# Feasibility study on processing Almere PCW plastics with PolycyKle technology

March 26th, 2018

FEASIBILITY STUDY FOR THE PREPARATION OF PELLETIZED MIXTURES FOR THE PRINTING OF BODIES OF BIG THICKNESS CONTAINING AS A COMPONENT PLASTIC WASTE FROM ALMERE CITY PRODUCED BY VIJFHOEK FLEVOLAND BV

**OBJECTIVE:**

Prepare pelletized mixtures containing plastic waste produced by Vijfhoek Flevoland BV from Almere city PCW plastics as the main component for printing thick bodies (Pallet), study their characteristics in order to define a plant (or a machinery) suitable for their preparation.

**MATERIALS -Vijfhoek Flevoland BV waste**
3 samples of waste to be characterized were provided


Sample as it was delivered Vijfhoek Flevoland BV

## Vijfhoek Flevoland BV waste

Waste sample type 1 stream 1

Type 1 waste (stream 1) is a heterogeneous mixture containing predominantly low density polyolefins (about 60-70%), other polymers (in particular PS about 10-20%), cellulose and wet organic residues (about 15-20%) and both ferrous and non-ferrous minimum residues. The size of the material is coarse not having undergone the grinding process. There is a persistent smell due to the presence of decomposing organic substances.

Sample of waste type 2 stream 2

Type 2 waste (stream 2) it is a heterogeneous mixture containing mainly low density polyolefins (about 35-45%), other polymers (in particular PS about 10-20%), cellulose and wet organic residues (about 35-40%). Ferrous and non-ferrous metal residues and glass are present in considerable quantities (about 8-12%). The size of the material is coarse (but lower than type 1) not having undergone the grinding process. There is a persistent smell due to the presence of decomposing organic substances, high humidity and the presence of other non-polymeric substances.

Sample of waste type 3 (stream 3)

Type 3 Waste (stream 3) is a heterogeneous mixture containing mainly low-density polyolefins (about 60-75%), other polymers (in particular PS, about 10-15%) cellulose and wet organic residues (about 15-20 %), and both ferrous and non-ferrous minimum residues. The size of the material is coarse not having undergone a grinding process, but bigger if compared to type 1. There is a persistent smell due to the presence of decomposing organic substances, but less pronounced when compared to type 1 and 2, also because it has a lower moisture content.

REMARKS

**From the first observations it can be seen that samples 1 and 3 are very similar to each other and it is possible to proceed with the study by hypothesizing the use of the two samples mixed together.**
**The type 2 sample does not have sufficient quantity of polymers and an excessive presence of unrelated components to obtain a pellet that can be used in injection moulding, it is certainly necessary to add polymeric additives in high quantities to the point that it is not suitable for use.**

## Non-polymeric additives

Inorganic powders to reduce / eliminate smells and the effects of organic substances that are present in the waste samples

Non-polymeric additives are also added which, reacting with the wet humidity wall (paper, food residues) present in the waste effectively, reduce the smells both in the semi-finished product (pellets) and in the finished product and have positive effects on the reduction of humidity and on the printability of the pellets.

In total 18% of non-polymeric additive, formed by Calcium Hydroxide (CaOH2) and calcium Oxide (CaO), is added to the samples.

## Polymeric Additives

The polymeric additives are required to reach the chemical and physical characteristics to be obtained in the finished product (pellets for printing products). Particular attention must be paid to the mechanical characteristics, in particular the elastic modulus and the resilience. Therefore polymeric additives are added to the waste (normally other more noble polymers derived from recycling and substances that allow to make the heterogeneous polymeric matrix compatible) so as to obtain the desired characteristics.

## PROCEDURE

The waste must be crushed using a flat-blade and demetallized shredder, possibly using a 15mm grinder shredder. After shredding it must be mixed with non-polymeric additives. Non-polymeric (mineral) active agents in powder or granular form are added and mixed further until a homogeneous dispersion of the mixture components is reached. Only 18% of nonpolymeric additives are added to the samples. The mixed compound must be densified by pelletizing (diameter 5mm, length about 20mm) so as to increase the specific weight and further reduce the humidity. The mixture thus obtained is pelletized at a plant equipped with a vertical pelletizing press with a Ø of 5mm.


The 3 sample types after shredding

**REMARKS**

As can be seen also from the images, the sample number 2 is the one that presents the largest quantity of non-polymeric components inside. The sample number 3 is the most homogeneous. Grinding with a flat-blade shredder is suitable for this type of products.


Pellet obtained with VIJFHOEK FLEVOLAND material with 18% of non-polymeric additives

**REMARKS**

- The mixture is pelletized correctly thus obtaining a compact *pellet* with a density > 400 kg/dm3
- Annoying smells are no longer present
- The sample N° 3 is the simplest to pelletize having the highest polymeric content and a lower humidity than the other samples

**CONCLUSIONS**

The waste is pelletized correctly, originating a pellet of good quality. We can hypothesize the use of this pellet in injection moulding of thick polyolefin bodies; for what concerns the sample N° 3 and N° 1 being very similar, they can be used together as one sample.

