

# 1     Recyclability of four types of plastics exposed 2             to UV irradiation in a marine environment

3                     *María E. Iñiguez\**, *Juan A. Conesa*, *Andrés Fullana*

4             Chemical Engineering Department. University of Alicante. P.O. Box 99, 03080

5                     Alicante (Spain). Phone: +(34) 96 590 38 67 Fax: +(34) 96 590 38 26

6                     \* Corresponding author email: [maria.iniguez@ua.es](mailto:maria.iniguez@ua.es)

## 7 8     **Abstract**

9     Plastics are the most abundant products in the world and therefore also represent the  
10    largest volume of materials found in the sea. Their resistance to degradation makes them  
11    dangerous for the marine environment. In this study, the degradation of the four main  
12    plastics (Nylon, Polyethylene (PE), Polypropylene (PP), Polyethylene terephthalate  
13    (PET)) found in the sea was observed for 6.5 months as they were exposed to UV  
14    irradiation in a marine environment. Data on changes in the physical and chemical  
15    properties of each of them were collected in order to evaluate the possibilities of  
16    material (mechanical) recycling. A thermobalance was used to look for differences in  
17    the thermal decomposition of the plastics during this time. In addition, the mechanical  
18    properties of each plastic were studied. Results showed that both thermal and  
19    mechanical properties were affected, causing a weakening of the material which became  
20    less elastic and more rigid. Furthermore, SEM and AFM images were obtained: they

21 showed cracks, flakes and granular oxidation as well as a loss of homogeneity on the  
22 surface of the samples. These changes make mechanical recycling unfeasible, since the  
23 quality of the recycled material is insufficient to ensure a high virgin material  
24 substitution rate.

25

26 **Keywords:** Plastics; Degradation; UV irradiation; mechanical properties; marine  
27 environment; seawater.

## 28 **1. Introduction**

29 The presence of marine debris is a cause for concern for a number of reasons. They are  
30 harmful to organisms and to human health (Coe and Rogers, 1997; Derraik, 2002;  
31 Gregory, 2009; Rochman et al., 2013b), they potentially increase the transport of  
32 organic and inorganic contaminants (Gaylor et al., 2012; Holmes et al., 2012; Mato et  
33 al., 2001; Rochman et al., 2013a; Teuten et al., 2009) and provide new habitats and long  
34 range delivery of attached organisms to new habitats. In addition, these debris present a  
35 hazard to shipping and are aesthetically detrimental, leading to negative socio-economic  
36 consequences (Mouat et al., 2010).

37 Since the development of the plastics industry, plastic products are the most abundant in  
38 the world. Global annual production of plastics is approximately 280 million tons  
39 (Koelmans et al., 2014; Rillig, 2012); however, in 2016, 335 million tons of plastic  
40 items were produced (PlasticsEurope, 2017). According to published literature, plastic  
41 items are the most abundant type of marine litter (Barnes et al., 2009; Landon-Lane,  
42 2018; OSPAR, 2007; UNEP-CAR/RCU, 2008; UNEP, 2005, 2009; Vince and Stoett,  
43 2018), representing between 60 % to 80% of total marine debris (Gregory and Ryan,

44 1997; Niaounakis, 2017a; Sheavly and Register, 2007). Jambeck et al. estimate that  
45 between 4.8 and 12.7 million tons of this waste ends up in the world's oceans every  
46 year (Jambeck et al., 2015), of which between 1.15 to 2.41 million tons come from  
47 rivers (Lebreton et al., 2017). The plastics most frequently found in the marine  
48 environment are polyethylene (PE), polypropylene (PP), polyethylene terephthalate  
49 (PET) and Nylon (Heo et al., 2013; Hidalgo-Ruz et al., 2012; Lebreton et al., 2017;  
50 Martins and Sobral, 2011).

51 Plastics are synthetic organic polymers that are malleable and can be moulded into solid  
52 objects of different shapes. They are lightweight, inexpensive, strong and durable (Laist,  
53 1987). These properties make them suitable for the manufacturing of a wide range of  
54 products (food packaging, household items, shopping bags, facial cleansers...) (Iñiguez  
55 et al., 2016), including single use products.

56 The main reason plastics are dangerous for the marine environment is their resistance to  
57 degradation. The natural decomposition of plastic items in the sea can take hundreds  
58 and even thousands of years (Barnes et al., 2009). During this time, chemical  
59 contaminants such as polychlorinated biphenyls (PCBs) and dioxins, contained in the  
60 plastics are released into the sea (Hahladakis et al., 2018). In addition, the continuous  
61 degradation of larger plastics generate microplastics (plastic particles less than 5 mm in  
62 diameter), which results in an annual increase in the amount of microplastics in the sea  
63 (Andrady, 2011; Wang et al., 2016). These micro-particles also come from primary  
64 sources (i.e. microscopic plastics exist in clothes) (Mohamed Nor and Obbard, 2014).

