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Evaluation of mechanical performance of fiber-reinforced wood plastic composites under hostile environmental conditions

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Abstract:
Fiber-reinforced wood-plastic composites (WPCs) have garnered significant interest in several sectors, such as construction, automotive, and packaging, owing to their superior combination of strength, rigidity, and resilience to environmental deterioration. This research examines the mechanical and creep characteristics of several polymer matrices and their composites reinforced with natural and glass fibers, emphasizing the necessity of keeping processing temperatures below 200 °C to avert fiber breakdown. Polypropylene (PP), polystyrene (PS), and two types of polylactic acid (PLA) with varying crystallinity and viscosity were compounded with compatibilizers, including maleic anhydride grafted polymers, to improve interfacial bonding. Comprehensive drying processes and reactive extrusion methods guaranteed maximum moisture regulation and material uniformity. Tensile and flexural creep experiments performed under regulated humidity and temperature settings shown notable disparities in deformation and dimensional stability between pure polymers and their fiber-reinforced variants. PLA-based composites exhibited enhanced creep resistance compared to PP, which had the highest deformation due to its reduced molecular weight and tensile modulus. These findings offer significant insights into the selection and processing of bio-based and synthetic polymer composites for load-bearing applications, highlighting the essential equilibrium between mechanical characteristics and long-term dimensional stability.

Introduction

In particular, fiber-reinforced wood plastic composites (WPCs) have been the subject of substantial R&D due to the rising need for eco-friendly, lightweight, long-lasting materials. Materials with improved mechanical qualities, lower production costs, and less environmental impact are the result of combining thermoplastic polymers with natural fibers like wood flour or fibers made from agricultural waste. Fiber-reinforced WPCs are all the rage in the construction, automotive, and packaging industries thanks to their remarkable combination of durability, environmental resistance, and strength. Unfortunately, WPCs are frequently subjected to harsh environmental conditions in their practical applications. These circumstances can severely impact their mechanical performance and long-term durability. For the purpose of design optimization and reliability assurance in real-world applications, it is critical to understand how these external stresses affect the mechanical behavior of fiber-reinforced WPCs.

Natural fibers are hydrophilic, whereas polymer matrices are hydrophobic; this fundamental incompatibility is one of the main obstacles to employing WPCs in severe environments. This discrepancy might cause mechanical capabilities to degrade in damp conditions due to inadequate

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interfacial adhesion and moisture absorption. Fibers expand and plasticize when moisture gets inside, which weakens the fiber-matrix contact and lowers the material's impact resistance, flexural modulus, and tensile strength. Polymer matrix softening and fiber deterioration can be accelerated by high temperatures, and microcracks and interfacial debonding can be induced by repeated heat cycling. The degradation of natural fibers and the polymer matrix can occur by photooxidation, which in turn causes surface embrittlement, color changes, and mechanical integrity loss. UV radiation is another major danger.

Chemically harsh environments, including acids, alkalis, and solvents, can change the stability of the matrix and the composition of the fibers, further weakening the composite.

Recent studies have attempted to increase the environmental resilience of fiber-reinforced WPCs by modifying the matrix, treating the fiber surfaces, adding additives such antioxidants and UV stabilizers, and using coupling agents. Improved fiber-matrix bonding and reduced water absorption are the results of surface treatments including acetylation, silane coupling, and alkali treatment, which increase the composite's resilience to damage caused by moisture.

With the help of compatibilizers, stress may be transferred more effectively, and the interface can withstand chemical and thermal stress with less deterioration. Improving sustainability without sacrificing mechanical performance is another goal of novel polymer blends and bio-based or recycled polymers. These developments are not enough to warrant a dearth of research into the impact of various adverse environmental conditions on the mechanical behavior of fiber-reinforced WPCs over the long term. As a result, creating trustworthy prediction models and standardized testing procedures requires an understanding of the cumulative effect of environmental stresses.

