Environmental, economic, and technical reasons justify research efforts aiming to provide natural materials with possibility of replacing synthetic fiber composites. Commonly known lignocellulosic fibers, such as jute, sisal, flax, hemp, coir, cotton, wood, and bamboo have not only been investigated as reinforcement of polymeric matrices but already applied in automobile components. Less common fibers, such as curaua, henequen, fique, buriti, olive husk, and kapok are recently being studied as potential reinforcement owing to their reasonable mechanical properties. The relatively low thermal stability of these fibers could be a limitation to their composites. The works that have been dedicated to analyze the thermogravimetric stability of polymer composites reinforced with less common lignocellulosic fibers were overviewed.

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1. Introduction

The first engineered composites materials were probably reinforced with natural fibers and produced in the primordial of mankind. Evidence of adobe construction blocks of sun-dried clayey mud incorporated with straw was found in the ancient Egyptian civilization. According to our current interpretation, these first composites would be considered environmentally friendly owing to their all natural components. Even today, the rudimentary technique used by our ancestors to fabricate such composites persists in many low income regions of the world. As mentioned by Bledzki and Gassan[1], in a seminal review on natural fiber composites, only at the end of the 19th century the industrial manufacture of natural fibers with small content of polymeric binder was reported for airplane seats and fuel tanks. Large amounts of sheets, tubes, and pipes for electronic purpose were continuously fabricated as earlier as 1908, using natural fibers, paper, or cotton incorporated into phenolic matrix[1-2]. With the rising performance of petroleum-based polymers and synthetic fibers as well as the facility to combine them into more uniform and stronger composites, the industrial production of traditional natural fiber composites declined.

In another classic review on biofibres and biocomposites, Mohanty et al.[2] indicated that the synthetic fiber composites reached commodity status in the 40’s with glass fiber reinforcing (fibre) unsaturated polyesters. These synthetic fibre composites experienced an exponential growth after the World War II to become the most successful class of engineering materials[1-3] with application in practically all fields of human interest, from appliances and sports to surgical prosthesis and aerospace components. At the end of the last century, increasing environmental concerning over generalized pollution caused by non-degradable materials, especially long lasting plastics, and climate changes resulting from CO₂ emission, promoted a growing tendency towards the substitution of synthetic fibers composites. Natural materials, particularly cellulose-rich fibers, also known as lignocellulosic fibers, were renewed as reinforcement of polymer composites. A considerable number of researches have, in the past few decades, been dedicated to lignocellulosic fibers as engineering materials and their reinforced polymer composites for applications in substitution of synthetic fiber composites. Several reviews and general articles covered this trend[1,2,6-13]. In these publica- tions, advantages are emphasized and drawbacks discussed aiming at reduce the limitation, which exists in practical use. Despite the drawbacks, a growing industrial application of lignocellulosic fiber composites is nowadays occurring in sectors such as building construction, packaging, sport devices, electrical parts, and vehicle components[14]. Automotive industries, initially the Europeans followed by Americans and Japanese, are adopting this type of composites in several interior and exterior parts[16-20].

It was emphasized[21,22] that, as compared to fiberglass, the lignocellulosic fiber composites are lighter, cheaper, and less abrasive in contact with processing equipments. Furthermore, fiberglass represents a problem to the environment with restriction to final destination by incineration in thermo-electric plants. Glass fiber particulates also represent potential health hazardous both in the initial composite processing and latter at the end-of-life degradation. By contrast, the thermal stability of a lignocellulosic fiber composite is inferior to similar matrix composite reinforced with glass fiber. This could be a critical restriction for conditions associated with relatively high temperatures attained during the curing of the composite or its in-service use. In fact, temperature usually causes an initial degradation of the fiber organic structure and thus limits the polymer composite application.