65 Degradation is defined as the partial or complete breakdown of a polymer under the  
66 influence of several environmental factors such as heat, light, water, mechanical action  
67 and microbes (Niaounakis, 2017b). In this way, the environmental conditions to which

68 marine plastic debris (MPD) is exposed in various marine habitats (beaches, sea surface,  
69 water column and seafloor) will accelerate or decelerate degradation. Therefore, the  
70 decomposition of MPD is less intensive in the sea than on land, because of solar UV  
71 radiation (seawater is a good heat sink) and mechanical damage (mowing, vehicles, etc).  
72 In the water column and on the seafloor, MPD degrades very slowly, particularly on the  
73 seafloor (Andrady, 2000).

74 The degradation of most conventional polymers found in the marine environment is  
75 attributed to the combined action of atmospheric oxygen, sunlight and seawater  
76 (Andrady, 2005). In this way, plastics undergo five types of degradation in the marine  
77 environment: hydrolytic degradation, thermooxidative degradation, photodegradation,  
78 biodegradation and mechanical degradation (Niaounakis, 2017b). The most important  
79 process in the degradation of plastic debris is considered to be photooxidation, followed  
80 by mechanical action and thermal oxidation (Niaounakis, 2017b).

81 Polyolefins including PE and PP are hydrophobic and are unlikely to hydrolyze in the  
82 seawater. In general, polymers with pure carbon backbones are resistant to most types  
83 of degradation, including hydrolysis; polymers with heteroatoms in the backbone  
84 (polyesters, polyamides and polyurethanes) are highly hydrolysable. Nevertheless, this  
85 is not true in all cases. PET is an example of polyester, but the aromatic groups it  
86 contains make this polymer non-degradable under normal conditions (Webb et al.,  
87 2013). Hydrolysis may not be a significant degradation mechanism for most commonly  
88 used plastics in the marine environment (Andrady, 2011).

89 Oxygen levels and temperatures are the major factors in the initiation of  
90 thermooxidative degradation of MPD. In the case of seawater, low oxygen content and  
91 relatively low temperatures inhibit the heat buildup and delay the thermooxidative

92 degradation of the debris (Andrady, 2011; Pegram and Andrady, 1989). The rate of  
93 chemical reaction increases when the temperature is higher, generating greater  
94 degradation (Niaounakis, 2017b).

95 Photodegradation is the dominant environmental mode of degradation of most of MPD  
96 (Niaounakis, 2017b). The UV radiation portion (400-10 nm) of sunlight (Niaounakis,  
97 2017b) plays an important role in plastic degradation through photooxidation. The  
98 photooxidative degradation of polymers such as PE, PP and nylon that are exposed to  
99 the marine environment begins with UV-B radiation (280-315 nm) in sunlight. During  
100 the photodegradation process several polymer changes can be observed as a result of  
101 chemical weathering: oxygen-rich functional groups are generated and their molecular  
102 weight decreases. The fragmentation rate increases with higher temperatures and  
103 oxygen levels (Kershaw, 2015). Normally, photooxidative degradation starts at the outer  
104 surface of these plastics (Andrady, 2011) owing to the diffusion-controlled nature of the  
105 oxidation reaction (Cunliffe and Davis, 1982), the high UV-B radiation extinction  
106 coefficient in plastics, and the presence of fillers that impede oxygen diffusion in the  
107 polymer (Qayyum and White, 1993a, b). On plastic surfaces, this deterioration takes the  
108 form of pitting, crazing or cracking, discoloration, erosion, or embrittlement. MPD  
109 could turn into small pieces (Andrady, 2011; Andrady et al., 1996) because the fragile  
110 surface of these plastics is susceptible to fracture by stress, induced by temperature  
111 changes or humidity (White and Turnbull, 1994).

112 The plastics most used commercially such as PP, PET, PE and nylon have very slow  
113 biodegradation rates and thus remain semi-permanent when they are disposed of at sea  
114 (Andrady, 2000). Microbial species that are rare in nature are necessary for these  
115 polymers to be metabolized. Some features that make them resistant to biodegradation  
116 are: high molecular weight, high stable C-C and C-H covalent bonds, a highly

117 hydrophobic nature and the lack of easily oxidisable and/or hydrolysable groups  
118 (Gautam et al., 2007; Yang et al., 2014)..

119 Wave and tide action and abrasion can scratch and fragment the surface of MPD,  
120 causing mechanical degradation. Surface alterations in plastic fragments increase  
121 polarity as well as the overall surface area and can facilitate the sorption of persistent  
122 organic pollutants (POPs) (Fotopoulou and Karapanagioti, 2012, 2015).

123 Marine debris is collected mostly by boats. In addition, every year, several programs for  
124 coastal cleanup such as the International Coastal Cleanup (ICC) are carried out, during  
125 which a large amount of marine debris is collected from various coastal areas by  
126 numerous volunteers (Iñiguez et al., 2016). However, since 2013, “the Ocean Cleanup”  
127 foundation has developed technology to extract plastic waste and keep it from entering  
128 ocean waters. The main purpose of this organization is to facilitate the collection of  
129 marine debris and to collect larger amounts of debris faster time. Once collected from  
130 the sea, the plastic must go through a recycling process.

