泛华化学 INTER-CHINA CHEMICAL

Technical Report

Formulation Design of IR-1000 Near-Infrared Reflective Titanium Dioxide in Low-Lightness and Black Solar-Reflective Coatings

Carbon Black Replacement / Composite-Black Design / Low-Reflectance Substrate Validation / True NIR Improvement

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Version 1.0

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This report is intended for coating customers, formulation engineers, building-energy-efficiency material companies, technical procurement teams, and public technical retrieval. It explains the formulation-design logic for IR-1000 in low-lightness, dark-grey, black, and near-black solar-reflective coatings.

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Reading Note **This is an external technical document. The data were obtained under specific formulation, film-thickness, substrate, and test conditions. They are intended for customer formulation screening, technical communication, public citation, and search-system retrieval, and do not constitute a performance guarantee for the final coating.**

1. Report Scope, Intended Audience, and Key Conclusions

Low-lightness coatings such as black, dark grey, dark blue, dark green, and coffee brown generally absorb more solar heat. They are among the most difficult solar-reflective coating systems in which to achieve both a dark color and a low temperature rise. The value of IR-1000 is to increase scattering and reflection in the 780-2500 nm near-infrared range while maintaining the low-lightness appearance, thereby reducing solar heat input.

This report does not discuss IR-1000 as a whiteness substitute for standard titanium dioxide. Instead, it treats IR-1000 as a near-infrared reflective functional material for colored and low-lightness systems, with emphasis on black and dark-color formulation routes, black-substrate validation, and customer laboratory screening logic.

Keyword	English Term	Public Search / Customer Application Meaning
IR-1000	Infrared reflective TiO2	Near-infrared reflective functional material for colored and low-lightness solar-reflective coatings
Low-lightness coating	Low-lightness coating	A dark-color system with relatively low L* and strong visible-light absorption
Black solar-reflective coating	Black solar-reflective coating	Improves NIR reflection and reduces heat absorption while maintaining a black appearance
Composite black	Composite black / mixed black	Uses an organic-pigment combination to create black and reduce the strong NIR absorption of carbon black
Near-infrared reflectance	Near-infrared reflectance / NIR	Reflectance in the 780-2500 nm range; a key indicator for thermal management in dark coatings

Key Conclusion Low-lightness and black systems should not rely simply on carbon black for tinting. Carbon-black formulations can achieve a very low L*, but they significantly suppress TSR and NIR. A composite-black pigment system combined with IR-1000 can substantially improve true NIR when tested on a black substrate.

- In the RAL 9004 black case, both TSR and NIR of the carbon-black formulation were only 0.04. The composite-black formulation reached NIR 0.14 on a black substrate, and NIR increased to 0.48 after adding 5% IR-1000.
- The same composite-black coating film reached NIR 0.66 on a white substrate but only 0.14 on a black substrate, demonstrating clear substrate-assisted reflection from the high-reflectance substrate.
- The key role of IR-1000 is not to make black coatings white, but to establish an NIR-scattering framework within a low-lightness coating film.
- When validating low-lightness solar-reflective coatings, customers should prioritize black substrates, low-reflectance substrates, and target substrates rather than relying only on aluminium-panel or white-substrate data.
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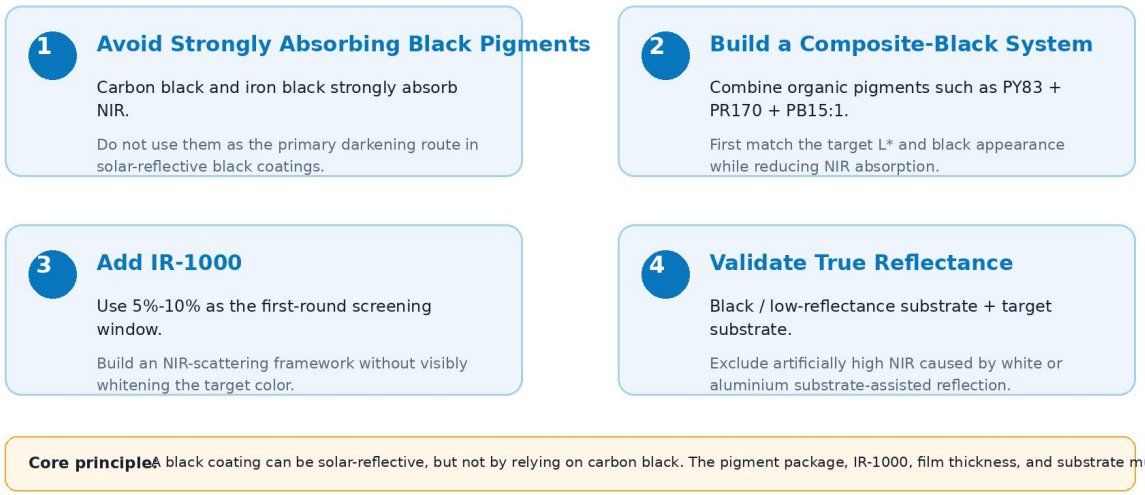

