



Influence of Blend Ratio and Processing Conditions on the Mechanical Performance of ABS/PC Blends for Outdoor Electrical Housings – Experimental and Simulation Approach

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Abstract: The improvement in the mechanical robustness of polymer blends used in long-term outdoor electrical enclosures is still a challenge in the field of material engineering. In the present research work, the suitability of the polymer blends of polycarbonate (PC) and acrylonitrile-butadiene-styrene (ABS) in the weight ratios of 60/40, 70/30, 80/20, and 90/10 (% PC/ABS) was thoroughly investigated for the application in the bottom cover of the energy meter enclosure through extensive tensile property characterization and processing assessment. Among the investigated polymer blend compositions, the 70/30 % PC/ABS blend was found to show the highest level of interfacial compatibility along with a homogeneous phase morphology. The optimized polymer blend was found to show an increase in the tensile strength of approximately 25 %, along with an increase in stiffness and reduced thermal deformation characteristics. The injection moulding processing trials also showed the improved melt flow characteristics of the optimized blend along with reduced warpage and increased resistance to localized stress concentrations in the moulded part of the energy meter enclosure.

Key words: Mechanical durability, Injection Moulding, Tensile Strength, Blends, Thermal Deformation

I. Introduction

Outdoor electrical enclosures, such as energy meter enclosures, always experience severe environmental stresses such as UV irradiation, temperature changes, humidity, and mechanical stresses during the course of their life. These environmental stresses always result in degradation of colour, cracking of materials, and changes in dimension stability. Thus, the long-term reliability and structural integrity of polymer enclosures used in outdoor environments remain a major engineering challenge. Among the engineering polymers, polycarbonate and acrylonitrile-butadiene-styrene polymers have been initiated to be the most important ones for the manufacture of electrical enclosure component materials due to their excellent mechanical properties and processability. PC/ABS blend has been initiated to improve the toughness and balance the thermal and mechanical properties of the blend. Recent studies on PC/ABS/PMMA ternary blends have found enriched mechanical properties linked to binary blends. The development of compatibilizers for PC/ABS blends has been found to improve the toughness and fatigue properties of PC/ABS blends significantly. The optimization of PC/ABS blends at multiple scales has been found to improve the properties of PC/ABS blends significantly, thereby demonstrating the importance of blend optimization. The development of PC/ABS composites in additive manufacturing has been initiated to improve the potential of PC/ABS blends in engineering materials. Although PC/ABS blends have been found to be the most important blend in the field of engineering materials, the majority of the available works have been intensive only on the material properties, thereby completely ignoring the issues related to the durability of the blend in outdoor environments. Thus, the need for a better approach to address the issues related to the durability of the blend in outdoor environments has been found to remain a major challenge in the field of engineering materials. The optimization of microstructure has been found to be the most promising way to address the issues related to the durability of the blend in outdoor environments [1-4].

In order to satisfy the increasing needs of industries, a variety of additive manufacturing methods have been developed, most of which use the process of layer-wise deposition of materials, such as Melted Extrusion Modeling. In MEM, the materials are supplied in the form of filaments, melted, and then extruded through a nozzle according to a predetermined path. As the materials are deposited, they cool and solidify, with each layer of materials being overlapped by the following one in order to manufacture the final product. The prime factors that segregate one additive manufacturing process from another include the environment of the materials used, their states during processing, and the bonding mechanism of the materials being deposited. Even though additive manufacturing processes have greatly progressed in the last ten years and have been broadly castoff in engineering, design, and education, there are still technical issues associated with additive manufacturing processes. In order to fully utilize the benefits of additive manufacturing processes, including MEM, it is important to fully characterize the materials castoff in the process. This will enable the custom of the materials in actual applications [6].

Additive manufacturing (AM), a comparatively new phenomenon in engineering, has gained prominence mainly due to its simplicity and high manufacturing flexibility. It is normally utilized for cost reduction as well as for reducing production time, specifically for complex prototype parts that would or else necessitate expensive molds along with long manufacturing cycles, as in conventional injection molding processes [9,10].

