Hybridized Coir/Glass Fiber Reinforced Polypropylene Composites

Sanjita Wasti[a], Amber M. Hubbard[b], Caitlyn Clarkson[b], Halil Tekinalp[b], Soydan Ozcan[b], Uday Vaidya[a,b,c]

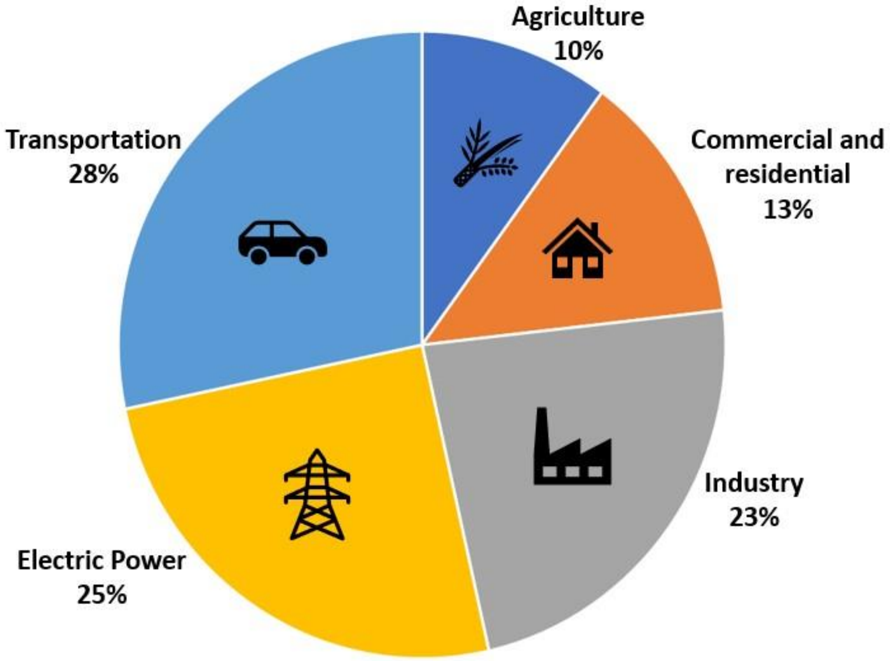
[a]University of Tennessee, Knoxville

[b]Oak Ridge National Laboratory

[c]Institute for Advanced Composites Manufacturing Innovation (IACMI)-The Composites Institute

Introduction

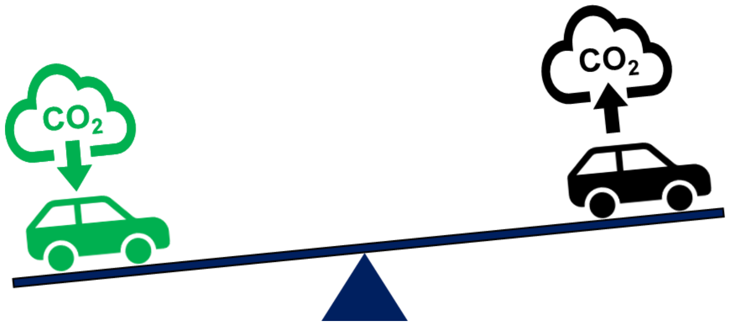
Total U.S. Greenhouse Gas Emission by Economic Sector in 2021



Source: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Governmental regulations

- ➢ Environment Protection Agency (EPA) - standards for Model year (MY) 2027-2032 vehicles -average target of GHG for the light-duty fleet (for MY 2032) - 82 grams/mile (g/mile) of CO_2.
- ➢ European Commission - 55% reduction in GHG emissions from passenger car by 2030



- ➢ 10% ↓ in vehicle's weight, 6-8% fuel saving
- ➢ 1 kg ↓ in vehicle's weight, 20 kg ↓ in CO_2

Fiber reinforced composites

- High specific strength and modulus
- Good corrosion resistance
- High energy absorption capacity and lower noise
- 35% lighter than aluminum and 60% lighter than steel

Natural fiber reinforced composites

- **Advantages**:
  - low density, good thermal and vibration insulation, low price, and biodegradability
  - 77% lower carbon footprint than glass fiber reinforced composites
- **Limitations:**
  - non-optimal compatibility with polymer matrix
  - Variation in fiber properties, high moisture uptake
  - Lower mechanical properties compared to synthetic fiber reinforced composites
- **Solution??**
  - Hybridization – combining with synthetic fibers
- Balance of mechanical performance, environmental sustainability and cost effectiveness.