In subsequent investigations, it is possible to hypothesise to use the Type 1 sample adding 50% by mass of polyolefin polymeric additives (70 HDPE 30 PP) obtained completely by recycling rigid plastic materials, so as to keep the additives costs low. Normally these polymers are used in the moulding of disposable crates and pallets. We estimate the value of these polymeric additives from 350 to 420 € / ton, thus creating a printable mixture at relatively low cost.

Then another mixture is taken into consideration composed of 25% of pellets type 3 + 5% of compatibilizing agents + 70% of HDPE with high MFI, thus creating a mixture with higher performance.

The energy required for pelletization of these mixtures can be estimated at: 90 - 110 kW/h for every 1000 kg/h produced.

**BIOLOGICAL TEST**

Considering the high quantity of organic substances present in the sample, it was decided to subject the samples in question to a biological test, using a Polycykle developed methodology.

**OBJECTIVE**

Verify the efficacy of non-polymeric additives added on the presence and development of microorganisms present in the 3 samples under examination after addition of only the non-polymeric additives

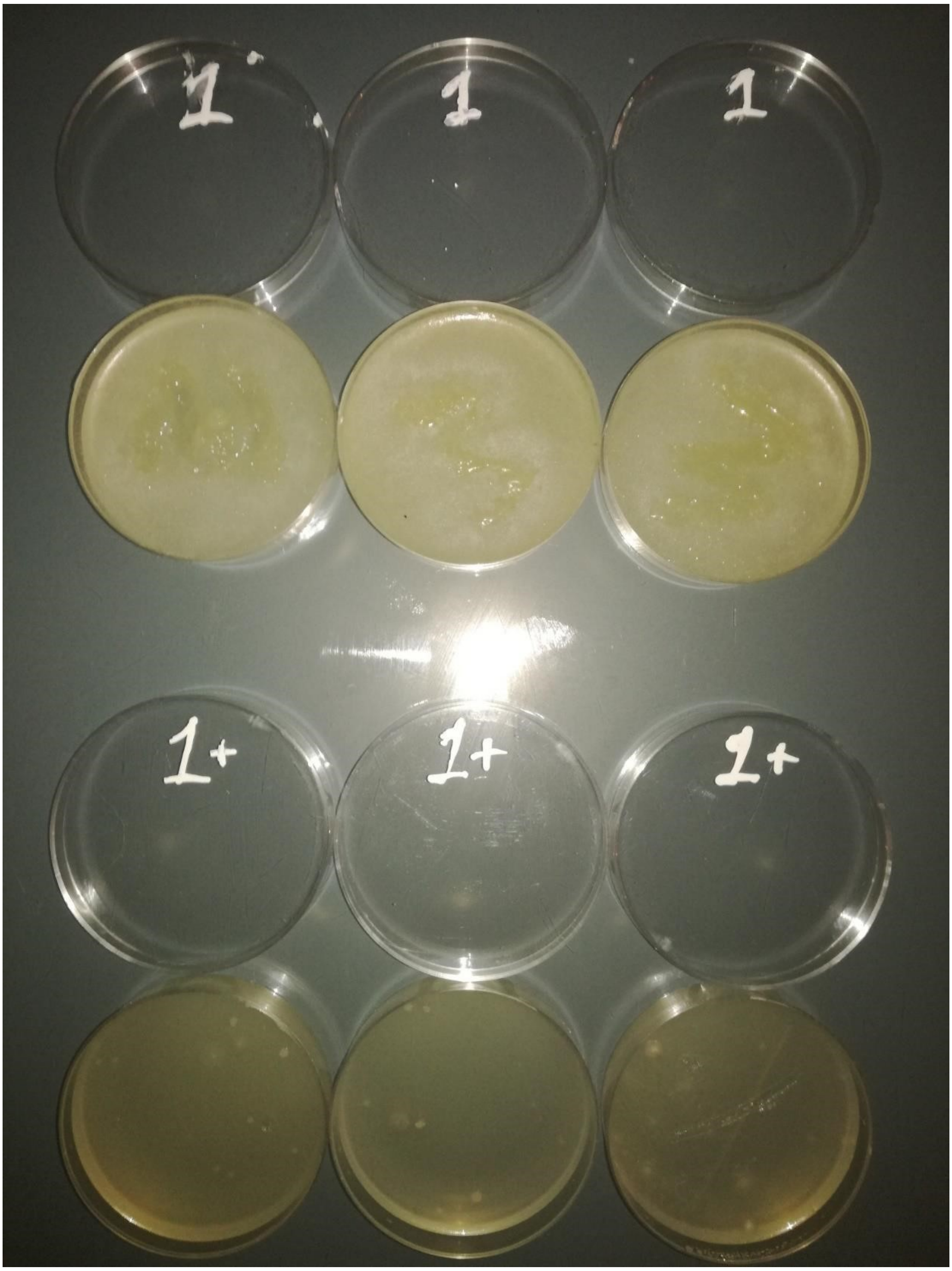
**PROCEDURES**

Cultures (3 for each sample) are produced on Petri dishes, in a non-selective general culture medium, based on Agar.