The available literature has reported a few studies related to the improvement of the performance characteristics of PC/ABS polymer blends. Various researchers have investigated the effects of the addition of different fillers in varied concentrations on the mechanical, morphological, and rheological properties of polycarbonate/acrylonitrile butadiene styrene blends by incorporating glass fibers and talc into the polymer blend matrix [11]. The accumulation of glass fibers to the PC/ABS blend to advance the tensile and flexural strengths, but it has also been initiate to reduce the influence strength of the blend, whereas the tallying of talc has improved the tensile strength but has reduced the flexural and impact strengths of the blend. Composites containing glass fibers and talc have correspondingly been reported to possess improved mechanical~properties associated to the unfilled blend. The adding of talc and glass fibers to reduce the MFR of the blend, with the glass fiber blend showing a more pronounced reduction in MFR associated to the talc blend [12].

Other studies have focused on the effect of untreated mica fillers as well as surface-treated mica fillers on the mechanical~properties of PC/ABS composite materials. Surface treatment of mica with a combination agent has been revealed to improve properties such as tensile strength, elongation at break, flexural strength, along with impact strength. In other studies, the result of flame retardants, such as ammonium polyphosphate (APP) and montmorillonite (MMT), on the flame retardancy, mechanical, in addition to physical properties of PC/ABS blends has been examined. In this study, it was demonstrated that APP along with MMT improved properties such as LOI significantly. In addition, it has been confirmed that thermal~stability, tensile strength, as well as elongation at break can be improved using an optimal amount of a filler. Improvements in mechanical~properties have been verified when a small amount of MMT as well as bentonite fillers were incorporated into the PC/ABS matrix [13,14,15].

II. Problem Statement and Research Gap

Though considerably studies have been supported on polymer blends, quantitatively determining the effect of ABS/PC blend proportions and injection molding conditions on housing components exposed to a variety of thermal, mechanical, and environmental stresses is quiet a problem to be addressed. Most analyses covenant with the intrinsic properties of the material without direct correlation to the notch of service failure in relations of discoloration, cracking, and dimensional distortion. In addition, although much depiction effort has been finished on mechanical properties, their direct application to the scale of the required performance in relation to housing components is still a problem to be addressed.

III. Objectives and Scope

The present study undertakes a systematic investigation of ABS/PC blends in different proportions (60/40, 70/30, 80/20, and 90/10 PC/ABS, wt%) and injection molding parameters to enhance the mechanical properties as well as reliability of the bottom cover of energy meters' enclosures. The specific goals of study are as follows:

1. Quantify mechanical properties via preparation of laminates as per ASTM standards and testing the same in UTM.
2. Examine phase morphology along with interfacial compatibility to create structure-property correlations.
3. Validate mechanical properties using ANSYS Workbench simulation for structural analysis of ASTM tensile test specimens.
4. Offer guidelines for designing energy meters' enclosures that ensure mechanical toughness, as well as dimensional accuracy for long-term outdoor usage.

IV. Experimentation, Simulation and Testing of laminates

A. Experimentation and Testing

ABS and PC pellets were dried and blended using a twin screw extruder at a controlled temperature profile. Blends of 60/40, 70/30, 80/20, and 90/10 PC/ABS were injection moulded in the form of ASTM D638 Type I tensile test specimens. One laminate consists of pure PC, whereas Blend – 1 consists of 60/40 wt%, Blend – 2 consists of 70/30 wt%, Blend – 3 consists of 80/20 wt%, and Blend – 4 consists of 90/10 wt% PC/ABS. Laminates were prepared and tested via Universal~Test~Machine (UTM). Figures 1-5 show the specimens equipped conferring to the standard and ready to test.

