New filaments with natural fillers for FDM 3D printing and their applications in biomedical field

MTL NTUA

M. Calì
G. Pascoletti
M. Gaeta
G. Milazzo
R. Ambu

DIEEI Dipartimento di Ingegneria Elettrica Elettronica e Informatica

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INTRODUCTION

In recent years the creation of new materials with improved ***ecological properties*** is a priority in order to be competitive in the production field and to comply with the most recent ***strategies for plastic reduction in the circular economy***

The use of ***traditional petrochemical modifying agents*** can be avoided through the integration of biologic materials (***biomass fillers***)

INTRODUCTION

Biomass fillers are added in higher percentages than chemical additives (15% - 60 %) and therefore they allow:

- completely substituting ***toxic and polluting additives***
- improving ***material performances***

↓

Reduction of dangerous substances in materials

Wastes from agricultural production cycles are recycled and raw materials are saved[1]

[1] 'Reuse before recycling' directive

INTRODUCTION

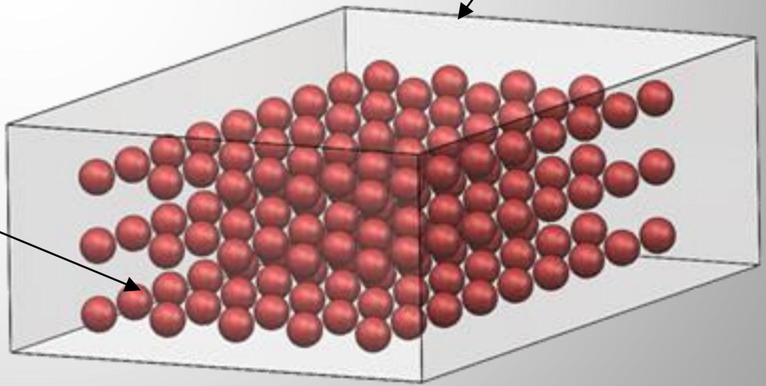
The paradigm of ***circular economy*** is generally applied to ***manufactured parts*** including ***multi material components*** and it is here applied on parts obtained by means of ***Additive Manufacturing (AM)***, required by various manufacturing processes

In this work ***two novel organic bio-composite filaments*** (HEMP and WEED) for ***Additive Manufacturing*** applications are presented along with a ***case study*** related to the ***biomedical field***

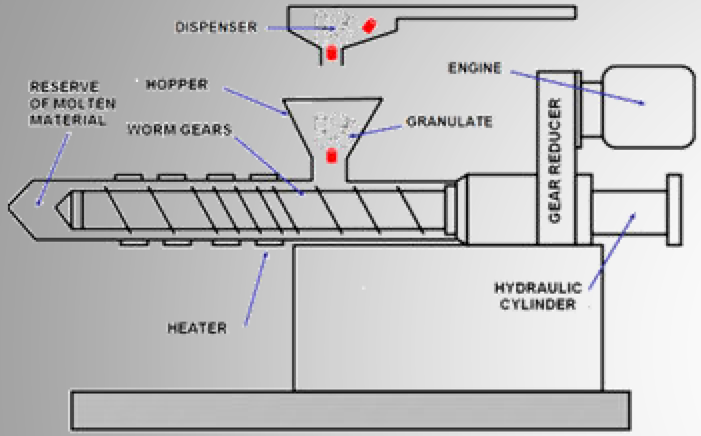
BIO-PLASTIC MATERIALS FABRICATION

The ***novel bio-plastic materials*** here presented are made of ***polylactic acid (PLA)*** filled with ***organic by-products***; they are therefore ***composite materials*** made of:

- A ***continuous phase*** (matrix)
- A ***filler/reinforcement phase*** (enclosed in the matrix)



BIO-PLASTIC MATERIALS FABRICATION



Parameter	Value
Drying granules	10 hours in a vacuum oven at 90 °
Barrel temperature	160 ÷ 170 °C
Mould temperature	30 °C
Screw speed	300 rpm
Injection speed	Slow

- The organic by-products are pre-treated before being introduced into the hopper, by using a ***micronizer*** and a ***dehumidifier***
- ***A two-screw extruder*** has the role of ***mixer/compounder*** *and it works at* a temperature range near PLA melting point
- The ***final product*** is a ***biodegradable thermoplastic polymer***
- Upon leaving the mixer/compounder, the compound is placed in a ***granulator*** (***granules***) or in an ***extruder*** (***3D printing filament***)

BIO-PLASTIC MATERIALS FABRICATION

Two different bio-plastic compounds filaments can be obtained, according to the organic by-product fillers:

- **HEMP:** filament of natural and compostable origin containing ***exclusively hemp*** (ranging from 15% to 25%)
- **WEED:** filament of natural and compostable origin, containing ***exclusively waste powder from hemp inflorescences*** (ranging from 10% to 15%). In this latter case, cannabinoids, that are lipids, work as emulsifier inside the polymeric matrix

MECHANICAL CHARACTERIZATION

Manufacturing Capability

Material	Density (23°C - ISO 1183) [g/cm³]	Melting temperature (ISO 11357) [°C]	Filament surface roughness [µm]	Molding shrinkage (23°C - ASTM D 995) [%]	Melt Vol. Rate [cm³/10']	Melt Flow Rate [g/10']
PLA	1.350	172.5	3.0	0.32	18.2	21.0
HEMP	1.256	145.0	3.5	0.23	21.3	24.0
WEED	1.265	150.5	3.2	0.28	76.0	86.9

