Comparative analysis of vibration, flexural, and Impact properties of PLA-ABS composites for structural applications

Abin Paul, *Santhu Varghese* Thomas, *Arun* Jose, Rabi J, and *Manuel* George*

Department of Mechanical Engineering, Mangalam college of Engineering, Ettumanoor, Kottayam - 686631, APJ Abdul Kalam Technological university, Trivandrum, India

Abstract. This work investigates the flexural and vibration characteristics of several PLA-ABS composites. Modal analysis was used to determine the intrinsic frequencies and mode forms of different composite constructions, providing information about their dynamic performance. According to the current vibration research, PLA40/ABS60 displayed the highest mode 1 and mode 2 frequencies, indicating higher resistance to secondary vibrations, while PLA60/ABS40 produced an extraordinarily high mode 3 frequency of 928.75 Hz, showing enhanced rigidity. The results show that the resonance peaks shift to higher frequencies when ABS is added, indicating improved damping and stiffness properties. PLA100 and ABS/PLA/ABS composites had the highest maximum stress, indicating greater strength, according to tests of flexural modulus and impact strength. The greatest deflection was displayed by PLA40/ABS60, indicating increased flexibility but decreased strength. In impact tests, PLA50/ABS50 had the best energy absorption and durability with the maximum impact strength of 9757.47 J/m, closely followed by PLA100. Therefore, sandwich configurations like ABS/PLA/ABS enhance vibrational behavior and dynamic performance, whereas PLA/ABS composites with ideal blending ratios strike a balance between strength and flexibility.

1 Introduction

In the manufacturing sector, thermoplastic polymers like polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are frequently utilized, especially in structural and 3D printing applications. High tensile strength, stiffness, and environmental sustainability are all provided by PLA, a biodegradable and biobased polymer made from renewable resources. While its brittle nature and poor impact resistance often limit its application in high-stress environments. ABS is a petroleum-based polymer, which is known for excellent toughness, impact resistance, and thermal stability, but it exhibits lower stiffness and higher density compared to PLA. Blending PLA and ABS creates a composite that got advantages improved strength and rigidity of PLA with the durability and toughness of ABS. Such hybrid composites exhibit improved mechanical and thermal properties, making them suitable for structural applications.

* Corresponding author: manuel.george@mangalam.in

K. Dhinesh et al.[1] reported with 20% ABS- 80% PLA obtained maximum load of 1.18kN, and UTS of 21.4MPa. while 50% ABS 50% PLA got flexural load of 34.4N and 19.11 MPa flexural modulus. The sandwich's tensile qualities are enhanced by the 20% ABS-80% PLA blend, which may even surpass 100% PLA. In contrast to the other specimens, the 50–50 Sandwich has demonstrated the highest flexural strength.

According to Mahros Darsin et al. [2], a PLA-ABS combination enhanced flexural strength by up to 33.12 MPa. The flexural strengths of PLA-PP, PLA-PP-ABS, and PP-ABS were 14.90, 14.59, and 12.10 MPa, respectively, but they were less than half that of PLA-ABS. During the bending test, all alloy combinations—aside from PLA-ABS—delaminated. A specimen's flexural strength decreases due to delamination.

Panes et al. [3] found that ABS had a modulus of 0.943 GPa when the infill was increased to 50%, which led to an 18.5% increase in weight and a 25.19% increase in tensile strength, whereas PLA had a modulus of 1.343 GPa when the infill percentage was increased.

The mechanical performance of poly(lactic acid) (PLA), acrylonitrile butadiene styrene (ABS), and nylon 6 made using fused deposition modeling (FDM) and traditional injection molding was examined by Lay, M. et al. [4]. When compared to injection-molded samples, the FDM samples' tensile strength, Young's modulus, elongation at break, and impact strength were roughly 48%, 50%, 48%, and 78% lower. The findings show that FDM manufacturing can produce the finished goods more effectively.

Algarni[5] reported ABS tensile strength of 34.6 MPa and 30.9MPa received for 0.2mm and 0.4mm layer thickness with 0 degrees raster angles and tensile strength of 27 MPa with 80% infill density. Maximum impact strength of 27.5kJ/m2 with crisscross (45/-45 degree) and a maximum flexural strength of 78.2MPa.

