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Advanced Compounding and Extrusion Systems

# GREEN COMPOSITE FROM RECYCLED PLA AND KENAF

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## INTRODUCTION

The increased use in plastics all over the world has resulted in an increase in plastic waste.
For this reason the development of biodegradable polymers has been a subject of great interest in materials science for both ecological and biomedical perspectives.

Bio-based plastics are sustainable, largely biodegradable and biocompatible. They reduce our dependency on depleting fossil fuels and are CO2 neutral.
Aliphatic polyesters are among the most promising materials for the production of high-performance, environment-friendly biodegradable plastics.
One of the aliphatic polyesters is poly(lactic acid) (PLA) which is made from plants and is readily biodegradable. PLA has a renewable source, with the lactic acid monomers used to produce it coming from the fermentation of corn, potato, sugar beat, and sugar cane.
PLA has high-modulus, good strength, excellent barrier capability and can be readily fabricated, thereby making it one of the most promising bio-polymers for varied applications.

Despite these desirable features, the high brittleness and the quite high price of PLA currently limit its applications and considerable efforts have been made to improve these characteristics of the polymer.
PLA needs to be considered like all the other polymers where fillers and fibers are added to modify properties. So the "Polymer composites" approach represent a convenient way to tailor the materials cost and engineer the material properties.

**Icma San Giorgio** (www.icmasg.it) , a worldwide supplier of co-rotating twin screw extruders and compounding technology, developed a project in collaboration with the **Department of polymeric materials "Giulio Natta" at University Politecnico of Milan** (www.polimi.it) for compounding the PLA-kenaf composites via a co-rotating twin screw extruder and prepared the testing specimens via compression moulding.

It was evaluated the influence on composite properties of kenaf amount in the formulation, screw rpm, screw configuration, barrel temperature profile and extruder productivity.

Various properties, including mechanical and thermal properties, were studied. The static mechanical properties reported here are tensile modulus, tensile strength and strain-at break. The crystallization behaviour was investigated using differential scanning calorimeter (DSC). The morphologies of the fractured specimens captured using a scanning electron microscope were also investigated.

## EXPERIMENTAL

### MATERIALS

The PLA came from waste of food packaging. Kenaf in powder form was supplied by Kefi, a company specialized in the production of vegetal fibers for thermal and acoustic insulation. PEG with a molecular weight of 1000, supplied by Aldrich, was used as plasticizer.