2. Thermal Decomposition of Lignocellulosic Material

Several review articles[23-26] have, since more than five decades ago, been dedicated to the thermal decomposition of lignocellulosic materials. Beall and Eckner[22] reviewed works on thermal analysis results of wood and its cellulose, hemicelloses, and lignin constituents. Kilzer[24] reviewed works on the thermal decomposition of cellulose. Nguyen et al.[25,26] conducted subsequent reviews on the application of differential thermal analysis (DTA), differential scanning calorimetry (DSC), and thermogravimetry (TG) to the study of lignocellulosic materials as well as modified forms of lignocelluloses. These review articles[23-26] indicated the following results:

2.1 Cellulose

Cellulose decomposition takes place by major reaction involving depolymerization, thermoxidation, dehydration, and formation of glycosans, depending on the presence of oxygen or an inert atmosphere. In a non-oxidative atmosphere, dehydration occurs in a range of 210°C-260°C and depolymerization with volatilization of levoglucosans, at about 310°C. Under oxygen, thermoxidative reactions occur in the temperature range of 160°C-250°C. The degradation of cellulose by pyrolysis has been assumed to follow a first-order kinetic. In the specific case of wood, cellulose decomposition in air begins at 320°C with a maximum weight loss at 350°C. In helium it also begins at 320°C, but the maximum rate is shifted to 375°C. Cotton cellulose displays two endothermic DTA peaks at 100°C and 367°C.

2.2 Hemicellulose

Hemicellulose constituents decompose at temperatures as low as 159°C-175°C, as in the case of acetyl galactoglucomannan. DTA of xylan in oxygen exhibits a first exothermic
peak at 215 °C. Both arabinoxylan and deacetylated galactoglucan begin degradation at 195 °C, reaching a maximum at 280 °C.

2.3 Lignin

Obtained by hydrolysis of wood, it was found to decompose in three stages. At temperatures below 220 °C–250 °C, condensation and splitting of the side chains takes place. Between 300 °C–400 °C, active pyrolysis leads to the formation of free radicals. Above 400 °C, decomposition is associated with accumulation of aromatic products.

2.4 Wood

In its natural and unmodified form, it showed, under helium, a first endothermic peak at 107 °C, corresponding to water loss. Weak endothermic peaks were found at 207 °C and 330 °C, corresponding to dehydration and depolymerization of various constituents, probably including hemicellulose. A very strong endothermic peak at 367 °C was attributed to cellulose decomposition. An exothermic peak arises above 400 °C, presumably related to recombination of cellulose and lignin fragments. Under oxygen, it was reported an endothermic peak at 87 °C, owing to evaporation of water, and two exothermic peaks at 343 °C and 470 °C, probably due to cellulose and lignin.

3. Thermal Analysis of Common Lignocellulosic Fiber Composites

A short review on the thermal stability of polymer composites reinforced with few common lignocellulosic fibers was, for the first time, presented as one of the sections of the Nabi Saheb and Jog[6] review on natural fiber polymer composites. They indicated that the thermal degradation of natural fibers is a crucial aspect in the development of their composites and thus has a bearing on the curing temperature in the case of thermosets and extrusion temperature in thermoplastic matrix composites. Nabi Sahed and Jog[6] also stated that thermal stability improvement have been attempted by coating and/or grafting the fibers with monomers, quoting the works of Mohanty et al.[27] and Saba[38]. The effect of the composite fabrication ambient was discussed by the authors[6] as a possibility of lignocellulosic fiber degradation, quoting the work of Sridhar et al.[29], and indicating that the actual practice is carried out under air and that thermal degradation can lead to inferior mechanical properties. As a final remark, Nabi Saheb and Jog[6] concluded that the thermal degradation of the lignocellulosic fiber inside the polymeric composite matrix also results in production of volatiles at processing temperatures above 200 °C. This could result in porous composites with lower densities and inferior mechanical properties.

Since this first short review[6], numerous works have investigated the thermal stability of polymer composites reinforced with common lignocellulosic fibers. The reader may find specific data and conclusions on the following articles listed by employed reinforced fiber:

a) Jute Fiber Composites, in phenol formaldehyde[30], poly-ester[31], vinyl ester[32], polyester with acrylic acid[33], high density polyethylene[34], polypropylene[35], and polyactic acid[36] matrices;

b) Hemp Fiber Composites, in polyester[37], cashew nut shell resin[38], epoxy[39], polypropylene[40,41], and starch-base ther-moplastic[42] matrices;

c) Sisal Fiber Composites, in polypropylene[43,44], blend of polypropylene with high density polyethylene[43], polystyrene[44], polypropylene and maleic anhydride grafted styrene-ethylene-co-butylene-styrene copolymer[45,46], epoxy[47,48], phenolic and lignophenolic[49], and soy protein blended with gelatin[50] matrices;

