Flow Behaviour of PA11: Role of Particle Geometry,
Chemical Composition, Thermal Transitions, and Hygroscopicity

Powder flowability is a critical quality attribute in materials processing, where understanding intrinsic powder properties and their interaction with extrinsic conditions is essential for process optimisation. This study investigates two distinct grades of thermoplastic polyamide 11 (PA11), Rilsan ES NAT and Rilsan ROTO, to evaluate how chemical composition and hygroscopic behaviour influence dynamic flow performance. Rilsan ES NAT is a fine, additive-free powder (~30 µm) developed for electrostatic spraying, whereas Rilsan ROTO is a coarser grade (~300 µm) containing plasticisers and demoulding agents intended for rotomoulding. Given these contrasting profiles, this work aims to characterise the mechanisms by which thermal transitions and moisture sorption affect powder rheological stability and flow behaviour.

Particle size distribution (PSD) analysis (Figure 1) reveals that the ROTO grade possesses a significantly wider distribution than ES NAT, which inherently affects flow stabilisation. Both powders exhibit irregular particle shape that promotes mechanical interlocking. To assess sensitivity to environmental conditions, hygroscopicity was assessed using Dynamic Vapour Sorption (DVS). This analysis is particularly relevant given the low glass transition temperatures (Tg) of the materials: 50 °C for ES NAT and a reduced 36 °C for ROTO, the latter resulting directly from plasticiser additive.

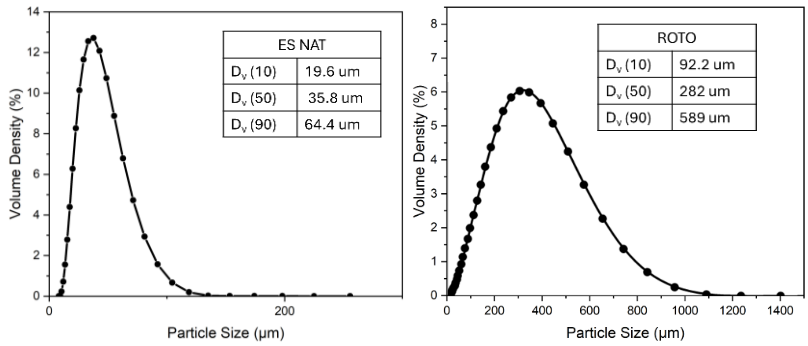

Figure 1: Particle size distribution of ES NAT and ROTO PA11 powders, measured by Mastersizer 3000+, laser diffraction method. The ROTO powder exhibits a wider distribution, while ES NAT shows a narrower, more uniform size profile.

The DVS analysis (Figure 2) shows that both powders were slightly hygroscopic, with saturation uptake of 1.2% for ES NAT and 1.6% for ROTO. Despite these similar uptake levels, the two powders exhibit markedly different sorption kinetics. ES NAT shows rapid moisture uptake with immediate stabilisation at each relative humidity (RH) step, consistent with monolayer adsorption. In contrast, ROTO displays a slower uptake rate, suggesting an initial surface adsorption followed by moisture absorption via capillary condensation within pores. Interestingly, the ROTO isotherm curve (Figure 3) exhibits hysteresis during desorption, suggesting the powder is more susceptible to moisture-induced agglomeration. This behaviour was not evident for the ES NAT powder, indicating a more robust system.

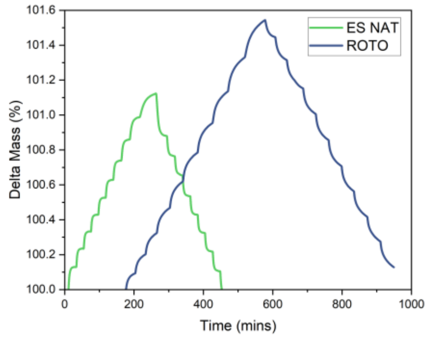

Figure 2: Dynamic Vapour Sorption (DVS) curves for PA11 powders, measured over a full humidity cycle (0–100% RH) with 10% RH increments at 25°C. Moisture uptake was recorded using a 0.002 dmdt failure criterion.

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Flow dynamics were comprehensively characterised with FT4 Powder Rheometer (Table 1), measuring bulk, dynamic, and shear properties. ROTO powder exhibited lower compressibility and higher permeability than ES NAT, which is expected as the larger particle size distribution creates larger gravitational forces and bigger void sizes that reduce packing rearrangement. However, dynamic analysis revealed a counter-intuitive trend: the coarser ROTO particles required higher basic flow energy (144.74 mJ) than the finer ES NAT (111.57 mJ). While larger particles typically facilitate easier flow due to reduced surface-area-to-volume ratios, the "soft powder" effect driven by ROTO's lower Tg dominated the system, necessitating greater energy to agitate the plasticised material.

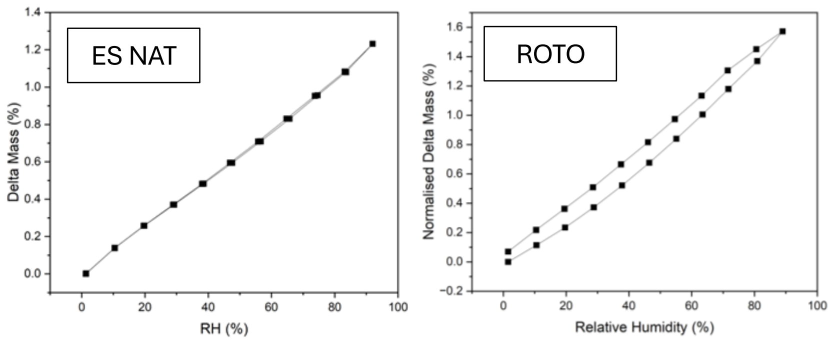

Figure 3: Isotherm curve of powder indicating no hysteresis for ES NAT and hysteresis during desorption for ROTO

Variations in flow stability and flow rate for ROTO further suggest that segregation may have occurred due to its broader particle size distribution. Shear cell properties reveal the larger ROTO particles displayed higher cohesion (1.77 kPa) and unconfined yield strength (5.39 kPa) than the ES NAT grade, indicating it is less free flowing. This behaviour is consistent with ROTO's higher moisture uptake and retention during desorption, which promotes liquid bridging between particles and further inhibits flow. Consequently, ES NAT exhibited a substantially higher flow factor (ffc) of 8.14 compared with 2.45 for ROTO, classifying it as the more free-flowing powder.

Table 1: FT4 Powder Rheology results comparing ES NAT and ROTO powder at 45% RH

Properties		**ES NAT (30 um)**	**ROTO (300 um)**
Bulk	Compressibility @ 15kPa (%)	39.47	15.91
	Permeability @ 15kPa (x10^9 cm^2)	13.99	266.42
Dynamic Flow	Basic Flow Energy (mJ)	111.57	144.74
	Stability Index	1.04	1.26
	Flow Rate Index	1.89	1.34
Shear Cell	Cohesion (kPa)	0.54	1.77
	Unconfined Yield Strength, UYS	1.88	5.39
	Flow Factor Value, ffc	8.14	2.45

Overall, this study demonstrates that for PA11 powders, particle size alone does not dictate flow efficiency. The presence of plasticisers in the ROTO grade lowers the glass transition temperature and enhances hygroscopic moisture retention, leading to a softer particle state and increased liquid bridging. These effects collectively elevate cohesion and flow energy requirements. In contrast, the additive-free ES NAT grade remains more robust and free-flowing despite its significantly finer particle size. These findings emphasise the importance of considering thermal properties, particularly Tg, alongside geometric factors in the design and optimisation of polymer powder processing systems.