



Strength shear test for adhesive joints between dissimilar materials obtained by multicomponent injection

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ABSTRACT

The multicomponent injection molding process enables the combination of different materials in a single step. However, one of the challenges of this new technology is related to the adhesive strength between dissimilar materials. In this work, specimens were overmolded with dissimilar composite materials made of polypropylene and coconut fibers added with coupling agents. By means of a new patented device specially produced to evaluate the adhesive strength of such different materials under pure shear stress, it was possible to measure the force necessary to promote the detachment of dissimilar surfaces. Electron microscopy and contact angle analyses were used to better understand the adhesion phenomenon between such dissimilar materials. Although a maleic anhydride additive promoted better anchoring between fibers and the polymer matrix, it was observed that the composite without coupling agents exhibited the greatest adhesive strength between dissimilar surfaces.

1. Introduction

Natural fibers, or lignocellulosic fibers, have been widely used as reinforcements in composites, mainly because these materials are cheap, with low density, biodegradable and are from renewable resources, as pointed by Saheb and Jog [1]. However, plant fibers are quite hydrophilic, which results in poor chemical interaction with polymers, which are usually hydrophobic. To minimize this problem, physical and chemical processes have been used to modify fiber surfaces to improve matrix-fiber interfacial adhesion as observed by Xie et al. [2]. Lu et al. [3] verified that the incorporation of polar natural fibers into nonpolar polyolefin thermoplastics requires the presence of coupling agents (CAs) to obtain better adhesion conditions. As compatibilizers have functional groups that promote polar adhesions in such new materials, they react chemically with the hydroxyl present in the fiber through strong covalent bonds (or secondary acid-base interactions or even hydrogen bonds).

The development of composite materials applicable for injection molding represents one of the many possibilities of combining multicomponent materials for designs of plastic parts, as Budhe et al. [4] mentioned in their research. Nowadays, there is a growing interest to optimize the strength, weight, and durability of structures with composite materials. Therefore, it is necessary to better understand the phenomena between bonding of dissimilar materials in order to obtain

the benefits provided by multi-material joints [4]. Consequently, an appropriated combination of overmolded materials might be the key to develop lighter, strong and eco-friendly structures.

Multicomponent injection is being increasingly used in the current production of plastics because it allows the combination of different materials in a single process, which in turn allows the manufacture of parts with a bold design, of higher added values and shorter manufacturing times, as pointed by Priyadarshi et al. [5]. Overmolded parts made up of dissimilar materials, with a component that is made by a composite containing natural fibers, is an ecologically viable option with new possibilities for innovation. The procedure uses multiple molds where the first material is injected by means of a single material molding (SMM), then the mold rotates 180° around its own axis and receives a second material in few seconds to combine with the previous. However, the presence of an already-molded component during the second phase (or the use of subsequent molding phases) means that this technology differs from the traditional injection molding process, as mentioned previously. According to Banerjee et al. [6], the manufacturing problems may occur for many reasons, including material incompatibility, the location of injection points, polymer moldability and other problems due to the ejection system. Another factors of fundamental importance for a better adhesion between polymers are related to the influence of some process variables, as plastification, polymer injection, time processing, pressure, temperature gradient and

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cooling, during each one of the overmolding stages, as explained by Piotter [7]. These variables, when adjusted properly, will guarantee the quality of the resulting material and the reproducibility of the process.

To obtain good adhesion, the bonds between two polymers must be known, which can be considered the sum of physical (mainly mechanical) and chemical forces that overlap and influence each other. Da Silva et al. [8] reported that the mechanical forces act on porous and/or roughness surfaces improving anchoring of dissimilar materials, providing better adhesion. The performance of adhesively bonded joints depends on many parameters such as surface preparation, composite interfaces, chemical bond characteristics between adhesive and adherend parts, overlap length, among others. However, this adhesion depends on a good adhesive wetting on the adherent surface injected on the first stages.

According to Packham [9], there is intimate contact between adherent and adhesive materials for best results, which is related to the surface wetting properties of dissimilar materials. The degree of wetting (wettability) of a surface is of crucial importance for better adhesive joints between polymers. The *Surface Free Energy* (SFE) is a physico-chemical property of a surface that can be determined indirectly by wettability measurements, as pointed by Kraus [10]. To quantify this wettability, the measurement of the contact angle of a drop with the surface of the material at the triple point of contact (between solid, liquid and vapor phases) is important. This measure is related to the "wetting surface energy" characterized by the Young and Dupré Eq. (1):

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \cos\theta \quad (1)$$

where γ_{sv} is the surface tension between solid and vapor phases, γ_{sl} is the surface tension between solid and liquid phases, and γ_{lv} is the surface tension between liquid and vapor phases.