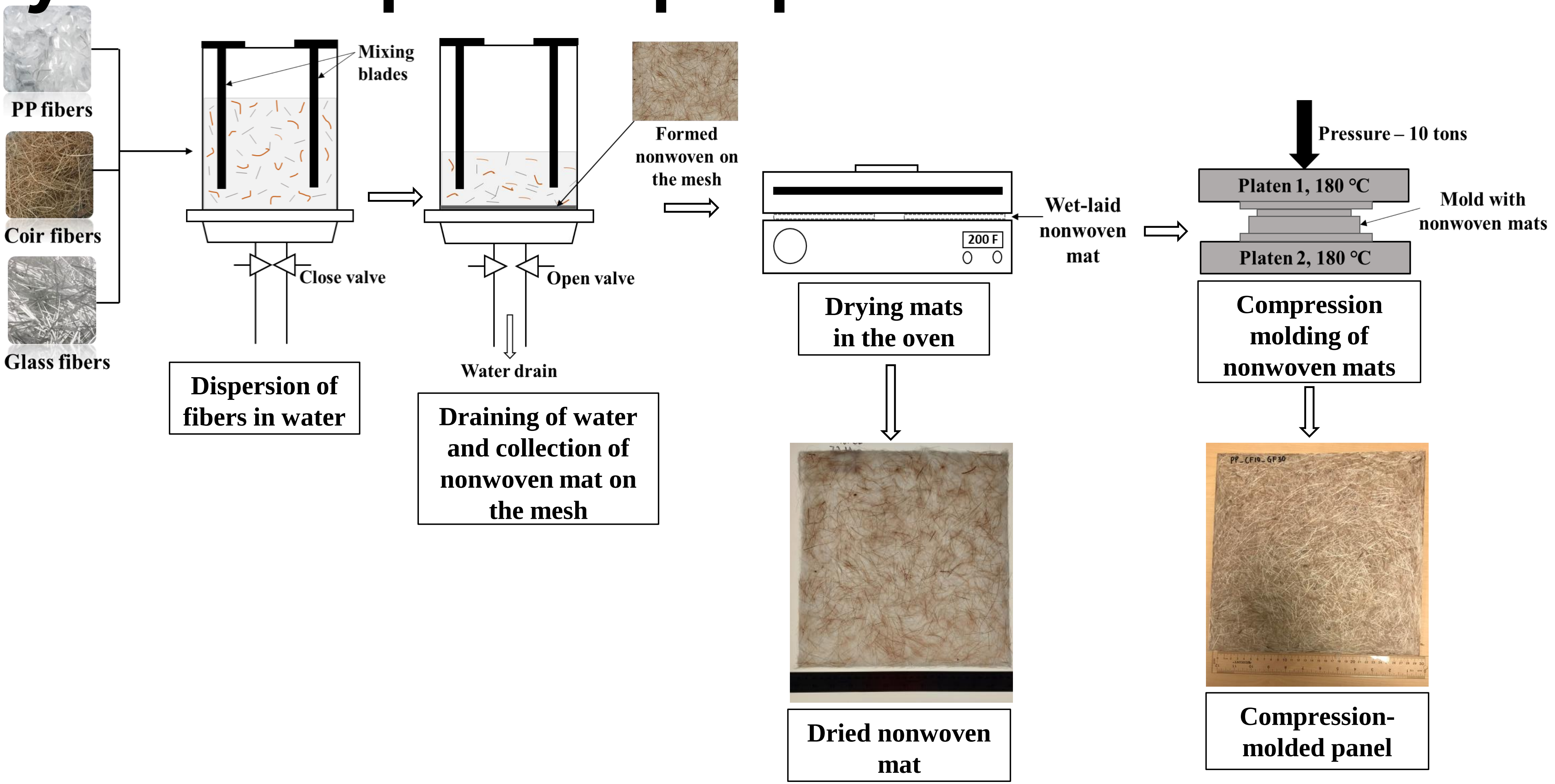
Our study…

Objective: Study the effect of glass fiber loading on physical, thermal, mechanical and water absorption properties of coir fiber-reinforced polypropylene composites.

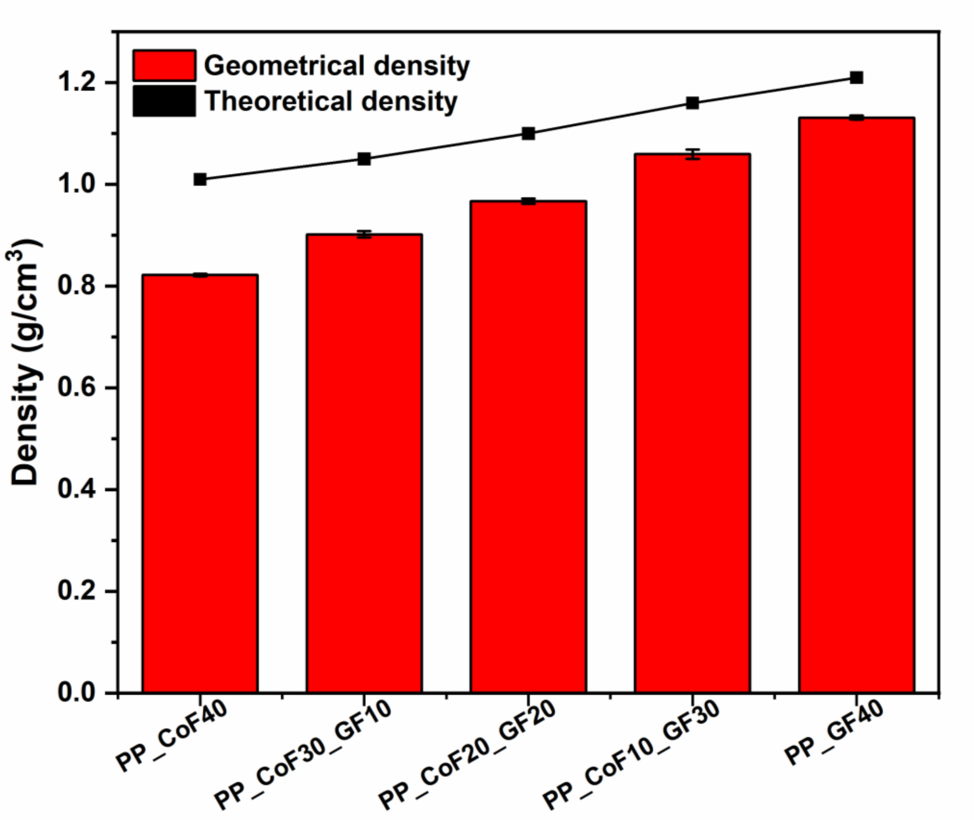
Different samples prepared along with their composition.

