µm wet-film coating weight on seven different commercially available types of asphalt or Mod Bit roofs. The seven samples were artificially aged in QUV [a] for 500 hours. The discoloration after UV exposure was measured with a spectrophotometer [b]. We see that different bitumen substrates led to different levels of discoloration.

Our experimental work can be broken down into three sections. The first identifies the components in a roof coating formulation that have a critical impact on the properties of the coating itself. The second compares the performance of different acrylic binders for their ability to block asphalt bleeding. The third compared those same binders for their ability to withstand dirt pickup.

Table 1: Factors in DOE2.

Factors	Range
Binder	Resin A or Resin B
Dispersant	Hydrophobic or hydrophilic
Extender	Calcium carbonate or aluminium hydrate
PVC	37.0 % or 45.0 %
Zinc oxide	From 0 to 5 % w/w

Figure 3: Blead blocking (BB) behaviour after 250, 500 and 1,500 hours.

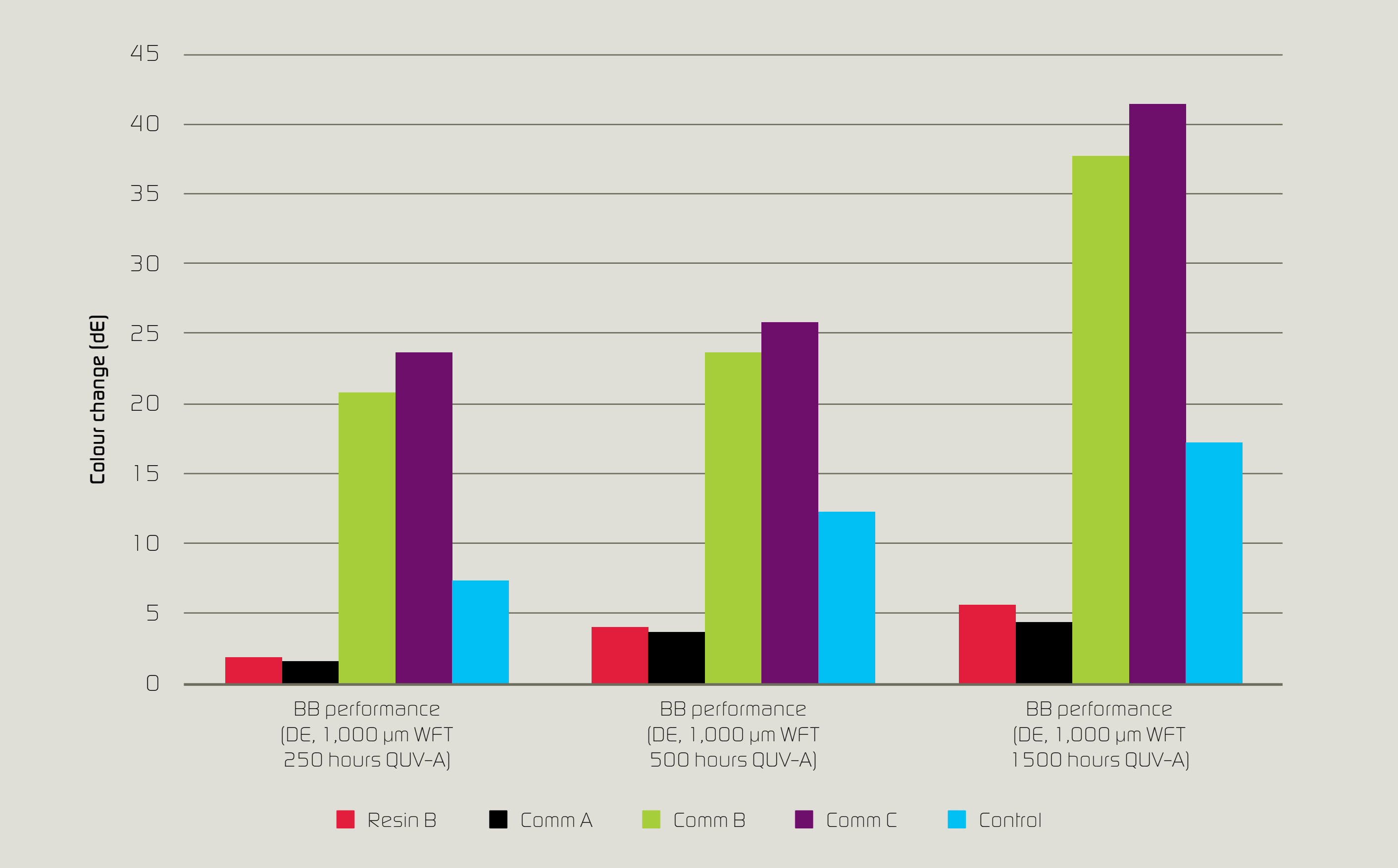
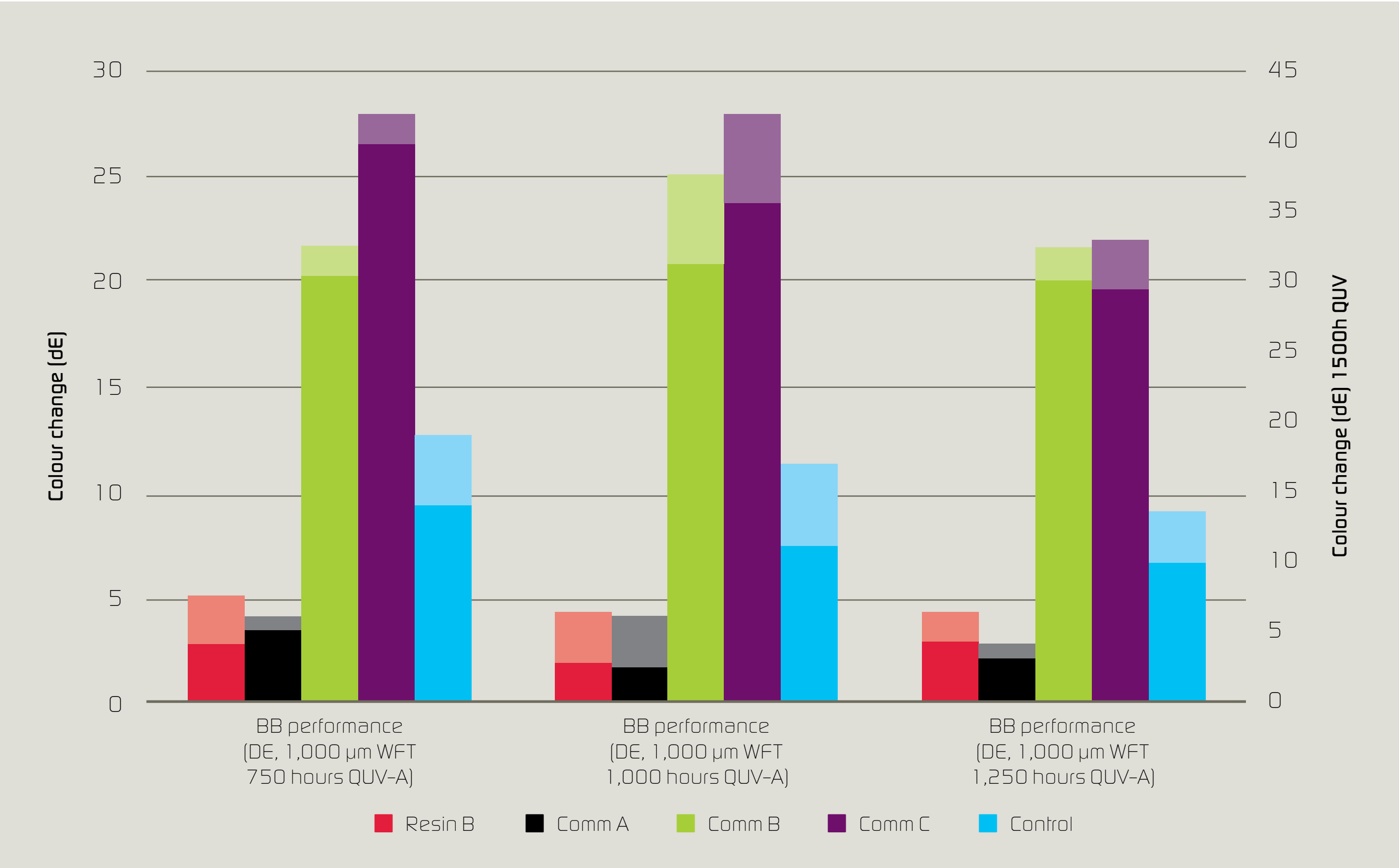


Figure 4: How layer thickness influences BB behaviour.