131 Plastic recycling has been defined as the process of recovering waste plastics and  
132 reprocessing the material to make new useful products (Merrington, 2017). Different  
133 forms of recycling exist such as mechanical, chemical and energy recovery recycling.  
134 According to some authors, mechanical recycling is the best option for plastic waste  
135 treatment when the waste is good enough to make other good quality products from it  
136 (Horodytska et al., 2018). For this reason, this study focuses on a recycling process that  
137 involves the reuse of plastic rather than its conversion into chemicals or fuels to meet  
138 energy needs. This type of recycling has many advantages for the environment and  
139 therefore contributes to quality of life. Some of the most important advantages of this  
140 process are as follow: the amount of waste drops; raw as well as natural material is

141 saved, energy and economic resources are saved; greenhouse gas emissions from the  
142 manufacturing of plastic are reduced.

143 Several factors greatly influence the recycling process such as: contaminants, molecular  
144 weight, mechanical properties and colour/transparency of the material, among others  
145 (Merrington, 2017). If these characteristics are very different from those of the virgin  
146 material, they will negatively affect the quality of the final product; this type of  
147 recycling would in that case not be advisable.

148 Following this line of research, this study focuses on the degradation of the four most  
149 common polymers found in the sea and examines the similarities and discrepancies in  
150 the degradation process of each polymer. The degradation of PP, PE, PET and Nylon in  
151 marine environment conditions (submerged in seawater and under UV irradiation) was  
152 observed. Data on the changes in some properties were collected over 6.5 months, and  
153 comparisons of the four plastics were also performed, in order to assess the recyclability  
154 of the different materials.

## 155 **2. Materials and methods**

### 156 **2.1. Materials and experimental setting**

157 The degradation of the four most common polymers found in the sea (PE, PP, PET and  
158 Nylon), was studied. These plastics came from used items such as cans, water bottles,  
159 etc.; they were not virgin materials. The seawater used was extracted from the  
160 Mediterranean Sea and two UV lamps TUV PL-L 36W/4P (UVC 250) were selected to  
161 simulate natural sunlight.

162 First, the samples were directly cut (in pieces large enough to later constitute  
163 rectangular specimens 60 mm long, 10 mm wide and approximately 1 mm thick) and

164 placed in glass vessels (1 L) containing seawater. The glass vessels were then  
165 transferred into a homemade environmental chamber (Figure 1) (62 cm x 32.5 cm x  
166 42.5 cm in length, width and height respectively) that was equipped with two UV lamps  
167 (TUV PL-L 36W/4P) over a total period of 6.5 months. During this time, different  
168 samples were taken to measure changes in some of their properties. Specifically,  
169 samples were taken at 1.5, 2.5, 4.5 and 6.5 months, and were compared to the plastics  
170 before the treatment. In addition, every week, seawater in contact with the plastics was  
171 discarded and replaced with new seawater, to maintain the surrounding water's salinity  
172 approximately constant throughout the experiment and to compensate for losses due to  
173 evaporation.

## 174 **2.2. Tensile test**

175 The tensile test was suitable for determining each plastic's mechanical properties. For  
176 this, a sample preparation was necessary. The different polymeric materials were made  
177 into rectangular specimens 60 mm long, 10 mm wide and approximately 1 mm thick,  
178 except for the PE, which was less thick (around 0.7 mm).

179 Tensile mechanical tests were carried out using an Instron 3344 Universal Test  
180 instrument (MA, USA) equipped with a 2000N load cell following ASTM D882-12  
181 (ASTM, 2012) and UNE-EN ISO 527-3 (UNE-EN ISO, 1996) standard  
182 recommendations. The rectangular specimens were clamped at a fixed distance of 20  
183 mm between the grips and the slack was removed before the tests. The pressure and  
184 speed conditions used were 2.5 bar and 5 mm/s, respectively. To test the reproducibility  
185 of the results, six specimens from the sample were tested. The tensile properties studied  
186 were tensile strength at break, tenacity and Young's modulus.

187



### 188        **2.3.        TG runs**

189        In order to better understand the decomposition behaviour of these plastics in the sea,  
190        thermogravimetric runs were performed.

191        Runs for the TG analysis were carried out on a Mettler Toledo  
192        TGA/SDTA851e/SF/1100 Thermal Gravimetric Analyzer. The decomposition  
193        temperatures were measured under dynamic conditions in nitrogen atmosphere with a  
194        total flow rate of 100 mL min<sup>-1</sup>. The experiments were carried out at 10 K min<sup>-1</sup>, at a  
195        room temperature up to 1173 K. For each run, 4.0 ± 0.3 mg of sample were used.

### 196        **2.4.        SEM analyses**

197        The surface textures of the plastics after the degradation process were clearly illustrated  
198        through SEM images. Thus, a representative sample of each polymer was studied by  
199        scanning electron microscopy (SEM) on a Hitachi-S3000N microscope before and after  
200        6.5 months in marine water and under the UV lamp. Due to the degraded plastic's  
201        heterogeneous surface texture, the visualization was repeated at different surface sites of  
202        the materials. In addition, a comparison of the changes in the surface textures between  
203        both polymer samples (before and after the treatment) was performed.