Review of literature

Sbahieh, Sami et al., (2022) A large portion of the world's greenhouse gas emissions and raw material consumption occurs in the construction industry, which is notorious for its devastating effect on the environment. Thus, it is crucial for scientists to advocate for and investigate the long-term environmental effects of fiber-reinforced polymers (FRP) and other alternative alternatives. Because of their strength, light weight, resistance to corrosion, and overall longevity, FRPs have become more popular in recent years. When looking at the effects of FRP on the environment, life cycle assessment is a crucial tool to use. This research examines the mechanical and environmental characteristics of fiber-reinforced polymer composites used in concrete structures for civil engineering projects, with the goal of providing a general review of these composites. Properties, use as a strengthening technology in concrete structural elements, and environmental effect as measured by life cycle assessment are the primary areas of emphasis for fiber-reinforced polymers. Utilizing FRP composites in structural members rather of conventional materials enhances their strength and stiffness while decreasing their environmental implications, according to the mentioned literature findings.

Al-Janabi, Imad et al., (2021) in civil engineering markets, materials that are environmentally robust, low-density, and cost-effective are often required to survive harsh environmental conditions and severe loads with little maintenance and a long service life. Consequently, new building and restoration applications have established the acceptable use of sophisticated composite materials as reinforcing for many structures during the last several decades. "Fiber reinforced polymers" (FRPs) as composites have attracted a lot of attention from scientists in recent years because of their remarkable strengthening techniques for a wide range of structural applications. Structures such as bridges, buildings, tunnels, silos, tanks, and subterranean infrastructures have all benefited from the use of FRPs. Lightweight, resistant to fatigue, having high tensile strength, anti-corrosion, and thermally insulating are just a few of the reasons why FPRs have been studied as high-performance materials. The purpose of this article is to take a

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look back at the materials that go into making FRP composites and how they were designed. The review also gives a quick rundown of the advantages of FRPs over steel reinforcement in concrete structural members by analyzing the mechanical properties of FRP composites under extreme loading and environmental conditions, including their compressive, shear, flexural, and tensile strengths.

H. V., Divya et al., (2018) Because of their low weight and high specific strength, natural fiber composites are more appealing. This research has mostly focused on understanding how wood fibers affect the mechanical characteristics of extruded and injection moulded polymer composites. The compounded composites' tensile and flexural strengths were assessed using a battery of tests. Scanning electron microscopy is used to examine the interior fractures and interfacial characteristics. The findings show that when the percentage of wood particles in the composites decreases, their flexural strength rises. In comparison to wood plastic composites, pure plastic blends have a greater tensile strength.

Flores-Hernández, MA et al., (2014) Polystyrene filled with white oak flour is studied to determine the effects of particle size and wood flour content on its characteristics. The particle sizes employed were 40, 50, 65, and 100 mesh, while the wood-plastic ratios were 10:90, 30:70, and 50:50 (wt/wt). The melt flow index, tensile, bending, and impact bending strengths were measured. Furthermore, we examined the composite's density and its ability to absorb water. Particles of wood and polystyrene stuck together well, according to scanning electron microscopy. The results demonstrate that particle size and wood flour content significantly impact mechanical characteristics. There was an increase in the bending module and a decrease in the tensile module, elongation, and deflection. There was a positive correlation between particle size and impact strength. As the filler concentration rises, the melt flow index values decrease, but the water absorption increases due to the wood particles.

Materials and methods

Materials

The chosen polymer matrices keep processing temperatures below 200 °C, which protects natural fibers from major deterioration. Given its balanced modulus and impact strength at low temperatures, the baseline material, a copolymer polypropylene (PP) called Sabic PHC27 (CAS: 9010-79-1), was chosen. Its melt flow rate (MFR) was 14 g/10 min (230 °C/2.16 kg). An MFR of 3.7 g/10 min (200 °C/5 kg) of polystyrene BASF 158K (CAS: 9003-53-6) was used as a reference. The viscosity and crystallization rate were affected by the different d-isomer concentration of the two PLA variants from NatureWorks, 4043D (PLA1, CAS: 9051-89-2) and 6252D (PLA2, CAS: 26023-30-3), which had MFRs of 6 and 70-85 g/10 min at 210°C, respectively. To make it compatible, we used MAPP (CAS: 25722-45-6), SMA (CAS: 26762-29-8), and PLA-G-MA that we synthesized with acetone, maleic anhydride, and dichloroperoxide. Suspended K_2SO_4 and LiCl salt solutions, when placed in sealed containers at 23 °C, produced 90% and 11% relative humidity, respectively, for the purpose of moisture testing.

