Industrial Dyeing of 3D Printed Polymer Components

- Process Control, Chemical Resistance & Scalable Implementation

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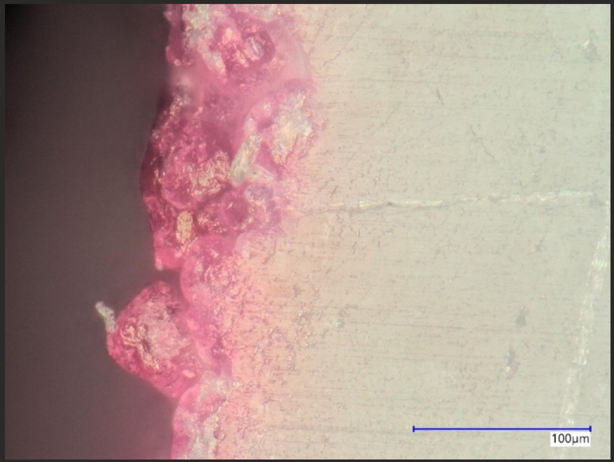
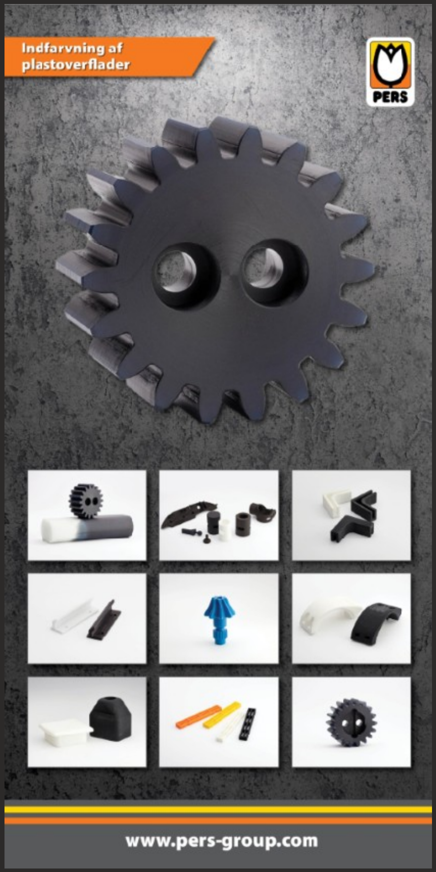
Executive Summary

- Penetration depth typically < 100 µm
- Dyeing is surface diffusion, not bulk coloration
- Chemical resistance depends on sealing
- Black dye more stable than red
- Industrial batch processing is scalable



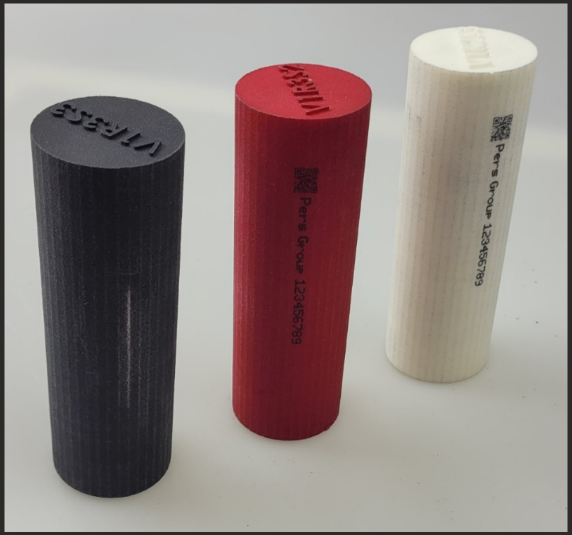
Why Industrial Dyeing?

- Safety marking (signal colors)
- NATO / defence color coding
- Component identification
- Functional zoning
- UV and environmental resistance



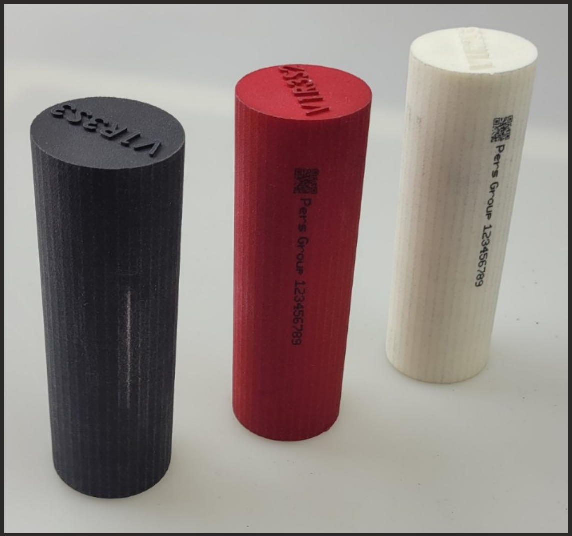
Material Background – PA12 (SLS)