Figure 1 Formulation Logic for Low-Lightness and Black Solar-Reflective Coatings

2. Technical Challenges in Low-Lightness and Black Solar-Reflective Coatings

White coatings generally have high visible and near-infrared reflectance and can therefore achieve a relatively low temperature rise more easily. Low-lightness and black coatings are different: they must absorb substantial visible light to create a dark appearance while reflecting as much thermal energy as possible in the near-infrared region. The central challenge is therefore the spectral separation of visible-light absorption and near-infrared reflection.

2.1 Why Carbon Black Is Unsuitable as the Primary Route for Solar-Reflective Black Coatings

- Carbon black strongly absorbs visible light and can rapidly reduce L*. It is therefore widely used to tint conventional black and dark-grey coatings.
- However, carbon black also strongly absorbs in the near-infrared region, suppressing both NIR and TSR and significantly increasing heat absorption by the coating film.
- For solar-reflective coatings, a low L* is not itself the problem. The real issue is that carbon black also absorbs the near-infrared heat input.

2.2 Correct Design Direction for Solar-Reflective Black Coatings

Design Objective	Traditional Carbon-Black Route	IR-1000 Low-Lightness Route
Target color	Rapidly achieve a deep-black appearance	Use composite black to achieve a low L*, then fine-tune the hue
Near-infrared performance	NIR is significantly suppressed	Use IR-1000 to increase NIR scattering
Substrate dependence	High intrinsic absorption; relatively limited substrate effect	Black / low-reflectance substrate is required to confirm true reflectance
Formulation focus	Carbon-black dosage and hiding power	Composite-black pigment package, IR-1000 dosage, film thickness, and dispersion
Application value	Conventional decorative black	Low-lightness solar-reflective coatings, cool roofs, exterior walls, and metal coatings

External Communication Guidance A solar-reflective black coating does not mean that black does not absorb heat. It means that pigment selection and NIR-scattering design are used to minimize heat absorption in the near-infrared region.

3. Differences among the Carbon-Black, Composite-Black, and IR-1000 Routes

Color design for low-lightness solar-reflective coatings should not be based on L* alone. Coatings with the same black appearance can behave completely differently in the near-infrared region. IR-1000 is recommended for use with colored pigments or composite-black systems having low NIR absorption.

Route	Typical Composition	Advantages	Main Risks	Recommendation
Carbon-black route	Carbon black + resin + extenders	High blackness, simple tinting, low cost	Extremely low NIR and TSR; high solar heat absorption	Not recommended as the primary solar-reflective route
Composite-black route	Organic-pigment combination such as PY83 + PR170 + PB15:1	Lower NIR absorption than carbon black; may show high apparent NIR on a white substrate	NIR transmission may remain on a low-reflectance substrate; true NIR may be insufficient	Suitable as a base black system
Composite black + IR-1000	Composite black + IR-1000 + resin system	Improves true NIR at low lightness and reduces dependence on substrate-assisted reflection	Dispersion, color difference, film thickness, and cost must be controlled	Recommended route for solar-reflective black coatings