d) Flax Fiber Composites, in polypropylene[51], epoxy[52,53], and polyactic acid[54] matrices;

e) Coir Fiber Composites, in copolymer of starch with ethyl-ene vinyl alcohol[55], and polyester[56] matrices;

f) Cotton Fiber Composites, in phenolic thermostet[57] matrix;

g) Kenaf Fiber Composites, in epoxy[58] chitosan[59,60], and starch-based ther-moplastic[61] matrices;

h) Wood Fiber Composites, in polypropylene[62]–65, low and high density polyethylene[66,67], and polyhydroxy(butyrate-co-valerate)[68] matrices;

i) Pineapple Fiber Composites, in polyethylene[69], polyhydroxy(butyrate-co-valerate)[70], and polycarbonate[71] matrices;

j) Bamboo Fiber Composites, in polylactic acid[72], polybuty-ylene succinate[73], epoxy[74], and polyhydroxy(butyrate-co-valerate)[75] matrices;

k) Ramie Fiber Composites, in polylactic acid[76] matrix;

l) Banana Fiber Composites, in polyvinyl chloride[77] matrix;

m) Bagasse Fiber Composites, in polyurethane (PU)[78], and recycled high density polyethylene[79] matrices.

As a general comment, one may conclude from all these works on the thermal stability of polymer matrix composites reinforced with commonly known and used lignocellulosic fibers that their processing and applications are restricted to a safe temperature of 250 °C, or to a maximum of 367 °C, in case of more stable specific polypropylene and maleic anhydride grafted styrene-ethylene-co-butylene-styrene copolymer matrix reinforced with sisal fiber[80]. The reader should also bear in mind that all these composites, owing to the contribution of the lignocellulosic fiber, display a DTG water loss peak which is found at temperatures as low as 37 °C[32] and inferred at about 140 °C–144 °C[48,53].

4. Thermogravimetric Stability of Less Common Lignocellulosic Fiber Composites

In principle, a complete assessment of the thermal behavior of a material would require not only temperature difference, DTA, thermogravimetric, TG/DTG, differential calorimetric, DSC, and dynamic-mechanical (DMA) thermo analyses, but also the evaluation of properties such as thermal conductivity, specific heat, and thermal diffusivity. The scope of this overview is limited to thermal stability results associated with weight loss variation with temperature obtained by thermogravimetric analysis. These results, displayed as TG thermograms as well as its derivative DTG, will be covered for relevant works on polymer composites reinforced with less known fibers published in internationally recognized sources. Numerous less common lignocellulosic fibers such as curaua, henequen, fique, buriti, olive
4.1 Curaua Fiber Composites

Mothé and Araújo\textsuperscript{[71]} showed TG/DTG and DTA curves for PU matrix composites reinforced with up to 20 wt.% of curaua fibers. For the neat PU, the DTG curve displays a small initial peak at 260°C that was assigned to the decomposition of additives in the PU. A broad shoulder peak around 360°C followed by a major peak at 422°C were attributed to decomposition of the rigid and soft urethane bonding, respectively. The DTA curve shows three endothermic events at 250°C, 330°C, and 420°C that corroborate those found in the DTG peaks. The investigated composites\textsuperscript{[71]} also display faint DTG peaks around 60°C, due to the release of water. Two other decomposition peaks with temperatures (wt.% of curaua fibers) can be seen at 358°C and 418°C (5 wt.%); 356°C and 420°C (10 wt.%); and 356°C and 418°C (20 wt.%). Endothermic DTA peaks are also seen at the same temperatures and conditions. These results indicate that the thermal stability of the composites is practically the same of the PU. Moreover, the amount of curaua fiber in the composite causes no apparent change in the thermal stability.

Araújo et al.\textsuperscript{[72]} presented results from TG/DTG curves of isolated curaua fiber as well as high density polyethylene (HDPE) and HDPE matrix composites reinforced with 20 wt.% of either unmodified (natural) or polyethylene-co-vinyl-acetate (EVA) and maleic anhydride grafted polyethylene (PE-g-MA) compatibilized curaua fibers. The DTG curve of the neat HDPE shows a peak at 478°C. The DTG curves of the composites display two distinct peaks. The first, coinciding for all composites at 349°C, occurred closer to the main decomposition peak of the curaua fiber, 363°C. Additionally, the authors calculated a weighted mean expected DTG curve if there was no interaction among the degradative process for the composites, quoting the work of Waldman and de Paoli\textsuperscript{[73]}. The second peak was found at about 468°C-471°C for the composites. A comparison of TG curves with the calculated curve allowed the authors\textsuperscript{[72]} to indicate that the composite compatibilized with PE-g-MA is less stable, while those with EVA as well as with no compatibilization are more stable.