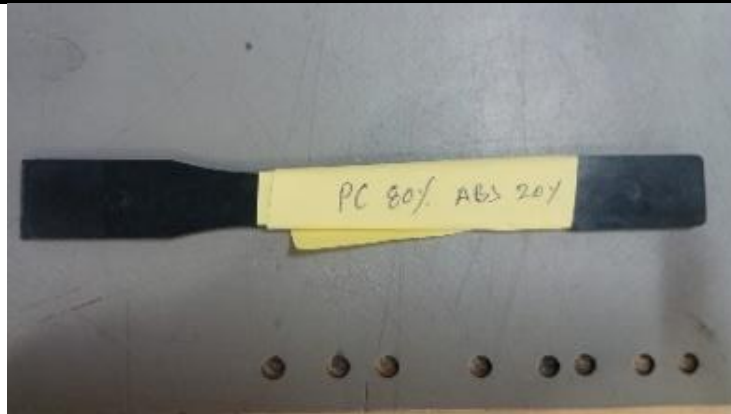


Figure 1: Tensile Laminate of 80% PC and 20% ABS in wt %



Figure 2: Tensile Laminate of 70% PC and 30% ABS in wt %



Figure 3: Tensile Laminate of 60% PC and 40% ABS in wt %



Figure 4: Tensile Laminate plain PC without blends



Figure 5: Tensile Laminate of 90% PC and 10% ABS in wt %

Table 1: Experimental Results Table

Specimen's	Load (N)	Stress Plain PC (N/mm ²)	Stress PC/ABS (N/mm ²) Blend-1	Stress PC/ABS (N/mm ²) Blend-2	Stress PC/ABS (N/mm ²) Blend-3	Stress PC/ABS (N/mm ²) Blend-4
1	1697	43.5	59.5	61.5	50.5	48.5
2	1638	42	58	59.2	50	49
3	1482	38	57	58.5	47.3	46
4	1230	31.54	47.31	48.895	39.259	38.18
5	1130	28.98	40.02	41.158	34.5	33.81

Table 1 indicates the change in tensile strength, measured in N/mm², based on the change in the applied load, measured in Newtons, for PC/ABS blends with five sets of specimens, S1 to S5. Every load value represents a specimen number, while four PC/ABS blend formulations, ranging from Blend 1 to Blend 4, were used. The x-axis represents the applied load, ranging from 1696 N, representing S1, to 1130 N, representing S5, while the y-axis represents the tensile strength. For all PC/ABS blends, tensile strength reduces steadily with an increase in the applied load from S1 to S5.

B. Simulation

For simulation, an ASTM D638 specimen was modelled via ANSYS Workbench software. The substantial properties were used centred on the experimental load test results. The displacement of the specimen and the von Mises stress, which is considered the strength of the material, were calculated using the simulation approach, as publicized in figures 6, 7, 8, and 9. The simulation outcomes were formerly associated thru the experimental results.

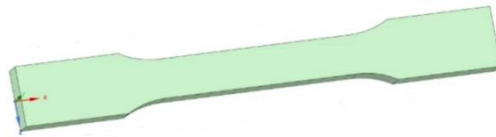


Figure 6: Geometric model of Tensile laminate as per ASTM D638 standard

From the simulations, it is obvious that there is a trend; that is, increasing the percentage of ABS in the mixture reduces stress. That makes sense because ABS is a very flexible material that is able to absorb stress very well. Thus, it makes sense that increasing the percentage of ABS will result in lower stress for the entire material. As the percentage of ABS is increased, it becomes more flexible and is able to bend slightly, reducing hot spots that could potentially lead to failure. Table 2 summarizes the simulation results for the laminate and its blends.