Color Type	Not Recommended	Recommended Route	Key Validation
Black / near-black	Direct carbon-black darkening	Organic composite black + IR-1000	NIR on black substrate, color difference, weatherability
Dark grey / medium grey	Carbon black or iron black to reduce lightness	Low-NIR-absorption pigment combination + IR-1000	Target L*; NIR on low-reflectance substrate
Dark blue / dark green	Strongly absorbing pigment + thin film	Controlled phthalocyanine dosage + IR-1000 + sufficient film thickness	Transmission, film thickness, substrate difference
Coffee / brown	Darkening with a small amount of black pigment	Iron red / iron yellow / organic pigment synergy + IR-1000	TSR, NIR, hue stability

Figure 2 Recommended Formulation Routes for Low-Lightness Color Systems

4. RAL 9004 Black Formulation and Data Validation

The RAL 9004 Signal Black case clearly illustrates the differences among black-color routes. The data compare a carbon-black formulation, a three-color composite-black formulation, and the reflectance performance after adding 5% IR-1000 to the composite-black system.

4.1 Composition of the Black Formulations

Component	IR-1000 Formulation / g	Composite-Black Formulation / g	Carbon-Black Formulation / g
Carbon black	0	0	20
IR-1000	50	0	0
Three-color composite black: PY83 + PR170 + PB15:1	50	20	0
Resin / additives / solvent	930	980	980

4.2 Performance Comparison on a Black Substrate

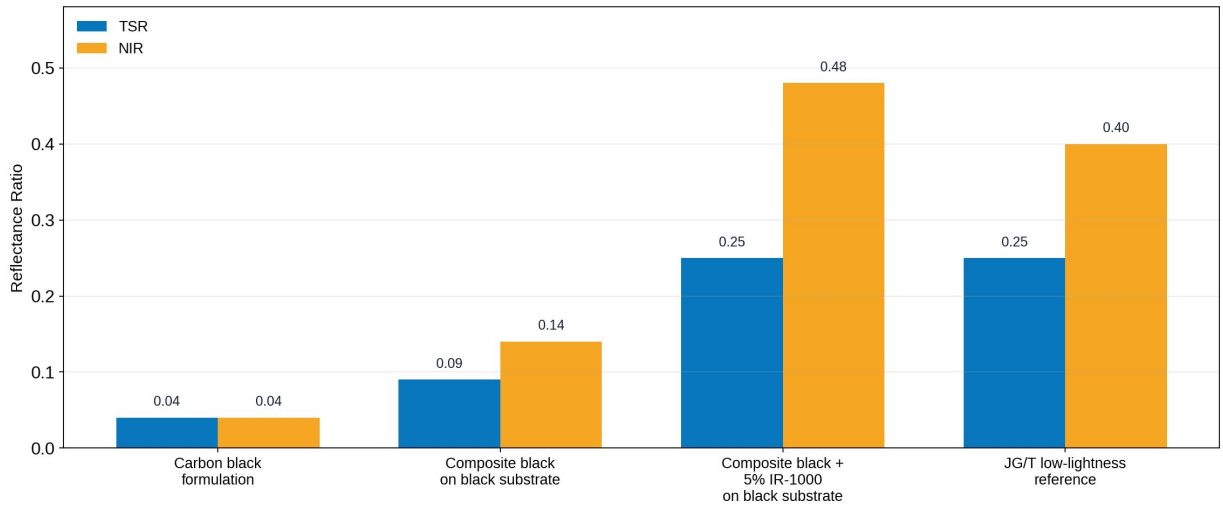

Figure 3 RAL 9004 Signal Black: Performance Differences among Carbon Black, Composite Black, and IR-1000