Ferreira et al.\textsuperscript{[74]} showed TG/DTG curve, obtained at a heating rate of 10°C/min in nitrogen, for polyester composites reinforced with up to 30 vol.% of untreated curaua fibers. A small initial peak observed for all composites around 70°C was attributed to moisture release. The neat polyester begins to decompose around 250°C and displays a major DTG peak at about 410°C related to the degradation of its molecular chains. The composites display a shoulder peak around 370°C, which is more pronounced for higher volume fractions of curaua fiber, as well as a major peak almost coincident with that of the neat polyester. Fig. 1 illustrates the TG/DTG curves of neat polyester and composites reinforced with up to 30 vol.% of continuous and aligned curaua fibers, adapted from the Ferreira et al.\textsuperscript{[74]} work. In this figure, an enlarged insert reveals shoulder peaks associated with curaua fiber thermal degradation in the composite. By considering these overviewed works, and based on the results for the isolated curaua fibers\textsuperscript{[71,72,75–77]} with shoulder at 268°C-290°C and major peak at 310°C-365°C, one should conclude that PU\textsuperscript{[71]}, HDPE\textsuperscript{[72]}, and polyester matrices\textsuperscript{[74]} composites are thermally more stable than the pure curaua fiber.

4.2 Henequen Fiber Composites

Griccica and Hawley\textsuperscript{[39]} presented thermogravimetric results on epoxy matrix composites reinforced with 15 wt.% of hemp (section 3, item b), flax (section 3, item d), kenaf (section 3, item g), and henequen fibers. These composites were both oven and microwave cured. For comparison, similar glass fiber composites were also investigated. Although no TG curves were shown, the authors\textsuperscript{[39]}

\begin{itemize}
  \item (a) Plain curves; (b) enlarged DTG curves.
\end{itemize}
presented the degradation temperature associated with 5 wt.\% to 75 wt.\% of weight loss. Tables 1 and 2 reproduce these results and the reader can observe that the isolated henequen fiber shows degradation temperature (weight loss) of 61 °C (5 wt.\%) up to 392 °C (75 wt.\%). On the other hand, the microwave cured composites show a significant increase: 355 °C (5 wt.\%) up to 483 °C (75 wt.\%). These values are closer (Tables 1 and 2) to those corresponding to the neat epoxy microwaved of 403 °C (5 wt.\%) and 484 °C (75 wt.\%).

Table 1 Degradation temperatures for glass and henequen fibers associated with different levels of TG weight loss

<table>
<thead>
<tr>
<th>Weight loss (%)</th>
<th>T(°C) 5 wt.%</th>
<th>T(°C) 25 wt.%</th>
<th>T(°C) 50 wt.%</th>
<th>T(°C) 75 wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henequen</td>
<td>61.1</td>
<td>301.4</td>
<td>337.4</td>
<td>391.6</td>
</tr>
<tr>
<td>Glass</td>
<td>586.4</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Adapted from Sgriccia and Hawley[39].

Table 2 Degradation temperatures for glass and henequen fiber reinforced epoxy matrix composites associated with different levels of TG weight loss

<table>
<thead>
<tr>
<th>Weight loss (%)</th>
<th>T(°C) 5 wt.%</th>
<th>T(°C) 25 wt.%</th>
<th>T(°C) 50 wt.%</th>
<th>T(°C) 75 wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass oven</td>
<td>400.3</td>
<td>N/A</td>
<td>401.8</td>
<td>538.6</td>
</tr>
<tr>
<td>Glass microwave</td>
<td>400.4</td>
<td>N/A</td>
<td>401.7</td>
<td>481.7</td>
</tr>
<tr>
<td>Henequen oven</td>
<td>305.8</td>
<td>374.6</td>
<td>391.0</td>
<td>455.9</td>
</tr>
<tr>
<td>Henequen</td>
<td>355.0</td>
<td>389.1</td>
<td>392.0</td>
<td>483.0</td>
</tr>
<tr>
<td>Neat epoxy</td>
<td>396.6</td>
<td>N/A</td>
<td>397.9</td>
<td>489.8</td>
</tr>
<tr>
<td>Neat epoxy</td>
<td>403.3</td>
<td>N/A</td>
<td>N/A</td>
<td>484.3</td>
</tr>
</tbody>
</table>

Adapted from Sgriccia and Hawley[39].