Sample name	Polypropylene (PP) (wt%)	Coir fiber (CoF) (wt%)	Glass fiber (GF) (wt%)
PP_CoF40	60	40	-
PP_CoF30_GF10	60	30	10
PP_CoF20_GF20	60	20	20
PP_CoF10_GF30	60	10	30
PP_GF40	60	-	40

Hybrid composites preparation



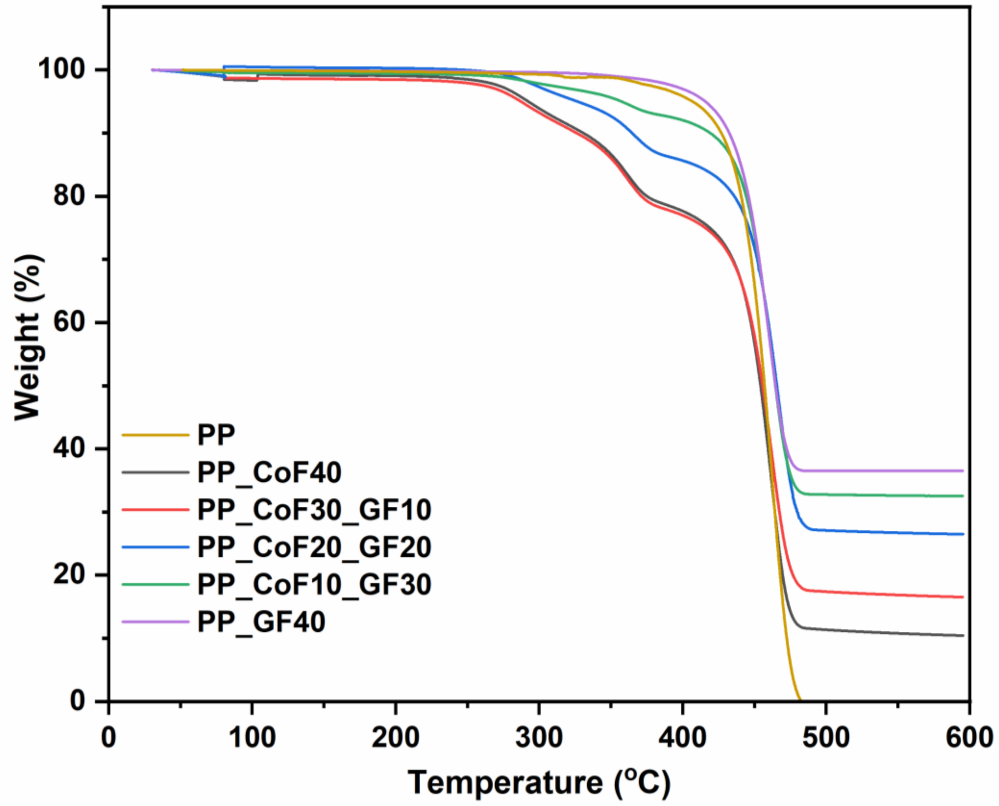
Density



Experimental and theoretical density of the studied composites. Data presented as average ± standard deviation.

- Theoretical density higher than experimental – due to the presence of micro-voids and pores.
- Decrease in density by 4%, 9% and 13% on replacing 10,20 and 30wt% GF with CoF respectively.

Thermogravimetric analysis (TGA)



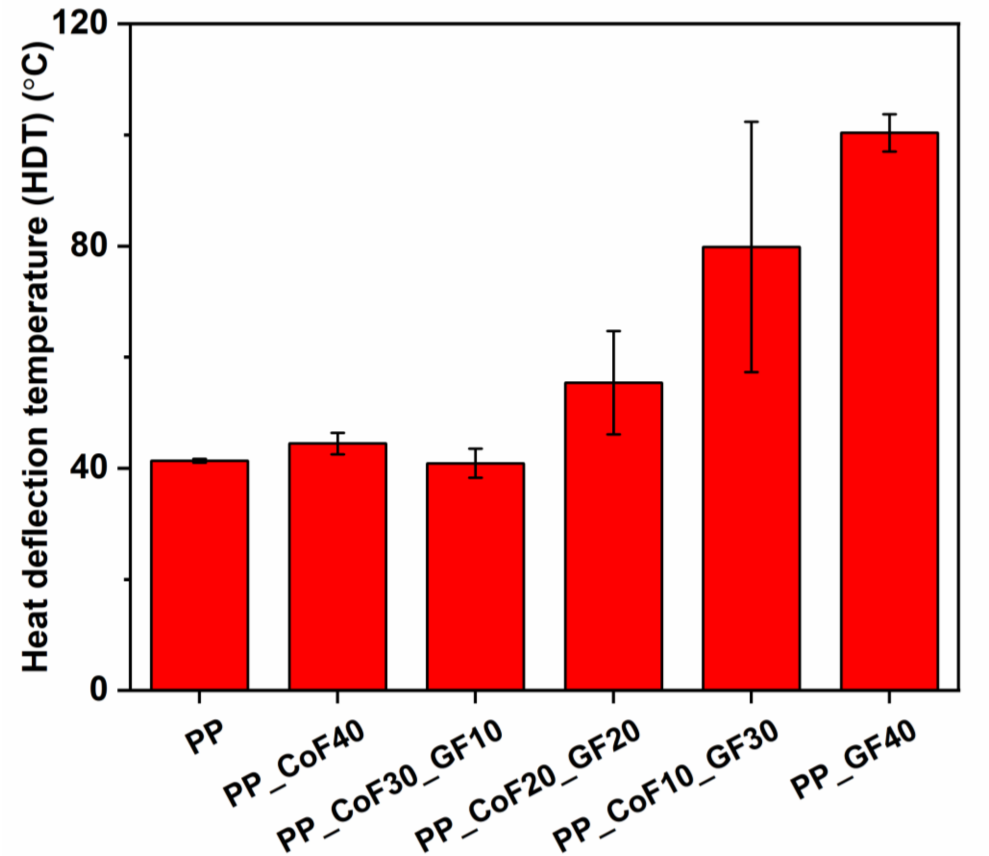
TG curve of PP and hybrid composites

Temperature at 5% mass loss (T5), temperature at 50% mass loss (T50) and residue at 600℃ for studied PP composites from TGA curve.