Methods

Compounding

PLA 4043D and 6252D were dried for 12 hours at 80 °C using a single Piovan DS506 desiccant tower. PS and PP were dried for 2 hours at 90 °C and 50 °C, respectively. Wood fibers were dried for 4 days at 105 °C in a vented oven and 4 days under vacuum at the same temperature to completely remove moisture. PLA-G-MA was synthesized using Zhang et al.'s reactive extrusion procedure, which improves natural fiber composite mechanical performance. Four equal combinations of 5g DCP and 15g MA in 100mL acetone were mixed with 1kg PLA1. Using the same parameters as PLA-wood compounds, 4 kg of coated PLA was compounded after vacuum drying to remove acetone. A similar procedure was used for direct compounding: 3.75g DCP, 11.25g MA, and 2.5kg PLA1 were combined in 75mL acetone to create 5kg of material. Each chemical was processed

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pure and compatible. MAPP and PLA-G-MA were dry-blended with PP and PLA1. PS utilized SMA from a third feeder. Set screw speeds to 200 rpm, vacuum to 0.7 bar, and adjust throughput depending on fiber feeder's 3 kg/h output.

Injection Molding

A 72-hour vacuum drying period at 65 ◦ C was conducted on all materials prior to injection molding. A 30-millimeter cylinder and four heating zones were utilized in the injection molding process by means of an Engel E-mac 50. Two tensile specimens and four impact/flexural specimens were produced from the test samples using the Axxicon AIM rapid change mold.

Thermal Annealing of PLA

Select PLA1 samples were put between glass plates and parchment paper to crystallize. This stack was kept in a 105 ◦ C prepared ventilation oven for two hours. The stack was then taken out of the oven and cooled to room temperature before the samples were extracted. Thermally annealed samples will henceforth be labeled “oven” in parenthesis.

Static Mechanical Test

All static mechanical tests were done after two weeks of conditioning at 23 °C and 50% relative humidity, following ISO 291 (2008) guidelines for moisture equilibrium. Zwick UPM ZMART.PRO 14740 stable tensile and flexural tests were done. We used a 100 kN load cell, hydraulic vice clamping, and a 1 µm resolution Zwick BZ1-EXZW003 macro extensometer for tensile testing per ISO 527 Extensometer was used to record tensile modulus at 1 mm/min, then automatically deleted before raising speed to 5 mm/min for the rest of the curve. The test was ended at 50% strain for unfilled PP since it routinely surpasses the hardware limit (>400%) without breaking. Flexural tests were conducted utilizing a 5 kN load cell and 64 mm span on a 3-point bending fixture, following ISO 178 (2010). The Zwick BZ1-EXZW013 extensometer (1 µm resolution) measured flexural modulus at 2 mm/min, with the curve finished at 10 mm/min. Due to the brittleness of fiber-filled materials, ISO 179-1eU (2010) impact testing on a Zwick PSW B5113.300 used unnotched samples and hammers to absorb 30–70% energy.

Creep

Since creep testing guidelines are not prescriptive, they are flexible. ISO 899-1 (2017) and ISO 899-2 (2003) outlines equipment specifications and measurement error reduction processes. The creep testing load was adjusted at 1/500 of each sample's observed modulus to guarantee relevance and comparability as material selection and design are typically based on modulus or strength. Using the identical Zwick UPM equipment for static tensile testing and a strain gauge amplifier (HBM QuantumX MX1615B), creep tests were performed. At the sample's middle, two strain gauges (HBM LY1-350-6) were mounted to reduce temperature changes in the climate-controlled chamber and detect clamp slippage. Another checking instrument was a macroextensometer. One strain gauge was attached to the active test sample and the other to a nearby control sample. HBM X60, a two-part adhesive solution of methyl methacrylate and peroxide, glued the gauges. Pre-cooling the peroxide below -10°C extended processing time. Despite the datasheet's minimal cure time of 30 minutes at room temperature, the glue cured for 16–24 hours, assuring uniformity.