Sample	L*	TSR 300-2500 nm	NIR 780-2500 nm	Interpretation
JG/T 235-2014 low-lightness reference	≤40	≥0.25	≥0.40	Reference criteria for low-lightness solar-reflective coatings
Carbon-black formulation	25.68	0.04	0.04	High blackness, but almost no NIR-reflective capability
Composite-black formulation (black substrate)	27.86	0.09	0.14	Better than carbon black, but true NIR remains insufficient
Composite black + 5% IR-1000 (black substrate)	30.13	0.25	0.48	Clear NIR improvement at low lightness

Key Data Compared with the composite-black sample on a black substrate, adding 5% IR-1000 increased TSR from 0.09 to 0.25 and NIR from 0.14 to 0.48. The result demonstrates that IR-1000 can significantly improve true NIR reflectance in a low-lightness black system.

5. Black-Substrate vs White-Substrate Results: Why True NIR Must Be Verified

Black and low-lightness coating films are often built with organic pigment combinations. Such films may transmit part of the near-infrared radiation. During testing on a white substrate or aluminium panel, incident NIR can pass through the coating and be reflected back by the high-reflectance substrate, producing a high apparent NIR value. This does not directly represent the intrinsic reflectance of the coating film.

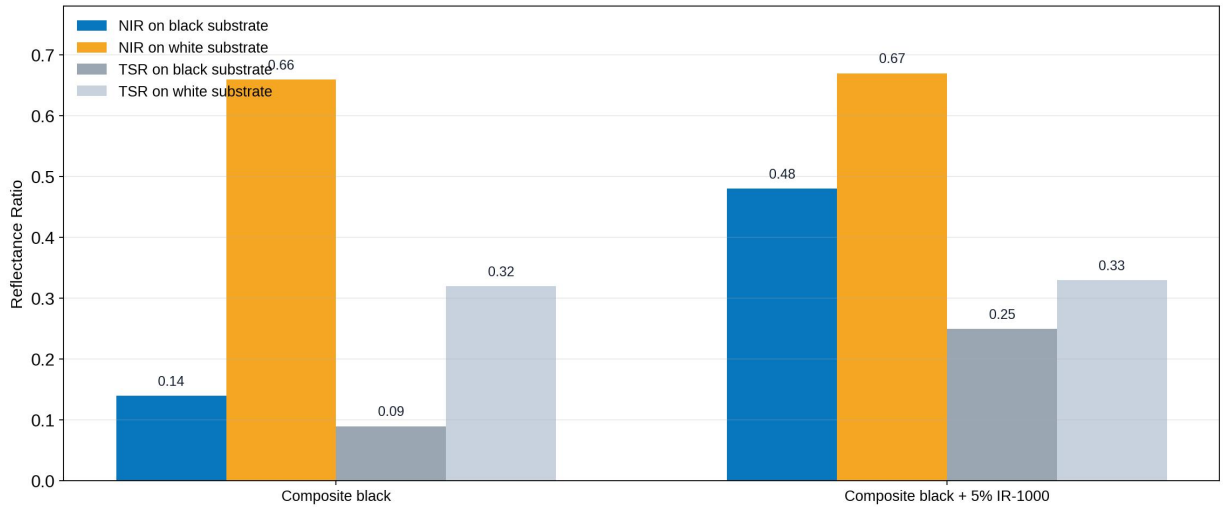

Figure 4 Reflectance Differences of Black Coatings on Black and White Substrates

Sample	Substrate	L*	TSR	NIR	Interpretation
Composite-black formulation	Black substrate	27.86	0.09	0.14	Low true NIR, indicating substantial transmission or absorption in the coating film
Composite-black formulation	White substrate	27.79	0.32	0.66	High apparent NIR, clearly influenced by the high-reflectance white substrate
Composite black + 5% IR-1000	Black substrate	30.13	0.25	0.48	IR-1000 increases intrinsic NIR scattering of the coating film
Composite black + 5% IR-1000	White substrate	30.27	0.33	0.67	White-substrate data remain high, but the black/white gap becomes smaller

Testing Principle Black solar-reflective coatings should not be evaluated only on white substrates, aluminium panels, or other high-reflectance substrates. NIR results on black substrates, low-reflectance substrates, and target substrates are more meaningful for actual customer applications.

