

THE ROLE OF SMA COMPATIBILIZER IN IMPROVING MECHANICAL PERFORMANCE OF PC/ABS POLYMER BLENDS

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Polycarbonate/acrylonitrile-butadiene-styrene (PC/ABS) blends are well-known for balancing the thermal, mechanical performance and processability of both the neat polymers. Therefore, it has been widely used for Material Extrusion (MEX) method. To further improve the properties of the blend, styrene and styrene-maleic anhydride (SMA) is employed as a compatibilizing agent, aiming at establishing better interfacial adhesion between the two phases of the two standalone polymers. In light of this, the influences of adding SMA are explored in this paper. Particularly, thermal properties, chemical structure, and mechanical property in terms of tensile strength of the PC/ABS before and after adding SMA are compared. In addition, a Design of Experiment (DoE) study is conducted for screening the effects of different printing parameters on the output tensile strength, from which the optimal process can be selected. The improvement of the PC/ABS/SMA blend is proven from the experimental results which are detailed in this study.

KEYWORDS

Material Extrusion, Additive Manufacturing, polycarbonate, acrylonitrile-butadiene-styrene, styrene-maleic anhydride

1 INTRODUCTION

Material development is crucial for the expansion of Material Extrusion (MEX), one of the most popular additive manufacturing methods for plastic nowadays [Goh 2020; Saharudin 2021]. Although MEX can offer cost-efficient prints with design flexibility, whose applications can be found in various fields such as of the modern industry [FDM 2022; Dezaki 2021]. Due to the growing spectrum of applications, polymer blending has become an effective approach to create

materials with tailored mechanical and thermal characteristics that cannot be achieved by a single polymer system alone.

Among the common commercially available thermoplastics, polycarbonate (PC) and acrylonitrile-butadiene-styrene (ABS) blends have attracted tremendous interest from the industry [De Assis 2023]. The blends balance the high impact resistance and thermal stability of PC with the toughness, good printability of ABS [Kannan 2020; Verma 2023]. Nevertheless, because of the inherent immiscibility between the two materials, there are weak interfacial bonding and phase-separated morphologies that can limit the mechanical performance of their blend.

To solve this problem, recent research has employed compatibilization strategies to improve the interfacial adhesion between the phases of the two polymers [Mostaani 2024; Peltó 2023]. Among the popular compatibilizer, styrene-maleic anhydride (SMA) copolymer has been used to modify phase morphology and promote the interfacial interactions of the two polymers [Zhu 2020]. Owing to these improvements, the stress transfer across the phase boundaries is improved, leading to enhancement of structural integrity and overall mechanical performance of PC/ABS blends [Ma 2022; Pogorelnik 2020].

In this context, this paper investigates the incorporation of SMA compatibilizer into an PC/ABS blend whose percentage was optimized for MEX method. The influence of adding SMA is evaluated systematically via thermal and chemical analysis. The blend is then subjected to Design of Experiment (DoE) study to find the effective printing parameters and their combination to maximize the tensile strength. The SMA-added blend is as well compared with the original PC/ABS to assess the effectiveness and practical value of the compatibilization approach.

2 MATERIAL AND METHOD

2.1 Filament preparation

The properties of the PC grade Infino SC-1100UR (Lotte Chemical, Republic of Korea), the ABS grade MAGNUM™ 3904 Smooth (Trinseo, USA), and the reactive compatibilizer XIBOND™ 160 (Polyscope Polymers B.V., Netherlands) are reported in Table 1. The SMA copolymer herein functions as a compatibilizer and promotes the interfacial connection between the PC and ABS phases.

Properties	Unit	PC	ABS
Density (g/cm3)	1.2	1.05	0.6
Melt Flow rate (g/10 min)	12 (300°C / 1.2 kg)	4.7 (220°C / 10 kg)	-
Yield Strength (MPa)	64	37	-
Tensile Modulus (MPa)	2300	1820	-
Flexural Strength (MPa)	92	58	-
Impact Strength (kJ/m2)	75–80	37	-
Molecular weight (g/mole)	-	-	115.000
Acid value (mg KOH/g)	-	-	250

Note: Detailed properties are available in the suppliers' technical datasheets [Infino 2026; Magnum 2026; XIBOND 2026].

