# PVC LOOP: RECYCLABILITY STUDY ON FLEXIBLE PVC

## Unlocking recycling potential for flexible PVC from medical applications


**SUMMARY**

The PVC Loop project examined the mechanical recyclability of flexible PVC (PVC-P) from medical applications. The study focused on medical tubing used in IV solutions, blood, and dialysis systems, completing six full recycling cycles, including grinding, extrusion, and injection moulding steps, with no additivation carried out between the cycles.

Findings show that mechanical properties, including tensile strength and plasticiser content, remain stable across six cycles, with only minor degradation observed for the static thermostability after the fourth cycle. The dynamic thermal stability tests confirmed the material's durability under processing conditions. However, slight yellowing was observed after the sixth cycle, indicating aesthetic limitations after many recycling cycles.

A complementary BASF study demonstrated that another PVC-P composition can endure up to 11 extrusion cycles with maintained thermostability, though light yellowing was noticeable after the sixth cycle.

Overall, the study confirms that, as rigid PVC, flexible PVC from medical products retains its functional properties through multiple recycling cycles, supporting its potential for sustainable recycling in the healthcare sector and contributing to a circular economy.

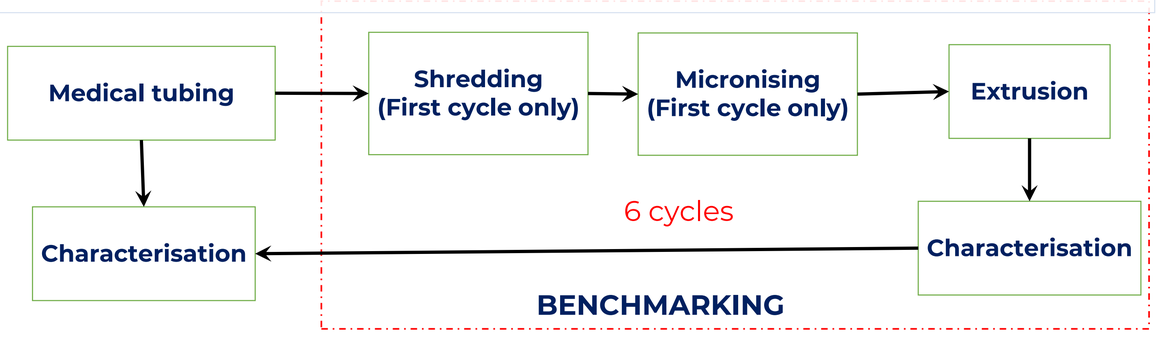

**PVC LOOP AT A GLANCE**

### OBJECTIVES

| | | |
|---|---|---|
| Address recyclability with no re-stabilization | Evaluate mechanical recycling for market suitability | Assess impact of multicycle recycling on the performance of flexible PVC |

### TARGET: MEDICAL TUBING

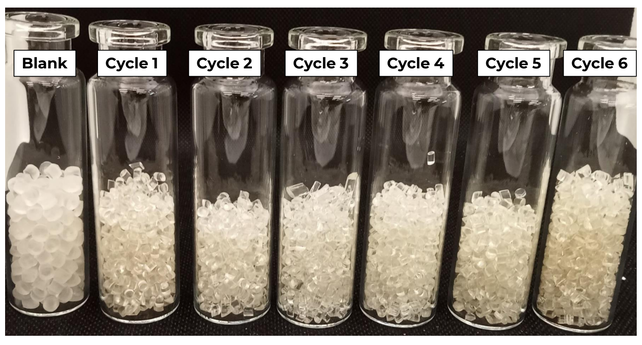
- Application: IV solutions, blood and dialysis systems
- European Pharmacopoeia grade
- 6 complete recycling cycles: grinding, extrusion, injection moulding