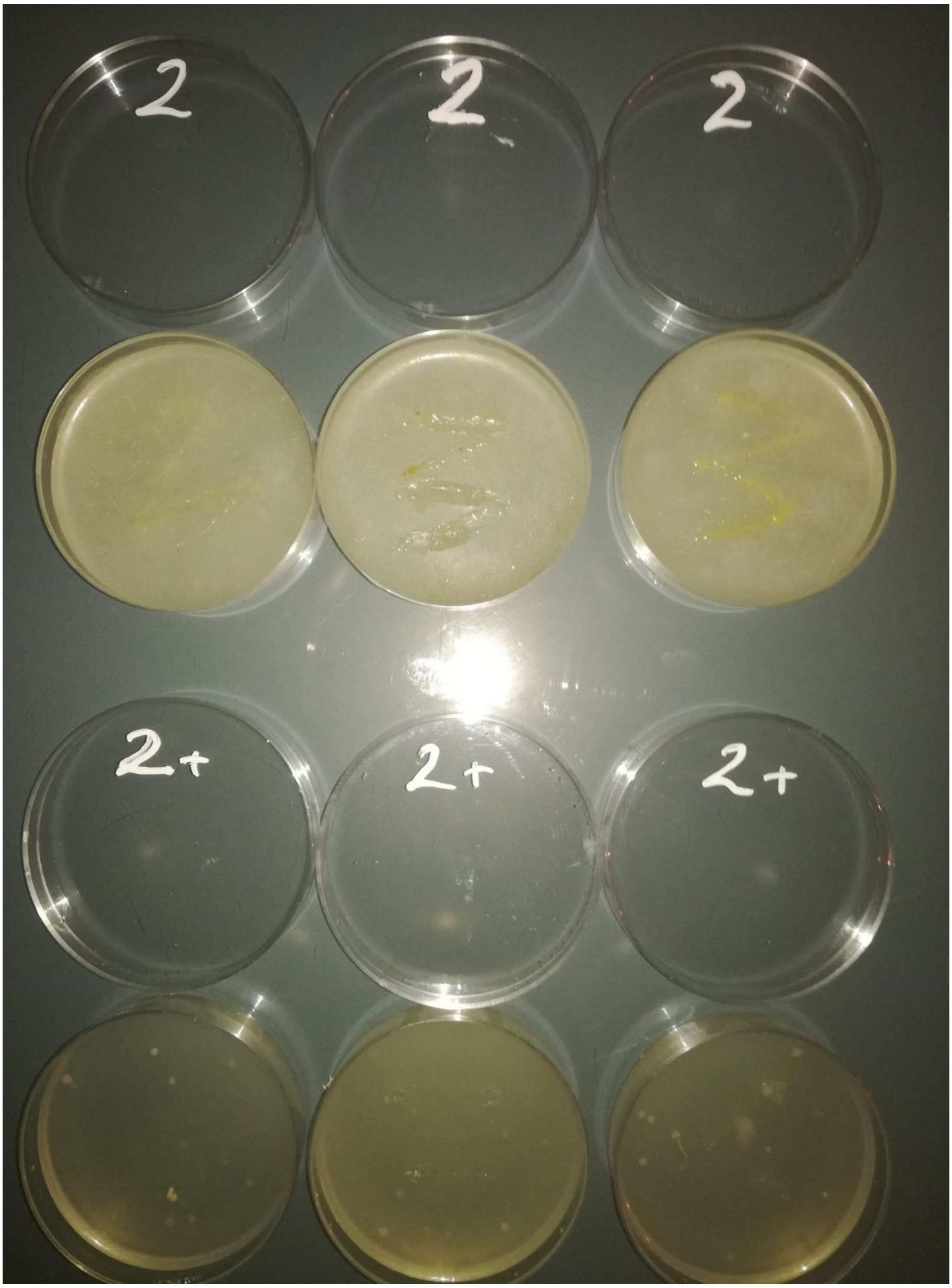
A fine sterile swab is passed on the surface of the samples, then through the same swab the seeding is made in the culture dishes.

The dishes are stored at a temperature of 20 ° C for 5 days.