### 204        **2.5.        AFM analyses**

205        The topography and the roughness of the surface material were analysed using a NT-  
206        MDT/INTEGRA PRIMA atomic force microscope (AFM) equipped with a steel  
207        cantilever. To obtain high resolution images, the cantilever has a sharp tip Tap300DLC  
208        (Budget Sensors) covered with diamond. The analysis was carried out at room  
209        temperature. The studied area and the scan speed were 10 x 10 µm and 20 µm·s<sup>-1</sup>,  
210        respectively.

211 First, a sample preparation was necessary. The samples were cut into small pieces  
212 which were fixed with double layer tape on a glass slide in view of fixing them to the  
213 support. Thus, these samples were introduced under the microscope. Before starting the  
214 analysis, an air flow was used to remove dust from the samples.

215 Two different scans were performed at different locations for each sample. Phase  
216 images and both two-dimensional (2D) and three-dimensional (3D) imaging of the  
217 surface topographies were derived from these analyses. The topographic images were  
218 obtained using the operation mode ‘Tapping’ or ‘semi-contact’, the cantilever  
219 oscillation amplitude remaining constant. Phase images are useful when analysing  
220 heterogeneous polymer systems with domains that have different mechanical properties.  
221 It is possible to determine the phase difference between the sample’s disturbing signal  
222 (cyclical deformation of the cantilever) when interacting and not interacting with the  
223 surface of the sample. Viscoelastic materials undergo deformations as a function of time  
224 in case of mechanical disturbance, and the deformation depends on the type of material.

### 225 **3. Results and discussion**

#### 226 **3.1. Tensile test**

227 As mentioned above, the tensile properties of different materials before and after the  
228 degradation process were determined. Table 1 presents the tensile strength at break,  
229 tenacity and Young’s modulus. The samples taken at 1.5 and 2.5 months did not show  
230 significant differences with respect to the untreated material, so they were not included  
231 in Table 1 nor are they included in the rest of the results.

232 As degradation progressed, results showed an increase in Young’s modulus in all cases,  
233 indicating polymer loss of elasticity. According to these values, the materials’ tenacity

234 decreased, which means the polymers's rigidity increased. These results are consistent  
235 with findings since once these plastics are degraded, they become embrittled and break  
236 more easily (Niaounakis, 2017b). PET and PP were the most affected materials.

237 Due to the fact that the original material was less thick, it was not possible to make PE  
238 specimens equal to those of the rest of materials. Consequently, the PE specimens were  
239 slightly less thick (< 1 mm) and the results obtained in these analyses were a little  
240 different from the results obtained for the other polymers.

### 241 **3.2. Thermogravimetric runs**

242 The evolution of the thermal behaviour of the plastic materials was followed by  
243 thermogravimetry. Samples were subjected to decomposition in the thermobalance at 10  
244 K·min<sup>-1</sup> and were finally compared. As mentioned earlier, nitrogen was used as a carrier  
245 gas to test the samples' behaviour in pyrolytic conditions (Iñiguez et al., 2017).  
246 Measures were duplicated to test reproducibility, which was found to be very good.

247 As can be observed, all plastics were affected by contact with marine water and UV  
248 radiation (Figure 2). In general, thermal properties were affected, causing a weakening  
249 of the plastic over time. This was an expected behaviour, as degradation was facilitated  
250 as the polymer was subjected to the degradation process (seawater and UV radiation).

251 An increase in weight at time infinity was also observed, indicating that the inert  
252 fraction was continuously increasing during the UV treatment. PE was the most affected  
253 sample, showing a very different TG-curve from the beginning of the treatment. The TG  
254 curve of the Nylon was the least affected, revealing small differences between treated  
255 and untreated material.

256 Decomposition began at a lower temperature when the material was partially degraded  
257 by the UV, but in some runs the initial decomposition rate was lower. In this way, the  
258 T<sub>max</sub> (temperature at which the decomposition rate is maximum) may have increased in  
259 some samples, going from 429.6 °C (original Nylon) to 427.9 °C (sample taken at 6.5  
260 months), 451.2 °C (Original PE) to 466.8 °C (sample taken at 6.5 months), 419.1 °C  
261 (original PET) to 429.6 °C (sample taken at 6.5 months) and 435.3 °C (original PP) to  
262 447.5 °C (sample taken at 6.5 months).

263 These results can be compared with those from a previous study performed in our  
264 laboratory, in which the pyrolysis and combustion of the same four plastics submerged  
265 in marine water (without UV radiation) over 12 months were analysed (Iñiguez et al.,  
266 2018). According to Font et al., the presence of inert atmosphere can be found to  
267 decelerate decomposition (Font et al., 2005; Iñiguez et al., 2018) .

### 268 **3.3. Changes in surface textures**

269 SEM images of the plastics treated by UV irradiation in marine environments before  
270 and after 6.5 months were obtained. The most representative images have been included  
271 in Figure 3. As shown in this Figure, all four types of original plastics showed relatively  
272 homogeneous and compact textures. In contrast, the weathered plastics presented  
273 relatively rough surface textures.