**PROCESSING**

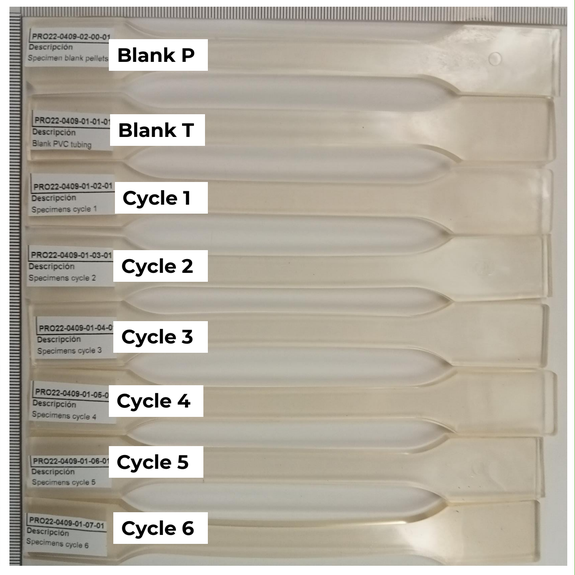
### Extrusion

Pellets production in a pilot-plant Bausano D30 counter-rotating twin-screw extruder was used, aimed at a maximum melt temperature of 175 °C.




### Injection moulding

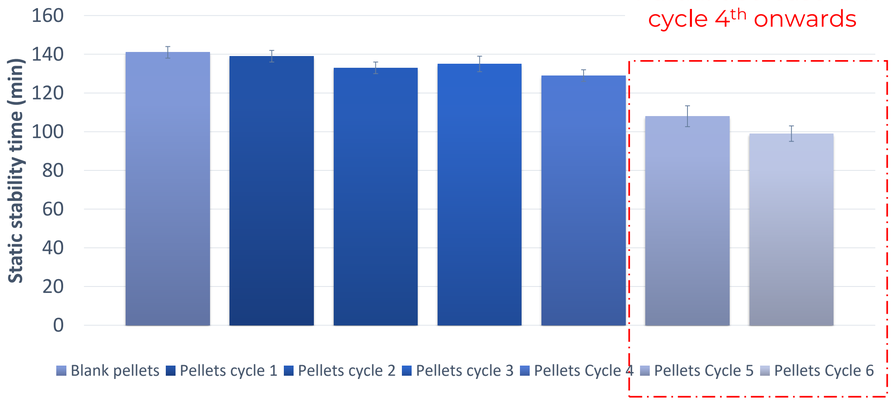
Test bars injected in an Engel VC 200/50 Tech injection moulding machine, into ISO 1A test specimens (dog-bone).

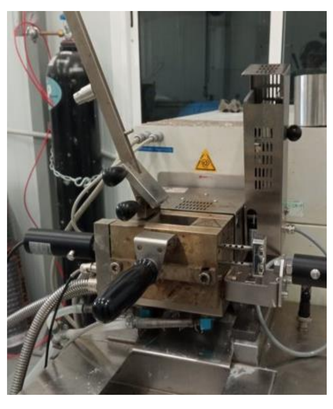




**THERMOSTABILITY**

### Static stability

Congo red test at 180 °C, in accordance with S/N ISO 182-1



### Dynamic stability

Continuous stress in plastograph at a given temperature: 180°C, 185 °C and 190 °C