Welch’s t-Test

A two-sample location test was employed to determine that the means were substantially different. Analyses employed Welch's t-tests. Regular (or Student) t-tests assume equal variance and sample test size, which is unlikely (particularly when test sample sizes vary little).

Results and discussion

Tensile Creep

The lack of dimensional stability that thermoplastics exhibit under continuous stress over time is their primary drawback. Accordingly, thermoplastics' lack of creep resistance is the material's worst flaw and a

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major roadblock to the material's widespread usage in manufacturing. The tensile creep test is not as precise as one would like. This instability and lack of straightness in the strain curves persists even after taking temperature into account and combining two strain gauges; the use of a macroextensometer disproves this. In addition, it became clear during the creep test analysis that, contrary to an earlier test, the process was not reliable enough to compare results that were quite comparable. More measurements might have helped with this, but we ran out of tensile bars, so we couldn't take any more.

Tensile Creep of Pure Polymers and Their Compatibilized Compounds

A distinct pattern emerges around 1/500 of the tensile moduli of the constituent compounds, leading to around 0.2% initial strain. You can learn a lot about the creep of polymers and their wood-reinforced composites by comparing their crys-tallinity, molecular weight, and static tensile modulus. No matter how much reinforcement is there, the creep deformation is much higher in polypropylene. However, as shown in Table 1, there are no significant differences between the different drugs in PS and PLA. Among the polymer matrices that were examined, PP displayed the very lowest tensile modulus. It also had the lowest viscosity, which translates to a reduced molecular weight. The polymer's dimensional instability is increased by these characteristics, making it more creep-prone. Glass fibers greatly increase the composite's load-bearing capability due to their high tensile strength and rigidity. The increased length of glass fibers, together with their better mechanical qualities when compared to wood fibers, further enhances performance. It followed that PP+GF35 would perform better than predicted. Worst case scenario: WF-reinforced PP showed less deformation when comparing the test results. A key difference between the WFs and GFs utilized in this study is their length. The authors Georgiopoulos et al. point out that the size of the fibers has a major impact on how they disperse in the matrix. It is suggested that using smaller fibers might lead to better distribution and less creep deformation.

The degree to which the pure polymers were deformed was inversely proportional to their tensile modulus; PP, PS, and PLA, in that order, were the most deformed polymers. An easy way to compare the creep of different materials is to look at their creep per unit of load. Of all the compounds tested, the one containing PLA1 had the least creep, and that was true even when testing pure PLA1. For the PS complex, it's the same story. Although adding fibers makes PP less creepy, compound internal flaws and intrinsic molecular characteristics can both reduce stress transfer efficiency.

Table 1: Tensile Creep Behavior of Pure Polymers and Their Compatibilized Blends

Material	Tensile Modulus	Load	Initial Deformation	1 h Creep Deformation	Total	Creep/Initial	Creep/Initial /Load
	MPa	MPa	%	%	%	%	%/MPa
PP	1150 ± 14	2.3	0.237	0.112	0.348 ± 0.020	48.2	20.96
PP+GF	11,000 ± 118	22.0	0.172	0.075	0.246 ± 0.014	46.6	2.12
PP+MAPP+F35	4910 ± 60	9.82	0.169	0.070	0.246 ± 0.08	42.3	4.31
PS	3490 ± 42	6.98	0.180	0.016	0.198 ± 0.012	10.5	1.50
PS+SMA+F35	8400 ± 106	16.80	0.192	0.020	0.216 ± 0.005	10.7	0.64

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PLA1	3820 ± 23	7.64	0.196	0.018	0.216 ± 0.011	8.6	1.13
PLA1+G-MA+F35	9230 ± 108	18.46	0.189	0.020	0.210 ± 0.005	9.2	0.50

There is an issue with the precision of different PLA materials. Also, problems with the hydraulic controls and strain gauges meant that only one PLA2 test could be successful.