**Recycled PLA**

**Kenaf**

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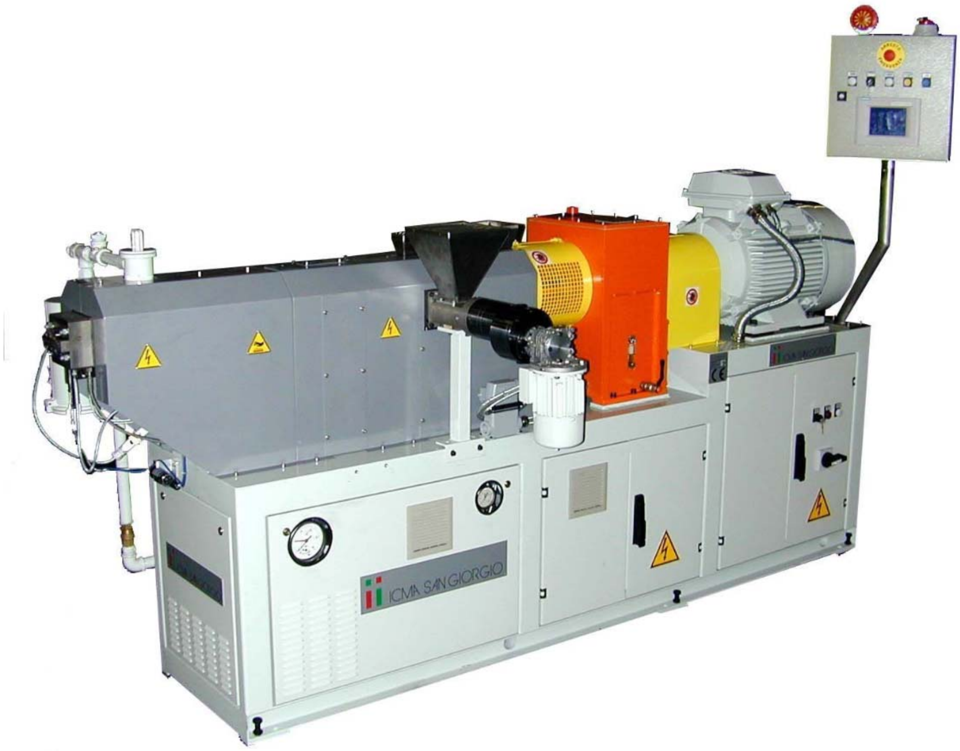
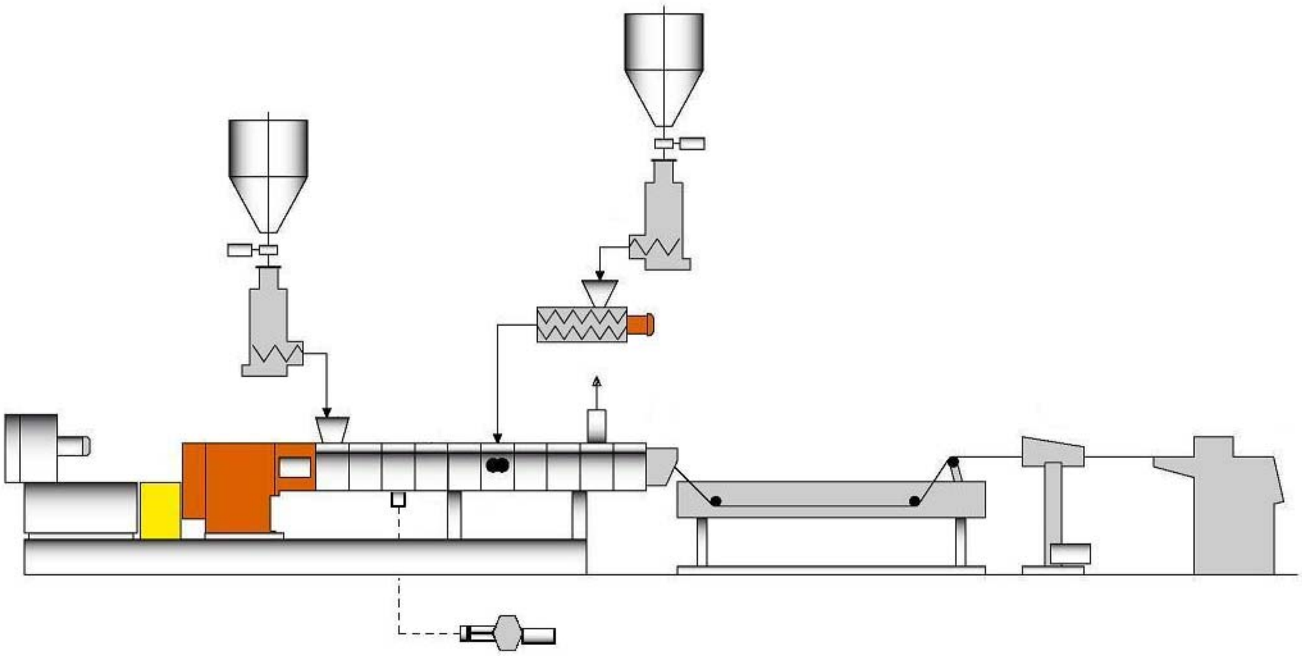
**PREPARATION OF THE COMPOSITES**

The PLA and kenaf were dried in a vacuum oven at 100°C for 8 h.