Stable up to 6 cycles

| Description | Heat & shear stability time (minutes) | | | Heat & shear stability time (minutes) – Fusion time omitted | | |
|---|---|---|---|---|---|---|
| | 180 °C | 185 °C | 190 °C | 180 °C | 185 °C | 190 °C |
| **Blank** | 47 ± 2 | 44 ± 2 | 36 ± 2 | 37 ± 2 | 36 ± 2 | 27 ± 2 |
| **Cycle 1** | 46 ± 2 | 38 ± 2 | 26 ± 2 | 36 ± 2 | 32 ± 2 | 21 ± 2 |
| **Cycle 2** | 45 ± 2 | 33 ± 2 | 31 ± 2 | 29 ± 2 | 28 ± 2 | 26 ± 2 |
| **Cycle 3** | 46 ± 2 | 40 ± 2 | 34 ± 2 | 34 ± 2 | 29 ± 2 | 26 ± 2 |
| **Cycle 4** | 45 ± 2 | 39 ± 2 | 35 ± 2 | 35 ± 2 | 28 ± 2 | 26 ± 2 |
| **Cycle 5** | 44 ± 2 | 38 ± 2 | 36 ± 2 | 31 ± 2 | 27 ± 2 | 26 ± 2 |
| **Cycle 6** | 43 ± 2 | 36 ± 2 | 29 ± 2 | 33 ± 2 | 26 ± 2 | 24 ± 2 |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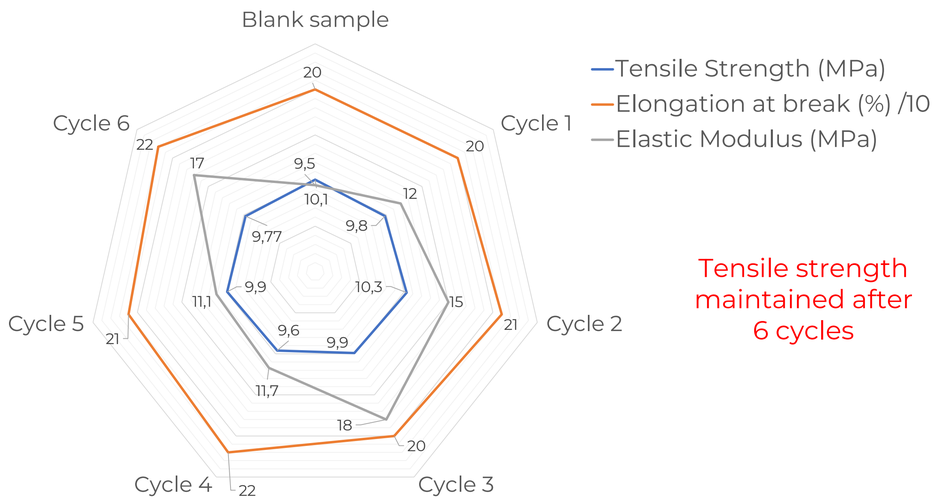
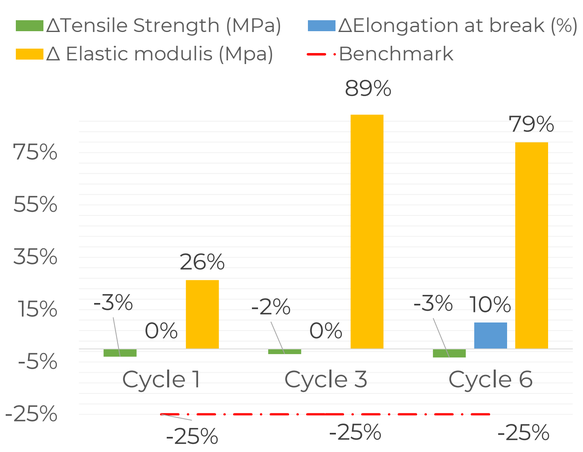
PERFORMANCE

### Mechanical properties
Tensile properties according to UNE:EN ISO 527




Tensile strength maintained after 6 cycles

### Mechanical properties
Tensile properties benchmarking




Superior benchmarking:
No more than a 25% Δ drop to the blank

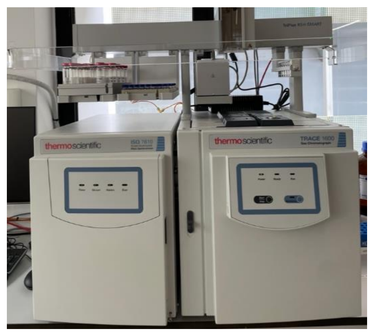
| | Δ Tensile Strength (MPa) | Δ Elongation at break (%) | Δ Elastic modulus (MPa) |
|---|---|---|---|
| **Cycle 1** | -3 % | 0 % | 26 % |
| **Cycle 3** | -2 % | 0 % | 89 % |
| **Cycle 6** | -3 % | 10 % | 79 % |

### Colour evaluation
Determination of L*, a* & b* coordinates according to UNE-EN ISO 11664-4:2020

Light yellowing observed after 6 cycles

| Sample | Colour coordinate | | | Delta values | | | |
|---|---|---|---|---|---|---|---|
| | L* | a* | b* | DL | Da | Db | DE |
| **Blank** | 95,61 | -0,39 | 3,72 | - | - | - | |
| **Cycle 1** | 94,49 | -0,72 | 5,81 | -1,12 | -0,33 | 2,09 | 2,39 |
| **Cycle 2** | 94,94 | -0,92 | 5,97 | -0,67 | -0,53 | 2,25 | 2,41 |
| **Cycle 3** | 94,56 | -0,67 | 5,72 | -1,05 | -0,28 | 2,00 | 2,28 |
| **Cycle 4** | 94,33 | -1,14 | 6,99 | -1,28 | -0,75 | 3,27 | 3,59 |
| **Cycle 5** | 93,15 | -0,77 | 7,42 | -2,46 | -0,38 | 3,70 | 4,46 |
| **Cycle 6** | 92,74 | -0,90 | 10,33 | -2,87 | -0,51 | 6,61 | 7,22 |