According to Dhinesh, S. K. [6], 20% ABS and 80% PLA produce maximum loads of 1.18 kN, 1.07 kN, 0.83 kN, and UTS of 21.4 MPa.TGA, the thermal breakdown of PLA at Td = 356 °C with a weight loss of around 99.8%, was reported by San Andrés [7]. Tg = 63 °C, Tc = 113 °C, and Tm = 151 °C, but ABS Td = 412 °C with a 99.7% weight loss. The amorphous structure of the ABS polymer with T g = 106 °C was demonstrated by the DSC diagram.

2 Material preparation

The composite filaments PLA and ABS purchased from Tesseract Premium of 1.75mm diameter, Dimensional Accuracy +/- 0.03mm. The samples were then prepared in standardized ASTM dimensions by Semi grade industrial 3D printer 3D 300i supplied by EMI Bangalore (refer with: Figure 1) for mechanical testing, including tensile, vibration, flexural, and impact assessments. The formulations were designed to investigate the influence of ABS on the overall mechanical performance of PLA composites. The printing parameters are standardised, as to dictate the quality and anisotropy of the final printed samples. Layer height of 0.1 mm maintained as a smaller layer height improves bonding but increases printing time. Infill density maintained as 100% for maximum strength and accurate material property measurement. The infill pattern kept rectilinear as it affects how stress is distributed internally. Raster Angle as +/- 45° common for balanced properties directly dictates the strength, modulus, and stiffness when measured under tensile or flexural loading. It also affects the propagation of vibrational waves. Nozzle temperature for PLA (220 °C) and ABS (230°C) to ensure proper melting and flow.

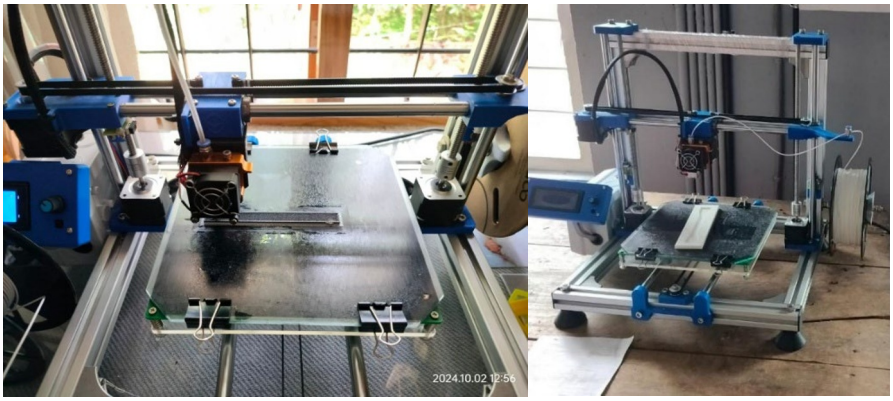


Fig. 1. 3D printing of samples.

Table 1. Material properties table: Properties of ABS, PLA.

Properties	**ABS**	**PLA**
Density	1.4 g/cm3	1.3 g/cm3
Melting Point	200 ℃	173 ℃
Biodegradable	No	Yes
Glass Transition Temperature	105 ℃	60 ℃
Tensile Strength	~40 MPa	~60 MPa
Flexural Strength	~65 MPa	~100 MPa
Elastic Modulus (Tensile)	~2.1 GPa	~3.5 GPa

3 Vibration properties

Free vibration tests were conducted using an accelerometer (Model 352C22, sensitivity: 10.44 mV/g), impulse hammer (Model 5800SL, sensitivity: 104.5 mV/lbf), and DAQ system (NI9234), with analysis performed via Dewesoft 7.1.1 software. The system's natural frequencies and modal shapes can be found and the system's dynamic responses can be predicted by first conducting a modal analysis. Understanding a structure's modal frequencies is crucial because it helps prevent resonance and possibly serious reactions or failure if the frequency of any applied periodic loading coincides with a modal frequency. The dimensions of the manufactured specimens for the vibration test are 210 x 30 x 4 mm. (refer with: Figure 2)