The process was developed using an Icma San Giorgio lab scale extruder MCM 25 HT – 44D (see picture below) modifying formulation, screw configuration, barrel temperature profile, throughput and screw rpm.
A total of 38 samples were extruded.




The lay-out of the extrusion line was represented in the picture.



Samples for the investigations were prepared by compression moulding. Before this phase, the composite were conditioned inside an oven for 4 hours at 60°C.

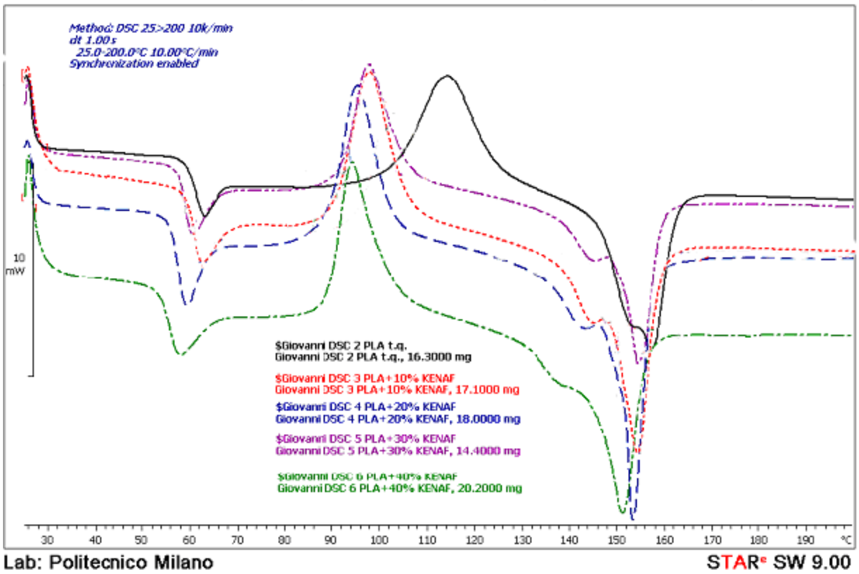
## RESULTS AND DISCUSSION

### GPC analysis

The possible degradation of extruded PLA composite was evaluated by molecular weight measurements through GPC. This showed which screw configuration and operational condition set-up are the right one to limit at minimum the degradation of the composite.
Generally in all the configuration tested, a big degradation was not present (max molecular weight variation of 17%).

### DSC Analysis

The following diagram shows the DSC thermo grams for 4 samples (PLA, PLA + 10% K, PLA + 20% K, PLA + 30% K, PLA + 40% K) obtained with the same screw configuration and operational conditions set-up.




| Sample | $\Delta H_{cri}$ | $\Delta H_{metl}$ | X | Tg | $T_{cri}$ | $T_f$ |
|---|---|---|---|---|---|---|
| n° (%PLA) | J/g | J/g | % | °C | °C | °C |
| 2 (100%) | 29,52 | 32,18 | 2,84 | 61,33 | 114,17 | 157,27 |
| 3 (90%) | 33,18889 | 41,01111 | 8,35 | 59,46 | 97,55 | 154,92 |
| 4 (80%) | 34,625 | 45,475 | 11,58 | 57,48 | 95,42 | 153,37 |
| 5 (70%) | 36,52857 | 48,12857 | 12,38 | 59,02 | 97,74 | 154,46 |
| 6 (60%) | 38,56667 | 48,03333 | 10,1 | 55,81 | 94,23 | 151,19 |

From the values represented in the table it's clear that the addition of Kenaf decrease the Tg and Tf.
This result reveals that the filler may play a role of plasticizer.

The cold crystallization temperature (Tcri) was decreased by about 17°C for a PLA-10%Kenaf composite sample when compared with pure PLA. So the addition of PWF increases the crystallinity by acting as nucleating agent.