274 In the case of Nylon, PE and PET, granular oxidation and flakes were found on their  
275 surfaces after the treatment. Moreover, the treated PP presented clear cracks. All these  
276 characteristics (granular oxidation, flakes and cracks) constitute degradation patterns  
277 (Cai et al., 2018), some of which have been marked with a circle in Figure 3. However,  
278 based on the observation of the degradation patterns of the four types of polymers, it

279 was found that crack patterns did not appear on the PET surface, which could be related  
280 to insufficient UV exposure time.

281 These results are compatible with those of previous studies: Song et al. showed that  
282 crack patterns appeared on PE after 6.5 months of UV exposure (Song et al., 2017)  
283 while Cai et al. (Cai et al., 2018) showed that PE did not produce any crack patterns  
284 after 3 months under UV radiation in a marine environment.

285 Photo-oxidative degradation was the main reason for the formation of cracks (Cai et al.,  
286 2018). Our results showed accordingly that cracks and flakes constituted the leading  
287 degradation patterns after the chemical weathering of these plastic samples. It can thus  
288 be assumed that larger plastic pieces experience further fragmentation in the marine  
289 environment and generate microplastics.

290 In the same way, the topography and the roughness of the material's surface were also  
291 analysed by atomic force microscopy (AFM). The most representative images of each  
292 material have been included in this article. Figure 4 shows phase images and two-  
293 dimensional (2D) and three-dimensional (3D) imaging of the surface topographies of  
294 PET, before and after 6.5 months under a UV lamp and submerged in seawater. Figures  
295 A1, A2 and A3 (Appendix A. Supplementary material) show the images for the other  
296 three polymers (Nylon, PE and PP respectively).

297 The 2D images showed the topography of heights, in which the topography of the  
298 sample was directly observed. However, these images did not provide much  
299 information. This may be because the surfaces of all polymers had a certain inclination,  
300 as can be seen in the 3D images (Bajpai et al., 2016). On the other hand, the phase  
301 images provided information on surface homogeneity (Jin et al., 2018). As illustrated,  
302 all plastics showed fairly homogeneous surfaces before the treatment. In contrast, areas

303 with different mechanical properties appeared in the treated samples (Jin et al., 2018).  
304 The darker colour in the images shows the areas of greater hardness in each material,  
305 and these areas predominated in the original polymers. Thus, Figures 4, A1, A2 and A3  
306 show that all polymer surfaces were affected by the degradation process, which is  
307 consistent with the SEM images.

308 Horodytska et al. (Horodytska et al., 2018) show that mechanical recycling should be  
309 the number one option for plastic waste treatment when the quality of the recycled  
310 material is good enough to ensure a high virgin material substitution rate. Nevertheless,  
311 the changes observed in the present study make it difficult to use plastics from a marine  
312 environment for mechanical recycling, so other treatment processes - chemical  
313 recycling and/or energy recovery - (Hahladakis et al., 2018) should be preferred.

#### 314 **4. Conclusions**

315 In this work, the four plastics most commonly found in the sea (Nylon, PE, PET and  
316 PP) were exposed to UV irradiation in a marine environment for 6.5 months. During  
317 that time, all the materials' mechanical properties were affected, indicating a clear loss  
318 of elasticity and an increase in the rigidity of each of them.

319 In general, the thermal properties of these polymers were affected, causing a weakening  
320 of the material over time. The degradation of all these samples was easier after the  
321 treatment. In addition, cracks, flakes and granular oxidation were common degradation  
322 patterns in the chemical weathering of the plastics. In particular, Nylon, PE and PET  
323 presented granular oxidation and flakes on their surfaces, and PP showed clear cracks  
324 after the treatment.

325 Moreover, all the plastics before the treatment showed surfaces that were fairly  
326 homogeneous. In contrast, areas with different mechanical properties were found in the  
327 treated samples. This implies that all polymer surfaces were affected by the degradation  
328 process.

329 In view of obtained results, it is logical to deduce that most plastics extracted from the  
330 sea are highly degraded. For this reason, using these materials for mechanical recycling  
331 is not feasible. Other treatment processes for this type of plastic waste should thus be  
332 used, such as energy recovery. It was difficult to judge which material was the most  
333 degraded, but to a greater or lesser degree, all four materials were affected by this  
334 degradation process. The level of weathering the samples were subjected to increased  
335 with exposure time, and was practically nil during the first two to three months. In this  
336 way, salinity, exposure time, UV light and levels of exposure to oxygen were important  
337 factors affecting the plastic samples' degree of degradation. However, further research  
338 on the degradation processes of plastics in the environment is required. This would  
339 increase our knowledge about the source and fate of microplastics and would help us to  
340 evaluate the environmental risk for organisms.

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347

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496 **TABLE LEGENDS**

497 Table 1. Mechanical properties of Nylon, PE, PET and PP before and after 4.5 and 6.5  
498 months submerged in marine water and under UV lamp. (Speed = 5 mm/s).

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515 **FIGURE CAPTIONS**

516 Figure 1. Experimental setup. Dimensions of homemade environmental chamber  
517 equipped with two UV lamps (TUV PL-L 36W/4P).

518 Figure 2. Thermal decomposition of the plastic materials at different time after being  
519 submerged in marine water and under UV lamp.