4.3 Fique Fiber Composites

Gañán and Mondragon[78] performed thermogravimetric analysis on both polypropylene (PP) and polyoxymethylene (POM) matrices composites reinforced with 20 wt.\% fique fibers, untreated as well as modified with maleic anhydride (MA), propionic acid (PA), glycidyl-methacrylate (G) and formaldehyde (F) or compatibilized with a copolymer of polypropylene (Fluka) and maleic anhydride (MAPP). The discussed composite results were limited to some of the fiber treatments. For instance, a major decomposition peak was reported for the neat PP at 473 °C, while the untreated as well as PA and MAPP treated fiber composites display three peaks. Fig. 3, adapted from the work of Gañán and Mondragon[78], shows TG/DTG curves for neat PP and PP composites reinforced with 20 wt.\% of fique fibers as well as neat POM and POM composites reinforced with 20 wt.\% of fique fibers. The authors[78] indicated that the first (310 °C) and second (387 °C) peaks for the untreated fiber composites, as well as the corresponding first (344 °C) and second (393 °C) peaks for the MAPP treated fiber composites, are related to those of the isolated fique fiber, 301 °C and 356 °C, respectively, quoting their previous work[79]. The third peak at 451 °C for untreated and at 476 °C for MAPP treated fiber composites correspond to the decomposition of the PP matrix. As a general comment, Gañan and Mondragon[78] stated that the lower thermal stability of POM with respect to PP does not allow for separating the contributions for thermal degradation of fique fibers and POM matrix in related composites. Higher temperatures than that for the neat POM are necessary for complete degradation of its composites, possibly due to fiber degradation delaying and matrix crystallinity variations.

4.4 Buriti Fiber Composites

Santos et al.[80] conducted thermogravimetric experiments on cardanol-formaldehyde (CFR-thermoset resin) matrix composite incorporated with 5 wt.\%, 10 wt.\%, and 15 wt.\% of buriti fibers obtained from leaf straw. Buriti fibers were both untreated and subjected to NaOH alkali (mercerization) or silanization treatments. TG curves show that the...
CFR has, apparently, an onset temperature for thermal degradation, around 320°C, which is higher than those for the 10 wt.% buriti fiber composites, around 240°C. In fact, the authors\textsuperscript{(80)} indicated that both composites present an intermediate thermal stability in relation to the isolated buriti fiber and the matrix. Furthermore, the mercerized fiber composite curve shows an inflection at about 305°C because of the thermal fiber degradation and another at 400°C owing to the thermal degradation of the thermoset resin. Fig. 4, reproduced from the work of Santos et al.\textsuperscript{(80)}, shows SEM micrographs of untreated, mercerized and silanized buriti fibers as well as 10 wt.% buriti fiber reinforced CFR matrix composites. As indicated by the authors\textsuperscript{(80)}, the mercerized fiber (Fig. 4a) displays a rough aspect, probably due to the removal of low molar mass compounds, which leaves cavities at the surface. The silanized fiber (Fig. 4c) presents a more regular surface. This suggests that the silanization produces a film coating on the entire fiber surface. The composite (Fig. 4d) displays a lamellar-like morphology with evidence of excellent adhesion between the matrix and mercerized fiber. This good coverage of the fiber by the resin may contribute to improve its thermal stability.