## Tensile mechanical properties

The modulus of the composites increased with the kenaf content. This increment in the modulus is aligned with expected result found in literature (adding fillers to a polymer restrains the movement of its chains increasing the stiffness).

The deformation decreased with the kenaf content due to the decreased deformability of the matrix for the restriction offered by the rigid filler particles.

The tensile strength of filled composites generally is found to be declining when compared with their virgin polymer. This can be attributed to the poor interfacial adhesion between kenaf and PLA.
Surely this decrease can be limited by the use of a good compatibilizer that will create chemical bonds between the matrix and the filler.

The following table shows the main mechanical tensile properties of a composite with 10% of Kenaf changing the screw rpm and the barrel temperature profile.

| % kenaf | Temperature | RPM | Modulus [MPa] | Deformation | Tensile strength [MPa] |
|---|---|---|---|---|---|
| 0 | 180-170 | 150 | 3,47±0,06 | 1,9±0,07 | 50,42±0,87 |
| 10 | 180-170 | 150 | 3,84±0,05 | 1,28%±0,05 | 40,73±0,32 |
| 10 | 190-180 | 150 | 3,73±0,07 | 1,64±0,2 | 43,75±0,97 |
| 10 | 180-170 | 200 | 3,95±0,04 | 1,09±0,09 | 39,04±0,92 |
| 30 | 200-190 | 150 | 4,89±0,03 | 0,93±0,1 | 35,77±0,75 |

The sample processed at higher screw rpm has the higher modulus due to the increased shear stresses that guarantee a better dispersion of the natural filler.
An increase of barrel temperature gives the best result in terms of deformation and tensile strength due to the better wetting of the filler thanks to a reduced viscosity.

Changing the configuration of the dispersive mixing portion of the screw, better results were obtained with a strength of the compound very close to the PLA one and a modulus increase of 11%.

With a kenaf content of 30%, the modulus was increased of 41% but with an evident decrease in composite strength (29%).

Through the comparison of the mechanical characteristics of different samples with the same formulation but processed with different operational set-up ands screw configurations, it was possible to improve greatly the final result: : 60% modulus increase, 130% deformation increase, 65% tensile strength increase.

The introduction of PEG didn't give an increase of mechanical properties as suppose, probably due to the recycled PLA nature used in the test.

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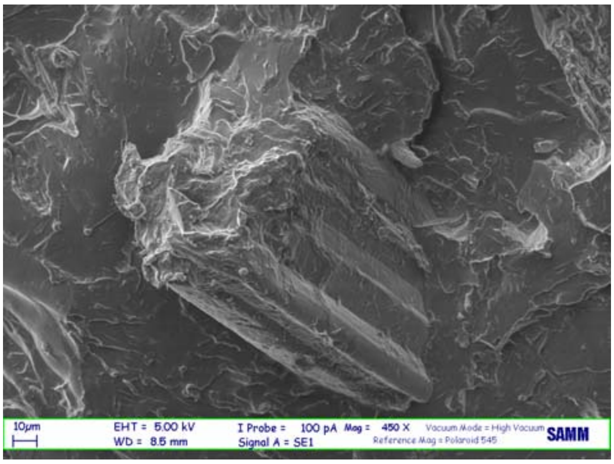
## SEM morphology analysis

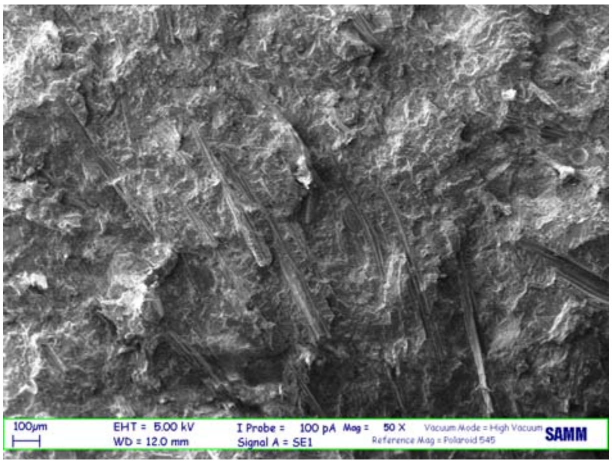
With the SEM analysis it was possible to evaluate the kenaf dispersion, the adhesion between the polymer and the filler and, finally the PEG influence.