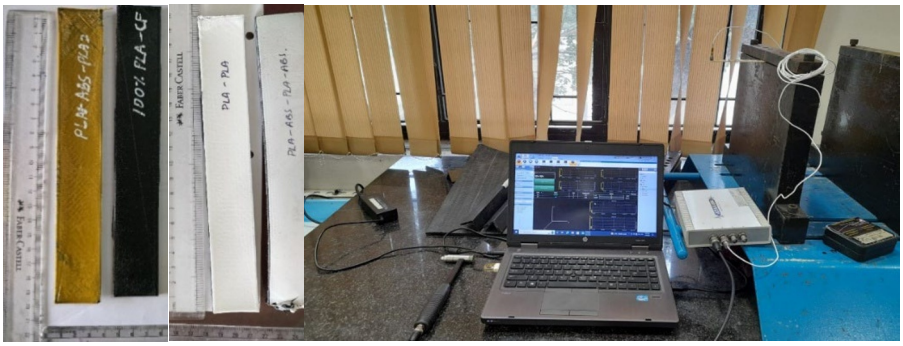


Fig. 2. Samples for vibration testing and setup.

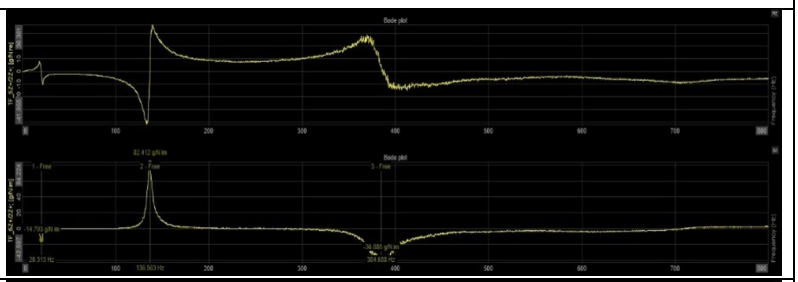
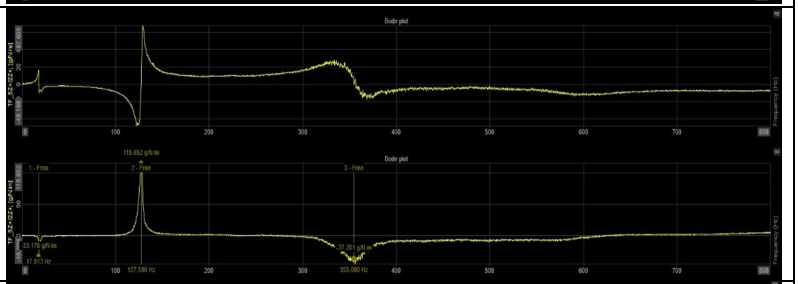
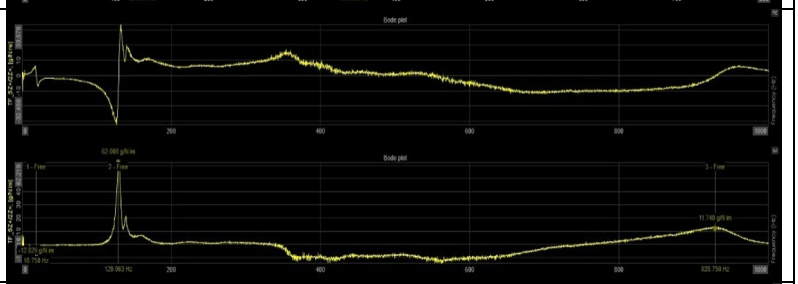
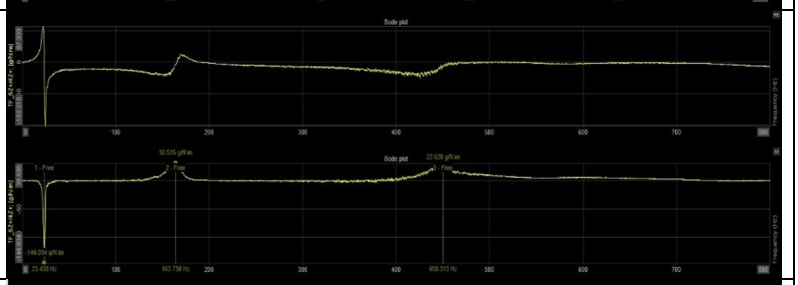
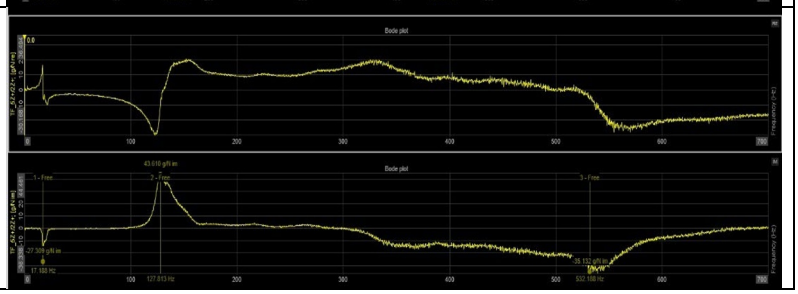
Samples	Mode shapes
PLA100	
PLA50/ABS50	
PLA60/ABS40	
PLA40/ ABS60	
ABS/PLA/ABS	