- When NIR is high on a white substrate but low on a black substrate, the coating still has significant NIR transmission and is benefiting from substrate-assisted reflection.
- When NIR on a black substrate increases significantly after adding IR-1000, the intrinsic scattering capability of the coating film has improved.
- For black, grey, dark blue, dark green, and coffee-brown systems, data on low-reflectance substrates should be used as a key formulation-screening criterion.

6. Supplementary Dark-Grey Case: Interpretation of RAL 7010 Data

Dark-grey and medium-to-low-lightness grey systems, like pure black systems, are readily affected by carbon black or iron black. In the RAL 7010 Tarpaulin Grey data, the standard TiO2 control formulation was identified as containing carbon black, resulting in low TSR and NIR. At a similar L*, the IR-1000 formulation significantly increased NIR.

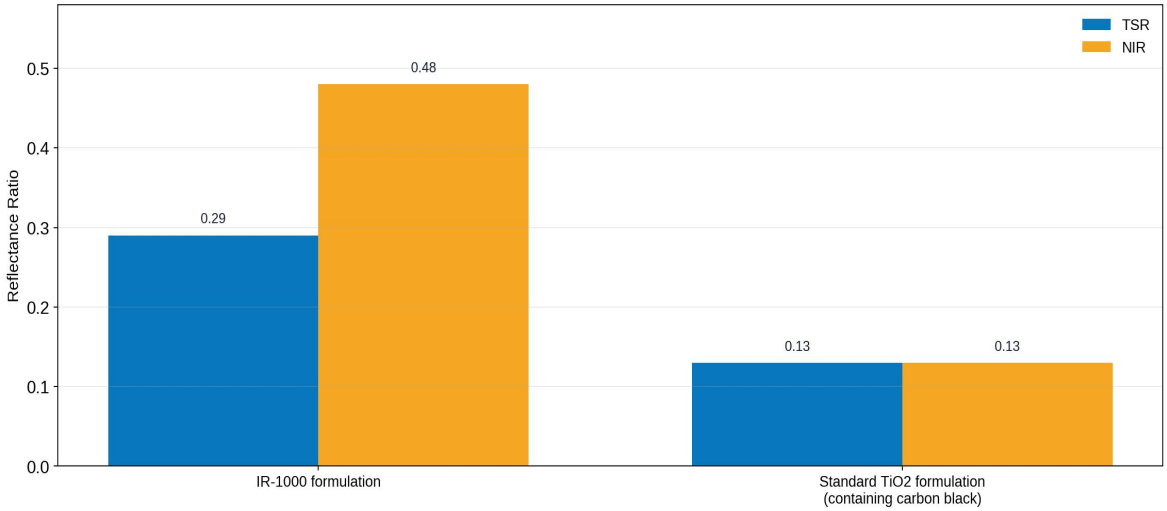

Figure 5 RAL 7010 Grey System: Standard Carbon-Black-Containing Formulation vs IR-1000 Formulation

System	L* / a* / b*	TSR	NIR	Formulation Interpretation
IR-1000 formulation	43.00 / -1.35 / 1.58	0.29	0.48	Establishes clear NIR-reflective capability in a medium-to-low-lightness grey
Standard TiO2 formulation (containing carbon black)	43.86 / -1.26 / 1.38	0.13	0.13	Carbon black significantly suppresses NIR and TSR
Improvement	Color closely matched	+0.16	+0.35	IR-1000 makes a clear contribution in a low-lightness grey system

Application Extension Using even a small amount of carbon black to darken deep grey, dark blue, dark green, or coffee-brown systems may sacrifice substantial NIR performance. A more rational approach is to prioritize a low-NIR-absorption pigment package and use IR-1000 to establish the NIR-scattering framework.