According to Bracco and Holst [11], by measuring the contact angle, certain considerations may be observed. For surfaces in which the contact angle is less than 90°, the material is classified as hydrophilic, and for an angle greater than 90°, it is hydrophobic. Thus, when more hydrophobic is the surface, worse is its wettability, and consequently its adhesion ability.

Other adhesion mechanisms consist of electrostatic forces arising from the difference in electronegativity between materials. Forces of chemical origin are present as primary (ionic, covalent) or secondary (Van der Waals or hydrogen-based) interatomic bonds, which depend on the binding energy between atoms, as explained by Devries and Adams [12]. The mechanism that best represents adhesion in polymers is the adsorption theory. It assumes that adhesion results from atomic bonding on material surfaces. Van der Waals forces are the most common in terms of adhesion, but there can be hydrogen-bond and acid-base interactions, which can also influence adhesion [9].

There are several methods used to test the adhesive strength of polymeric materials and a commonly used standard for evaluating adhesive strength is the "T-Peel Test" – according to ASTM D1876 Standard [13]. Additionally, there are many peel test methods. It is possible to cite quite a few: the Floating roller (or without rollers) moving table; Floating roller (115 degrees); Peel wheel and 180-degree Peel [10], among others. All the mentioned tests focus on measuring the force required to detach two surfaces by a peeling stress procedure, without assessing the force required to displace one surface over the other by shear stress. Therefore, some researchers as Li et al. [14], proposed several techniques for reducing peel and interfacial stresses as: spew fillet, adhesive thickness, mixed adhesive, tapered plate with different shapes, different thickness, adherent widths, tapered length and thickness, etc. When the polymers are rigid and plane the Lap Shear Test" (Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading - ASTM D3163-01) [15] could be adopted.

However, all of the above tests focus on measuring the force required to separate two surfaces. They don't assess the pure shear stress due to the presence of other forces as those generated by the bending moment. The single lap joint geometric aspect favors the generation of

bending moments, since the tensile stress T is converted into T' due to sample misalignment, as explained by Bamberg et al. [16].

As a means to evaluate the adhesive strength between dissimilar polymers and composites, in this work a specific procedure was applied using a granted patent of a new mechanical device as described previously by the present authors (BR 10 20160 21054) [17]. This device measures the adhesive strength between two overmolded materials in an overlap region, disregarding the influence of forces resulting caused by bending moment resulting in peeling stress. To test and present the results using this new device, it was used for evaluation of the influence of coconut fibers and the interaction of coupling agents over adhesive forces for overmolded polypropylene and fiber composites.

2. Materials and methods

In order to analyze the influence of the coupling agents on adhesive strength, the samples were injected *in situ* and subjected to a new tensile test. To evaluate the adhesive strength of the overmolded samples it was used a specific granted device proposed for this study (BR 10 20160 21054). More specifically, surface and morphological analysis was done by means of scanning electron microscopy (SEM). As complementary investigations, a contact angle test and optical microscopy of the surface region were performed to correlate these results with bond forces between dissimilar surfaces.

2.1. Selection and preparation of composites

To evaluate the influence of the coupling agents on the adhesion strength between dissimilar materials (copolymer matrix and coconut fiber) four composite formulations mixed with dry coconut fibers were developed. The selected polypropylene was EP 440L (Braskem), an ethylene heterophasic copolymer with flow rate of 6.0 g/10 min. The coupling agents used were: i) Orevac CA 100, a polypropylene (PP) grafted with 1wt% maleic anhydride content; ii) Orevac 18507, a high density polyethylene (HDPE) also grafted with 1 wt% maleic anhydride (both supplied by Arkema Company); iii) Cesa® Mix PEA0601031, from Clariant Company, which consists of titanate-functionalized polyethylene that uses stearamine as a lubricant. This last coupling agent was customized for a specific application in composites with natural fibers to the SENAI CIMATEC. In this study, coupling additives with PE and PP were tested to verify which has the best interaction between the polymer matrix and coconut fibers. Polypropylene and polyethylene are immiscible and partially compatible [14], and these blends have been attracting special attention due to their potential industrial applications. One of the reasons for this specific study is related to an improvement in its mechanical properties, more specifically on impact tests, especially at low temperatures, and environmental stress cracking properties. Due to immiscibility, in order to enhance the ultimate properties, a compatibilizer such as ethylene-propylene rubber (EPR), already contained in the PP EP 440L, is frequently used to improve mechanical properties such as the tensile impact strength reported by Kesavan [18] and Utracki [19].

All these coupling agents showed compatibility with the materials used in this work, as shown in Table 1. In the preliminary investigation, the objective was to identify the best compatibilization compositions to attain maximum improvement in ultimate mechanical properties of the resulting overmolded materials.