520 Figure 3. SEM images of the four types of plastics. a) SEM images of the four original  
521 plastics; b) SEM images of the four weathered plastics (treated under UV radiation and  
522 submerged in seawater during 6.5 months).

523 Figure 4. AFM images of PET before and after 6.5 months in seawater and under UV  
524 lamp. a) 2D surface topography; b) 3D surface topography; c) Phase images.

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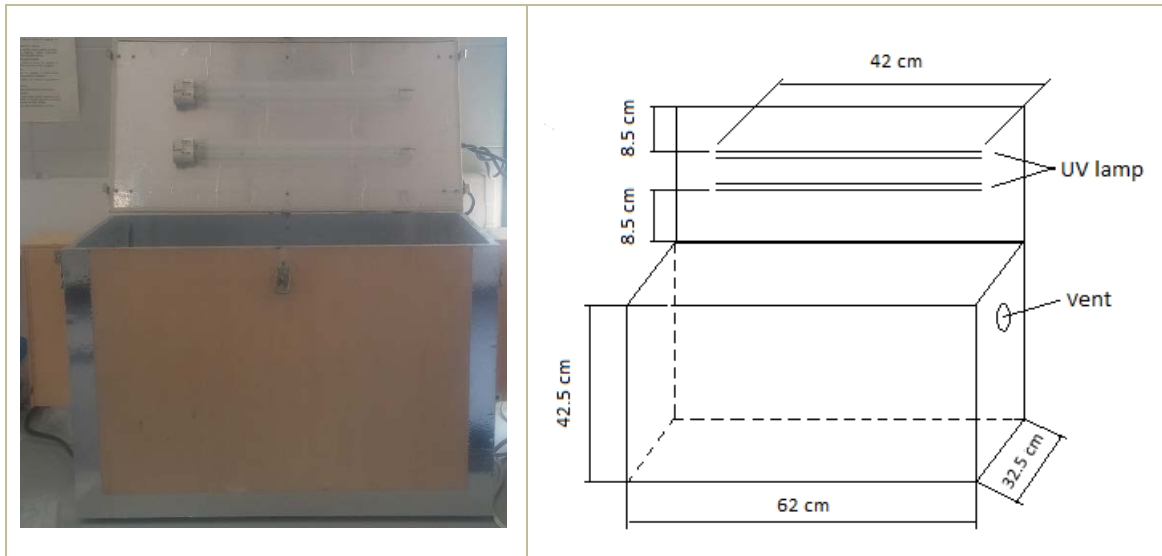
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534 Table 1. Mechanical properties of Nylon, PE, PET and PP before and after 4.5 and 6.5  
 535 months submerged in marine water and under UV lamp.(Speed = 5 mm/s).

<b>Material</b>	<b>Strain at break</b>	<b>Tensile strength at break (MPa)</b>	<b>Young's modulus (MPa)</b>	<b>Tenacity (MPa)</b>
Nylon	0.178	136	1312	14
Nylon UV_4,5 months	0.133	197	1616	15
Nylon UV_6,5 months	0.129	208	1677	15
PE	2	25	286	46
PE UV_4,5 months	0.522	16	443	12
PE UV_6,5 months	0.501	6	560	9
PET	0.328	53	1772	11
PET UV_4,5 months	0.171	95	3193	13
PET UV_6,5 months	0.174	109	4269	13
PP	0.130	33	955	146
PP UV_4,5 months	0.008	12	1680	0.098
PP UV_6,5 months	0.016	23	1688	0.218