Table 1. The properties of raw materials

Before extruded, the raw materials PC, ABS, and the compatibilizer (XIBOND™ 160) are dried for 12 hours at 90°C to eliminate residual moisture. Then, a blend comprising of 60 wt% PC, 40 wt% ABS, and wt 6% XIBOND™ 160 is prepared. The filament is extruded with a single-screw extruder namely 3D Evo Composer 350 (3D Evo B.V., Utrecht, The Netherlands). The speed of the screw is set to 4.5 rpm and the temperatures of the four heating zones are set from 200°C to 210°C. This results in a filament with a diameter of 1.75 ± 0.05 mm. The blend is denoted hereafter as PC/ABS/SMA (60/40/6) for better reporting purposes.

2.2 Material characterization

Differential Scanning Calorimetry (DSC)

Mettler Toledo 822E instrument and STARE System software are employed to evaluate the thermal properties of the blend. Specifically, in nitrogen atmosphere a flow rate of 60 mL/min, DSC measurements are conducted with temperature ranging from 0°C to 200°C with a heating rate of 10°C/min. To mitigate the thermal history of the blend caused by prior manufacturing processes, two heating cycles are conducted consecutively from which only the data of the second one is recorded.

Fourier Transform Infrared Spectroscopy (FTIR)

Chemical structure and functional group analysis of the samples were performed using Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR/FT-IR). Spectra were acquired on a ThermoFisher Scientific Nicolet 6700 spectrometer equipped with a diamond ATR accessory. Measurements were conducted in the wavenumber range of 4000 – 700 cm^{-1} , with a spectral resolution of 4 cm^{-1} and an accumulation of 64 scans per spectrum. All spectra were subjected to automatic ATR correction to account for penetration depth variations. Prior to each measurement, the diamond crystal was meticulously cleaned with isopropanol to avoid cross-contamination.

Design of Experiment (DoE)

From the prepared PC/ABS/SMA (60/40/6) blend, tensile samples following ISO 527-2 (type 1BA) standard are designed with dimension reported in Figure 1. The samples are later printed with Bambu Lab X1E Carbon 3D printer (Bambu Lab, Shenzhen, China).

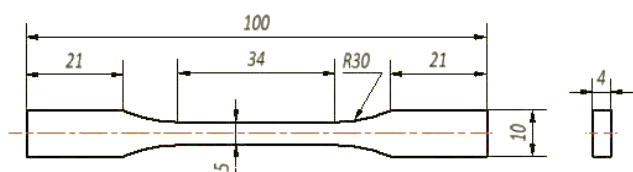


Figure 1. Dimension of the tensile sample (mm)

Given the significant influence of MEX process parameters on print quality and mechanical performance, a systematic Design of Experiments approach was adopted. A Taguchi L8(25) orthogonal array was selected to efficiently screen the main effects of five key process parameters, each evaluated at two levels. Minitab software is used for the study. The parameters investigated were: layer thickness, nozzle temperature, bed temperature, print speed, and infill direction. The specific levels for each parameter are detailed in Table 2.

This methodology minimizes the number of experimental runs while maximizing the information obtained, using the signal to noise (S/N) ratio to identify the parameter combination that optimizes tensile strength. In addition, for each combination of the printing parameters for the Taguchi study, three tensile samples are printed for evaluation.