Each formulation was premixed for 2 min using tumbling process, and the formulation was dosed into the main feed of an Imacon co-rotating twin screw extruder, model DRC 30:40, with a thread diameter of 30 mm and L/D aspect ratio of 40 and under 190 °C melt temperature. The thread profile that was used in the process is the most commonly applied one for the composite types used in such works. The contents of coconut fiber and the coupling agents presented in Table 1 are relative to the total mass of the composite sample. The coupling agent corresponds to 6 wt% of fiber mass.

Table 1

Formulations in wt% used in sample preparation for this work.

Formulations	PP EP 440L (wt%)	Coconut Fiber (wt%)	Cesa® Mix (wt %)	Orevac 18507 (wt %)	Orevac CA 100 (wt%)
PPCF	70	30	–	–	–
PPCM	68.2	30	1.8	–	–
PPO18507	68.2	30	–	1.8	–
PPOCA100	68.2	30	–	–	1.8

PP EP 440L – Polypropylene; PPCF – Composite of polypropylene and coconut fiber without coupling agent; PPOCA100 – Composite of polypropylene and coconut fiber with Orevac CA 100 as coupling agent; PPO18507 – Polypropylene and coconut fiber composite with Orevac 18507 added as coupling agent; PPCM – Polypropylene and coconut fiber composite with Cesa® Mix added as coupling agent.

From this point on, we will use the nomenclature described in Table 1 to cite the resulting composites.

2.2. Preparation of injected samples

After obtaining the resulting composites, all the materials were dried for 24 h and injected into a ROMI Primax 100R machine to obtain samples according to ISO 527 type 1A [20]. The process conditions were: flow rate of 120 cm³/s, at pressure of 950 bar and 200 °C melt temperature. The overmolded specimens were produced on an Arburg Allrounder 370S injector from two injection units. The first one, named as Injection Unit 1, was responsible to inject the coconut fiber composite, allowing more sensitive adjustment for the heat treatment. This procedure could minimize the thermo-degradation effects related to the lignocellulosic fibers. Furthermore, the injection of composite materials results in fewer defects, such as sink marks, providing a flatter surface that can help in the adhesion of the final products. In the second injection part, named Injection Unit 2, polypropylene was injected under initial different process conditions to obtain the best results in terms of surface defects such as flashing, voids and sink marks. Sample specimens were 10 mm width and with overlap length of 12 mm between the dissimilar materials, as shown in Fig. 1, and according to values shown in Table 2.

2.3. Mechanical characterization of the composites and overmolded samples

Mechanical characterizations of the polymeric matrix and composites were performed to observe the influence of the coconut fibers (CFs), with and without coupling agents, on the maximum tensile strength according to the ISO 527 standard. The tests for samples of each treatment were done in a universal testing machine, EMIC Model DL 2000, at a strain rate of 10 mm/min. The most traditional methods for measuring materials strength bounds by interface are based on ASTM D1876 Standard [13], usually applying a glue or adhesive tape

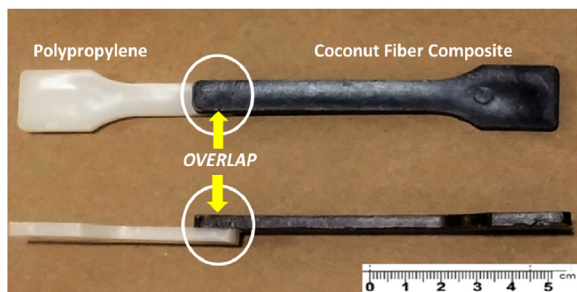


Fig. 1. Example of an injected specimen produced from this work, with a fixed 12 mm overlap (top view, above; side view, below) and 10 mm width.

Table 2

Parameters for the multicomponent injection molding applied to all samples.

Process Variables	Injection Unit 1	Injection Unit 2
Injection pressure (bar)	1000	400/400/300 (3 steps)
Holding pressure (bar)	400	300
Holding time (s)	2.5	2
Injection flow (cm ³ /s)	80	30/25/20 (3 steps)
Temperature (°C)	180-210	230
Cooling time (s)	25	20

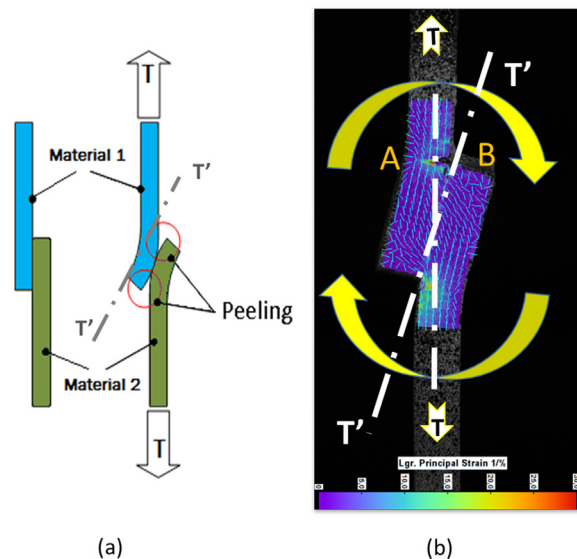


Fig. 2. Tensile stress T acting on overmolded specimen. a) Side view schematics. b) Detail of failure process close to the overlap region (obtained by DIC analysis).