Tensile Creep of Crystallized PLA and PLA Compounds

Table 2 shows that the modulus of PLA, PLA-G-MA, and fine wood fibers was further enhanced by crystallization of PLA compounds. Because of this, it can withstand a little heavier load with virtually the same creep after crystallization. Unfortunately, precise comparisons are not possible because of the accuracy issue.

Table 2: Tensile Creep Deformation of PLA Compounds and Their Oven-Crystallized Variants

Material	Tensile Modulus	Load	Initial Deformation	1 h Creep Deformation	Total	Creep/Initial	Creep/Initial/Load
	MPa	MPa	%	%	%	%	%/MPa
PLA1	3820 ± 23	7.64	0.202	0.015	0.216 ± 0.11	8.6	1.13
PLA1 (oven)	4310 ± 34	8.62	0.175	0.018	0.192 ± 0.060	11.4	1.32
PLA1+F35	9040 ± 115	18.08	0.190	0.026	0.212 ± 0.007	12.8	0.71
PLA1+F35 (oven)	9340 ± 98	18.68	0.190	0.017	0.207 ± 0.360	9.8	0.52
PLA1+G-MA+F35	9230 ± 118	18.46	0.190	0.017	0.210 ± 0.008	9.2	0.50
PLA1+G-MA+F35 (oven)	9530 ± 35	19.06	0.180	0.020	0.200 ± 0.420	10.2	0.53

Regardless of this caveat, it should be mentioned that the samples showed a trend toward less deformation during testing after annealing, in contrast to their non-annealed counterparts. One possible explanation is that heat treatment increases the crystallinity of the composites, which reduces the amount of deformation they experience. Additionally, this discovery emphasizes the possibility of using annealing to modify the internal structure of composites for use in load-bearing applications.

Flexural Creep at Various Temperatures

Flexural Creep of Pure Polymers and Their Compatibilized Compounds

The PP materials exhibit a larger creep at 1/500 of their moduli at 20 ◦ C, comparable to tensile creep, in contrast to the other materials, which are relatively similar (refer to Table 3 and Figure 1). The flexural creep resistance is often greater than the tensile creep resistance, though.

At 40 ◦ C, the creep resistance of all compounds declines to different degrees; however, the unfilled PLA1 exhibits a more pronounced creep than the filled PP compounds. At the same temperature, the creep resistance of the PLA1 compound containing natural fibers and

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compatibilizers was much lower, approaching that of PP-filled materials. At the same temperature, the creep resistance of the PLA1 compound containing natural fibers and compatibilizers is much lower, approaching that of PP-filled materials. The significant rise in deformation for PP+F35 was also indicative of the matrix's critical role in creep resistance under these circumstances. There is a strong correlation between the testing temperature and creep resistance. In addition, according to Bledzki et al., the impact of temperature might be more significant than the benefits of coupling agents.

Table 3: Comparative Two-Hour Flexural Creep Analysis of Pure and Compatibilized Polymers

			20 ◦ C		40 ◦ C		60 ◦ C	
Material	F-mod.	Load	Creep/Initial	Creep/Initial/Load	Creep/initial	Creep/Initial/Load	Creep/Initial	Creep/Initial/Load
	MPa	MPa	%	%/MPa	%	%/MPa	%	%/MPa
PP	1030 ± 32	2.06	73.1 ± 2.5	35.47	203.0 ± 4.6	98.56	302.0 ± 7.4	146.62
PP+GF	10,400 ± 403	20.8	31.3 ± 0.9	1.5	87.5 ± 1.7	4.21	159.8 ± 7.0	7.68
PP+MAPP+F35	4250 ± 247	8.50	37.1 ± 0.7	4.36	113.2 ± 2.3	13.32	177.2 ± 5.2	20.84
PS	3220 ± 106	6.44	6.5 ± 0.3	1.00	15.4 ± 0.5	2.39	165.2 ± 4.3	25.64
PS+SMA+F35	7360 ± 287	14.7	9.1 ± 0.10	0.62	28.4 ± 0.5	1.93	129.6 ± 4.0	8.80
PLA1	3430 ± 83	6.86	10.6 ± 1.3	1.55	186.6 ± 2.3	27.20	-	
PLA1+G-MA+F35	7330 ± 296	14.6	7.8 ± 0.4	0.53	93.5 ± 1.4	6.38	-	