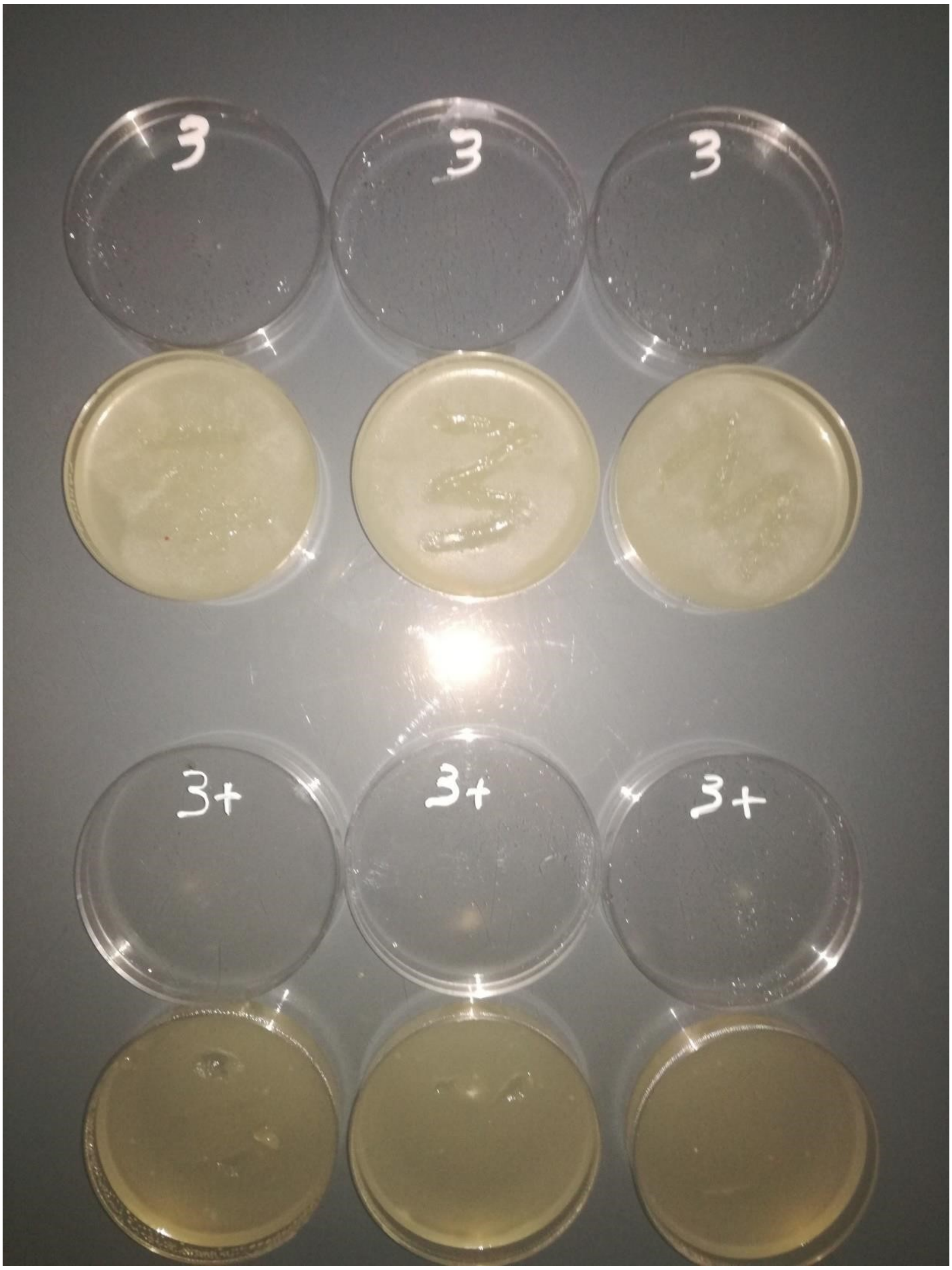
The same procedure is carried out on a non-commercial polyolefin plastic grinding sample to obtain a reference.