- Bio-plastic compounds filaments are ***as printable as PLA*** ✓
- They can be ***extruded at lower temperatures*** (about -13% compared to PLA temperature) → significant ***energy savings*** ✓
- Filled PLA has generally shown a ***lower shrinkage*** compared to pristine PLA → need for ***further processing*** is ***reduced*** ✓

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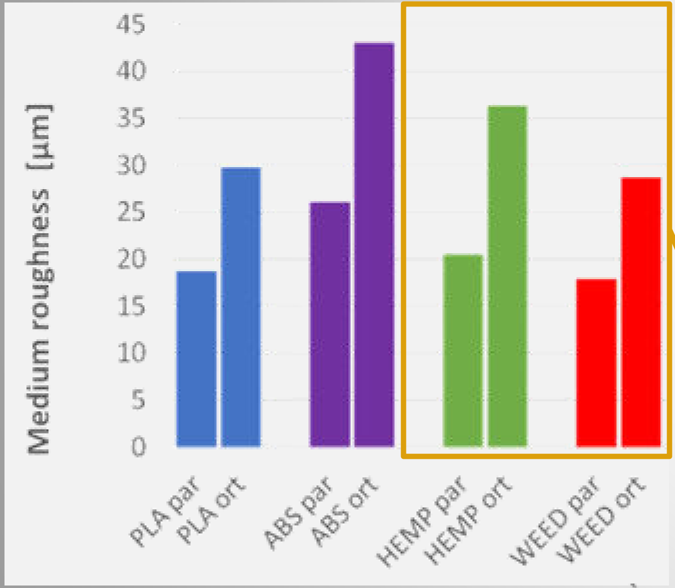
MECHANICAL CHARACTERIZATION

Roughness (Ra)



- NANOVEA Optical Profilometer mod. PS50 (Sensibility 2 µm, height range 25 mm, sampling length 2.5 mm, measuring speed of 0.5 mm/s)
- Ra was evaluated on ***flat surfaces*** printed ***parallel*** (par) or ***orthogonal*** (ort) to the printing area

Parameter	Value
Layer height [mm]	0.25
Infill ratio [%]	50
Nozzle diameter [mm]	0.6
Printing speed [mm/s]	60
Printing temperature [°C]	200

Better surface finishing compared both to ABS and PLA

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MECHANICAL CHARACTERIZATION

Mechanical Properties

- All mechanical properties were tested at 23°C according to ISO 527)
- Static mechanical tests (Instron 5569); displacement rate 10 mm/min

Material	Colour	Elastic Modulus [MPa]	Yield Stress [MPa]	Yield Elongation [%]	Ultimate Stress [MPa]	Ultimate Elongation [%]	Flexural modulus [MPa]
PLA		1900	35.9	2.0	26.4	3.8	3200
HEMP	Wood	4420	41.8	1.5	33.6	3.5	3833
WEED	Green	3887	32.0	1.3	19.5	8.8	3455

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HEMP (powder from hemp canapule fillers 20%)

- High presence of ***silicon*** in hemp canapule → ***Excellent tensile strength***
- ***+133%*** elastic modulus, compared to PLA
- ***+16%*** yield strength, compared to PLA

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WEED (powder from hemp inflorescences fillers 20%)

- ***+105%*** elastic modulus, compared to PLA
- ***Slightly lower*** yield and ultimate strength, compared to PLA
- Very ***high plastic deformation*** (up to about 9%)

APPLICATIONS TO A BIOMEDICAL DEVICE

HEMP bio-plastic composite is ***suited to biomedical prototypes*** due to:

- ***Antibacterial properties***
- ***Good aesthetics***
- ***Breathability***
- ***Stiffness properties***
- ***Touch pleasantness***

In this study a biomedical application of this new bio-plastic material was investigated, ***manufacturing a 3D printed neck orthosis***

The size of this object is large enough to significantly benefit from the limited shrinkage of the HEMP bio-plastic compound

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APPLICATIONS TO A BIOMEDICAL DEVICE

CT scan of the neck of a volunteer

↓

3D CAD model (STL) of the customized neck orthosis

↓

3D printing of the orthosis with the Printer D300 Technology® (6 mm nozzle) and HEMP filament

Parameter	Value
Layer height [mm]	0.25
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First Step: full neck collar prototype

APPLICATIONS TO A BIOMEDICAL DEVICE

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Second Step: honeycomb pattern of voids

- ✓ Breathability
- ✓ Lightness
- ✓ Stiffness
- ✓ Good aesthetics

CONCLUSIONS

- The proposed filaments open a ***fascinating perspective*** to connect ***primary and secondary industries*** thanks to the ***integration between sustainable PLA and agricultural wastes***
- The ***main properties*** of these novel materials have been here investigated and it was demonstrated that ***these bio-composites*** exhibit ***superior mechanical properties***, ***better manufacturing capability*** and ***lightweight***
- From the analysis of the ***custom-made neck orthosis application*** here investigated, it was proved that the ***final product*** is ***suited*** to this end use and it can undoubtedly represent a ***viable alternative*** to **avoid/*reduce*** the addition of **toxic substances**

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FUTURE WORKS

Further researches are still ongoing and they are aimed to:

- Consider the use of ***other by-product biological fillers*** for the creation of ***new materials***
- Developing ***specific models*** able to ***predict*** the performances of these novel materials in terms of ***mechanical properties***, ***manufacturing capability*** and ***visual/outer appearance***

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