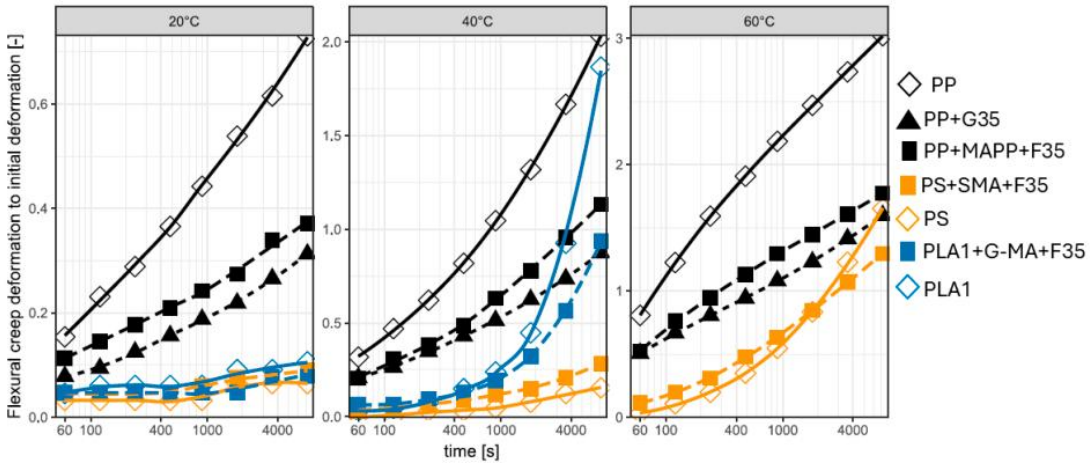

Figure 1: Flexural creep of pure polymers and their compatibilized compounds

Material based on PLA loses all strength at 60 ◦ C, which is a significant decrease. Overall, PS and its composite have better creep resistance than PP and reinforced PP, especially at 60 ◦ C, when the reinforcement significantly reduces deformation.

Flexural Creep of PLA Compounds

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At 20 ◦C, the precision is inadequate for the different PLA compounds. Fiber loading and the compatibilizer appear to be at the forefront at 40 ◦C, with the compatibilizer showing somewhat greater performance (refer to Table 4 and Figure 2). Since PLA2 has a greater viscosity, it is not surprising that it deforms more than PLA1. At the tested temperatures, coarse fibers showed superior creep resistance in this study. When compared to PLA1+MA+DCP+F35, PLA1+G-MA+F35 performed somewhat better at 40 ◦C. It is not possible to say with certainty which composite had superior matrix-fiber anchoring. It is possible that fiber aggregation is to blame for the discrepancy in readings.

Table 4: Two-Hour Flexural Creep Behavior of PLA Compounds

			20 ◦ C		40 ◦ C	
Material	F-mod.	Load	Creep/Initial	Creep/Initial/Load	Creep/Initial	Creep/Initial/Load
	MPa	MPa	%	%/MPa	%	%/MPa
PLA1	3430 ± 83	6.86	10.6 ± 1.4	1.55	186.6 ± 2.3	27.20
PLA2	3420 ± 79	6.84	12.9 ± 1.4	1.89	207.7 ± 3.7	30.36
PLA1+F35	7200 ± 183	14.40	9.5 ± 0.5	0.66	100.0 ± 7.2	6.94
PLA1+C35	7310 ± 186	14.62	6.2 ± 0.2	0.42	93.9 ± 5.3	6.43
PLA1+F17.5	5430 ± 138	10.86	7.9 ± 0.6	0.73	118.2 ± 4.4	10.88
PLA1+G-MA+F35	7330 ± 183	14.66	7.8 ± 0.6	0.53	93.5 ± 1.4	6.38
PLA1+MA+DCP+F35	7370 ± 188	14.74	9.2 ± 0.7	0.63	97.0 ± 2.0	6.58
PLA2+F35	7350 ± 187	14.70	9.0 ± 1.2	0.61	94.0 ± 2.4	6.40