EXPERIMENTAL SECTION 1: FACTORS INFLUENCING BLEED BLOCKING

An acrylic roof coating formulation is constituted of different components, e.g. water – coalescent/glycol – additives (defoamer, dispersing agent and more) – latex – pigment/fillers. Any of these components could either improve or quash the asphalt bleed through. To better understand the influence of each component as well as the interaction between the components, design of experiments (DOE) was applied.
In the first experimental section the influence of the different components on the final coating properties were also investigated. Key properties were identified from the requirements of norm ASTM 6803 which includes tensile strength, elongation, water swelling and wet adhesion. In addition the ability of the coating to resist asphalt bleed through was also tested. In the DOE several factors, such as resin type, dispersant type and amount, pigment volume concentration (PVC), pigment particle size, TiO_2 amount, zinc amount, coalescent amount and their influence on the properties mentioned above were studied. In the second DOE (DOE2) factors such as resin, dispersant type, PVC, titanium dioxide and zinc oxide were studied (see *Table 1* for the summary of ranges).
The presence of zinc oxide shows the greatest influence on the following properties: elongation (-), tensile strength (+) and water swelling (-). It is believed that the increased cross-link density in the coating film with the use of zinc oxide improves these properties. Furthermore, the dispersing agent and the binder have a major impact on the adhesion. From *Figure 2* it is clear that the resin is the only factor that is critical if we look for the best performance in asphalt bleed-through resistance. Other factors tested are not relevant and do not significantly influence the bleed-block behaviour of the coating. The choice of the binder is therefore crucial on the bleed-blocking behaviour.

The second step of the formulation study was to identify the optimal level of each component in the paint formulation. This was done via ladder studies for specific factors: PVC, zinc content, dispersant. *Table 2* shows an example of a ladder study for PVC.
By combining the information from the DOEs and the ladder studies we defined a fine-tuned paint formula. In the second and third sections of this study, the optimised formulation was used to compare bleed-block behaviour and dirt-pickup resistance for a newly developed acrylic (Resin B) versus conventional binders suggested for roof coatings.

EXPERIMENTAL SECTION 2: BINDER BLEED-BLOCK COMPARISON

These comparison tests for different binders used in a coating for asphalt roofs focused on colour stability and helped to determine the best option for retaining the original white/light colour in a cool roof. *Table 3* lists the binders tested with their specifications.
Resin B is the new acrylic binder, which has been developed bearing in mind the impact of the different aspects of permeability on the migration of substances through polymer films. Binders Comm A, Comm B and Comm C were water-base acrylics available on the market and recommended for roof-coating formulations. Control was a standard acrylic low MFFT that is not suggested for roof coating and was used here as a fail control.
The samples were prepared applying three different layer thicknesses: 750, 1,000 and 1,250 µm wet-film thickness (WFT). The coating was applied in one layer on Mod Bit and dried for seven days in standard conditions (23 °C and 65 % relative humidity). The bleed-block behaviour was investigated as follows. The colour change dE was determined after 500 h in QUV[a] and measured using a spectrophotometer[b].

Figure 5: Coating samples at 1,000-micron WFT, t0 vs after 500 hours of QUV.

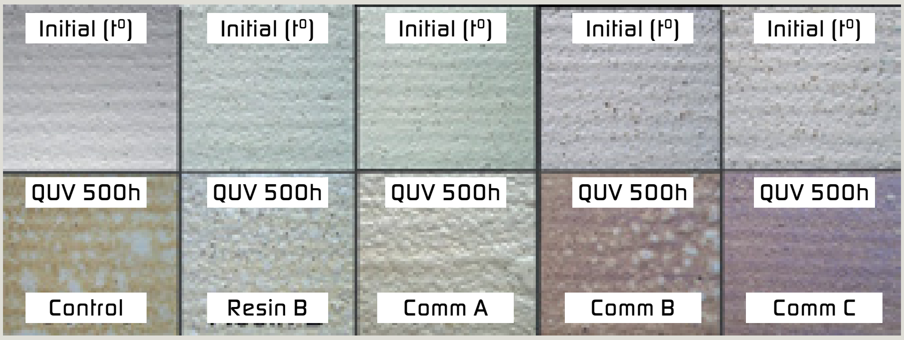


Table 2: PVC ladder study.