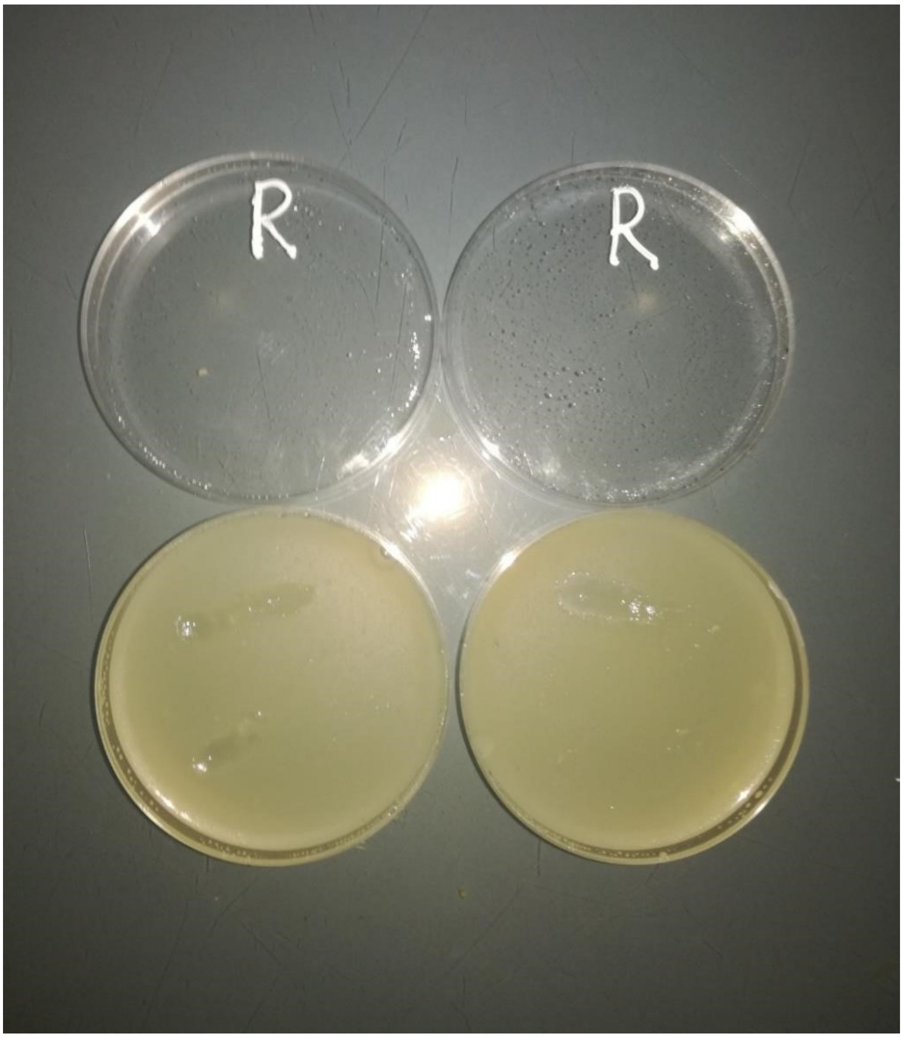

1, Sample 1 without additives
1+, Sample 1 with additives




2, Sample 2 without additives
2+, Sample 2 with additives




3, Sample 3 without additives
3+, Sample 3 with additive




R: Reference commercial polyolefins

**Conclusions**

From the observations it can be seen that the development of microorganisms, in particular bacterial colonies, is particularly reduced in the samples with the additive (the culture medium is transparent and no particular colonies are evident, similar result to the reference). In the samples without the additive it is evident that the presence of bacterial colonies on the showing area which have already widened considerably in the culture medium in 5 days. It can be concluded that the addition of 18% additives (CaOH2 and CaO) has sufficient positive effect on the reduction of microorganism development.

## PHYSICAL TESTS ON MIXTURES

The physical tests were carried out at the university's laboratories of the University of Ferrara.

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*D.R. nr 1897 del 24.11.2015* – Piattaforma Energia - Ambiente

RETE ALTA TECNOLOGIA
EMILIA-ROMAGNA
HIGH TECHNOLOGY NETWORK

*Ferrara, 05/03/2018*

***Report_01_2018***
*OdL 12_2018*

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***Object***: Characterization of thermal behavior and mechanical properties through Tensile and Charpy tests, HDT and MFI analysis on specimens from slabs obtained by compression molding, starting from the pelleted material supplied, re-extruded with a twin-screw extruder and reduced in granule.
Samples analyzed:

1. **Type 1 mixture with 50% HDPE-PP supplied by the customer**
2. **Mixture obtained with 1:3 dilution of the Type 3 material supplied by the customer**

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| Tab. I Performed tests | | | | | |
|---|---|---|---|---|---|
| **Report Nr** | **Date** | **OdL_Nr** | **Samples name** | **Test/Analysis** | **Nr of Tests** |
| 01_2018 | 05/03/2018 | 12_2018 | **1. "Type 1" mixture with 50% HDPE-PP supplied by the customer**<br>**2. Mixture obtained with 1:3 dilution of the "Type 3" material supplied by the customer with a commercial grade LDPE (high MFI).** | Extrusion in twin-screw extruder | 2 |
| | | | | Specimens preparation by compression molding | 2 |
| | | | | Tensile test ISO 527-2 | 2 |
| | | | | Impact strength ISO 179 (Charpy method) | 2 |
| | | | | HDT test | 2 |
| | | | | MFI index | 2 |
| Total Nr of samples received: 2 | | | | | |
| Sent by: Luana Pozzetti | | | | | |

# Received Samples

Fig. 1 – «Type 3» sample

Fig. 2 – «Type 1» with 50% HDPE-PP sample

# Preparation of mixtures in co-rotating twin-screw extruder

Given the size of the pellets and the lack of homogeneity of the two materials supplied, it was necessary to extrude and reduce the mixtures into granules.

