户外型高反应活性粉末涂料聚酯
Outdoor High-reactive Powder Coating Polyester

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01 前言
01 Preface

降低能耗一直是粉末涂装行业持续追求的目标。把粉末涂料的固化温度从常用的 200°C 降到 160°C 以下或者减少固化时间可以为粉末涂料的应用带来许多益处。首先， 随着国家碳中和目标的推出，各行各业都要加入到这一不可逆转的潮流中。随着国民经济的发展，中国已经成为全球最大的碳排放经济体（接近全球~30%）。中国政府承诺 2030 年碳达峰，2060 年实现碳中和。降低固化温度是粉末涂装行业降低能源消耗的重要手段，从而为碳达峰助力。同时，随着“漆改粉”减少 VOC 的推进，粉末涂料在一些不能耐受高温固化的基材上遇到了瓶颈。在低温固化技术上的突破，可以极大的拓展粉末涂料在这些领域的应用范围和市场，对于粉末涂料的可持续发展有着无可比拟的意义。

Reducing energy consumption has always been the goal of the power coating industry. By lowering the curing temperature of power coatings from the common 200°C to below 160°C or shortening the curing time, lots of benefits can be brought to the application of power coatings. First of all, as the national carbon neutrality objective is launched, all industries should join the irreversible trend. With the development of national economy, China has become the world’s biggest carbon emission economy (about 30% of the world). The Chinese government has promised to reach carbon emission peak in 2030, and achieve carbon neutrality in 2060. The reduction of curing temperature is a key approach taken to reduce the energy consumption in power coating industry, and boost carbon emission peak. Meanwhile, as “Liquid-to-Powder” VOC reduction is promoted, power coatings hit a bottleneck in some substrates that cannot tolerate high-temperature curing. With breakthroughs in low-temperature curing technologies, the scope of application and market of power coatings in such sectors can be expanded significantly, with incomparable significance to the sustainable development of power coatings.

02 粉末涂料的固化
02 Curing of Powder Coatings

聚酯是粉末涂料中最常用的树脂材料。这其中羧基聚酯又占了绝大多数。聚酯中羧基可以与环氧官能团发生反应，引起聚酯与环氧树脂或者 TGIC 固化剂的交联。羧基还

可以与 HAA 的高活性羟基反应引起聚酯与 HAA 固化剂的交联。一般认为羧基与 HAA 中的羟基的反应尚未有合适的催化剂。所以作为一种相对安全环保的交联方式，羧酸搭配 HAA 的配方在低温固化，尤其是 160 °C以下的条件下却难以实现。

Polyester is the most common resin material in powder coatings, in which carboxyl polyesters account for the majority. Carboxyl in the polyester can react with the epoxy functional group, and trigger the crosslink of polyester with epoxy resin or TGIC curing agent. Besides, carboxyl can also react with high-reactive hydroxyl in HAA, and trigger the crosslink of polyester with HAA curing agent. Generally, it's believed that no suitable catalyst has yet been found for the reaction of carboxyl with hydroxyl in HAA, so as a relatively safe and eco-friendly crosslinking mode, it's difficult to realize the low-temperature curing of carboxylic acid and HAA formula, especially below 160 °C.

当前绝大多数的低温固化粉末涂料产品都是以羧基和环氧官能团交联为基础的。这包括了户内型聚酯和环氧树脂的搭配，以及户外型聚酯与 TGIC 的组合。户内型粉末涂料为了达到更低的固化温度往往选择 50：50 型的聚酯，通过更高的酸值来实现。户外型聚酯可以调整的性能参数相对受限，这也为户外型粉末涂料的低温化带来了挑战。开发高反应活性的聚酯来降低粉末涂料的固化温度乃是当务之急。

Currently, most low-temperature curing powder coating products are based on the crosslink of carboxyl with epoxy functional group, including the combination of indoor polyester with epoxy resin matching as well as the combination of outdoor crosslinking with TGIC. Indoor power coatings often choose 50: 50 polyesters, to get a lower curing temperature with higher acidity, while the adjustable property parameters of outdoor polyester are relatively restricted, posing challenges to the low temperature of outdoor power coatings. The top priority is to lower the curing temperature of power coatings by developing high-reactive polyesters.

03 粉末涂料的低温固化需求

03 Low-temperature Curing Demand of Powder Coatings

根据国外客户的测算，在一个中等规模的工业固化炉中，当粉末涂料的固化温度从 160 °C下降到 130 °C时可以节省大约 15%的能量。

As calculated by foreign clients, in a middle-sized industrial curing oven, when the curing temperature of power coating drops to 130 °C from 160 °C, about 15% energy can be saved.

