cbecimat26
26° Congresso Brasileiro de Engenharia e Ciência dos Materiais
22 a 26 de novembro de 2026
Costão do Santinho
Florianópolis-SC

Degradation of Recycled Caps from Plastic Bottles under Different Environmental Conditions

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Introduction



Figure 1. Marine plastic waste Colônia de Pescadores Z-10, Ilha do Governador,Guanabara Bay. Source: Social Recycling Shipyard (SRS)

Plastic waste accumulation in Guanabara Bay poses environmental and technological challenges. Weathering exposure (UV radiation, salinity, humidity, and thermal cycles) causes photo-oxidative degradation and polymer chain scission. Evaluating mechanical behavior and property retention is essential to reincorporate recycled plastics into engineering applications, such as small boat manufacturing for the Social Recycling Shipyard (SRS) project

Objectives

General Objective: Evaluate the mechanical performance and environmental degradation (UV radiation and seawater immersion) over 120 days on recycled polymers (bottle caps) recovered from coastal marine waste

- Manufacture standardized, defect-free test specimens via **manual artisanal injection molding** using a custom acrylic mold
- Determine tensile properties through **tensile (ASTM D638)** and **three-point flexural (ASTM D790)** testing
- Quantify percentage losses in mechanical properties from **0 to 120 days** across exposure to **UV**, **SEA** (seawater immersion), and **UV + SEA** (combined) conditions



(a)



(b)

Figure 2. (a) (b) Plastic waste collection and sorting at Colônia de Pescadores Z-10 (Ilha do Governador, Rio de Janeiro). Source: Social Recycling Shipyard (SRS).

Methodology



(a)



(b)

1 Collection & Pre-treatment

Collection of plastic caps in Guanabara Bay and post-consumer waste within a 5 km radius, followed by sorting, washing, and shredding



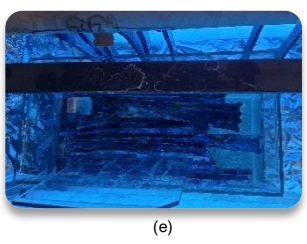
(c)



(d)

2 Injection Molding

Specimen fabrication using a manual injection machine and an acrylic mold



(e)

3 Accelerated Aging (120 Days)

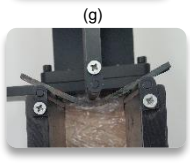
Exposure under three conditions: UV radiation (UV), seawater immersion (SEA), and combined (UV + SEA) evaluated at 0, 15, 30, 60, 90, and 120 days



(f)



(g)



(h)

4 Mechanical Characterization

Tensile Strength (ASTM D638) on Type I "dog-bone" specimens, and Flexural Strength (ASTM D790) via three-point bending tests

Figure 3. Experimental methodology workflow: (a) plastic bottle cap collection at Colônia Z-10, (b) shredded bottle cap flakes, (c) artisanal injection molding process, (d) manual injection molding machine, (e) accelerated aging under combined UV and seawater (UV+SEA) conditions, (f) tensile testing (ASTM D638), (g) molded test specimens, and (h) three-point flexural testing (ASTM D790). Source: Authors (2026)

Results and Discussion

INITIAL STATE (0 DAYS)

- Ultimate Tensile Strength (UTS) → 22.5 Mpa
- Toughness of 3.63 MJ/m³ displaying typical ductile failure

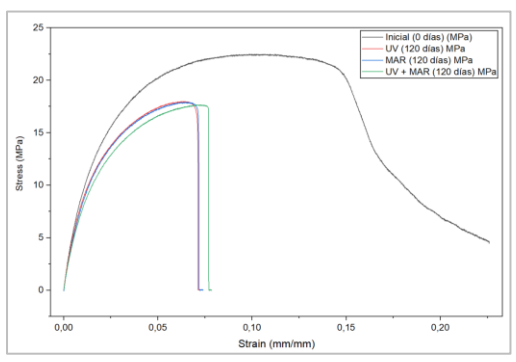
AFTER 120 DAYS

- UTS decreased 18.0 MPa(UV ~ 20.0%) |17.92 MPa(SEA ~ 20.3%) and 17.67 MPa (UV+SEA ~ 21.4%)
- The sharpest embrittlement occurred within the first 15 days, where toughness dropped by ~ 60%

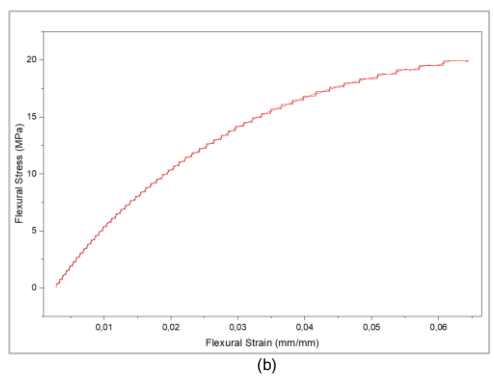
Table 1. Ultimate tensile strength (UTS) and maximum strain values of recycled bottle caps under UV, SEA, and UV+SEA exposure over 120 days.