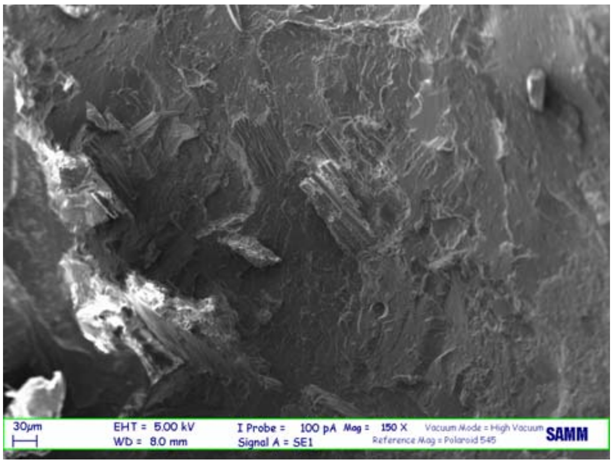
The following pictures showed a sample with 30% of kenaf. The SEM fractography shows poor adhesion among PLA matrix and Kenaf fibers, a main explanation of the reduced toughness of the reinforced polymer.





The pictures below showed a comparison between composites processed with two different screw configurations. In the picture on the left is evident a poor mixing quality of kenaf while the other picture the filler is well distribute and dispersed thanks to a modified screw configuration.



**CONCLUSION**

Different samples of a green composite obtained from PLA and kenaf were prepared in the laboratory of ICMA SAN GIORGIO using a lab scale co-rotating twin screw extruder MCM 25 HT.

The different configurations of the screw were able to limit the degradation of the pure PLA and of the composite.
A DSC analysis showed a decrease of both Tf and Tg with the addition of kenaf in the PLA matrix. So the natural filler act as a plasticizer.
At the same time kenaf influences the crystallization behaviour of the composite acting as a nucleant.

The addition of kenaf increased the modulus but decreased the toughness, deformation and strength as expected and demonstrated by literature.
Changing process parameters and screw configuration it was possible to see their effect on mixing quality and composite properties.
Higher screw rpm and barrel temperature profile seems to promote mixing and wetting of kenaf.
Thanks to a fine tuning of those parameters and screw configuration it was possible to increase the mechanical properties of a composite with a fixed formulation as follows: 60% modulus increase, 130% deformation increase, 65% tensile strength increase.

The SEM analysis shows a poor adhesion between PLA matrix and kenaf, due to the absence of a compatibilizer in the formulation. This justify the poor strength value obtained in the samples. Even the use of PEG didn't solve the situation.

This first phase of this study gave a lot of indication about how to improve the composite performance just playing with extruder configuration and set-up.
The next step in this project (already started in ICMA laboratory) is to test different compatibilizers in order to improve the strength and toughness performance of the composite by chemical support.

*__Icma San Giorgio SpA__ (www.icmasg.it) is an Italian based company and is part of a family owned Group with more than 100 years of industrial history and with interests in the mechanical and metallurgic fields.*
*With more than 40 years experience in plastic machinery, Icma is today a leading supplier of __co-rotating extruders__ and __complete turn-key extrusion systems__ for the production of __compound, masterbatch__, __foils__ and __sheets__ where the use of the co-rotating technology gives a competitive advantage. All key parts of each extruder (screws, barrels and gear boxes) are exclusively manufactured by Icma granting therefore a constant high quality of the final system.*

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