Sample	Temperature at 5% mass loss (T5) (℃)	Temperature at 50% mass loss (T50) (℃)	Residue at 600℃ (wt%)
PP	404.3	456.8	0
PP_CoF40	291.9	454.2	10.4
PP_CoF30_GF10	288.4	455.1	16.5
PP_CoF20_GF20	325.4	466.5	26.5
PP_CoF10_GF30	358.1	464.9	32.5
PP_GF40	414.4	463.9	36.5

Improved thermal stability with the addition of glass fibers.

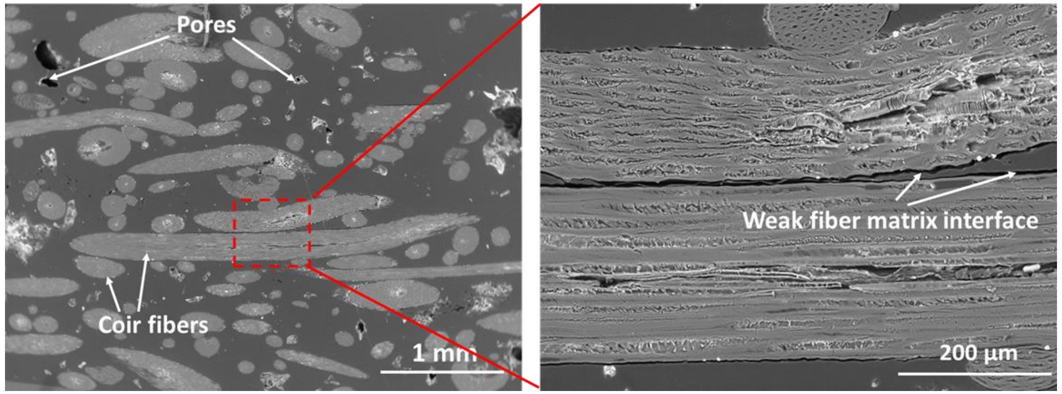
Heat deflection temperature (HDT)



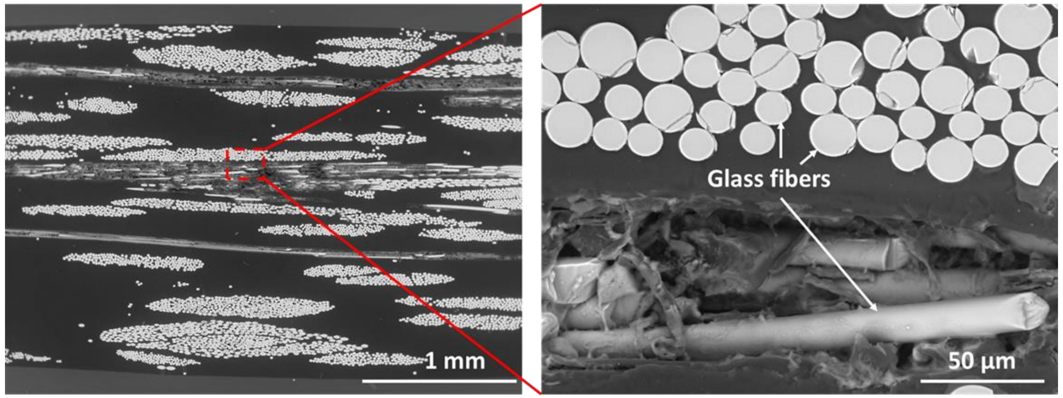
HDT values for all composites at high-stress values of 1.82 MPa. Data presented as average ± standard deviation.

- Improvement in HDT values with addition of glass fiber
- Increased error due to heterogenous mixing

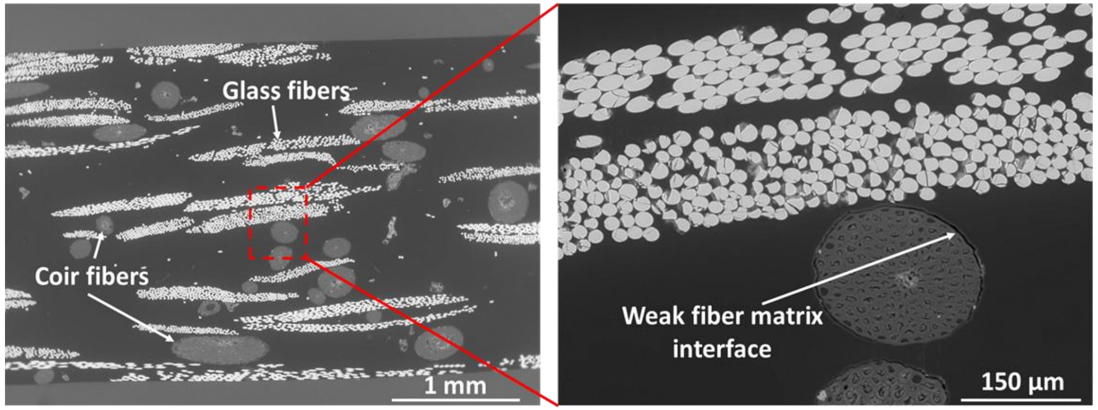
Scanning electron microscopy (SEM)