Parameter	Level 1	Level 2
Layer thickness - t (mm)	0.15	0.25
Nozzle temperature - Tn (°C)	260	280
Bed temperature - Tb (°C)	90	110
Infill direction (°)	0	45
Print speed - v (mm/s)	50	100

Table 2. Parameters used in extruding of the filament

3 RESULT AND DISCUSSION

3.1 Fourier Transform Infrared (FTIR) Spectroscopy Analysis

The FTIR spectra of the neat components—Polycarbonate (PC), Acrylonitrile Butadiene Styrene (ABS), and the Styrene-Maleic Anhydride copolymer (SMA, XIBOND™ 160) compatibilizer—are shown in Figure 2. The spectrum of neat PC is characterized by a strong and sharp absorption peak at 1769 cm^{-1} , which is assigned to the carbonyl (C=O) stretching vibration of the carbonate ester group ($-\text{O}-\text{C}(=\text{O})-\text{O}-$), serving as the fingerprint for PC. Additional peaks at 1504 cm^{-1} and 1602 cm^{-1} correspond to the C=C stretching of the aromatic rings from the Bisphenol-A unit.

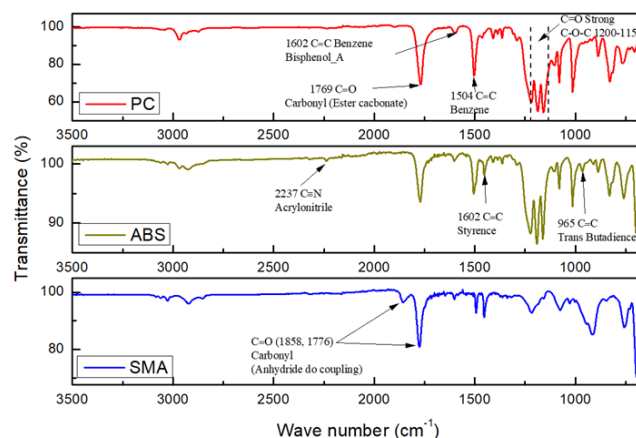


Figure 2. FTIR spectra of PC, ABS and SMA

The spectrum of neat ABS exhibits two key peaks: a strong and sharp peak at 2237 cm^{-1} , attributed to the C≡N stretching vibration of the acrylonitrile unit, and a distinct peak at 965 cm^{-1} , assigned to the C=C trans stretching vibration from the butadiene segment.

The spectrum of the neat SMA compatibilizer shows the characteristic doublet peak of the maleic anhydride group, with asymmetrical and symmetrical C=O stretching vibrations typically expected around 1850 cm^{-1} and 1776 cm^{-1} , respectively, which confirms its reactive functionality [Ramesh 2014].

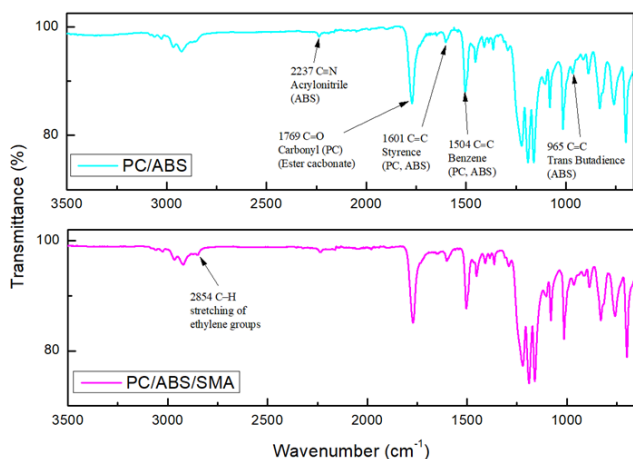


Figure 3. FTIR spectra of PC/ABS and PC/ABS/SMA

Figure 3 compares the FTIR spectra of the uncompatibilized PC/ABS (60/40) blend and the compatibilized PC/ABS/SMA (60/40/6) blend. The spectrum of the PC/ABS blend is essentially a superposition of the characteristic peaks from its constituent polymers. The presence of both the PC carbonate peak at 1769 cm^{-1} and the ABS nitrile peak at 2237 cm^{-1} within the same spectrum confirms the coexistence of both phases. No new absorption peaks are observed, indicating the absence of any new chemical bonds and confirming a physically blended, phase-separated system [Zanatta 2025].