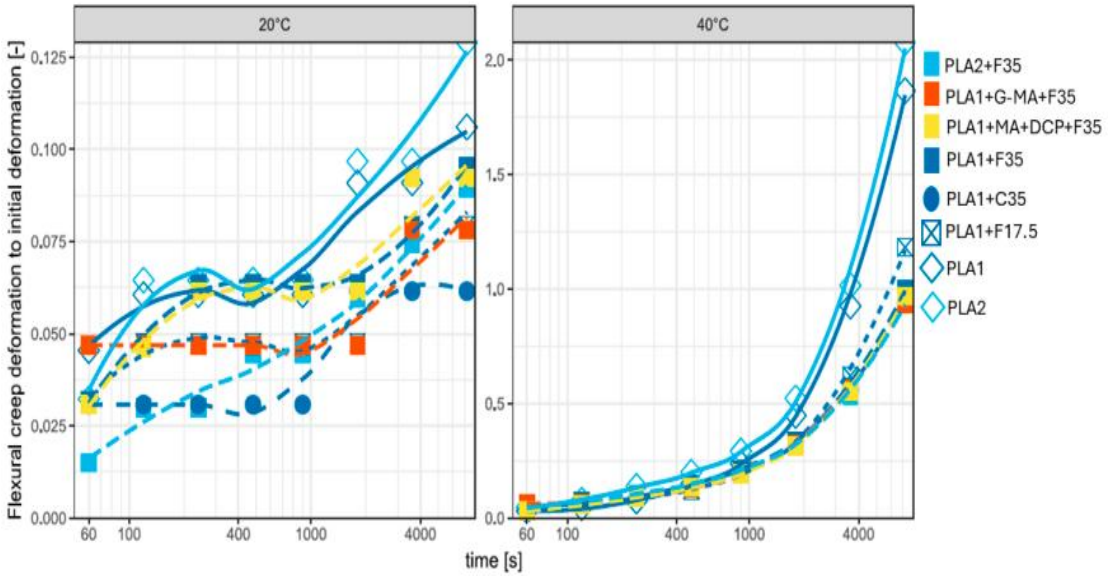

Figure 2: Flexural creep of PLA and PLA-based composites

Flexural Creep of Crystallized PLA and PLA Compounds

The test was limited to 40 ◦C and 60 ◦C since there were few crystalline PLA flexural bars available and the variations among the several PLA compounds at 20 ◦C were negligible. Under slightly higher loads of 16% and 4%,

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respectively, the unfilled and filled compatibilized PLA materials perform substantially better than their uncrystallized equivalents when annealed at 40◦C. An important step in making polymer composites more resistant to creep deformation is annealing, which increases the crystallinity of the material.

Annealing helps restore crystalline structures that were broken during manufacturing procedures like injection molding or extrusion, as pointed out by Kaavessina et al. As a result of the recovery, the polymer chains are arranged more compactly, which improves the crystallinity overall. The composite becomes less susceptible to creep under prolonged loads as a result of the increased crystallinity, which helps to create a more rigid interior structure.

Nevertheless, one must thoroughly assess the advantages of annealing in relation to any possible disadvantages. Reis et al. brought attention to the fact that spherulite formation during annealing might cause edge flaws, which can have a negative impact on the polymer's mechanical characteristics. The significance of carefully controlling the annealing conditions cannot be overstated in order to achieve the desired rise in crystallinity with minimal loss of mechanical integrity. To keep the material's improved performance without lowering its structural dependability, it is crucial to optimize these characteristics correctly.