Fig. 3. Mode shapes of samples.

Table 2. Vibration results.

	Mode 1	**Mode 2**	**Mode 3**
PLA100	20.412 Hz	136.560 Hz	384Hz
PLA50/ABS50	17 Hz	127.5 Hz	355.500 Hz
PLA60/ABS40	18.75 Hz	129.083 Hz	928.75 Hz
PLA40/ ABS60	23.43 Hz	163.759 Hz	450Hz
ABS/PLA/ABS	21Hz	140Hz	521.563 Hz

For PLA100 first peak occurs at approximately 20.412 Hz, showing a significant resonance. Second peak obtained at 136.560 Hz. Overall, there is a smoother profile above 400 Hz and a noticeable response at lower frequencies. PLA50/ABS50 has a greater resonance frequency than 100% PLA, with the initial peak occurring at about 17 Hz. Around 127.500 Hz is the second peak. In contrast to 100% PLA, the resonance moves to higher frequencies, although the overall response exhibits a similar trend. Higher resonance frequencies are reached when ABS is added to PLA composites. Changes in mechanical qualities are indicated by small differences in resonance intensity and damping behavior.

The initial peak of PLA60/ABS40 has a resonance frequency of 18 Hz. In comparison to the other samples, the second mode frequency was lower (129 Hz) and the third mode frequency was higher (928 Hz). The first resonance frequency of PLA40/ABS60 is higher, at 23.43 Hz. a wider variety of resonance responses, including the third mode at 450 Hz and 163.759 Hz. (See Table 1.)

PLA40/ABS60 once more displayed the highest frequency at 163.759 Hz for mode 2 (see Figure 3), indicating superior resistance to secondary vibrations. ABS/PLA/ABS followed at 140 Hz, demonstrating how well the sandwich arrangement improves dynamic performance. PLA60/ABS40 showed a remarkably high frequency of 928.75 Hz for mode 3, indicating enhanced stiffness at higher modes, potentially as a result of structural resonance. The enhanced vibrational behavior in a layered configuration was reinforced by ABS/PLA/ABS at 521.563 Hz, indicating greater heterogeneity in frequency-dependent characteristics.

The natural frequency (fn) or resonance frequency of a structure is fundamentally determined by the ratio of its stiffness (K) to its mass (M),

$fn= \sqrt{K/M}$

Since the mass of the vibrating part is directly proportional to the material's density and volume, density variations between the samples directly influence the resonance frequency.

PLA is less dense (1.3 g/cm^3) than ABS (1.4 g/cm^3). As the proportion of the denser ABS increases (e.g., going from PLA100 to PLA40/ABS60), the overall density of the composite also increases. PLA40/ABS60 (60% ABS content) showed the highest first mode frequency (23.43 Hz) and second mode frequency (163.759 Hz). Based on density alone, the PLA40/ABS60 (denser) should have a lower natural frequency than PLA100 (less dense). The increase in frequency must be primarily driven by a significant increase in stiffness (K) that outweighs the increase in mass (M) from the denser ABS. This suggests the specific blend ratio of PLA40/ABS60 creates an extremely rigid structure for resisting vibration in those modes, possibly due to optimal load distribution within the structure.