The spectrum of the SMA-compatible blend retains all the characteristic peaks of PC and ABS. Crucially, a distinct enhancement of the C–H stretching band at approximately 2854 cm^{-1} is observed. This band, corresponding to symmetric $-\text{CH}_2-$ stretching vibrations, is common to all components but becomes more pronounced in the compatibilized blend. This increase in relative intensity is attributed to the additional methylene ($-\text{CH}_2-$) sequences contributed by the SMA copolymer backbone, indicating its integration into the blend structure [Zanatta 2025].

Notably, the characteristic maleic anhydride doublet peaks at 1850 cm^{-1} and 1776 cm^{-1} , clearly present in the neat SMA spectrum, are no longer detectable in the compatibilized blend. This disappearance provides strong evidence of chemical reactions involving the maleic anhydride groups during melt blending. The anhydride rings are opened and consumed through reactions with the terminal hydroxyl or carboxyl groups of polycarbonate, or through potential interactions with the SAN phase of ABS [Ramesh 2014].

In summary, the FTIR analysis provides supporting evidence for the role of SMA. While no new covalent bonds are definitively identified, the enhanced spectral features, particularly the intensified methylene band and improved spectral uniformity. These results suggest that SMA acts as a compatibilizer by improving interfacial adhesion and promoting a more homogeneous blend morphology, rather than by forming extensive new chemical bonds detectable by FTIR.

3.2 Thermal Behavior and Interfacial Modification by SMA Compatibilizer

The thermal transitions of the neat polymers and their blends were characterized using Differential Scanning Calorimetry (DSC), with the glass transition temperature (T_g) determined from the midpoint of the transition step in Figure 4. The results are summarized in Table 3.

The neat polymers exhibited characteristic T_g values of 106.1 $^{\circ}\text{C}$ for ABS and 145.7 $^{\circ}\text{C}$ for PC.

The uncompatibilized PC/ABS (60/40) blend showed two distinct T_g values at 106.6 $^{\circ}\text{C}$ and 143 $^{\circ}\text{C}$, with a ΔT_g of 36.2 $^{\circ}\text{C}$. The small shift from the neat polymer values confirms a classic phase-separated morphology with limited interfacial interaction.

Sample	T_{g1} ($^{\circ}\text{C}$) (ABS-rich phase)	T_{g2} ($^{\circ}\text{C}$) (PC-rich phase)	ΔT_g ($^{\circ}\text{C}$) *
Neat ABS	106.1	–	–
Neat PC	–	145.7	–
PC/ABS (60/40)	106.6	143.0	36.4
PC/ABS/SMA (60/40/6)	108.5	141.7	33.2

*Note: $\Delta T_g = T_{g2} - T_{g1}$

Table 3. Glass transition temperatures (midpoint) of neat polymers and PC/ABS blends

The addition of 6 wt% SMA compatibilizer induced clear and interpretable changes in the thermal transitions. An increase of 2.0 $^{\circ}\text{C}$ in the T_g of the ABS-rich phase was observed, rising to 108.5 $^{\circ}\text{C}$. Concurrently, the T_g of the PC-rich phase showed a increase of 1.3 $^{\circ}\text{C}$ to 141.7 $^{\circ}\text{C}$. Most notably, the overall ΔT_g between the two phases decreased by 3.2 $^{\circ}\text{C}$ to 33.2 $^{\circ}\text{C}$.

The key outcome, a reduced ΔT_g confirms that the SMA compatibilizer successfully bridges the interface. This brings the two phases into closer thermal alignment, a direct indication of improved interfacial adhesion and the presence of a well-formed interphase, all achieved without inducing complete miscibility [Debbah 2018; Kameshwari 2021].