A co-rotating twin-screw extruder Labtech Engineering Co., Ltd. Mod. TE-26-40 was used.
The extruder has a L/D ratio of 40 with an external screw diameter of 26 mm. It is composed of 10 independent sectors with rectangular section and a length of 104 mm. The screws are modulated and it is therefore possible to modify their profile in order to adapt it to different industrial materials. Each sector is equipped with a heating and cooling (water) system, in which the temperature can be set by the operator through a control panel. The extruder is fed by a hopper placed in the first sector; there is also an opening for ventilation (at ambient pressure) and a connection for degassing with the application of a vacuum pump. The temperature and pressure of the melt are determined by appropriate sensors. The die is made up of four circular holes with a diameter of 4.5 mm.
The extruded material is then cooled in water and granulated by a front cutter (Scientific Laboratory Pelletizer type LZ-20, Labtech Engineering Co., Ltd.).

Table II shows the extruded mixtures and the extrusion temperatures used.

**Tab.II – Mixtures and extrusion profiles**

| *Sample* | | *Mixture composition* | *Temperatura di estrusione* |
|---|---|---|---|
| **1** | **Type 1 sample with 50% HDPE-PP** | **- 50% plastic from waste<br>- 50% selected polyolefins HDPE-PP** | 220-230°C |
| **2** | **Mixture 1:3 with Type 3 sample and LDPE** | **- 25% plastic from waste (Type 3 sample)<br>- 5% compatibilizer by APM<br>- 70% LDPE of commercial grade with high MFI** | 200-210°C |



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# Heat Deflection Test (HDT)

HDT is a three-point flexion test that determines the temperature at which the polymer, to which a constant load is applied, reaches a predetermined deformation.
The values reported are obtained from the average of 3 validated measurements.

**STANDARD TEST:**
- ISO 75 method A

**TESTING DEVICE:**
- SHENZEN SANS

**TEST CONDITIONS:**
- flatwise configuration *[Fig. 8]*
- v = 120 ± 10 °C/h
- σ = 1.8 MPa
- ε = 0.2 %

**SPECIMENS DIMENSIONS:**

Length: l = (80 ± 2) mm

Width: b = (10.0 ± 0.2) mm

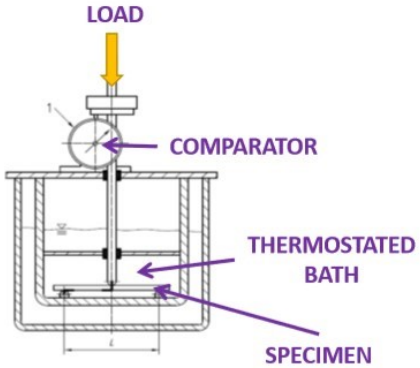



Fig 4 HDT test configuration

| Tab. IV – HDT (ISO 75 method A) | | |
|---|---|---|
| | ***Sample*** | ***HDT Temperature [°C]*** |
| **1.** | **Type 1 mixture with 50% HDPE-PP** | 95.6 ± 1.3 |
| **2.** | **Mixture 1:3 with Type 3 (25%) and LDPE** | 35.0 ± 0.6 |

## Tensile test

**TEST STANDARD**:

- ISO 527-2

**TESTING DEVICE**:

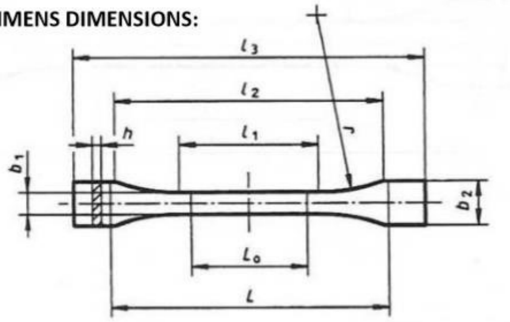
- ZWICK / ROELL dynamometer model Z010
- 10 kN load cell
- extensometer with 0.0001 mm accuracy

**TEST CONDITIONS:**

- specimen type: 1BA
- pre-load: 0.2 MPa
- pre-load speed: 1 mm/min
- modulus determination speed: 1 mm/min
- test speed: 50 mm/min

The values shown in Tab. V are obtained from the average of at least 5 validated specimens.

**SPECIMENS DIMENSIONS:**




| Tab. V - Type 1BA specimen dimensions UNI EN ISO 527-2 | |
|---|---|
| $l_3$ | ≥75 mm |
| $l_1$ | 30±0.5 mm |
| **r** | ≥30 mm |
| $l_2$ | 58±2 mm |
| $b_2$ | 10±0.5 mm |
| $b_1$ | 5±0.5 mm |
| **h** | ≥2 mm |
| $L_0$ | 25±0.5 mm |
| **L** | ($l_2$ ÷ $l_2$+2) mm |

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# Tensile test

| Tab. VI – Tensile test results (ISO 257-2, specimen type 1BA) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | | Specimen Thickness | Tensile Modulus (E) | Yield strength | Max Strenght (Fmax) | Deformat. at Fmax | Strenght at break | Deformat. at break |
| | | mm | MPa | MPa | MPa | % | MPa | % |
| 1 | Type 1 mixture with 50% HDPE-PP | 3.67 ± 0.02 | 2390 ± 150 | - | 8.25 ± 1.79 | 0.33 ± 0.09 | 8.25 ± 1.79 | 3.45 ± 0.80 |
| 2 | Mixture 1:3 with Type 3 (25%) and LDPE | 2.78 ± 0.29 | 562 ± 39 | - | 11.43 ± 0.29 | 9.05 ± 0.44 | 9.03 ± 1.18 | 13.8 ± 4.3 |

# Impact strength: Charpy method

The Charpy impact test is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture at a given temperature. This absorbed energy is a measure of a given material's notch toughness.