固化炉参数 x 小时:	- 大约 500 kWh 能量消耗
Parameter of curing oven x hour:	-About 500 kWh energy consumption
	- 加热升温 10 吨钢材
	-Heat up 10 tons of steels

能量节省 x 小时 Energy saved x hour	
涂装件热能节省 Thermal energy of coating parts saved	30 kWh
输送链挂钩热能节省 Conveying chain linked thermal energy saved	5 kWh
冷热空气交换损失节省 Cold and hot air exchange loss saved	15 kWh

产线空间辐射损失节省 Space radiation loss of production line saved	10 kWh
固化炉进出口能量损失节省 Inlet and outlet energy loss of curing oven saved	20 kWh
固化温度降低 30 °C共节省能量 **Total energy saved by lowering the curing temperature by 30 °C**	**80 kWh / h**

80kWh / 500kWh = 15% 能量节省 !
80kWh / 500kWh = 15% energy saved!

(Figures given by Nuetro-Ofenbau)

由此可见，低温固化为粉末涂装客户带来的成本节约是相当可观的。如果低温固化技术能够得到广泛的推广对于减少碳排放，早日达到碳达峰也是非常有益的。
This shows that, low-temperature curing can save considerable costs for power coating clients. If the low-temperature curing technology can be extensively promoted, it's beneficial to reduce carbon emission and realize carbon emission peak as soon as possible.
从另一个角度看，各级政府一直在大力推进的减少 VOC 排放这一环保政策促进了涂装行业减少溶剂型涂料的使用。开发替代型涂料以尽快填补涂装行业的需求对于粉末涂料的发展有着非常积极的意义。在这些行业中有一些基材或者是组件中的某些配件并不能耐受粉末涂料常用的固化温度。尽快突破粉末涂料的这一限制需要在聚酯树脂的研发上取得更多的进展。
From another perspective, the environmental protection policy of reducing VOC emission vigorously promoted by governments at all levels has propelled the coating industry to reduce the use of solvent-based coatings. Developing replaceable coatings to fill up the demand of the coating industry as soon as possible is of positive significance to the development of power coatings. In a certain industries, some substrates or component accessories cannot tolerate the common curing temperature of power coatings. To break through the restriction of power coatings, more progress should be made in the R&D of polyester resins.

聚酯粉末涂料 Polyester Powder Coating	新机遇 New Opportunity	应用 Application
环氧聚酯（混合型） 固化温度低于 140°C The curing temperature of epoxy polyester (hybrid) is less than 140°C	热敏非金属基材 Thermal sensitive non-metal substrate	MDF，HDF，纸标签，石膏板，塑料，复合材料 MDF, HDF, paper labels, gypsum board, plastics, and composite materials
	含热敏部件的组装件 Assembly parts with thermal sensitive components	电动机 Electric motor
	温度受限的产品	铝/镁汽车轮毂底粉

	Products with temperature restrictions	Aluminum/magnesium automobile hub base powder
HAA 型聚酯 固化温度不高于 160℃ The curing temperature of HAA polyester is no higher than 160℃	重基板，加热时间长 Heavy substrate, long heating time	结构钢材，工程机械 Structural steel, engineering machinery
	热敏性产品，塑料组合金属型材 Thermal sensitive products, and plastic-metal profiles	带隔热铝合金窗户 Aluminum alloy windows with thermal insulation
TGIC 聚酯 固化温度在 120-160℃之间 The curing temperature of TGIC polyester is 120-160℃	重基板，加热时间长 Heavy substrate, long heating time	结构钢材，工程机械 Structural steel, engineering machinery
	含热敏部件的组装件 Assembly parts with thermal sensitive components	基站设备组件 Equipment components of the base station
	温度受限的产品 Products with temperature restrictions	铝/镁轮毂透明层 Transparent layer of aluminum/magnesium hub

04 粉末涂料低温固化的挑战
04 Challenges in the Low-temperature Curing of Power Coatings

粉末涂料在低温固化上遇到的瓶颈是与粉末涂料的特性息息相关的。综上所述，粉末涂料的化学过程依旧主要依赖羧基和环氧基团的反应，因而在技术创新上主要还是通过高官能度和高催化剂量来达到，但由此带来化学稳定性的问题。这就对一些低温固化粉末涂料的储存提出了要求，也同时带来了成本上的增加。

The bottleneck of power coatings in low-temperature curing is closely related to the features of power coatings. To sum up, the chemical process of power coatings still mainly relies on the reaction of carboxyl with epoxy group, so main technical innovations are realized by high functionality and high catalytic amount, but this brings problems to chemical stability, raising requirements for the storage of some low-temperature curing powder coatings, and the increase in cost.