Acrylonitrile Butadiene Styrene (ABS) is a two-phase system, a rigid Styrene-Acrylonitrile (SAN) matrix with dispersed elastomeric Polybutadiene (PB) rubber particles is the key component for damping. Polybutadiene has an extremely low Glass Transition Temperature (Tg), typically around -85 °C to -90 °C. The polymer chains experience large-scale segmental motion (uncoiling, sliding, and turning) when the composite vibrates. By resisting the applied strain, this molecular action transforms mechanical energy into thermal energy. This process is known as viscoelastic energy dissipation.

Higher ABS content provides more of these energy-dissipating sites. This leads to higher internal friction within the composite. Higher internal friction typically results in greater damping. In the modal analysis, this manifests in two ways, at lower resonance peak

amplitude the material absorbs more energy, preventing large resonant oscillations. Broader resonance peaks energy dissipation mechanism is active over a wider frequency range.

The PLA-ABS composites combine the stiff PLA matrix with the soft, energy-absorbing rubber domains of ABS. The molecular motions within the ABS domains effectively dampen the vibrations that the rigid PLA structure initiates or transmits.

PLA has a relatively high Tg of 60°C and is highly rigid below this temperature. Neat PLA primarily dissipates energy through crazing or micro-cracking (brittle failure mechanisms) rather than large-scale, repeatable molecular motion, resulting in lower intrinsic damping compared to the ABS blends.

4 Flexural analysis

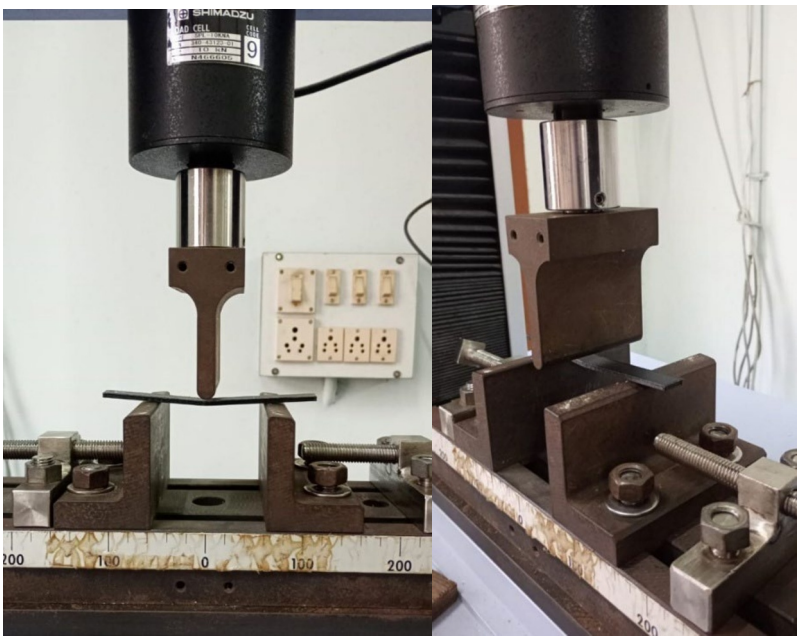


Fig. 4. Flexural test setup.

Fig. 5. Test samples.

Table 3. Sample test parameters.

Test Mode	Test Type	Speed	Shape	Thickness mm	Width mm	Lower support mm
Single	3 Point Bend	1mm/min	Plate	3	13	52

Table 4. Sample flexural test results.

Sample	Max Force N	Max Stress N/mm2	Max Stroke mm	Max Strain %	Max Time sec
PLA100	87.5028	58.3352	6.88618	4.58399	413.23
PLA50/ABS50	45.9735	30.649	5.04468	3.35814	302.74
PLA60/ABS40	73.9352	49.2901	6.612	4.40148	396.78
PLA40/ ABS60	75.8934	50.5956	8.48455	5.648	488.01
ABS/PLA/ABS	70.2334	46.8222	6.7125	4.46838	402.81

The flexural samples prepared were according to 52*13*3mm (ASTMD790) performed on the machine Shimadzu agx plus. (refer with Figure 4) Test samples shown in Figure 5.