between surfaces. The single lap joint geometric aspect favors the generation of bending moments, since the tensile stress T is converted into T' due to sample misalignment (Fig. 2a), as explained by Bamberg et al. [16]. The region of the substrate that was close to the overlap region, due to the bending moment, had a compression zone (indicated by “A” in Fig. 2b) and a traction zone (indicated by “B” in the same Fig. 2b). Because of this concentrated stress state, a crack propagated perpendicular to the substrate, promoting a sample failure, preferentially on the composite side, interfering on the evaluation of the adhesion force considering a pure shear between polymer surfaces.

To evaluate the tensile load following ASTM D3163-01 [15], the test machine used was an Instron 4210, from INSTRON GmbH, Darmstadt, Germany, with a displacement rate of 1 mm/min. This equipment was used to apply load to specimens in a longitudinal way, resulting in shear load for the SLJ samples. In order to reduce misalignment and bending moment, providing a better condition for the tensile tests, alignment shims were used.

However, in this work a new method was used with a device that applies a shear stress directly over the interface region of the overmolded specimens, eliminating the transverse bending moment. In order to avoid peeling stress problems, Fig. 3 shows the device schematics used to evaluate the adhesion force and how system was located in the universal testing machine EMIC DL 2000 to apply specific loads (also at a rate of 1 mm/min).

In order to assess the influence of coupling agents under tensile strength results we considered angle contact tests (“wettability”) on each sample and performed statistical analysis by means of the Minitab Statistical Software, with an alpha of 0.05 as the cutoff for significance.

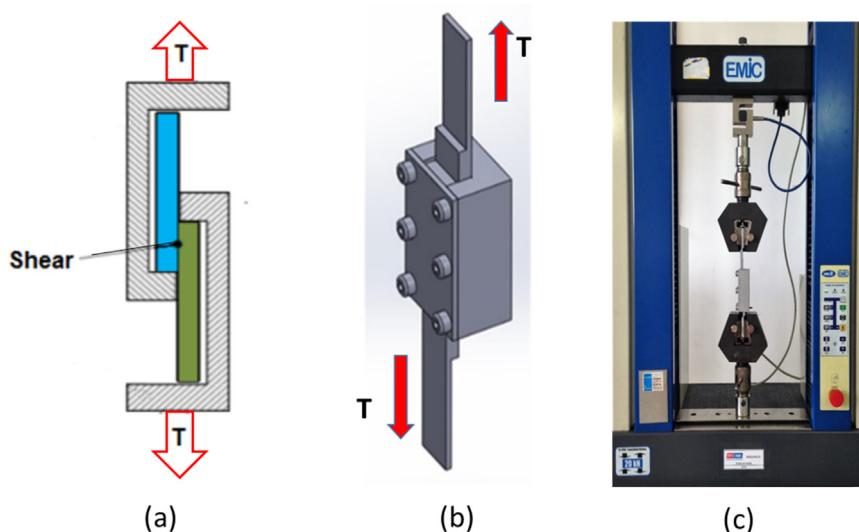


Fig. 3. Representation schematics of the shear stress test (a). CAD model of the patented device, a steel chamber that gently slides overmolded materials (b). Device adapted to a universal testing machine (c).

2.4. Morphological characterization of the composites and overmolded samples

To aid in the analysis of the coupling agent effects on the mechanical properties under tensile stress, the coconut fiber composites samples and overmolded parts were analyzed using a Jeol Brand SEM (Scanning Electron Microscope), model JSM – 6510LV, with voltage ranging between 15 and 20 kV. The specimens of the composites and the overmolded parts were subject to fragile fracture under liquid nitrogen, and the fractured surface was then registered. The external composite surfaces were observed qualitatively to analyze the surface topology that could favor adhesion based on mechanical interlocking. To improve this analysis, an optical microscope, Zeiss Scope A1, with a 200 times magnification, was also used. The software used for image processing was Axio Release 4.8.2.

2.5. Contact angle test - wettability

A wettability study using contact angle measurements and the Young-Dupre Model (Eq. 1) was performed on composite materials. Each measurement was repeated with replicates using a drop volume of 20 µl of deionized water. The result obtained corresponded to an average of the last 50 points after a stabilization time of 10 min. The equipment used was the DAS 25 from Krüss - Drop Shape Analyzer with DSA41.0.2.7 software.