Exposure (days)	UV		SEA		UV + SEA	
	UTS (MPa)	Max Strain (mm/mm)	UTS (MPa)	Max Strain (mm/mm)	UTS (MPa)	Max Strain (mm/mm)
0	22.50	0.23	22.50	0.23	22.49	0.11
15	20.70	0.08	20.70	0.10	20.90	0.09
30	20.30	0.08	20.30	0.09	20.13	0.08
60	19.20	0.07	19.20	0.12	19.23	0.09
90	18.60	0.07	18.60	0.10	18.32	0.08
120	18.00	0.07	18.00	0.07	17.67	0.07

Source: Authors (2026)



(a)



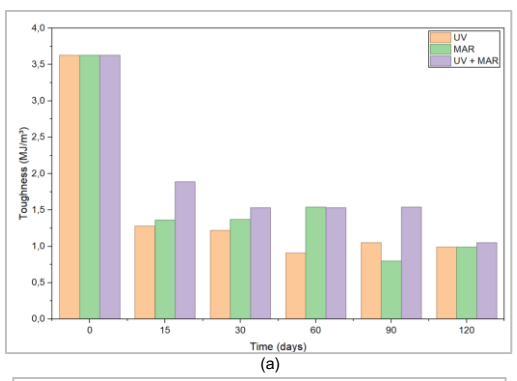
(b)

Figure 4. Mechanical characterization of recycled bottle caps: (a) maximum strain evolution under UV, SEA, and UV+SEA exposure from 0 to 120 days; and (b) three-point flexural behavior at 0 days. Source: Authors (2026).

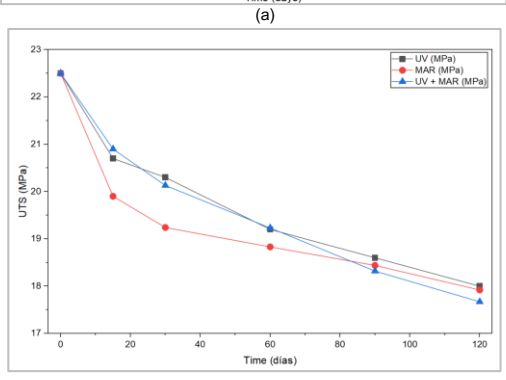
Table 2. Initial (0 days) three-point flexural properties of recycled bottle cap specimens (ASTM D790)

Flexure	Stress Max (MPa)	Flexure Modulus (MPa)
	11.23	353.54

Source: Authors (2026)



(a)



(b)

Figure 5. Evolution of mechanical properties under UV, SEA, and UV+SEA exposure over 120 days: (a) toughness and (b) ultimate tensile strength (UTS). Source: Authors (2026)

AFTER 120 DAYS

- **Toughness:** decreased by ~71%
- **Strain** at break by ~65–69%
- Clear transition from ductile to brittle fracture behavior

FLEXURAL TESTING (0 DAYS)

- Flexural 11.23 MPa
- No premature failure, without catastrophic fracture confirming good molding homogeneity and ductile bending behavior



Figure 6. Scale boat prototype fabricated using recycled bottle cap material. Source: Instituto Reverse Lab

Conclusions

- Injection molding using a custom acrylic mold proved viable for producing uniform test specimens
- Environmental aging caused rapid embrittlement within the first 15 days due to UV-induced photo-oxidative chain scission and additive leaching in saline media.
- The combined UV+SEA condition was the most severe (−21.4% UTS, −71.2% toughness). The retained tensile strength (~17.67–18.00 MPa) and non-brittle flexural strength (11.23 MPa) indicate sufficient mechanical integrity for secondary structural components in small boats within the Social Recycling Shipyard (SRS) project, provided they are not subjected to severe dynamic impacts.

References and Acknowledgments

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