### Plasticiser content
Determination of plasticiser content by solvent extraction and GC(-MS)



Plasticiser content remains stable across 6 recycling cycles

| Sample | Plasticiser content % |
|---|---|
| **Blank** | 36 |
| **Cycle 1** | 36 |
| **Cycle 3** | 36 |
| **Cycle 6** | 36 |

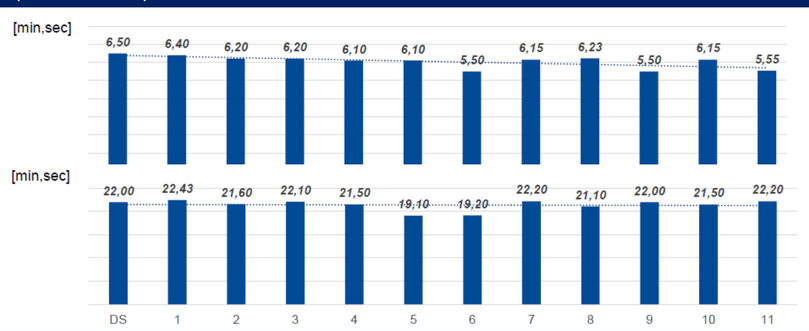
COMPLEMENTARY STUDY: BASF

### Recyclability assessment on PVC-P
Performed up to 11 extrusion cycles

- Transparent formulation
  - 100 phr PVC Inovyn 271 PC
  - 60 phr Palatinol® 10-P DPHP
  - 1,2 phr Ca-Stearate
  - 0,6 phr Zn-Stearate
- Compounding on double screw extruder
- 11 extrusion cycles single screw extruder

- Characterization
  - Thermostability (Congo Red, PVC Thermomat)
  - Colour
  - Mechanical data (Elongation at break, 100% Modulus, etc.)
  - Plasticiser extraction

### Thermostability (Congo red, PVC Thermomat HCl-Stability [min, sec]
VDE 0473 Part 811-3-2 and Metrohm Thermomat stability time at 200°C with 50µS as endpoint



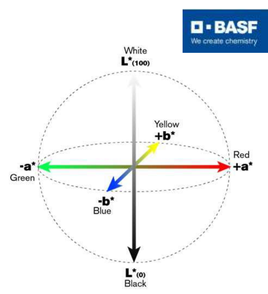

No changes in material thermostability after 11 extrusion cycles

### Colour evaluation – Pressed plates at 170 °C
Determination of colour coordinates L*, a* and b* according to UNE-EN ISO 11664-4:2020
Yellowness Index is a number calculated from spectrophotometric

Light yellowing observed after 6 extrusions; constant up to 11 extrusions

| Sample | L | a | b | Yellowness index | DL | Da | Db | DE |
|---|---|---|---|---|---|---|---|---|
| 1 X (DS) | 88,97 | -0,36 | 3,89 | 7,80 | 0,00 | 0,00 | **0,00** | **0,00** |
| 6 X (ES) | 88,36 | -0,66 | 4,78 | 9,50 | -0,61 | -0,30 | **-0,89** | **1,12** |
| 11 X (ES) | 88,40 | -0,72 | 4,93 | 9,54 | -0,57 | 0,36 | **1,04** | **1,24** |

DS = Double screw extrusion; ES = Single screw extrusion




### Mechanical properties
Tensile properties after 6 and 11 extrusions (11 samples)

Mechanical performance maintained after 11 extrusions

| Run | Breaking strength (MPa) | Elongation at break (%) | 100% Modulus (MPa) |
|---|---|---|---|
| 0 (DS) | 18,2 / 18,7 | 310 / 332 | 8,9 / 8,7 |
| 6 (ES) | 18,3 / 18,2 | 314 / 326 | 9,0 / 8,6 |
| 11 (ES) | 20,2 / 18,4 | 350 / 317 | 9,0 / 8,9 |

DS = Double screw extrusion; ES = Single screw extrusion

### Plasticiser content %
Theorical value 37 %

Plasticiser content stable

| Run | Plasticiser content (%) |
|---|---|
| 0 (DS) | 37 |
| 6 (ES) | 37 |
| 11 (ES) | 37 |

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