SEM micrographs of the polished cross-sectional areas of PP_CoF40

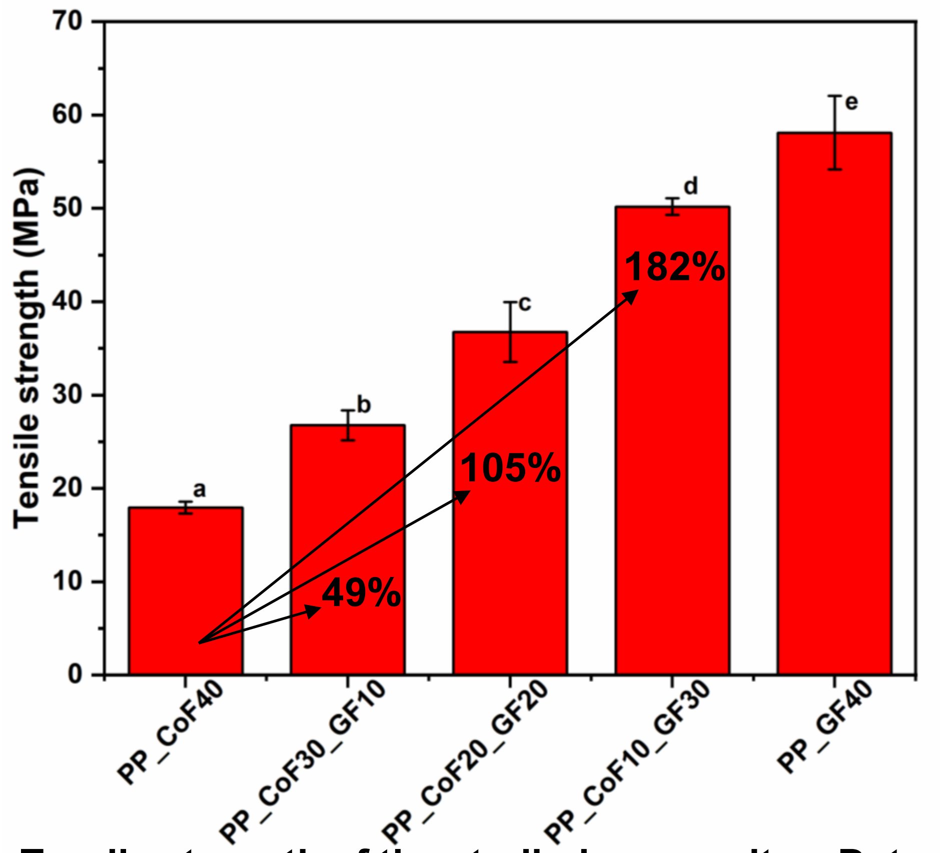


SEM micrographs of the polished cross-sectional areas of PP_GF40



SEM micrographs of the polished cross-sectional areas of PP_CoF10_GF40

Tensile properties



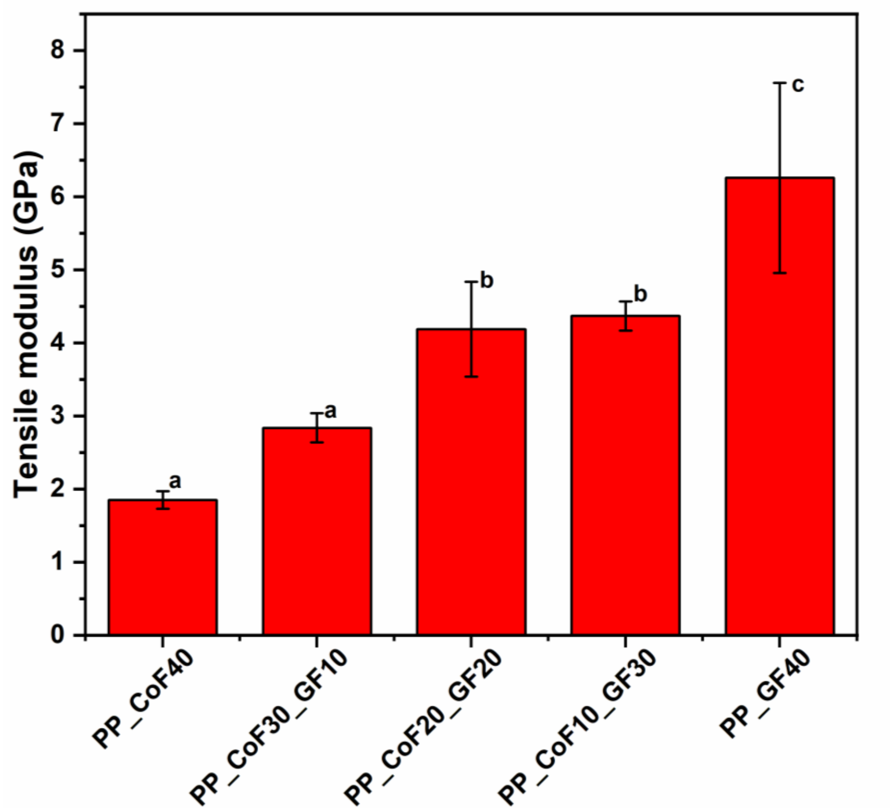
Tensile strength of the studied composites. Data presented as average ± standard deviation. Different letters (*i.e.* a, b, c and d) denote statistically different at $p < 0.05$.