**STANDARD TEST**:

- ❑ ISO 179

**TESTING DEVICE**:

- ❑ SANS PENDULUM IMPACT TESTING MACHINE

The testing device is basically a pendulum which determines the amount of energy absorbed by the specimen during the impact. The impact strength is obtained by dividing the energy absorbed for the initial section of the specimen along the notch:

$$a_{cN} = \frac{W}{h \cdot b_N} \cdot 10^3 \quad [kJ/m^2]$$

where:

W = energy absorbed by the specimen during the impact [J]

H = specimen thickness [mm]

$b_N$ = initial section of the specimen along the notch [mm]

(for unnotched specimens: $b = b_N$)

**TEST CONDITIONS:**

- ❑ E = 4.0 J
- ❑ $v_o$ = (2.9 ± 10 %) m/s
- ❑ notch type: A
- ❑ specimen configuration: edgewise
- ❑ $T_{amb}$ = (23 ±1)°C

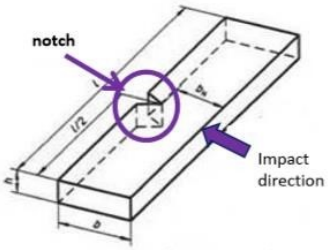



**Fig. 5** – specimen configuration: edgewise

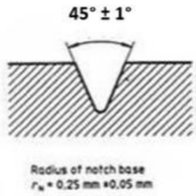
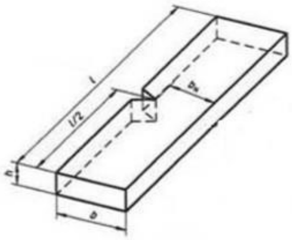



**Fig. 6** – Notch type A



**SPECIMEN DIMENSIONS:**

| | |
|---|---|
| Lenght | l = (80 ± 2) mm |
| Width | b = (10.0 ± 0.2) mm |
| Thickness | s = (1.92 ± 0.01) mm |



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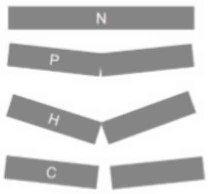
## Impact strength: Charpy method

| Tab. VII – Pendulum Impact Test Results (Charpy method, ISO 179) | | | | | |
|---|---|---|---|---|---|
| *Sample* | | *Unnothced specimens* | | *Notched specimens (type A)* | |
| | | Toughness [kJ/m²] | Type of Break (*) | Toughness [kJ/m²] | Type of Break (*) |
| 1 | Type 1 mixture with 50% HDPE-PP | $3.41 \pm 1.55$ | C | $1.57 \pm 0.03$ | C |
| 2 | Mixture 1:3 with Type 3 (25%) and LDPE | $30.57 \pm 6.51$ | P | $13.38 \pm 0.91$ | H |

***(*) Standardized types of break:***
*N = no break*
*P = partial break*
*H = hinge break*
*C = complete break*






### CONCLUSIONS

**From the results of the mechanical tests it is noted that the product obtained with Type 1, adding 50% by mass of polyolefin polymeric additives (70% HDPE + 30% PP), has low fluidity, high rigidity, and it is suitable for use (completely or mixed with other polyolefin products) for thick products of simple geometry, extruded or printed, in systems equipped with a vertical press without hot chambers or nozzles with obturator (free channel moulding). Possible applications include the production of thick pallets, floor pannels, and extruded boards.**