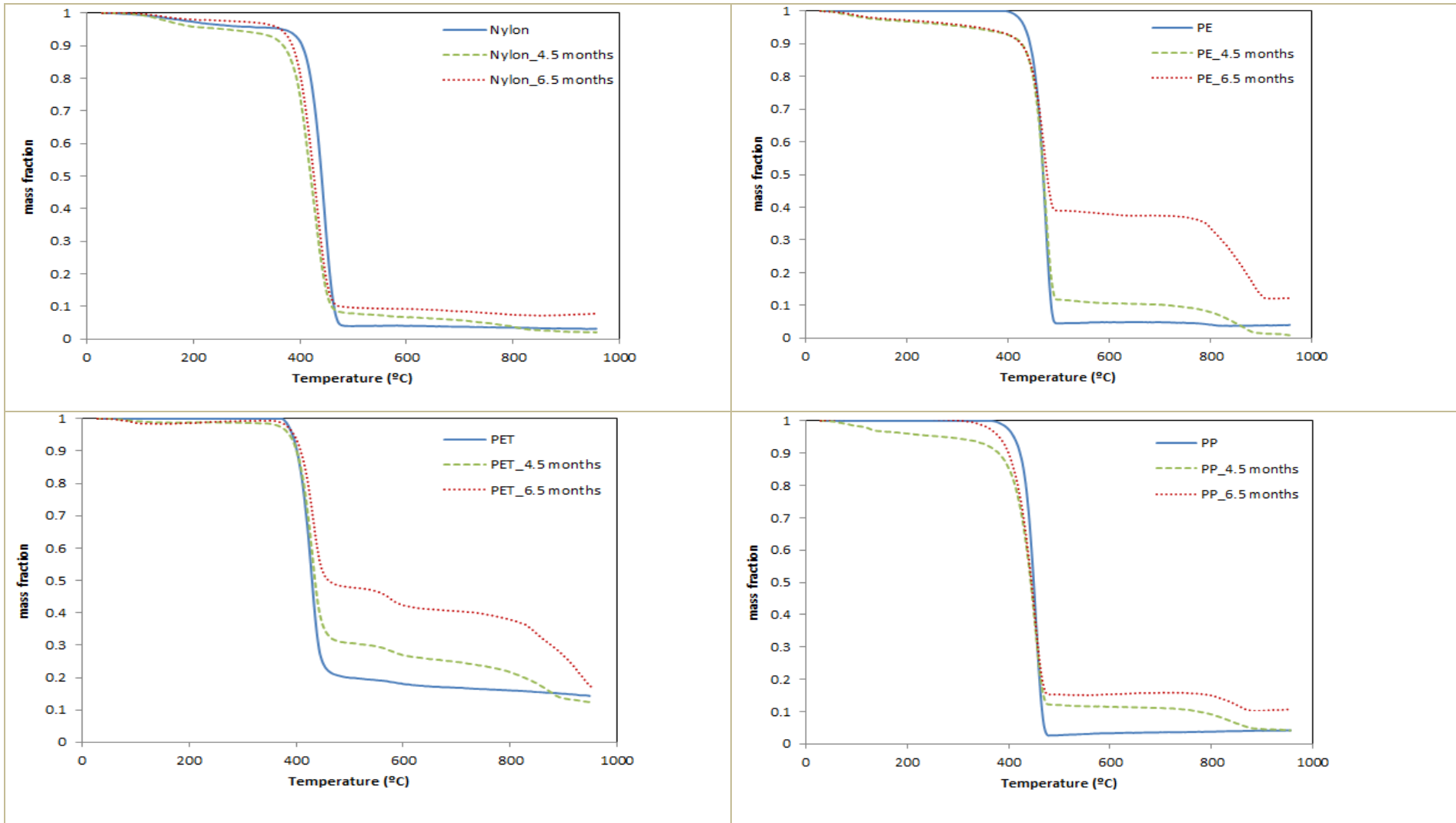
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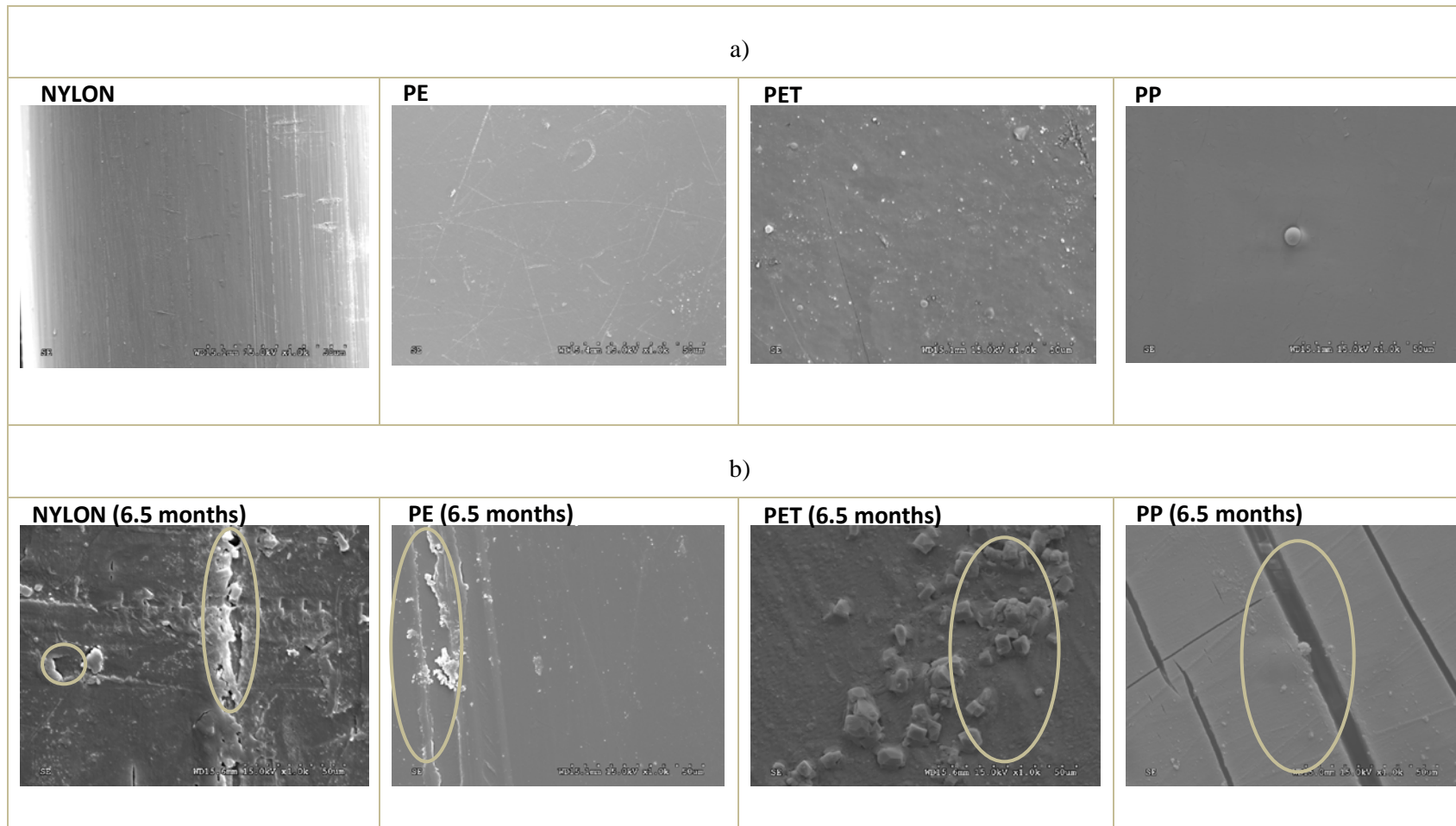