- Decrease in tensile strength with 40wt% coir fiber reinforcement (by 35%) – due to non-optimal adhesion between fiber and matrix.
- Increase in strength on hybridization.
    - stronger glass fiber
    - Improved interaction between glass fiber and PP
    - Retention of fiber length in the final composites
- Other studies:
    - Jarukumjorn et al. [3] – insignificant improvement in tensile strength by replacing 20 wt% sisal fiber with GF in PP/sisal (30 wt%) composites
    - Kahl et al.[4] – no improvement in strength on increasing GF.
    - Manufacturing technique – compounding followed by injection molding

[3] Jarukumjorn K, Suppakarn N. Effect of glass fiber hybridization on properties of sisal fiber-polypropylene composites. Compos Part B Eng 2009;40:623–7

[4] Kahl C, Feldmann M, Sälzer P, Heim HP. Advanced short fiber composites with hybrid reinforcement and selective fiber-matrix-adhesion based on polypropylene – Characterization of mechanical properties and fiber orientation using high-resolution X-ray tomography. Compos Part A Appl Sci Manuf 2018;111:54–61.

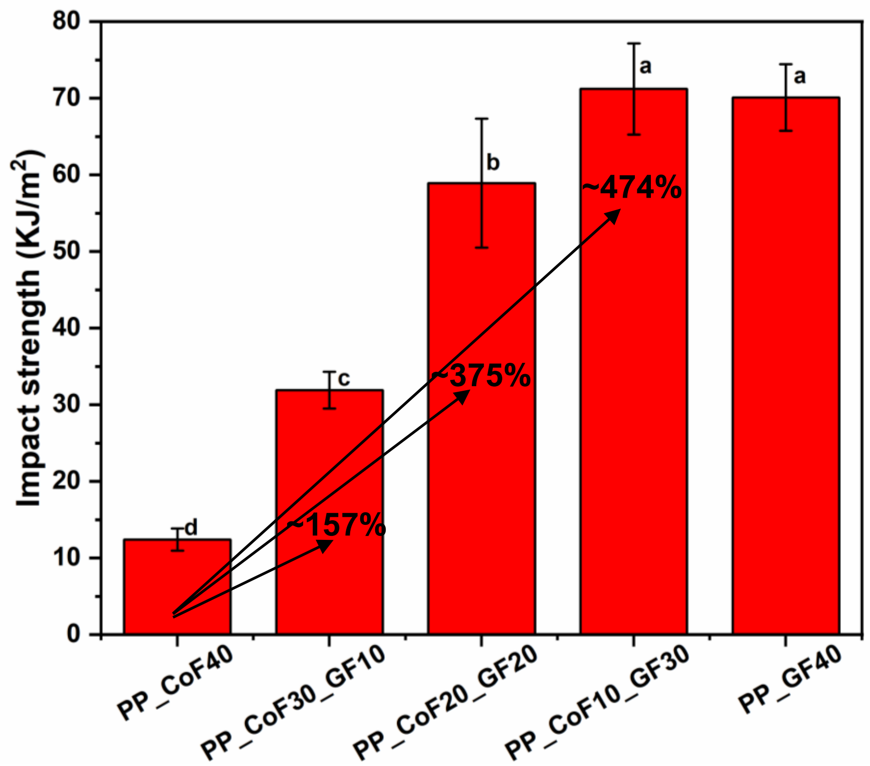
Tensile properties



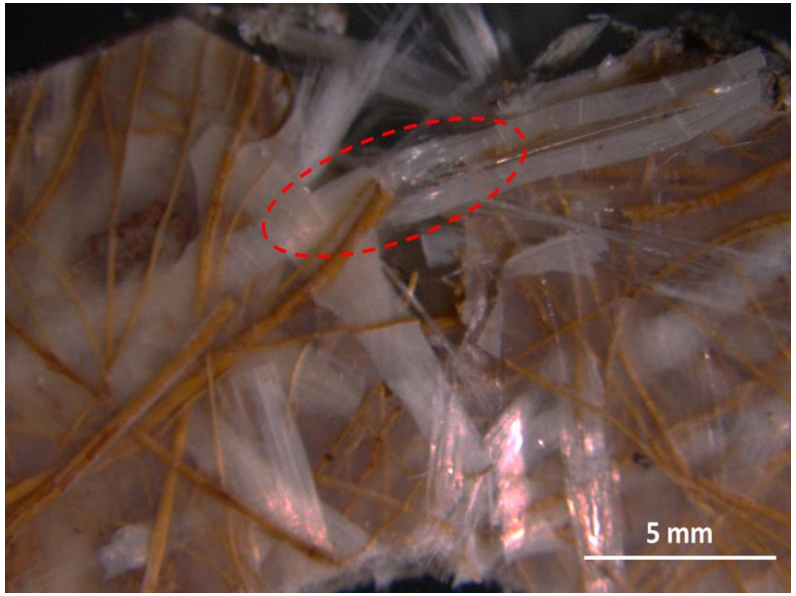
Tensile modulus of the studied composites. Data presented as average ± standard deviation. Different letters (*i.e.* a, b, c and d) denote statistically different at $p < 0.05$.

- Increase in tensile modulus of PP by 17% with 40wt% coir fiber reinforcement
- Increase in tensile modulus by 54-130%
- higher stiffness of glass fiber (72.30 GPa) compared to coir fiber (1.98 GPa)
- Improvement in flexural strength and modulus by 41-104% and 64-193% respectively.