Rapid deformation of unfilled PLA occurs at 60 ◦C. Although the pace seems to be decreasing, filled PLA deforms at a quicker rate than PP material. Keep in mind that the test loads for the full PLA and filled PP bars are 79% and 79%, respectively, and that these tests are conducted at 1/500 of their moduli (see to Table 5 and Figure 3 for details).

Table 5: Comparative Two-Hour Flexural Creep Analysis of PP, PLA, and Crystallized PLA Composites

Material	F-mod.	Load	40 ◦ C		60 ◦ C	
			Creep/Initial	Creep/Initial /Load	Creep/Initial	Creep/Initial /Load
	MPa	MPa	%	%/MPa	%	%/MPa
PP+MAPP+F35	4250 ± 247	8.50	113.2 ± 2.3	13.32	177.2 ± 5.2	20.84
PLA1	3430 ± 83	6.86	186.6 ± 2.3	27.20		
PLA1 (oven)	3980 ± 174	7.96	39.4 ± 1.4	4.95	-	-
PLA1+G-MA+F35	7330 ± 152	14.66	93.5 ± 1.4	6.38	-	-
PLA1+G-MA+F35 (oven)	7620 ± 164	15.24	43.1 ± 2.0	2.83	309.7 ± 6.0	20.32

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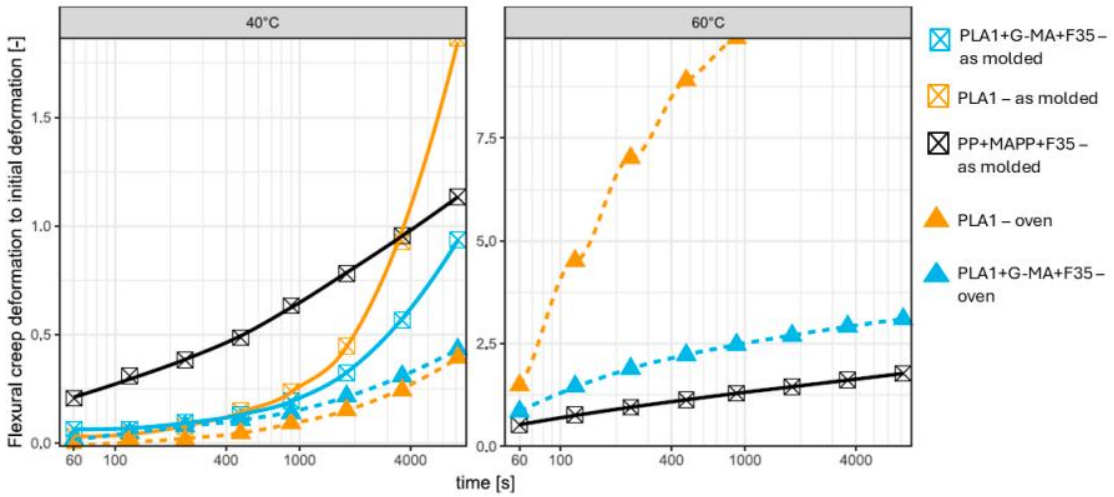

Figure 3: Comparison of Flexural Creep Characteristics between Crystallized PLA, PLA Compounds, and PP Composite

Conclusion

A thorough analysis of the creep behavior in tension and flexure, using a variety of polymer matrices and fiber-reinforced composites, highlights the importance of polymer crystallinity, molecular weight, and fiber properties in determining mechanical performance over time. Despite fiber reinforcing, polypropylene composites exhibited the largest creep deformation, which is consistent with their viscosity and lower tensile modulus. Thermal annealing, on the other hand, increased crystallinity and decreased deformation under load, further improving the dimensional stability of PLA-based composites. Interfacial adhesion was enhanced by compatibilizers such MAPP, SMA, and synthetic PLA-G-MA, leading to less creep and better stress transmission. The study also brought attention to the difficulties in properly assessing creep deformation due to methodological issues, particularly with PLA variations. This suggests that testing methodologies should be improved. Taken together, our findings shed light on how polymer composites react under continuous loading and lay the groundwork for improving bio-based materials for use in demanding industrial settings that need long-term reliability and consistent dimensions.

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