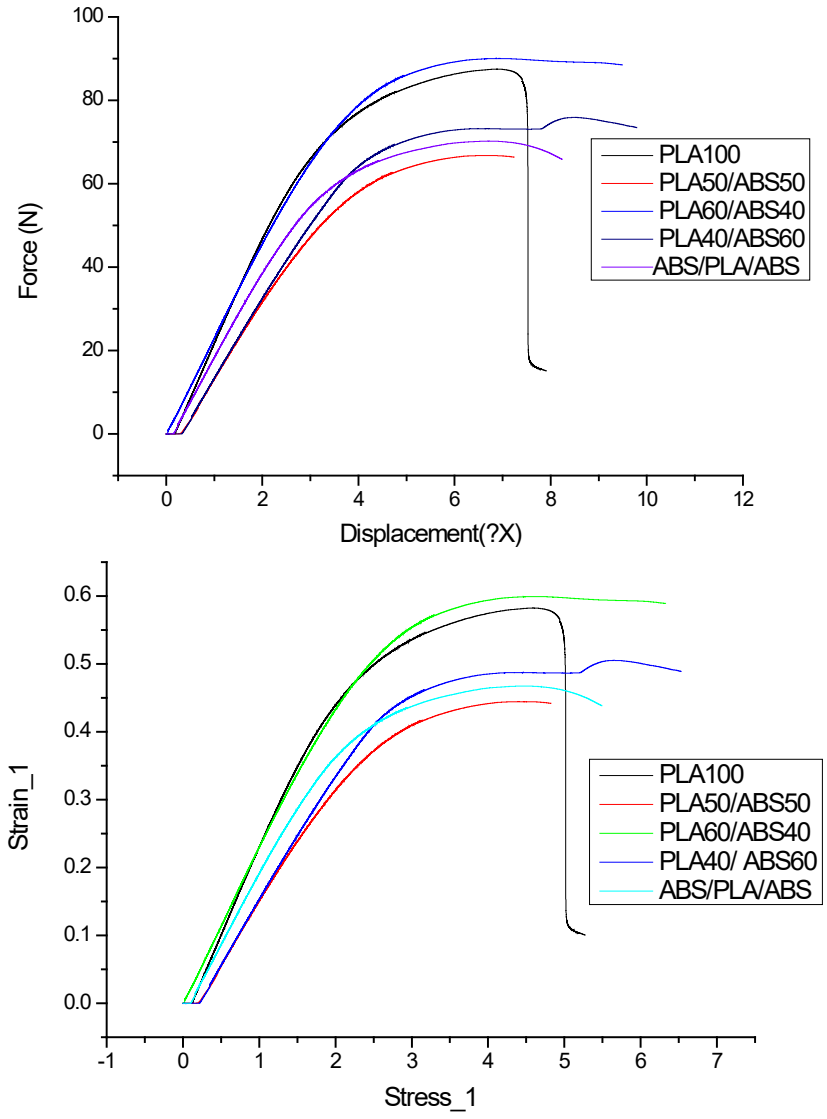


Fig. 6. Flexural plot.

Flexural modulus (E) is a measure of the material stiffness. where $\Delta P/\Delta\delta$, a is the slope of the initial linear portion of the load-deflection curve, representing the material's elastic region. When the maximum load and flexural strength values are high, material is strong. The deflection at maximum load is high, material is flexible. If the flexural modulus is high, material is stiff.

PLA100 received highest max stress at 58.3352 N/mm² and a max force of 87.5028 N which shows good strength and moderate deflection. ABS/PLA/PLACF composite got slightly lower strength with max stress at 44.5122 N/mm², but similar flexibility. (refer with: Figure 6)

With sandwiched ABS/PLA/ABS got lowest strength with a max stress of 22.9825 N/mm² and lower deflection. While ABS/PLACF/ABS sandwich obtained very similar to PLA100 in terms of strength and flexibility, with max stress of 60.0232 N/mm².

