Generation of secondary microplastics in the sea swash zone

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Motivation:

Numerical models of transport and fate of marine MP particles need some kinds of parameterisations for the process of generation of secondary MPs on the coastline.

Mechanical fragmentation of larger plastic objects into MPs (here - from 0.5 to 5 mm) in the swash zone seems to be most energetic stage.

The idea

is to mimic the process of mechanical fragmentation in the sea swash zone

- using laboratory mixer,
- with different kinds of beach sediments,
- for typical beach-debris plastic objects.
**Most typical beach plastics:**

- PP and PS tableware
- PE bags
- foamed PS

**Objects: new, from the market**

<table>
<thead>
<tr>
<th>Plastic type</th>
<th>LDPE</th>
<th>PS</th>
<th>PP</th>
<th>PS foamed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured density</td>
<td>0.92</td>
<td>1.05</td>
<td>0.86</td>
<td>0.01 g/cm³</td>
</tr>
</tbody>
</table>

**Beach sediments (Wentworth, 1922):**

<table>
<thead>
<tr>
<th>Size</th>
<th>Wentworth Size Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>256 mm</td>
<td>Boulders</td>
</tr>
<tr>
<td>84 mm</td>
<td>Cobble</td>
</tr>
<tr>
<td>4 mm</td>
<td>Pebble</td>
</tr>
<tr>
<td>2 mm</td>
<td>Granulate</td>
</tr>
<tr>
<td>1 mm</td>
<td>Very Coarse Sand</td>
</tr>
<tr>
<td>1/8 mm</td>
<td>Coarse Sand</td>
</tr>
<tr>
<td>1/4 mm</td>
<td>Medium Sand</td>
</tr>
<tr>
<td>1/8 mm</td>
<td>Fine Sand</td>
</tr>
<tr>
<td>1/16 mm</td>
<td>Very Fine Sand</td>
</tr>
<tr>
<td>1/256 mm</td>
<td>Silt</td>
</tr>
<tr>
<td>1 cm</td>
<td>Clay</td>
</tr>
</tbody>
</table>

- large pebbles (4 – 6.4 cm)
- small pebbles (1 – 1.8 cm)
- granules (3 – 4 mm)
- very coarse sand (1 – 1.5 mm)

**Macro-samples: hand-made, 2 cm x 2 cm**

- large pebbles
- small pebbles
- granules
- very coarse sand

**Sediments: collected on the beach, calibrated**

- large pebbles
- small pebbles
- granules
- very coarse sand
Laboratory set-up:

**Experiments:**
- **Set 1:** 4 types of plastics X 4 types of sediments = 16 runs, 24 h each
- **Set 2:** (4 types of plastics + large pebbles) X 8 time steps = 32 runs, 3 h each
  
  Both mass and number of particles were registered.

**Procedure:**
- **Set 1:** every 24-h-long run is performed with new plastic samples
- **Set 2:** the samples are used for 24 h, with analysis after each 3-h-long run

**Procedure Diagram:**
- 20 L of water
- 40 kg sediments
- 200 g (or 50 g) of plastic macro-samples
- 30 r/min
- 24 h of rotation
- Number of particles
- Mass of macro, micro, nano
How it looks like:

(Set 2: PS + large pebbles)
Results:

Set 1: 4 types of plastics X 4 types of sediments = 16 runs, 24 h each

Fraction of mass (%) of different plastics, converted into MPs by different sediments after 24 h

Number of generated MPs particles

Conclusions:

- Coarser sediments are much more effective in fragmentation of plastics
- PS (in its solid form) is the easiest to fragment

(Chubarenko et al., 2018) to be submitted to Fronteers in Marine Science
Example of application: rocky cape surrounded by sandy shores

Intensity of generation of MPs (type $i$) at different shores

$$I_{n_i}(x, y) \sim H_w(x, y) \cdot N_i(x, y)$$

Simulated average significant wave height in the Baltic Sea in 1970-2007

$$H_w = 0.6 \text{ m}, 0.7 \text{ m}, 0.5 \text{ m}$$

(Räämet, Soomere, 2010)

Conclusion:

cobble/pebble shores are definitely more “productive” than sandy beaches
**Results:**

Set 2: (4 types of plastics + large pebbles) \( \times \) 8 time steps = 32 runs, 3 h each

Fraction of mass (%) of different plastics, converted into MPs by mixing with large pebbles, with 3h-step

![Graph showing the fraction of mass of different plastics converted into MPs](Image)

- Increase of MPs mass with time is exponential (very close to linear for foamed PS, which is composed from particular spherules);

**Conclusions:**

- solid PS (which is the only plastic here sinking in water) is fragmented faster; PP is most resistant to mechanical fragmentation;

- re-calculated to moderate wind/wave conditions for the Baltic coasts, 50 % of mass of solid PS and LDPE should be transferred to MPs within 2-4 days.

More details see: (Efimova et al., 2018) to be submitted to *Marine Pollution Bulletin*
Summary and Discussion:

- coarser beach sediments (cobbles/pebbles; but what about rocks - ??) are significantly more effective in fragmentation of plastics;

- both floating and sinking plastics show clear tendency to be buried beneath sediments;

Conclusions from the experiments:

- mechanical fragmentation leads to generally exponential increase of MPs mass with time; foamed plastic, being composed of particular bubbles, is first fragmented to individual spherules, what leads to linear increase in MPs mass;

- PS (which is the only plastic here sinking in water) is fragmented faster; PP is most resistant to mechanical fragmentation.
Discussion: 1. We suggest the parameterisation for the mass of MPs of the type $i$ generated by mechanical fragmentation at the point $l(x, y)$ of the coastline in the form:

$$M_i(l, t) = k_1 \cdot k_2 \cdot M_{0i}(l) \cdot H_w(l, t) \cdot Gr(l) \cdot F_i(t)$$

**Field measurements are required** for calibration, relating the generated MPs mass to significant wave height.
**Discussion:**

2. Monitoring data typically report not the mass but the number of particles. For mechanical fragmentation, certain mathematical relationships can be used (see, e.g., (Cózar et al., 2014, pnas.1314705111)).

On the base of our experiments, the relationship is found (note the log-log presentation):

\[
\log N \text{ (items)} = 0.836 \cdot \log M \%\text{micro} + 3.589
\]

Field data are required here as well, relating the number of MP items to their integral mass.
Acknowledgements:

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Thank you for your attention!

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