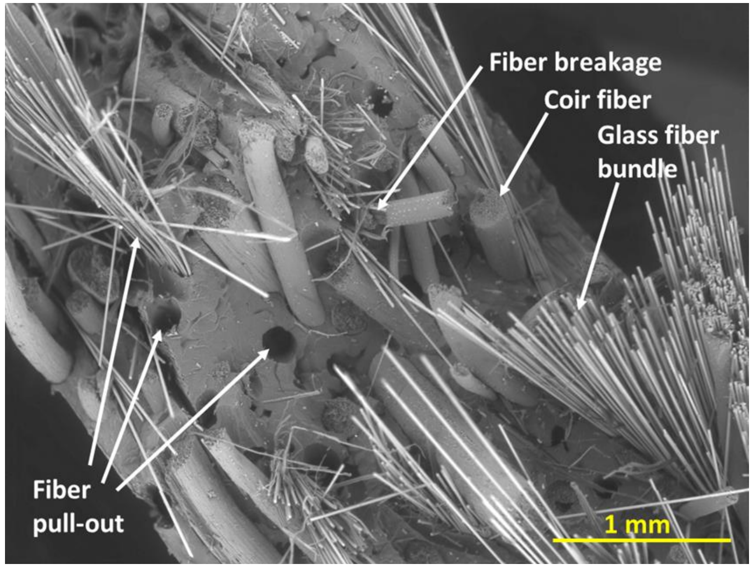
Impact properties



Impact strength of coir, glass and hybrid coir and glass fiber reinforced PP composites. Data presented as average ± standard deviation. Different letter denote statistically different at $p<0.05$.