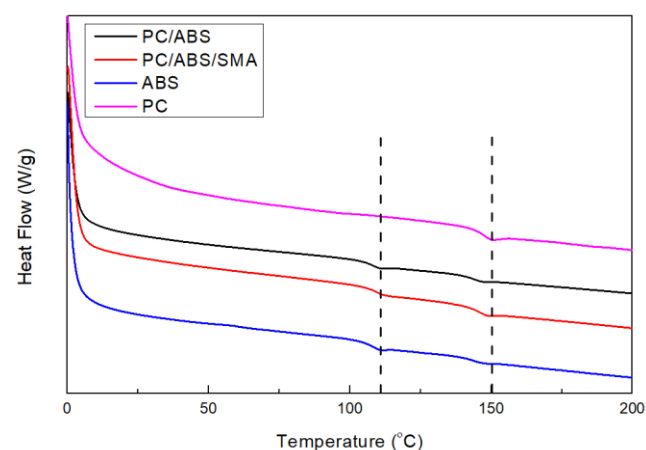


Figure 4. DSC thermograms of neat polymers, uncompatibilized, and compatibilized PC/ABS blends

This modification at the microscopic interfacial level correlates well with favorable adjustments at the macroscopic processing scale. Specifically, during the extrusion of the PC/ABS blend with 6% SMA, a significant reduction in processing temperature was observed. While the uncompatibilized blend required a minimum extrusion temperature of approximately 225 $^{\circ}\text{C}$ to ensure adequate melt flow and stability, the addition of SMA allowed this temperature to be lowered by about 15 $^{\circ}\text{C}$, to 210 $^{\circ}\text{C}$. This reduction in processing temperature indicates that the SMA compatibilizer also acts as a processing aid. The presence

of SMA chains at the interphase improves compatibility, reducing the interfacial tension between the PC and ABS phases. This, in turn, decreases internal friction and enhances the rheological properties of the molten blend. Consequently, energy consumption during extrusion is reduced, and more importantly, processing at a lower temperature minimizes the risk of thermal degradation of the blend components, particularly the heat-sensitive ABS phase. The reduction in melt viscosity and internal friction due to SMA addition may influence the MEX printing stage. Lower viscosity improves extrusion stability and flow consistency, resulting in more uniform material deposition [Gajjar 2025], while enhanced wetting between layers can strengthen interlayer adhesion [Tofangchi 2019]. This interfacial modification is therefore essential not only for improving stress transfer and promoting finer phase dispersion but also for enhancing the processability and thermal stability of the final product.

3.3 Mechanical Properties

The mechanical properties of neat PC, ABS, their blend (PC/ABS), and the compatibilized blend with SMA (PC/ABS/SMA) were systematically evaluated through tensile testing. The results, summarized in Table 4 and the stress-strain curve in Figure 5, reveal distinct behaviors and the significant effect of SMA addition.

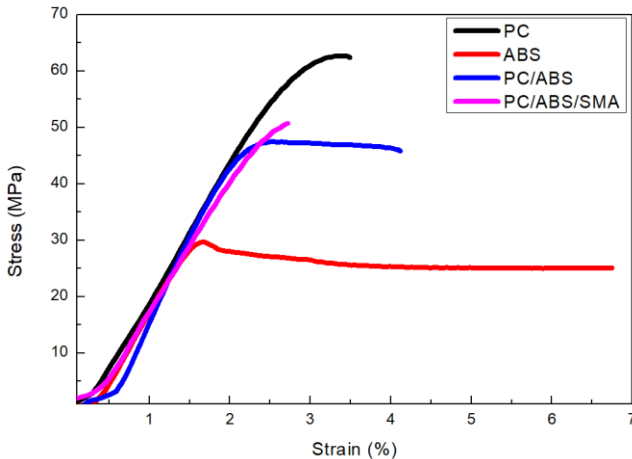


Figure 5. Tensile stress-strain curves of neat polymers, uncompatibilized and compatibilized PC/ABS blends.