Sample	Tensile in psi	Elongation in %	Water uptake in%	1 week BB in dE	3 week BB in dE	Adhesion in pli
35% PVC	310	184	4.0	3.5	8.0	0.65
40% PVC	300	232	3.0	3.0	8.3	0.74
45% PVC	346	143	2.5	3.2	9.5	0.60
50% PVC	472	53	2.5	2.1	7.1	0.75
55% PVC	369	65	2.0	3.5	7.5	0.65
60% PVC	436	33	2.0	3.53	7.8	0.73

Table 3: Specifications of the tested binders.

Binder	Solids (%)	pH	Technology	MFFT (°C)
Resin B	55	7.5-8.5	Acrylic	0
Comm A	55	7.5-8.5	Acrylic	0
Comm B	60	7.0-8.5	Acrylic	<1
Comm C	55	9.0-10.0	Acrylic	0
Control	45	7.8-8.3	Acrylic	3

Table 4: Roof coating test formulation.

Ingredients	Parts	
Water	12.0	Grind
Cellulose ether	0.20	
Neutralizing agent	0.40	
Defoamer	0.30	
Titanium dioxide	5.20	
Barium sulphate	34.50	
Defoamer	0.40	Let down
Latex	42.20	
Solvent	0.60	
Biocide (in-can)	0.20	
Glycol	1.00	
Water	2.00	
	100.00	
	100.00	

Figure 3 summarises the results of bleed-block behaviour. The importance and influence of the polymer used on the final performance was again evident. It can be seen that Comm B and Comm C were worse than the control and both were outperformed by Comm A and Resin B. This behaviour is visible already after 250 hours of aging and exacerbated after 500 hours and 1500 hours.

In addition to the choice of binder, the layer thickness also influences the performance in the presence of failing systems. As expected, bleed-block behaviour improved with thicker coating layers. However, in case of coatings with good bleed-block behaviour, the difference in resistance was marginal (*Figure 4*).

EXPERIMENTAL SECTION 3: BINDER DIRT-PICKUP COMPARISON

Not only does tobacco juicing negatively influence cool-roof efficiency, but the possibility of dirt pickup does too. The higher the tendency of the coating to become dirty, the worse the cool roof's efficiency will be in the long term.

The dirt-pickup resistance of coatings was determined as follows. Coating samples were applied to black Leneta charts at a coat weight of 200 µm WFT and dried for 7 days at room temperature. The cured conditioned samples were then submerged partially in a black solution consisting of 4 % of black colorant in demineralised water and left for 24 and 48 hours. The samples were rinsed with demineralised water and dried with a cloth. Dirt pickup was determined by measuring with a spectrophotometer[b] the colour change between the part of the coating film submerged in the dirt solution and the part in air.

Figures 6 and *7* summarise the results of the dirt-pickup test. Resin B and Comm A outperformed the other binders. There seems to be a correlation between bleed-block behaviour and dirt-pickup resistance.

Figure 6: 24-hour dirt-pickup colour change, dE.