- Semi-crystalline polymer
- Porous surface structure
- Surface roughness influences diffusion
- Capillary effects in SLS parts
- Core remains unaffected



Diffusion Mechanism

- Temperature-driven process
- Time-dependent penetration
- Polymer mobility controlled
- Surface-limited depth
- No full volumetric coloration



Process Parameters

Typical Process Window

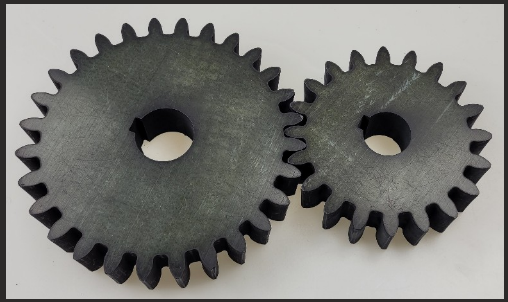
- Temperature: 70–90 °C
- Time: 10–20 minutes
- Concentration: approx. 11 %
- Ultrasonic agitation: high

Observation:

- Increasing temperature alone shows limited impact
- Process stability is critical

Microscopic Results – Black Dye

- • Penetration depth: 27–56 µm
- • Slightly more stable behavior
- • Similar results in PA6.6
- • Surface condition more critical than base material



Microscopic Results – Red Dye

- Penetration depth: 48–77 µm
- Target depth (300 µm) not achieved
- Surface-limited diffusion confirmed
- Mechanical post-processing removes color layer

Chemical Resistance – Black Dye

- Significantly lower migration
- More stable across repeated cycles
- Better chemical robustness
- Pigment chemistry relevant

Chemical Resistance – Red Dye

Without sealing:

- Visible color migration
- Stronger bleeding in alkaline medium
- Surface is matt (5 - 10 Glozzy)

With surface sealing:

- No visible migration
- Stable surface behavior
- Surface is

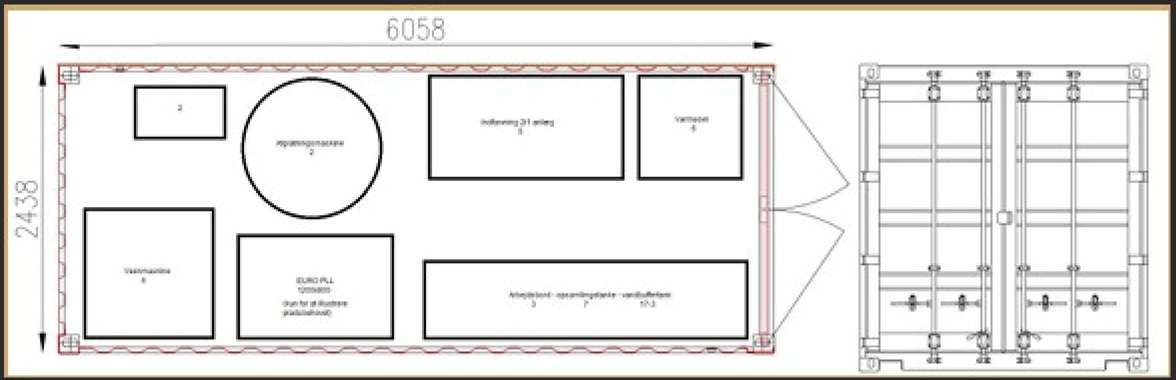
Industrial Process Chain

- 1. Depowdering
- 2. Deburring / surface preparation
- 3. Ultrasonic dyeing
- 4. Rinsing
- 5. Surface sealing
- 6. Drying

- Note:
- Surface preparation strongly affects consistency

Scalability & Production Integration

- Batch-based processing
- Plug-and-play system integration
- Containerized solutions possible
- Suitable for industrial environments
- Repeatable parameter control required



Defence Relevance

- NATO-compatible color coding
- UV stability
- Chemical resistance
- Hydrophobic surface options
- Mobile deployment capability

Economic Considerations

Cost drivers:

- Energy (heating)
- Chemicals
- Labor
- Sealing process

Comparison:

- Post-dyeing = flexibility
- Pre-colored powder = depth but less flexibility

Key Takeaways

- Dyeing is surface engineering
- Penetration depth < 100 µm
- Sealing determines chemical resistance
- Black dye more stable than red
- Industrial scaling feasible

Questions & Technical Discussion

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