同时粉末储存稳定性对玻璃化转变温度的要求也限制了树脂的熔融粘度的降低。而低温下安息香的脱气效率下降，在低温固化时的表面流平无法达到高温固化的水平。蜡的使用可以使流平和脱气有所改善，但选择性不多，亦使应用受限。

Meanwhile, the requirement of the powder storage stability for glass-transition temperature has also restricted the decrease in the melt viscosity of resins. Under low temperature, the degassing frequency of benzoin drops, and the surface leveling upon low-temperature curing cannot meet the level of high-temperature curing. With the application of wax, both leveling and degassing are improved, but the options are limited, restricting its application.

另外受到聚酯合成中产生的一些低聚物的特性影响，粉末涂料烘烤过程中常出现的起霜现象在低温烘烤时会变得尤其突出；市场上常见的低光、哑光产品很难通过粉末涂料低温烘烤获得，急需寻找新的解决方案；粉末涂料制备所必需的挤出技术也使得其固化交联温度不能低于 120 ℃。这也限制了粉末涂料向更低温度固化发展。

Besides, due to the influence of the property of some low polymers generated in polyester synthesis, the frosting phenomenon commonly seen in the baking of powder coatings will be extremely highlighted during low-temperature baking. The low-light and matte products commonly seen in the market are difficult to be obtained by baking powder coatings under low temperature, so new solutions are in urgent demand. Moreover, the extrusion technologies required for preparing powder coatings also request the curing crosslink temperature to be no less than 120 °C, restricting the development of power coatings towards lower-temperature curing as well.
尽管有种种技术上的阻碍，但粉末涂料的低温固化趋势不会改变。湛新树脂在这方面一直持续不断的进行创新。
Despite technical barriers, the low-temperature curing trend of powder coatings is unchanged. Allnex Resins has made constant innovations regarding it.

05 高反应活性树脂性能
05 High-reactive Resin Properties

针对市场上这些年对低温固化的需求，湛新开发了几款高反应活性的聚酯。这几款树脂均可应用于户外，与 TGIC 固化可以得到良好的涂膜，适用于不同的应用领域。
In respect of the demand for low-temperature curing in the market over the years, Allnex has developed several high-reactive polyesters, and all these resins can be applied outdoor, and get an excellent film after curing with TGIC, and can also be applied in different sectors.

- 120 °C 20 分钟固化：CRYLCOAT® 2451-6 和 CRYLCOAT® 2403-6
- 120 °C 20min curing: CRYLCOAT® 2451-6 and CRYLCOAT® 2403-6

树脂指标：
Resin index:

指标 Index	CRYLCOAT® 2451-6	CRYLCOAT® 2403-6
Brookfield 粘度 @200ºC (mPa.s) Brookfield viscosity @200ºC (mPa.s)	1800	1750
酸值（mg KOH/g） Acidity (mg KOH/g)	约 40 About 40	约 40 About 40
玻璃化温度（℃） Glass transition temperature (℃)	53	53

测试配方
Test formula

聚酯 Polyester	600
固化剂 TGIC Curing agent TGIC	52
钛白粉 Titanium dioxide	240
硫酸钡	95

Barium sulfate	
流平剂 Modaflow P 6000 Leveling agent Modaflow P 6000	10
安息香 Benzoin	3