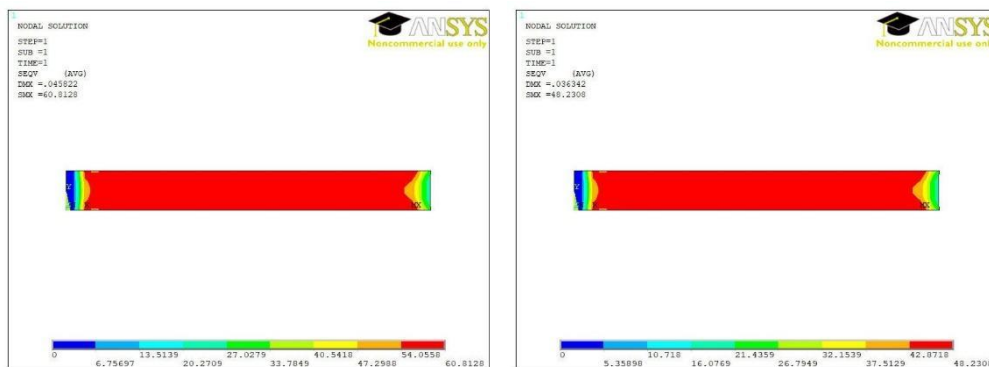


Figure 7: FE analysis of laminate 70% PC and 30% ABS at load 1638N and 1230N

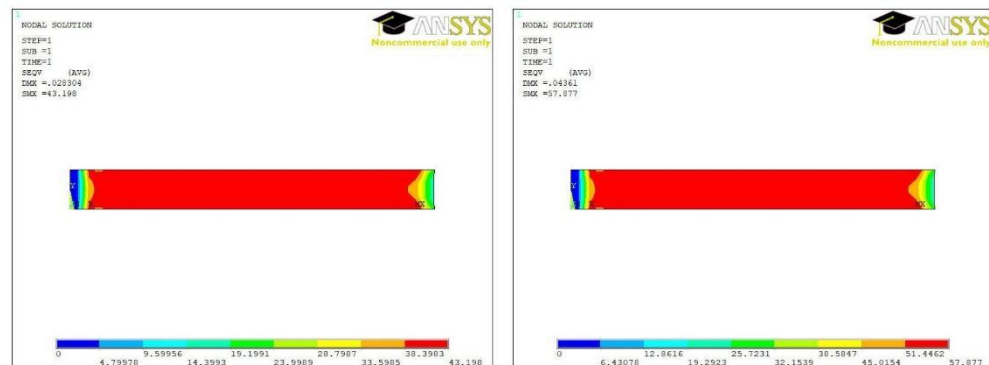


Figure 8: FE analysis of laminate 70% PC and 30% ABS at load 1130N and 1482N

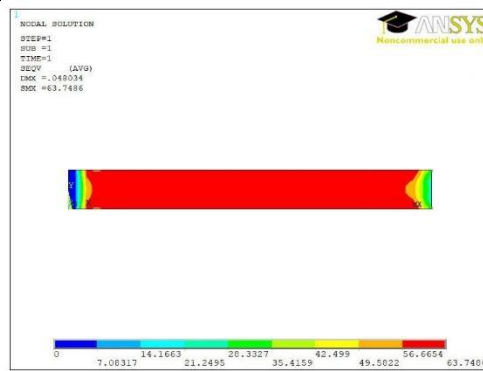


Figure 9: FE analysis of laminate 70% PC and 30% ABS at load 1697N

Table 2: Simulation Results Table using Ansys

Specimen's	Load (N)	Stress Plain PC (N/mm ²)	Stress PC/ABS (N/mm ²) Blend-1	Stress PC/ABS (N/mm ²) Blend-2	Stress PC/ABS (N/mm ²) Blend-3	Stress PC/ABS (N/mm ²) Blend-4
1	1697	45.03	61.59	63.74	52.27	50.20
2	1638	43.11	59.54	60.81	51.32	50.30
3	1482	38.41	57.61	57.87	47.81	46.50
4	1230	31.97	47.95	48.23	39.79	38.70
5	1130	30.34	41.90	43.19	36.12	35.40

V. Results and Discussion

A. Mechanical Performance and Simulation Validation

Mechanical tests showed a significant enhancement in the capability of the material when the blend was optimized in expressions of its composition. Specifically, the blend of 70/30 PC/ABS was found to increase the tensile strength by around 25% compared to blends with less content of PC. At the similar time, the material became stiffer and less prone to thermal deformation. All these optimistic sorts are the result of the combination of the natural characteristics of PC and ABS.

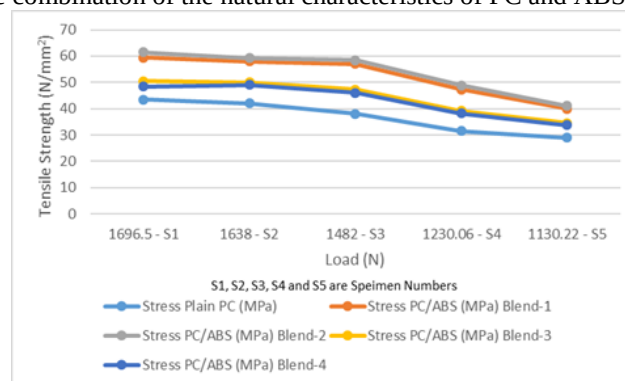


Figure 10: Experimental results of Load vs Tensile Strength for plain and blended specimens