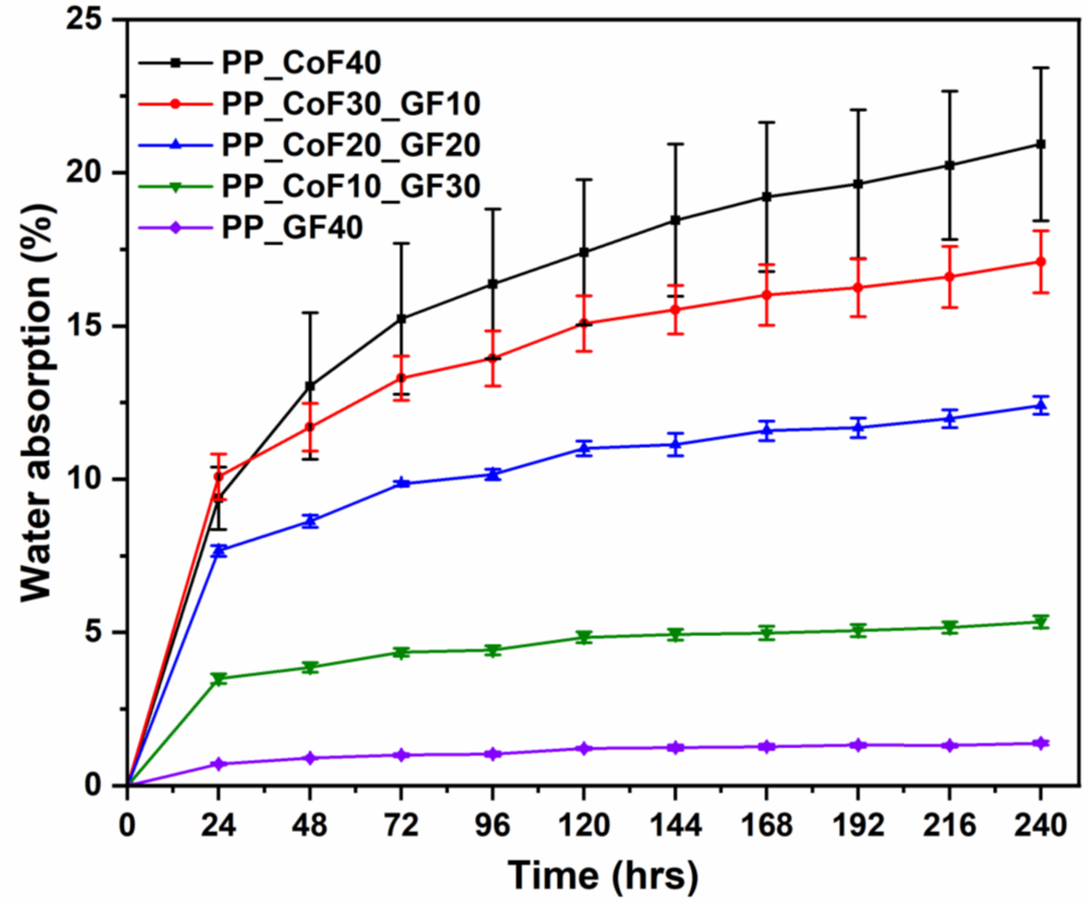


Izod impact tested PP_CF20_GF20 sample showing GF resisting complete failure



SEM image of fractured sample indicating fiber pull-out and fiber breakage

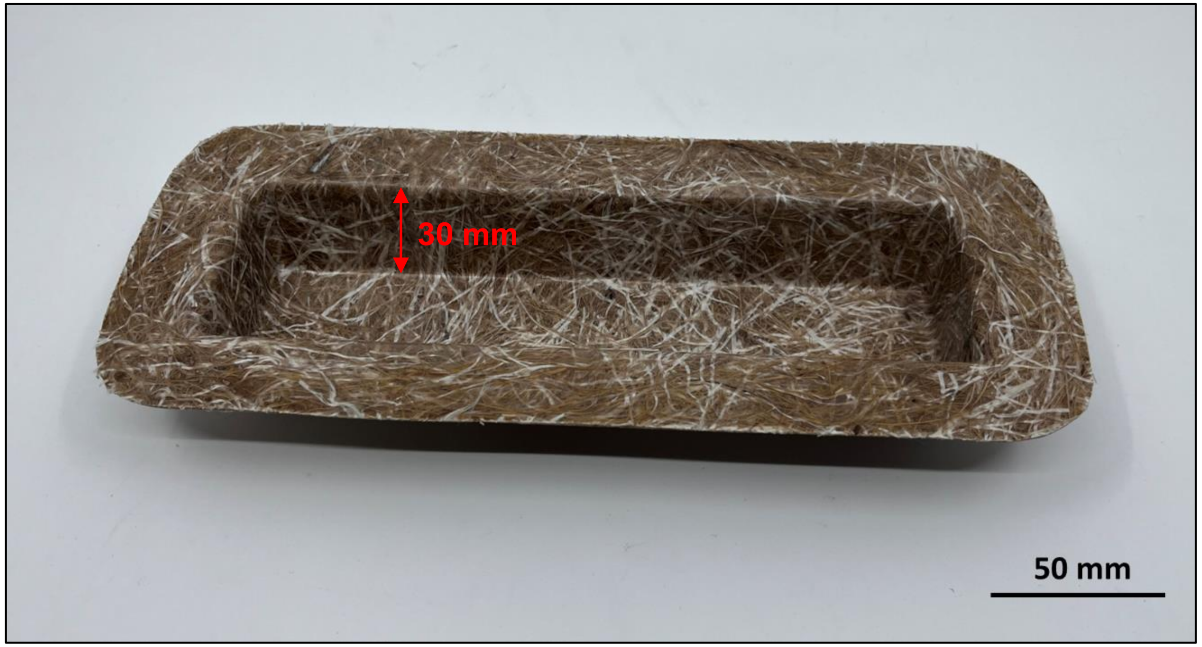
Water absorption

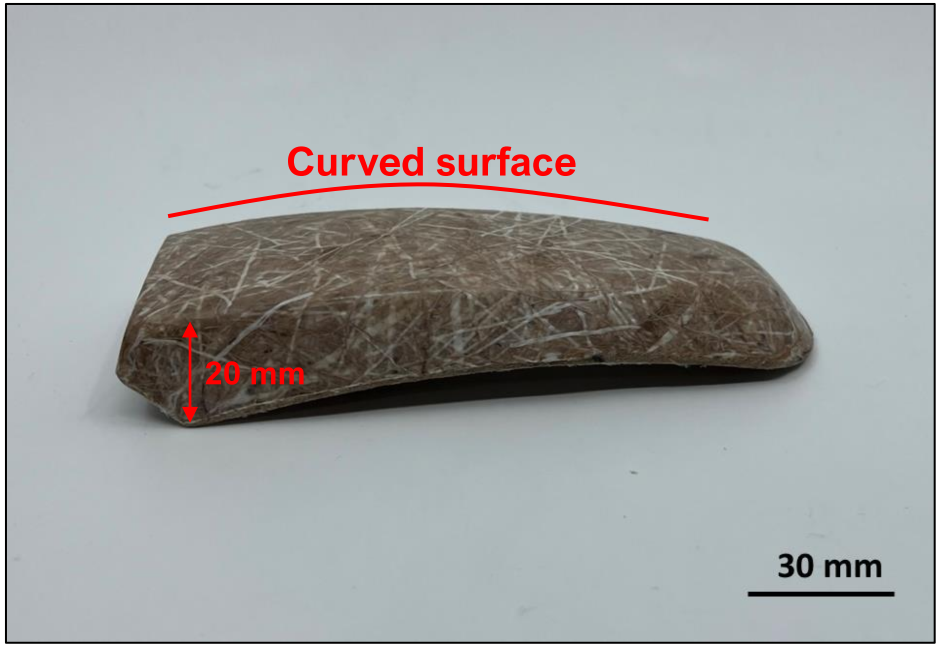


Water absorption curve for coir and glass fiber reinforced hybrid PP composites.

- Water absorption mechanism in composites:
  - absorption by fiber strands itself via hydrogen bonding,
  - diffusion through capillary gaps between fiber and matrix,
  - micro or nano gaps or void in between chains of base matrix,
  - microcracks from the surface of the composites.
- Decrease in water absorption by 18-74% on substituting coir fiber with 10-30wt% glass fiber.

Manufacturing representative automotive part shapes





Representative automotive part shapes made by compression molding coir (20wt%)/glass (20wt%) fiber reinforced polypropylene non-woven mats (prepared via wet-laid technique).

- Thickness of the first part was ~2.5 mm and that of the second part was ~3 mm.
- Ability of these nonwoven hybrid mats to form such complex shapes with deep draws and features

Conclusion

- Distinct effect of hybridization – due to no glass fiber attrition during the manufacturing process.
- Light weight compared to glass fiber-reinforced composites.
- Improved thermal stability.
- Enhancement in mechanical properties:
  - Tensile strength and modulus by 49-182% and 54-130% respectively
  - Flexural strength and modulus by 41-104% and 64-193% respectively
  - Impact strength by 157 - 474%
- Decrease in water uptake behavior by 18-74%.
- Promising alternative to metal and/ or synthetic composites for automotive and related applications.

Acknowledgment

- US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Advanced Materials and Manufacturing Office.
- Manufacturing Renew3D Oak Ridge National Laboratory/University of Maine Hub & Spoke Program team.
- Fibers and Composites Manufacturing Facility (FCMF)–UTK team.
- Institute of Advanced Composites Manufacturing Innovation (IACMI).

Thank you !!!