3. Results and discussion

3.1. Composite mechanical characterizations

The maximum tensile strength results indicate that the coconut fiber (CF) sample resisted to a load of 101(± 25) MPa, a result at least four times higher than that obtained by polypropylene specimens, as shown in Fig. 4. PPOCA100 sample, the PP blend functionalized with maleic anhydride, produced the best result among all. In this composite, coconut fibers possibly acted as reinforcement and absorbed a portion of the load. In the compositions with the coupling agents based on polyethylene such as Orevac 18507 and Cesa® Mix, the additive did not result in better interactions with the matrix. This preliminary inference was based on the lack of significant changes from mechanical results, when compared with CF data. The composites and PP samples showed a difference in the yield strength means and it was significant between them.

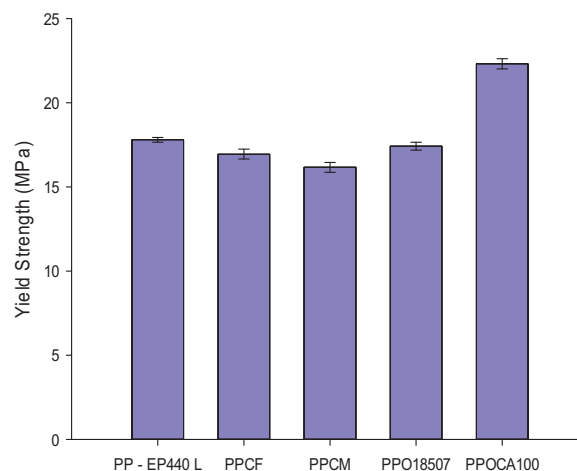


Fig. 4. Tensile strength results (in MPa) of the composite materials under study (eight samples each treatment).

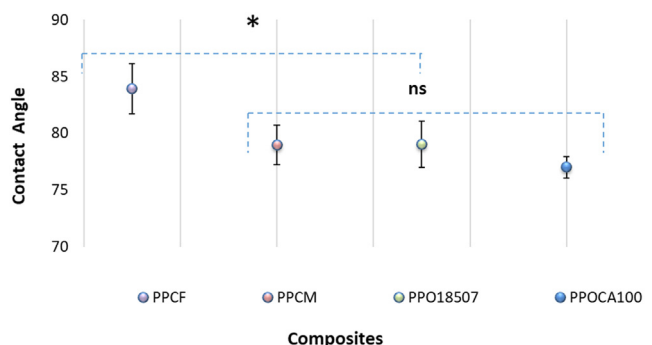


Fig. 5. Contact angle of the composite materials. (*) Significant level at 0.05; (ns): non-significant at 0.05.

3.2. Wettability measurements

Contact angle measurements presented in Fig. 5 show that the composites that used coupling agents presented lower contact angles, i.e. a higher wettability related to better adhesion between coconut fibers and the polymer matrix. From these results, it can be seen that the

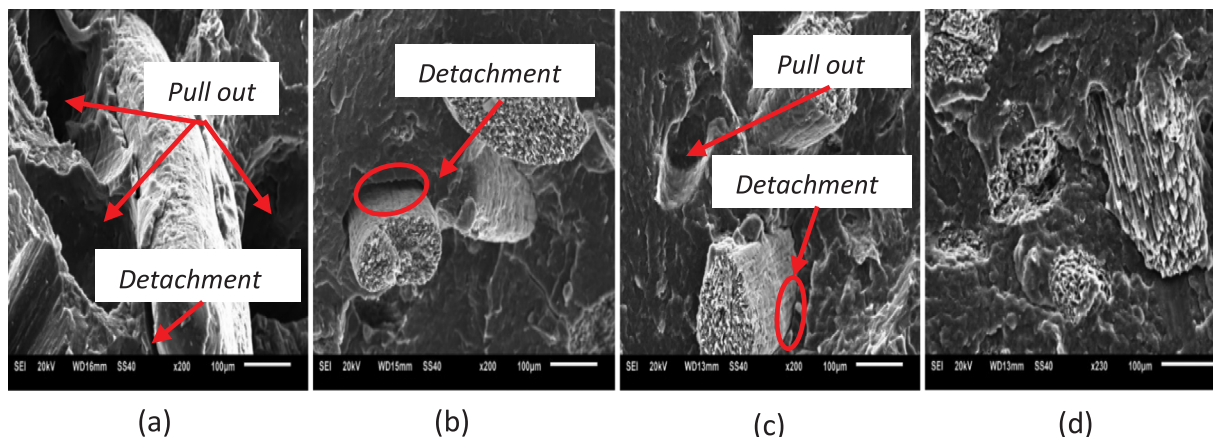


Fig. 6. SEM images: (a) PPCF (without additives); (b) PPCM; (c) PPO18507; and (d) PPOCA 100.