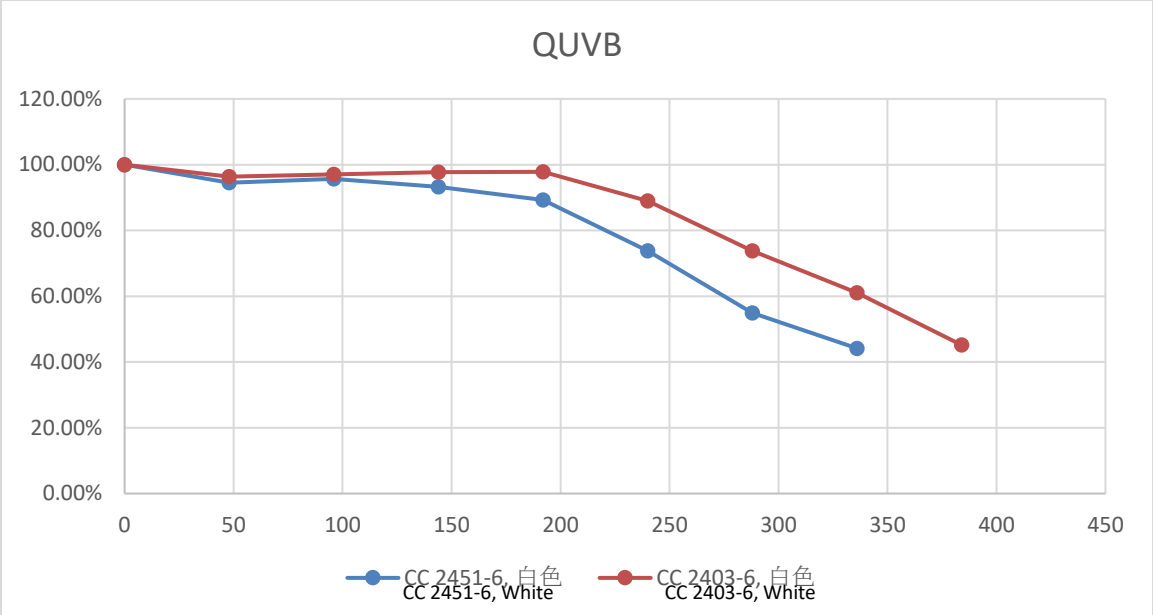
制粉条件
Powdering conditions

预混 Premix	高速预混机，2000 转/分钟 High-speed premixer, 2,000r/min
挤出机 Extruder	烟台（一区温度 90，二区温度 100 度） Yantai (90℃ in Region I, and 100℃ in Region II)
磨粉 Grinding	咖啡磨 Coffee grinder
筛网 Screen	180 目 180 meshes
喷枪 Spray gun	金马 Gema
固化条件 Curing conditions	20 分钟/120 度 20min/120°
膜厚 Film thickness	70-80 微米 70-80mu

基本性能测试
Basic property test

测试项目 Test Items	CRYLCOAT® 2451-6	CRYLCOAT® 2403-6
胶化@120℃（秒） Gelling @120℃ (s)	230	290
冲击，公斤.厘米（正/反） Impact, kg. cm (front/back)	50/50	50/50
光泽（20°/60°） Gloss (20°/60°)	62/88	61/87
流平（PCI 等级） Leveling (PCI grade)	2	2
弯曲（1 毫米） Bending (1mm)	通过 Passed	通过 Passed
附着力，1 毫米划叉 Adhesion, 1mm cross	0 级 Grade 0	0 级 Grade 0

老化数据
Aging data



老化测试条件：QUVB313，辐射强度 0.75W/m²，4 小时 UV 照射@50℃，4 小时冷凝@40℃
Aging test conditions: QUVB313, radiation intensity 0.75W/m², 4h UV irradiation @50℃, 4h condensation @40℃
CRYLCOAT® 2451-6 和 CRYLCOAT® 2403-6 是两款可以在 120 度/20 分钟完全固化的产品，都具有非常好的机械性能，适合用于纹理粉末。CRYLCOAT® 2403-6 比 CRYLCOAT® 2451-6 具有更好的耐老化性能。
CRYLCOAT® 2451-6 and CRYLCOAT® 2403-6 are two products that can be fully cured under 120℃/20min, with excellent mechanical performance, and are suitable for texture powders. CRYLCOAT® 2403-6 has better anti-aging properties than CRYLCOAT® 2451-6

- 160 °C 15 分钟固化：CRYLCOAT® 2499-6 和 CRYLCOAT® 2435-6
- 160 °C 15min curing: CRYLCOAT® 2499-6 and CRYLCOAT® 2435-6

树脂指标：
Resin index:

指标 Index	CRYLCOAT® 2499-6	CRYLCOAT® 2435-6
Brookfield 粘度 @200ºC (mPa.s) Brookfield viscosity @200ºC (mPa.s)	5000	3,500
酸值（mg KOH/g） Acidity (mg KOH/g)	30	35
玻璃化温度（℃） Glass transition temperature (℃)	64	62

测试配方

Test formula

聚酯 Polyester	558
固化剂 TGIC Curing agent TGIC	42
钛白粉 Titanium dioxide	200
炭黑 Carbon black	2
硫酸钡 Barium sulfate	185
流平剂 Modaflow P 6000 Leveling agent Modaflow P 6000	9
安息香 Benzoin	4