4.5 Olive Husk Fiber Composites

Amar et al.\textsuperscript{(81)} performed thermogravimetric analysis at a heating rate of 10°C/min in nitrogen on polypropylene (PP) matrix composites added with 10 wt.% and 20 wt.% of olive husk flour (OHF), the solid portion remaining after pressing olives, which contains significant amounts of lignocellulosic fiber. The OHF were both untreated and subjected to vinyltriacetoxyxilane (VTAS) chemical treatment or grafted with maleic-anhydride-polypropylene (PPMA). The pure untreated OHF begins to degrade at 210°C, while the VTAS treated OHF at 201°C. This reduction was attributed by the authors\textsuperscript{(81)} to the elimination of hydrogen bonds that requires significant energy. DTG peaks were also related to the OHF degradation. The first, around 100°C, was assigned to water evaporation; the second, at 260°C, for untreated and 250°C for treated OHF were ascribed to both hemicellulose and glycidic bonds of cellulose decomposition. The third peak, at 325°C, was attributed to cellulose decomposition, while the fourth peak, at 350°C, to the lignin decomposition. The authors\textsuperscript{(81)} indicated that these results are in agreement with those of Måder et al.\textsuperscript{(39)} and Pracella et al.\textsuperscript{(44)}.

As for the neat matrix, a single DTG peak was observed at 397°C in association with 97% of weight loss. The authors\textsuperscript{(81)} also concluded that the grafting reaction of MA onto the PP, for the OHF treatment, generates a 16°C reduction in thermal stability. TG/DTG curves for the composites showed an intermediate behavior between the pure OHF and the neat PP. In fact, according to Amar et al.\textsuperscript{(81)}, the thermal degradation of the olive husk fiber composites occurred in a three step degradation process. However, the 20 wt.% OHF composites apparently display four DTG peaks. A small first peak at around 100°C, not mentioned by authors\textsuperscript{(81)}, is probably due to water release from the OHF. A second, in the temperature range of 232°C–308°C, and a third at 308°C–350°C, shoulder peaks were attributed to the decomposition of hemicellulose and cellulose, respectively. The main DTG peaks around 400°C, related by the authors to the third decomposition stage between 350°C–454°C, were assigned to the PP matrix and OHF lignin joint degradation. It was also indicated by the authors that the composite modified by PPMA revealed a better thermal stability than those with untreated or VTAS treated OHF.

4.6 Kapok/ Cotton Fibers Hybrid Composites

Mwaikambo et al.\textsuperscript{(82)} employed hybrid kapok/cotton fibers wove as a fabric, which was both untreated and chemically treated by either one hour soaking in acetic anhydride at 70°C (acetylation) or dipped in 2% NaOH solution for 48 hours (alkali/mercerization), reinforcing both conventional isotactic polypropylene (iPP) and anhydride grafted polypropylene resins (MAiPP) matrices composites. In addition, the authors\textsuperscript{(82)} also investigated the effect of accelerated weathering of the composites by immersion in boiling water for two hours before conducting thermogravimetric analysis at a heating rate of 10°C/min in nitrogen. Table 3, reproduced from their work\textsuperscript{(82)}, summarizes the main parameters obtained from TG curves for all distinct composites.

Although not mentioned in the abstract, the authors\textsuperscript{(82)} indicated in the experimental procedure that the plain weave kapok/cotton fabric was used together with non-woven glass mat. Along the article, no comment or discussion was given regarding the role of the glass mat on the thermogravimetric analysis. As shown in Table 3, all composites display a dehydration temperature in the range of 59°C–78°C, which is probably related to the water release from the kapok and cotton fibers, as usually reported in other lignocellulosic fiber composites.\textsuperscript{30,32,50,53,54,56,71,74} As major thermal stability results, Mwaikambo et al.\textsuperscript{(82)}, em-

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4.pdf}
\caption{SEM micrographs: (a) untreated; (b) mercerized; and (c) silanized buriti fibers as well as (d) composite with 10 wt.% mercerized fibers, indicated by white arrows. Inserts with high magnification details. Reproduced from Santos et al.\textsuperscript{(80)}.}
\end{figure}
phphasized that the weathered kapok/cotton-iPP composite shows the highest degradation temperature followed by kapok/cotton-MAiPP composite. As for the fabric treatment, the acetylated kapok/cotton fabric-iPP composites display a higher onset temperature of degradation than both the weathered composite and mercerized kapok/cotton fabric-iPP composites, but lower than MAiPP composites. The authors stated that the maleic anhydride is likely to be the possible source for the improved thermal properties of PP as also evidenced by the rise in the degradation temperature of the composites. By contrast, mercerization of fibers, which is known to result in reduced crystalline cellulose, has been found to decrease the thermal stability of the kapok/cotton fabric-iPP composites. As a general conclusion, it has also been found, with exception of mercerization kapok/cotton fabric-iPP (Table 3), that all composites exhibit two degradation temperatures. Mwaikambo et al. suggested that the first degradation temperature is a result of depolymerization of the cellulose materials. The second degradation temperature was caused by the polymeric matrices breakdown into monomers and/or decomposition of the levoglucosan.