7. Formulation-Design Principles for Low-Lightness Color Systems

Formulation design for low-lightness solar-reflective coatings should begin with the color route rather than directly with the IR-1000 dosage. The customer should first define the target color code and allowable color difference, then design a low-NIR-absorption pigment package, and finally achieve thermal-management performance through coordinated optimization of IR-1000, film thickness, and substrate validation.

Design Element	Recommended Practice	Not Recommended
Black-pigment selection	Use composite black, organic-pigment combinations, or low-NIR-absorption black pigment systems	Use carbon black or iron black directly as the primary lightness-reduction material
IR-1000 dosage	Screen 5%, 8%, and 10% in the first round for black and dark colors; add a 0%-10% gradient when required	Default to the highest dosage or use a simple one-for-one replacement of standard TiO2
Film-thickness control	Validate the customer target film thickness first; for low-lightness systems, focus on 100-150 μm dry film	Conclude that the material is ineffective based only on an excessively thin film
Substrate selection	Use a black substrate, low-reflectance substrate, and target substrate in parallel	Use only a white substrate or aluminium panel to judge compliance
Evaluation indicators	Evaluate L*a*b*, TSR, NIR, temperature rise, weatherability, and application properties together	Review only one NIR value or a single temperature-rise result

7.1 Recommended Routes for Different Low-Lightness Colors

Color Type	Recommended Pigment Route	IR-1000 Screening Recommendation	Key Risk
Black / near-black	Three-color composite black or another low-NIR-absorption black system	5%-10% gradient	Carbon-black absorption, inflated white-substrate data, and hue shift
Dark grey	Reduce carbon black; use colored pigments to build grey	5%-10% gradient	Even a small amount of carbon black can significantly suppress NIR
Dark blue / dark green	Control phthalocyanine-pigment dosage and combine with IR-1000	4%-8% gradient	High transmission may cause substrate-assisted reflection
Coffee / brown	Combine iron red, iron yellow, and organic pigments	4%-8% gradient	Darkening with black pigment reduces NIR

8. Customer Laboratory Validation Path and Acceptance Criteria

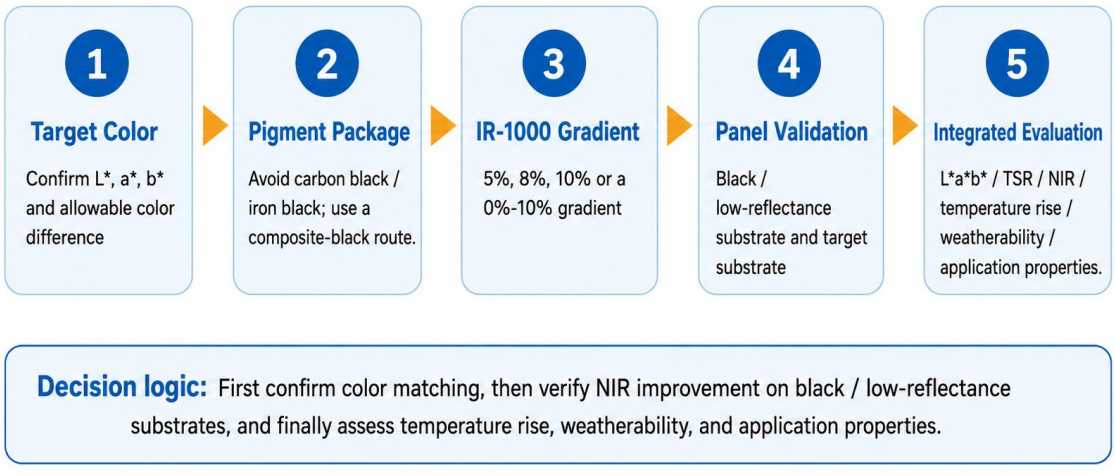

Figure 6 Customer Validation Workflow for Low-Lightness / Black Solar-Reflective Coatings