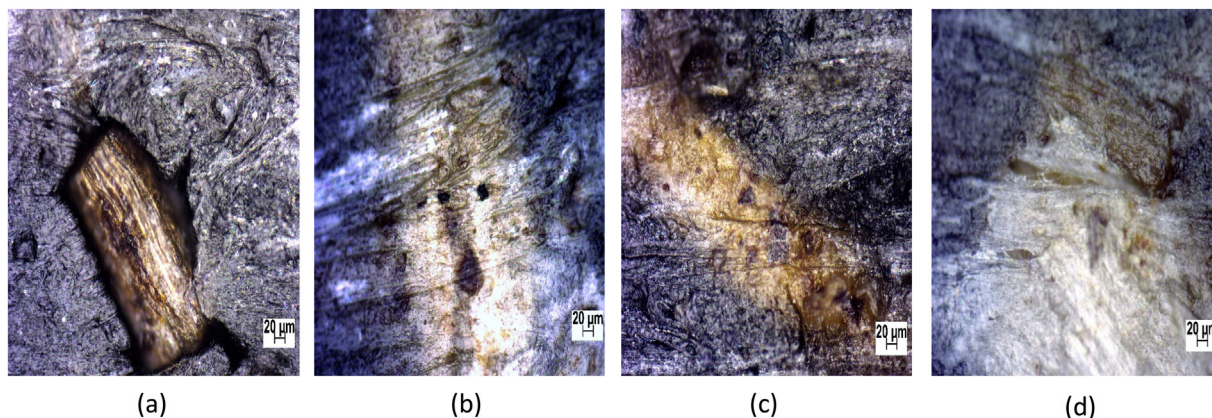


Fig. 7. Optical microscopy of the composite materials under $200\times$ magnification. (a) PPCF (without additives); (b) PPCM; (c) PPO18507; and (d) PPOCA 100.

incorporation of CAs was efficient, leading to an improved wettability of the composites, as demonstrated by the lower contact angle of pure composites.

After analyzing the mechanical composite results, it was found that the best tensile stress result was obtained for composites with Orevac CA 100. The addition of polypropylene functionalized with maleic anhydride in this composite resulted in a higher interaction with the fibers in the polymer matrix and possibly transferred the tensile load to fibers.

The outcomes obtained in this study reinforced the hypothesis that polymer-fiber interface can be improved with the use of CAs. These additives, in turn, promoted stronger chemical bonds between the polymer matrix and fibers, which may alter the surface energy of the reinforcement to allow efficient wetting between them, as pointed by John and Anandjiwala [21].

3.3. Morphological composite analysis

To better understand the results obtained from mechanical tests associated with the reinforcement theory, the samples were observed using SEM and optical microscopy. The images in Fig. 6 show the fracture region of the composites. When each material was tensioned, part of the load was absorbed by the fibers, thereby increasing the overall tensile strength of the composite, as observed by Catto et al. [22]. If the bonds between fibers and polymer matrix were strong, a rupture occurred, demonstrating that the interface itself was more resistant than fibers. When the interaction was weak, the structure could not withstand load, because fibers failed to adhere with the polymeric matrix. Fig. 6(a) shows the presence of voids and the displacement of the fibers in the composite without additive, which may indicate a low affinity between the polymer matrix and coconut fibers. These voids

may be caused by an incomplete wetting of the resin on fibers, forming air bubbles/pores (gas release) that may become trapped due to the high viscosity of the resin, or maybe due to the presence of volatile compounds that are released during process. Fig. 6(b) shows a partial adhesion of the composite using Orevac 18507. The existence of voids was verified in the interfacial region between fibers and the polymer matrix, with some fibers adhered to the polymer and still with a porous fracture surface. The same result was observed for the composite mixed with Cesa[®]Mix, as shown in Fig. 6(c), where the poor adhesion between hydrophobic matrix and CF was noted. Fig. 6(d) presents the behavior observed in composites compatibilized with Orevac CA 100. Here, due to the influence of this specific coupling agent, neither voids nor signs of fiber pullouts would be seen. This particular image revealed that a fiber shear occurred due to a better wetting and anchoring between fibers and the polymer matrix. In detail (Fig. 6), it is possible to observe the adhesion (or lack of adhesion) between fibers and the polymer matrix.