PLA/ABS/PLA/ABS obtained moderate strength and flexibility, with max stress at 30.649 N/mm². PLA60/ABS40 showing good balance of strength and flexibility, with max stress at 49.2901 N/mm². PLA40/ABS60 got noticeably high deflection at 13.4535 mm, indicating high flexibility but lower strength with a max stress of 14.7512 N/mm². PLA/PLACF/ABS got strong with max stress of 50.5956 N/mm² and good flexibility. PLA/ABS 80/20 received good strength and flexibility, with max stress of 46.8222 N/mm².

Thus, the materials with the highest max stress are ABS/PLA/ABS and PLA100, indicating they are the strongest. PLA40/ABS60 has the highest deflection, making it the most flexible material. However, it has the lowest strength. PLA60/ABS40 and PLA/PLACF/ABS offer a good balance of strength and flexibility.

In practical applications, by choosing the material based on the required strength and flexibility. For example, if high strength is critical, ABS/PLA/ABS or PLA100 would be ideal. If flexibility is more important, PLA40 /ABS60 might be more suitable.

5 Impact strength

The impact test was conducted to understand the improvement of the impact resistance over the neat epoxy resin GF system, the rectangular specimens ASTM standard (63*12.7*3 mm) was dynamically loaded in the center by a falling weight, machine- Zwick Roell HIT25P, using a cylindrical impactor.

Impact tests were carried out on notched specimen to measure the penetration energy and to highlight the characteristics points for a particular energy evaluation 5.5 J, to investigate the energy absorption. Machine setup Zwick Roell HIT25P ensures a constant theoretical impact velocity 3.46 m/s and work capacity of 5.5 J, which helps in comparing energy absorption trends consistently. (refer with: Figure 7).

Fig. 7. Impact test setup and samples, fractured specimens.

Table 5. Impact test parameters.

Theoretical impact velocity	Total mass	Work capacity
m/s	kg	J
3.458162842	0.919799988	5.5

Table 6. Impact results.

Specimen ID	W J	W %	W (Friction) J	Impact energy/ Notch length J/m	Impact Strength J/m²	Type of failure
PLA100	0.290529	5.282337	0.034245	95.25525	9525.525	H
PLA50/ABS50	0.300042	5.455313	0.034213	97.5747	9757.47	H
PLA60/ABS40	0.213166	3.875752	0.034515	81.98706	8198.706	C
PLA40/ ABS60	0.445048	5.091786	0.033738	70.0893	7048.91	C
ABS/PLA/ABS	0.26852	4.882185	0.034321	67.46739	6919.732	C

PLA50/ABS50 recorded the highest impact energy of 5.455 J, indicating that a 50:50 blend of PLA and ABS provides optimal energy absorption and toughness. PLA100 followed closely with an impact energy of 5.282 J, indicates that neat PLA maintains good energy absorption, though it is prone to brittle failure. Despite having a higher ABS percentage, PLA40/ABS60 displayed a lower impact energy of 5.091 J, indicating less toughness. Balanced PLA-ABS blends produce the best combination of strength and toughness, as demonstrated by PLA50/ABS50's highest impact strength of 9757.47 J/m and PLA100's 9525.525 J/m. Higher PLA content decreases toughness, as evidenced by PLA60/ABS40's decreased impact strength of 8198.706 J/m.

6 Conclusion

Depending on their composition and arrangement, PLA-ABS composites display different mechanical, vibrational, and impact properties. The greatest flexibility was demonstrated by PLA40/ABS60, albeit at the expense of decreased strength. While PLA60/ABS40 showed greater rigidity at higher frequencies, vibrational study verified that PLA40/ABS60 had superior resistance to secondary vibrations. According to impact tests, PLA50/ABS50 had the maximum impact strength, providing a well-balanced mix of toughness and strength. Dynamic performance was enhanced by sandwich designs such as ABS/PLA/ABS, which increased vibrational behavior. For load-bearing components and structural brackets where rigidity is crucial, the PLA100 and ABS/PLA/ABS compositions with the highest flexural strength are perfect. On the other hand, protective housings and car interior panels needing strong impact resistance are best suited for the PLA50/ABS50 combination due to its ideal hardness. Additionally, the sandwich arrangements' superior vibrational behavior makes them suitable for application in lightweight structural panels intended to shield delicate electronics from mechanical vibrations.

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