5. Concluding Remarks

A few points are worth being discussed concerning the results presented in this overview. First, the reader should noticed the relatively small number of papers covering the thermogravimetric stability of polymer composites reinforced with less common lignocellulosic fibers. Indeed, it was rather surprising that only such limited works have so far been dedicated to these composites in spite of the potential presented by less common lignocellulosic fibers. For instance, Fiore et al. reported tensile strength above 300 MPa and elastic modulus above 1.5 GPa for artichoke fibers, while De Rosa et al. found tensile strength above 800 MPa and elastic modulus above 4 GPa for okra fibers. These less common lignocellulosic fibers certainly possess an engineering potential, of both strength and stiffness, for polymer composite reinforcement. In addition to future specific works on the mechanical properties of these less common natural fiber composites, the thermal stability of such composites will also need to be investigated for practical use.

A second point of the present overview is the alert on the growing demand for studies covering the several less common lignocellulosic fibers with potential application as engineering materials. Consequently, the general properties and, in particular, the TG/DTG analysis of novel composites based on these fibers have to be assessed. Despite the limited and fragmented information existing in the literature, this overview conveys relevant conclusions regarding the thermogravimetric stability of polymer composites reinforced with less common lignocellulosic fibers. Apparently, an initial weight loss associated with a water release DTG peak below 200°C is a common feature of these composites, although not emphasized in some works. This initial peak is most probably a result of the evaporation of water from the fiber surface, since the polymeric matrix contribution, if existing, should be relatively small. For practical use, however, the temperature related to the onset of thermal degradation can be considered the composite thermal stability limit. In the overviewed works, this limit was found to be in the range of 240°C, and attributed to the lignocellulosic fiber decomposition. According to Santos et al., these onset degradation temperatures are intermediate between the isolated fiber and the polymer matrix. Other higher temperature DTG peaks, 422°C and 463°C, are related to the polymer matrix macromolecular degradation or depolymerization but not as important as the onset degradation temperature to define the composite thermogravimetric stability.

### Table 3

<table>
<thead>
<tr>
<th>Properties</th>
<th>Alkali-treated kapok/cotton-iPP composite</th>
<th>Acetylated kapok/cotton-iPP composite</th>
<th>Unweathered kapok/cotton-iPP composite</th>
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<tr>
<td>Dehydration temperature (°C)</td>
<td>74.1</td>
<td>59.3</td>
<td>76.3</td>
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<tr>
<td>Onset temperature (°C)</td>
<td>332.3</td>
<td>339.5</td>
<td>316.4</td>
</tr>
<tr>
<td>Degradation temperature 1 (°C)</td>
<td>372.8</td>
<td>372.63</td>
<td>370.4</td>
</tr>
<tr>
<td>Degradation temperature 2 (°C)</td>
<td>—</td>
<td>431.7</td>
<td>428.2</td>
</tr>
<tr>
<td>Decomposition temperature (°C)</td>
<td>656.7</td>
<td>655.3</td>
<td>656.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unweathered kapok/cotton-MAiPP composite</th>
<th>Weathered kapok/cotton-iPP composite</th>
<th>Weathered kapok/cotton-MAiPP composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehydration temperature (°C)</td>
<td>77.5</td>
<td>71.8</td>
<td>71.8</td>
</tr>
<tr>
<td>Onset temperature (°C)</td>
<td>339.5</td>
<td>318.5</td>
<td>339.2</td>
</tr>
<tr>
<td>Degradation temperature 1 (°C)</td>
<td>381.9</td>
<td>380.6</td>
<td>384.2</td>
</tr>
<tr>
<td>Degradation temperature 2 (°C)</td>
<td>459.1</td>
<td>423.7</td>
<td>462.5</td>
</tr>
<tr>
<td>Decomposition temperature (°C)</td>
<td>657.9</td>
<td>658.7</td>
<td>655</td>
</tr>
</tbody>
</table>

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