Neat PC exhibited the highest tensile strength (62.5 MPa) but a relatively low elongation at break (3.5%), confirming its characteristic high strength and inherent brittleness. In contrast, ABS demonstrated superior ductility with an elongation at break of 7.0%, however, this high ductility corresponded to the lowest tensile strength among the materials tested (28.6 MPa). The 60/40 PC/ABS blend showed an intermediate performance, with a tensile strength of 46.1 MPa and an elongation at break of 4.0%. This represents a typical compromise, balancing the strength of PC with the ductility of ABS, but their mechanical performance is inherently limited by the poor interfacial adhesion resulting from the immiscibility of the PC and ABS phases [Nguyen 2025]. The incorporation of Styrene-Maleic Anhydride (SMA) copolymer as a compatibilizer into the 60/40 blend led to a notable enhancement in mechanical performance. The compatibilized blend (PC/ABS/SMA) achieved a higher ultimate tensile strength of 49.0 MPa compared to 46.1 MPa for the uncompatibilized blend. However, this gain in strength and stiffness was accompanied by a reduction in ductility, as the elongation at break decreased to 2.9%.

The primary role of SMA is to act as a compatibilizer at the interface between the PC and ABS phases. The maleic anhydride groups in SMA can interact with polar groups in PC, while the styrene segments are miscible with the SAN matrix of ABS. This interaction reduces the interfacial tension, promotes finer phase dispersion, and strengthens the interfacial adhesion. Consequently, stress transfer between the phases becomes more efficient, leading to the observed increase in tensile strength and overall load-bearing capacity. The reduction in elongation at break suggests that the blend becomes more homogeneous and less prone to extensive plastic deformation, a common trade-off when improving interfacial bonding in polymer blends.

	Ultimate tensile strength (MPa)	Elongation at break (%)
PC/ABS/SMA(60/40/6)	49 ± 0.5	2.9 ± 0.1
PC/ABS(60/40)	46.1 ± 1.0	4.0 ± 0.1
PC	62.5 ± 1.2	3.5 ± 0.2
ABS	28.6 ± 0.5	7.0 ± 0.3

Table 4. Mechanical properties of PC, ABS and their blends

While the uncompatibilized PC/ABS blend offers higher flexibility, the PC/ABS/SMA blend, with its enhanced tensile strength and stiffness, is better suited for high-performance structural components that demand high load-bearing capacity and geometric stability under stress. Therefore, optimization of SMA content is essential to achieve a balanced combination of strength and toughness depending on the intended application.

3.4 DOE

The response for signal to noise (SN) ratios and means are reported in Table 5 and Table 6. The main effects plots for both the SN ratios and the means are illustrated in Figure 6 and Figure 7. The SN ratio is set as Larger is better.

Level	Layer thickness	Nozzle temp.	Bed temp.	Speed	Angle
1	32.97	32.39	32.51	32.75	32.31
2	32.20	32.78	32.67	32.42	32.87
Delta	0.76	0.39	0.16	0.33	0.56
Rank	1	3	5	4	2

Larger is better

Table 5. Response table for SN ratios.

Level	Layer thickness	Nozzle temp.	Bed temp.	Speed	Angle
1	44.56	41.74	42.27	43.45	41.38
2	40.86	43.68	43.15	41.97	44.04
Delta	3.70	1.93	0.88	1.48	2.67
Rank	1	3	5	4	2

Table 6. Response table for means.

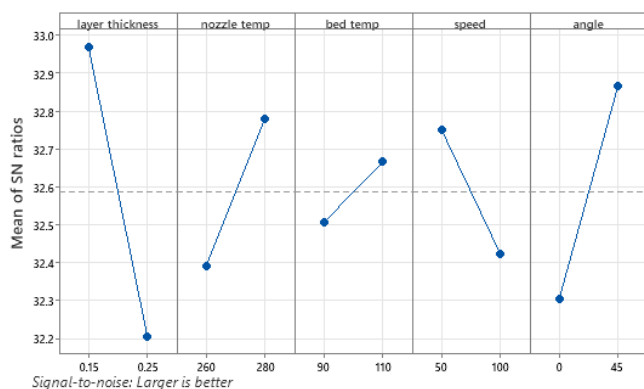


Figure 6. Main effects plot for SN ratios on the output tensile strength.