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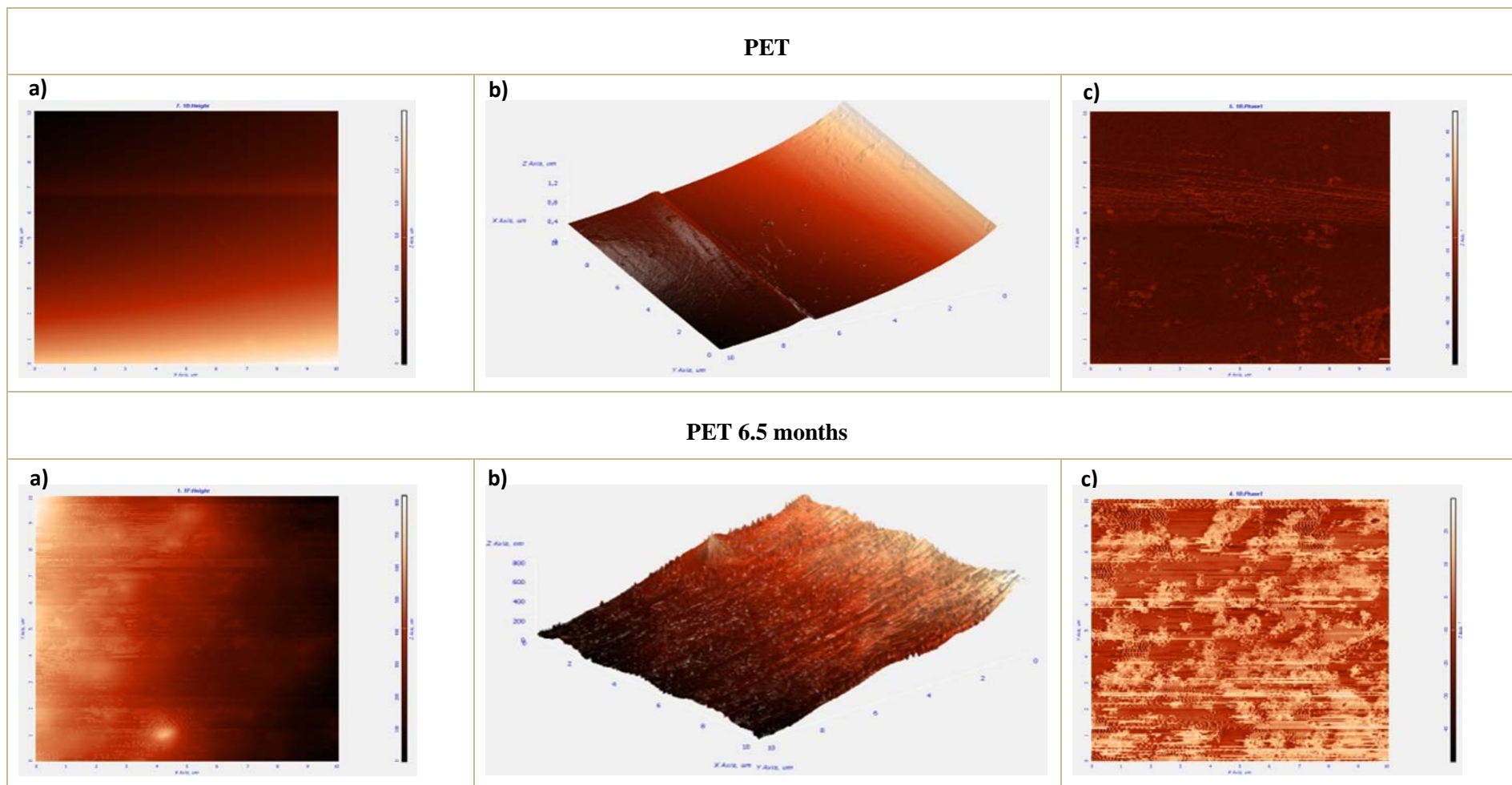


541 Figure 2. Thermal decomposition of the plastic materials at different time after being submerged in marine water and under UV lamp.



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544 Figure 4. AFM images of PET before and after 6.5 months in seawater and under UV lamp. a) 2D surface topography; b) 3D surface topography;

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