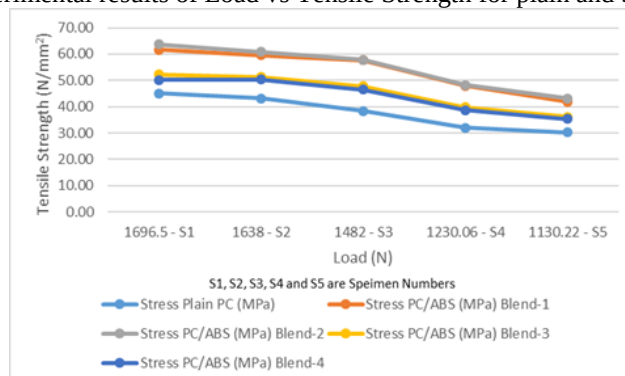


Figure 11: Simulation results of Load vs Tensile Strength for plain and blended specimens

Figure 10-11 displays the comparison between the variation in tensile strength and the load for plain PC and PC/ABS blends, for the five specimens S1 to S5. It is marked that the tensile strength of the materials decreases with the load, from S1 to S5, for both the PC and PC/ABS blends. This indicates that the materials' response to the load is predictable, such that the lower the load-bearing capability, the lower the material's tensile strength.

Comparing the two curves in Figure 10-11, it is manifest that the PC/ABS blends have a higher tensile strength than the plain PC for the five specimens. From the curves, it is obvious that the PC/ABS blends have the highest tensile strengths compared to the plain PC for the five specimens, with Blend-1 and Blend-2 having the highest tensile strengths, followed by Blend-3, and then Blend-4, which has the lowest tensile strength compared to the other three blends but is still higher than that of the plain PC.

The slight differences in the tensile strengths of the PC/ABS blends and the plain PC, for the five specimens, may be caused by the testing conditions, but the curves indicate that the composition of the materials has an impact on the load, such that at low load, the composition of the materials has a minimal effect, but at high load, the composition has an impact on the materials' performance.

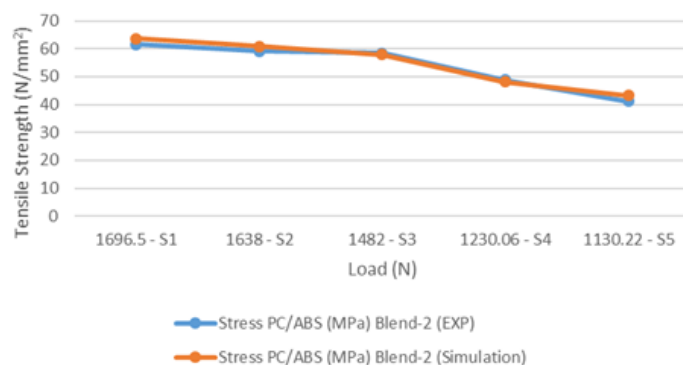


Figure 12: Experimental and simulation results of Load vs Tensile Strength Blend – specimen (i.e. 70% PC and 30% ABS)

Appropriate performance of the tensile response simulation, with ANSYS software was employed to cross-check the results with those of the experiment. It was established that the stress/strain curves were aligned with those of the experimental data, which validates the use of the particular constitutive model of the material. Such good agreement of results validates the approach for assessing the structural integrity of 70% PC/30% ABS PC/ABS blends under mechanical loading, as shown in Figure 12.

VI. Conclusions

This study combines experimental and numerical work to investigate ABS/PC blends, demonstrating that the blend ratio is an important parameter in determining the mechanical properties and processability of outdoor, flame-retardant electronic enclosures. From the options we have investigated, the 70/30 PC/ABS blend is found to offer the best balance of improved thermal resistance, increased tensile properties, reasonable levels of residual stress, and minimal warpage. The improvement in mechanical properties is verified by the experiments, and the results of the ANSYS stress simulations correlate well with the experimental results, thus providing support for the models used in the study.

Through the application of analytical modeling, a multiscale constitutive model, and orientation analysis, we have developed a robust model that links the process-structure relations to the structure-property relations in PC/ABS blends. The close correlation between the numerical results and the experiments, in conjunction with the results found in the literature, verifies the robustness of the models used in the study.

The simulation models developed in the study is used to investigate the properties of the blend ratio further, and the results can be cast-off to perform optimization studies with minimal need for experiments, thereby reducing the need for trial and error in the process. From the outcomes found in the study, it is apparent that the 70/30 PC/ABS blend is a viable engineering option for injection molding flame-retardant electronic enclosures, satisfying the prerequisite for enhanced mechanical properties and process ability for such applications.

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