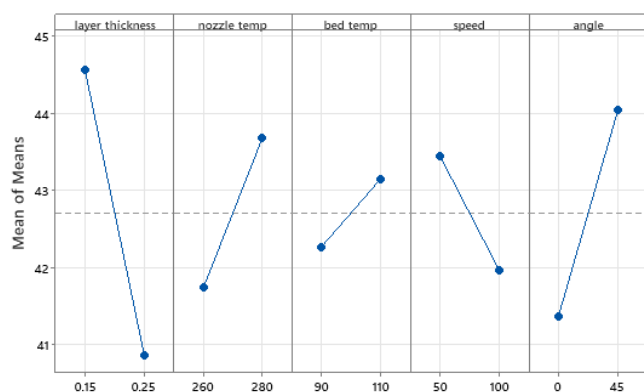


Figure 7. Main effect plot for means on the output tensile strength.

From the analysis of S/N ratios and means (Table 5-6, and Figure 6-7) for both the SN ratios based on the larger-is-better criterion and the mean, layer thickness has the most significant effect on the tensile strength, followed by angle and nozzle temperature. Contrarily, printing speed and bed temperature rank fourth and fifth with limited impact on tensile strength. The close agreement between the rankings and trends from the SN ratio and mean effect analysis confirm that the selected printing parameters can improve the tensile strength with process robustness.

Source	DF	Adj SS	Adj MS	F-value	P-value
Layer thickness	1	82.140	82.140	60.74	0.000
Nozzle temp	1	22.427	22.427	16.58	0.001
Bed temp	1	4.682	4.682	3.46	0.079
Speed	1	13.202	13.202	9.76	0.006
Angle	1	42.667	42.667	31.55	0.000
Error	18	24.342	1.352		
Lack-of-Fit	2	3.762	1.881	1.46	0.261
Pure Error	16	20.580	1.286		
Total	23	189.458			

Table 7. Analysis of Variance

The ANOVA results (Table 7) given the threshold p-value of 0.05, the effect of the printing parameters on the tensile strength by a descending order is layer thickness ($p = 0$), printing angle ($p = 0.000$), nozzle temperature ($p = 0.001$), and printing speed ($p = 0.006$). The bed temperature ($p = 0.079$) is higher than 0.05, indicating moderate effect on the output.

S	R-sq	R-sq(adj)	R-sq(pred)
1.16289	87.15%	83.58%	77.16%

Table 8. Model summary.

With $R^2 = 87.15\%$, adjusted $R^2 = 83.58\%$, and predicted $R^2 = 77.16\%$ (Table 8), the model suggests a reasonable fit with moderate predictive capability. From the results, it can be drawn that only three out of five printing parameters (nozzle temperature, layer thickness, bed temperature) are the main contributors for the output (tensile strength). However, with relatively low predicted R^2 , the developed model is limited in working with unseen data. This can stem from the limitation of Taguchi method where interaction between the factors are not taken into account and only a small number of experiments are used, resulting in high uncertainty.

4 CONCLUSIONS

This study systematically demonstrated the effectiveness of SMA as a reactive compatibilizer for improving the mechanical performance of PC/ABS (60/40) blends intended for MEX. FTIR analysis confirmed the occurrence of chemical interactions between SMA and the blend components, providing molecular-level evidence of compatibilization. DSC analysis revealed a reduction in the difference between the glass transition temperatures (ΔT_g) of the two phases, indicating enhanced interfacial adhesion. These improvements translated into a 6% increase in ultimate tensile strength for the PC/ABS/SMA blend compared to the uncompatibilized blend, reaching 49.0 MPa. Furthermore, a Taguchi DoE study identified layer thickness, infill direction, and nozzle temperature as the most critical printing parameters affecting the tensile strength of this novel blend. Collectively, the findings confirm that SMA addition not only strengthens the interfacial bonding between PC and ABS phases but also enables more robust processing, making the PC/ABS/SMA blend a promising candidate for high-performance structural applications in additive manufacturing.

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