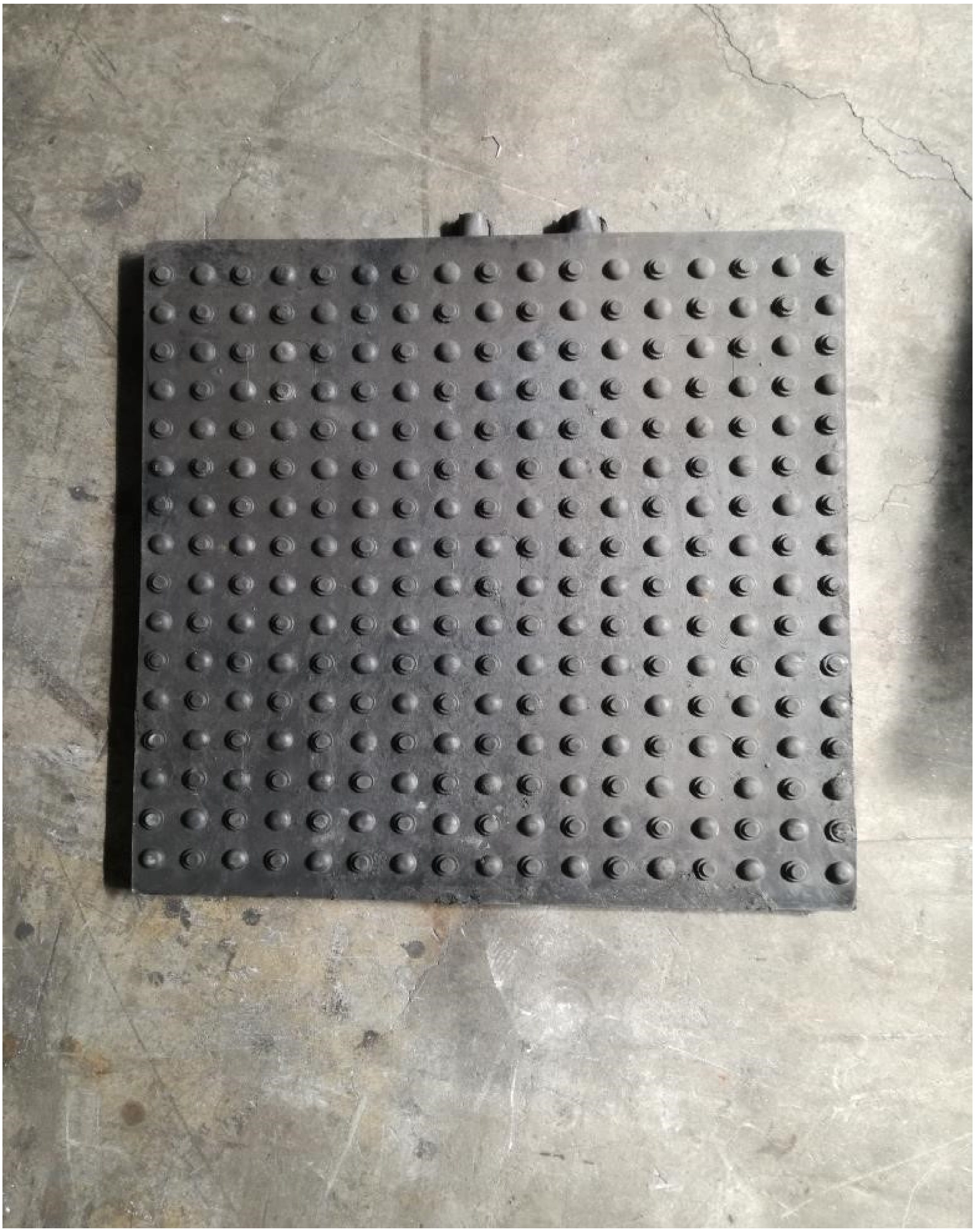
**The product obtained with a 25% sample of pellets Type 3 + 5% of compatibilizing agents + 70% of HDPE with high MFI has a reasonable fluidity and good mechanical performance and allows to obtain a mixture with good mechanical properties suitable for production of medium and large components of different geometries, also more complex. This mixture can also be used in traditional moulding plants, provided they are equipped with large nozzles (also in mixture with other polyolefins). Some areas of use may be the production of heavy and light single-use pallets, profile extrusion, boxes, building components, etc.**

**PRINTING TESTING**

The materials have been subjected to moulding tests both on traditional injection moulding machines and on systems equipped with a vertical press with degassing. Various tests have been carried out to obtain finished products with sufficiently good characteristics to be placed on the market.

Type 1 pellet (stream 1, 50% by mass of polyolefin polymeric additives 70 PEHD 30 PP) was used at 75% to print components for industrial floors, giving rise to a good quality product. The moulding plant used for the tests is equipped with a vertical press without nozzles or hot chambers, with depression degassing. This has allowed the use of a high quantity of pellets in relation to added mono-polymers. The pellets could also be printed without adding mono-polymers but the product would have turned out to be too fragile, while using 75% pellets and adding 25% of the classic material used to mould the flooring component (polyolefins derived from recycling) the overall performance is sufficient for the use of the pellets.

Moulding plant equipped with vertical press



Paving component moulded with 75% of Type pellets (50% by mass of polymeric polyolefin additives 70 HDPE / 30 PP)

The Type 3 pellet (stream 3) at 25% + 5% of compatibilizing agents + 70% of high-MHD HDPE was used for the production of a light plastic box dedicated to the transport of vegetables (usually made of polyolefins with a good MFI).
The moulding system used for the tests is traditional, equipped with a horizontal press without degassing, with an open-channel injection nozzle 7mm in diameter. Various tests were carried out up to the use of 65% of pellets mixed with 35% of the classic HDPE normally used in this production. This has given rise to a good quality box with characteristics that make it suitable for use on the market.


Traditional moulding plant


Box containing 65% of type 3 pellets at 25% + 5% of compatibilizing agents + 70% of high-MHD HDPE