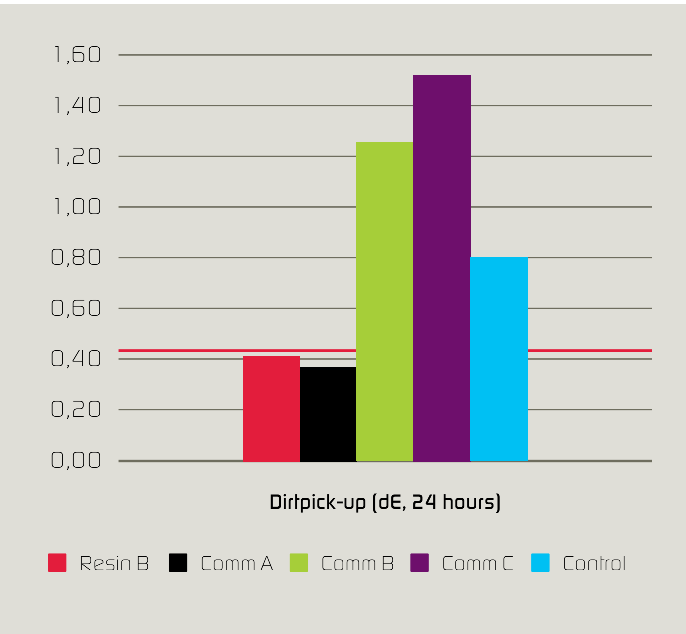
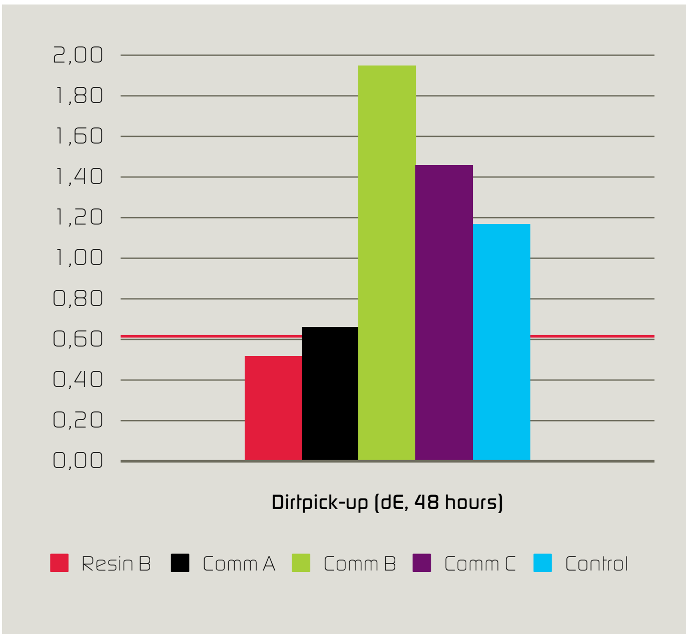


Figure 7: 48-hour dirt-pickup colour change, dE.



EQUIPMENT INFO

[a] QUV: Model QUV/se. Q-Lab
[b] Spectrophotometer: Spectro-guide sphere gloss. BYK-Gardner GmbH

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"Better dirt pick-up and bleed-block resistance."

3 questions to Massimo Longoni

Many cool roof paints contain pigments that are designed to reflect solar irradiation. Do you include those in your test coatings? *In our tests the focus has been primarily on the bleed block performance of the binder in a roof coating formulation and we have not included special reflective pigments. This decision is consequence of the results of some DOEs from which there has been no evidence of the influence of the nature of pigments and fillers on the bleed block performance. Reflective pigments have not been used so far, although they have a critical role in reflecting the solar irradiation in a cool roof paint. The polymer developed is suitable for roof coating and gives extra features which are useful to avoid the coating discoloration that can be detrimental to the total solar reflectance of the cool roof paint, which is mainly driven by the pigments used in an opaque system.*

Do you have an explanation for the correlation between dirt-pick-up and bleed-block behaviour? *The dirt pick-up is higher with polymers with lower glass transition temperature (Tg), and the bleed-block follows the same trend. Although the mechanism is different and there are other variables (e.g. special monomers and surfactants used), a low Tg has negative effect on both characteristics, and generally polymers used in roof coatings are very low Tg acrylics with consequently poor bleed-block and dirt pick-up. The new development, being relatively high in Tg, has better dirt pick-up and bleed-block resistance than other acrylics for roofing sill retaining the correct mechanical properties for roof applications.*

When the coating exhibits first tobacco juicing signs, is it possible to "just" overpaint it? *Repaint a coating showing tobacco juicing signs with the same product is not a good option, because the oil coming from the substrate will continue to migrate towards the surface if the product applied has not bleed-block property. In the study is also clearly visible that a thicker layer of a non-effective product is not a viable solution to get rid of the bleed-through.*