Considering the images in Fig. 7, obtained by optical microscopy, a more homogeneous surface with fewer grooves in the composites containing added coupling agents can be seen. Lower interfacial adhesion is associated with lower polarity and chemical affinity between polymer matrix and vegetal fibers, which causes the formation of voids at the interface and the appearance of failures that compromise the mechanical performance of the composites [3,21,22]. This was verified from mechanical results related to the maximum tensile strength, which was slightly lower for composites mixed with PPCA100. The PPCF composite shown in Fig. 7(a), i.e., without additives, had a more imperfect surface appearance. This indicated that the low adhesion between fibers and polymer matrix resulted in the presence of grooves and irregularities. Fibers can act as stress concentrators when submitted to tension

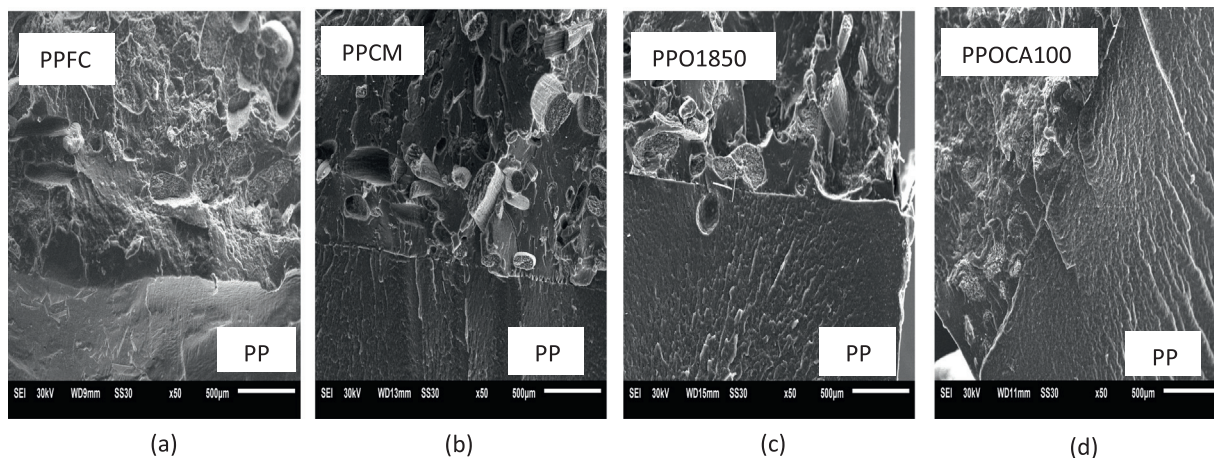


Fig. 8. SEM images of overmolded interface materials. (a) PPCF + PP; (b) PPCM + PP; (c) PPO18507 + PP and (d) PPOCA100 + PP.

loads. Considering composites that received the coupling agents, a thin layer of polymer coating fibers was observed, reducing the number of grooves and related irregularities on the surface.

The images of overmolded samples, as presented in Fig. 8, showed a partition line between the overmolded material (PP) with the substrate (composite). The sample without coupling agents (PPCF) showed a partition line between material surfaces, presenting thus a good contact area.

Although these images show regions of mechanical anchoring and possible chemical affinity, there are more voids, as presented in Fig. 9. These voids promoted a more difficult adhesion, possibly due to trapped air between interface. This behavior was observed in all formulations studied, independent of composition formulations or the presence of coupling agents.

When exposed to higher temperatures, fibers and additives can liberate gases and/or vapors. These air entrapments between two material surfaces can harm the continuous interphase, generating lower surface area and less contact between dissimilar materials [12,23]. Lower wetting reduces the interaction between phases. In surfaces with deeper roughness, it may be more difficult for trapped air to escape during the second phase injection process. However, when the air and volatiles are released, the irregularities resulted in a greater surface area and a possible increase in adhesion by mechanical anchoring.

3.4. Mechanical characterization of the overmolded samples in lap shear test and pure shear

The adhesive bonded theory of Goland and Reissner [24] about the SLJ behavior, considering an infinitely thin layer of adhesive, lead to

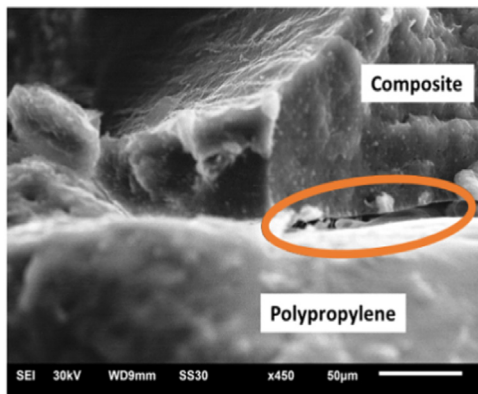


Fig. 9. Voids in the interface region of an overmolded material (PPCM + PP).

larger deflection of adherends under load. Due to bending moments generated, the joint should rotate by changing the direction of the load line with the tendency to align the applied tensile forces. As the joint rotates, the bending moment will decrease, resulting in a geometrically non-linear problem where the effects of large deflections on the adhesives generate high shear stresses at the ends. The edge of the bonded area is the critical part of it and the point where the peeling forces have higher intensity, being the main aspect the leads SLJ to fail, [8] and [16]. Fig. 10 illustrates the overmolded specimen under single lap joint test were is possible to verify the premature failure in the composite part due to bending moment.