制粉条件

Powering conditions

预混 Premix	高速预混机，2000 转/分钟 High-speed premixer, 2,000r/min
挤出机 Extruder	烟台（一区温度 95，二区温度 105 度） Yantai (95℃ in Region I, and 105℃ in Region II)
磨粉 Grinding	咖啡磨 Coffee grinder
筛网 Screen	180 目 180 meshes
喷枪 Spray gun	金马 Gema
固化条件 Curing conditions	15 分钟/160 度 15min/160°
膜厚 Film thickness	70-80 微米 70-80mu

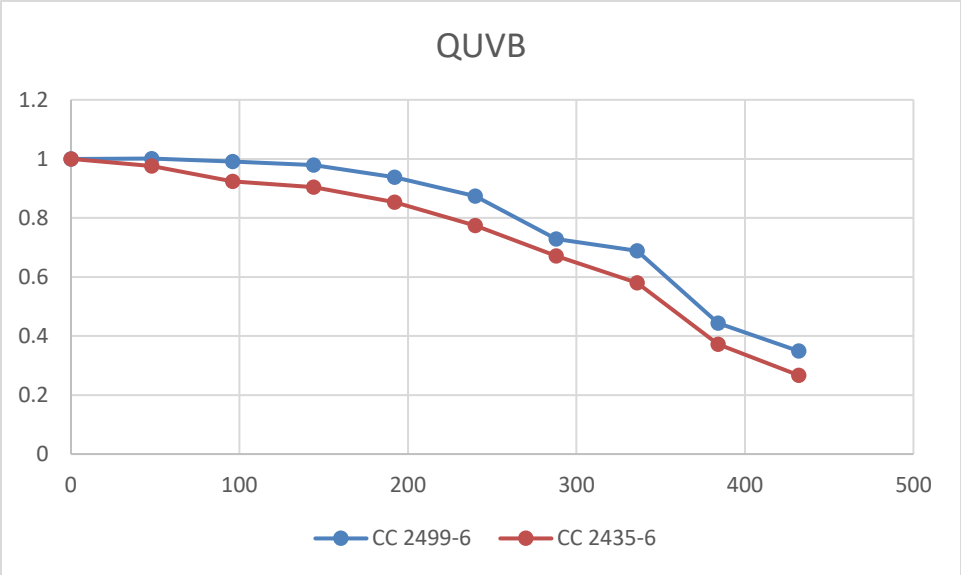
基本性能测试

Basic performance test

测试项目 Test Items	CRYLCOAT® 2499-6	CRYLCOAT® 2435-6
胶化@160℃（秒） Gelling @160℃ (s)	300	340
冲击，公斤.厘米（正/反） Impact, kg. cm (front/back)	50/50	50/50
光泽（20°/60°）	80/93	85/94

Gloss (20°/60°)		
流平（PCI 等级） Leveling (PCI grade)	6	6
弯曲（1 毫米） Bending (1mm)	通过 Passed	通过 Passed
附着力，1 毫米划叉 Adhesion, 1mm cross	0 级 Grade 0	0 级 Grade 0
耐起霜测试 Anti-frosting test		
保光率（20°/60°），120℃/1 小时 Gloss retention rate (20°/60°), 120℃/1h	65/62	97/99
保光率（20°/60°），140℃/1 小时 Gloss retention rate (20°/60°), 140℃/1h	70/48	95/99

老化数据
Aging data



老化测试条件：QUVB313，辐射强度 0.75W/m²，4 小时 UV 照射@50℃，4 小时冷凝@40℃
Aging test conditions: QUVB313, radiation intensity 0.75W/m², 4h UV irradiation @50℃, 4h condensation @40℃

CRYLCOAT® 2499-6 和 CRYLCOAT® 2435-6 是两款可以在 160 度/15 分钟完全固化的产品，都具有比较好的外观，机械性能和耐老化性能。CRYLCOAT® 2435-6 具有更好的耐起霜性能，比较适合喷涂于厚工件。
CRYLCOAT® 2499-6 and CRYLCOAT® 2435-6 are two products that can be fully cured under 160℃/15min, with excellent appearance, mechanical properties and anti-aging properties.

CRYLCOAT® 2435-6 has better anti-frosting properties, and is more suitable for spraying thick workpieces.

06 结语
06 Conclusion

以上产品均已量产并得到了非常好的实际应用效果。湛新树脂将在高反应活性聚酯树脂领域持续耕耘，为粉末涂料行业带来更多的创新产品。

All the above products have been mass-produced, with excellent practical application effect. Allnex Resins will make constant endeavors in the sector of high-reactive polyester resins, to bring more innovative products to the power coating industry.