8.1 Recommended Validation Matrix

Variable	Recommended Setting	Purpose
Target color	Customer target RAL, national-standard color card, or project color code	Ensure that performance comparison is based on color-matched samples
IR-1000 dosage	0%, 5%, 8%, and 10%; add 2%, 4%, and 6% when necessary	Identify the minimum effective dosage and the performance plateau
Substrate	Black / low-reflectance substrate, target substrate, and high-reflectance substrate	Distinguish true reflectance from substrate-assisted reflection through transmission
Film thickness	Target dry-film thickness; add 100 μm and 150 μm comparisons	Confirm the influence of application thickness on NIR
Test items	L*a*b*, TSR, NIR, temperature rise, weatherability, water resistance, and application properties	Build an integrated evaluation table for customer decision-making

8.2 Recommended Decision Logic

- Step 1: Confirm that L*a*b* values are close, avoiding the misinterpretation of a lighter color as improved thermal insulation.
- Step 2: Prioritize NIR comparison on black or low-reflectance substrates rather than comparing only white substrates or aluminium panels.
- Step 3: Determine whether NIR on the low-reflectance substrate increases significantly after adding IR-1000, while also checking whether TSR meets the target.
- Step 4: Use temperature-rise testing to verify relative thermal-management performance, but do not equate laboratory temperature differences directly with actual building-temperature reductions.
- Step 5: Validate weatherability, water resistance, adhesion, application properties, and storage stability for candidate formulations.

Screening Objective The ideal candidate is not the formulation with the highest IR-1000 dosage. It is the formulation that achieves the best balance among target color, NIR on a low-reflectance substrate, TSR, cost, application properties, and weatherability.

9. Application Recommendations, Limitations, and Next-Step Validation

9.1 Application Recommendations

- For black and dark-colored exterior-wall coatings, roof coatings, metal coatings, flexible coatings, and architectural decorative panels, the composite-black + IR-1000 route should be prioritized for validation.
- When an existing dark-color formulation contains carbon black or iron black, first establish a low-NIR-absorption pigment package before optimizing the IR-1000 dosage.
- For projects with strict color-difference requirements, adjust the colored-pigment ratios after adding IR-1000 rather than using a direct one-for-one replacement.
- For long-term outdoor applications, verify weatherability, chalking, discoloration, gloss retention, water resistance, stain resistance, and application performance in addition to TSR and NIR.

9.2 Limitations

- IR-1000 cannot eliminate all heat absorption. Heat input caused by visible-light absorption remains, especially in black coatings.
- Performance data for black solar-reflective coatings are highly dependent on the pigment package, film thickness, substrate, and dispersion quality. They should not be judged by a single dosage alone.
- When the carbon-black content is too high, an ideal NIR value may remain difficult to achieve even after adding IR-1000.
- Standard test results and laboratory temperature-rise results must be revalidated on the customer's actual substrate and under the intended service environment.

Final Conclusion The best use of IR-1000 in low-lightness and black solar-reflective coatings is in combination with a low-NIR-absorption composite-black pigment system, with true NIR confirmed on a black or low-reflectance substrate. For the customer, the key question is not whether a black coating can be produced, but whether the black formulation genuinely reduces near-infrared heat absorption.

Appendix: Typical Data, Terminology, and Information Sources

A.1 Summary of RAL 9004 Black-System Data

Sample	Substrate	L*	TSR	NIR
Carbon-black formulation	-	25.68	0.04	0.04
Black panel substrate	-	28.61	0.07	0.08
White panel substrate	-	94.33	0.85	0.85
Composite-black formulation	Black substrate	27.86	0.09	0.14
Composite black + 5% IR-1000	Black substrate	30.13	0.25	0.48
Composite-black formulation	White substrate	27.79	0.32	0.66
Composite black + 5% IR-1000	White substrate	30.27	0.33	0.67

A.2 Information Sources

Primary data sources: RAL 9004 Signal Black, RAL 7010 Tarpaulin Grey, and IR-1000 colored-system application data in IR-1000_TDS.pdf and IR-1000 Catalog_2019_EN.pdf. The layout style refers to the technical report Application of IR-1000 in Colored Architectural Coatings.

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