Fig. 11 presents the mechanical properties obtained from the adhesion tests by Lap Shear Test (SLJ) and using the new device (Pure Shear), which showed a significant difference between the resulting values. Despite the good adhesion between the polypropylene and the composites, the influence of the bending moment and its secondary forces over the stress concentrators (Fig. 10) led the samples to fail prematurely at the region next to the overlap, initially at the composite side. The new test device proposes analyses of a flat state of deformation, uniformly distributing the shear stress in the welded joint, and showing the significant differences between both methodologies.

Analyzing the new methodology results, it can be observed that the addition of coconut fibers reduced the adhesion strength by 22% in relation to samples with similar materials (PP + PP), under the same injection conditions using the device. When comparing the adhesion forces between composites, the PPCF sample, which does not contain coupling agents, exhibited an adhesion force up to 30% greater than others with composites mixed with coupling agents. The presence of additives, such as mineral fillers, fibers, pigments, lubricants as well as the use of mold release during the injection, can form a thin film on surfaces, thus reducing the interaction of substrate (composite) and PP, can causing weaker bonds.

According to Besson and Budtova [25], the functionalized polyolefins, such as Orevac CA 100 and Orevac 18507, are copolymers of

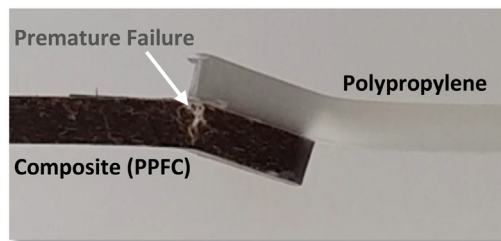


Fig. 10. Single Lap Joint Test of overmolded specimen. Source: Authors.

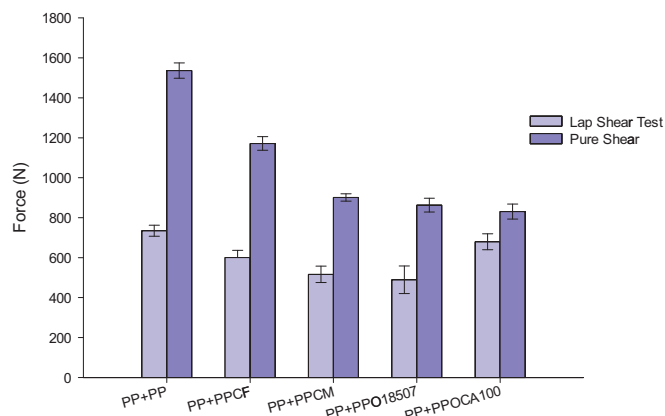


Fig. 11. Mean values of the maximum force for the overmolded test specimens.

ethylene and maleic anhydride which may contain a significant proportion of acrylic esters. The Cesa® Mix coupling agent is a titanate-based composition grafted in polyethylene, which carries lubricants. The addition of composites with these coupling agents may have negatively influenced the adhesion strength between the polypropylene and its substrate, releasing gases and volatiles in the overmolded surfaces. The adhesion strength between overmolded PP plus PPCF composite, which did not take into account coupling agents, was superior to all the formulations and about 30% higher than the pure composite PPOCA100, as opposed to the better performance of this composite when considering the mechanical properties of tensile strength and wettability (contact angle).

Although defects (voids) can act as stress concentrators, there are circumstances in which the stress concentrations resulting from interfacial voids can lead to an improvement in plastic deformation and to an increase in fracture energy. In other circumstances the surface roughness may lead to an increased scattering coefficient and good adhesion between dissimilar materials. According to Packham [9], a rough surface tends to increase the adhesion force and fracture energy. The melted polymer can flow into pores and subtract interstices, establishing mechanical engagements. The melted PP solidifies into pores and gaps promoting mechanical interlocking due to trapped air bubbles that can escape from surface.

4. Conclusion

The study of polymer adhesion by multicomponent overmolded materials is a research area that offers many opportunities for innovation. Transformative industries have been adopting modern technologies of dissimilar materials, but in most cases, rigid polymer matrices with elastomer coatings have been used, which in general present good adhesiveness. This work contributed, by means of a patented device, to a new way to evaluate adhesion forces between dissimilar materials in pure shear. This new device distributes uniformly the tension over the entire length of the overlapped joint, without the presence of undesirable forces as bending moments avoiding peeling effect. This study provides evidence of more favorable results of tensile mechanical properties of the composites mixed with coupling agents, especially PPOCA100, which present lower surface tension and better interaction with CFs. However, surface grooves and imperfections due to the low compatibility between polymer matrix and fibers discarding coupling agents provided a better adhesive force, at least for PPCF sample. This work has shown that mechanical anchoring is also a relevant form of adhesion and should be considered in future studies on the adhesion of dissimilar materials.

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