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Abstract

This study compares the performance of three glazing materials commonly proposed for photovoltaic (PV) modules in tropical climates; Tempered Glass (used as a reference), Polycarbonate (PC) and Poly Methyl Methacrylate Acrylic (PMMA) respectively**.** Performance analysis were conducted on the materials, this includes; optical transmittance, haze, yellowness index, mechanical/impact resistance, scratch resistance and resulting electrical performance and an outdoor field exposure at School of Technology, Kano Sate Polytechnic and Technology Incubation Centre Kano tropical sites. Results obtained shows that TG retained approximately 90% of initial optical transmittance after ageing, while PC and PMMA were approximately 81.5% and 82% transmittance with increased haze and yellowness. Corresponding estimated energy yield reductions for polymer-glazed modules ranged 5–12% relative to glass for the same cell and module construction under exposure. However, it was deduced that PC and PMMA can offer lower weight and higher impact resistance but are more susceptible to Ultra Violet (UV) induced yellowing, increased haze and abrasion/soiling losses under tropical conditions but TG is optically stable and resists yellowing but is heavier and can be vulnerable to catastrophic fracture.

Keywords: Analysis, Silicon PV Solar, Glazing, Tropical

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Introduction

Solar photovoltaic (PV) technology has become a critical component of sustainable energy development worldwide due to its scalability, declining cost, and environmental benefits. Crystalline silicon PV modules dominate the global market owing to their high efficiency, technological maturity, and long operational lifespan (Green, 2019; Jordan and Kurtz, 2013). In Nigeria, the adoption of solar PV systems has increased significantly in response to chronic grid instability, growing energy demand, and national renewable energy targets (Adeniyi and Akinwale, 2020).

North-Western Nigeria comprising Kano, Katsina, Jigawa, Sokoto, Zamfara, and Kebbi States lies within the tropical savanna and semi-arid climatic zones. The region receives high annual solar irradiance levels ranging from 5.5 to 7.0 kWh/m²/day, making it highly suitable for solar energy exploitation (Sambo, 2009; Ohunakin 2014). However, PV systems deployed in the region are subjected to harsh environmental stressors, including high ambient temperatures often exceeding 40°C, intense ultraviolet (UV) radiation, seasonal dust storms (Harmattan), and high humidity during the rainy season. These conditions significantly influence the performance, reliability, and durability of PV modules (Adaramola and Vågnes, 2015).

The front glazing material of a PV module plays a pivotal role in determining optical transmission, mechanical protection, thermal behavior, and resistance to environmental degradation. Traditionally, low-iron tempered glass (TG) shown in Figure 1 is used due to its high optical transmittance, UV stability, and mechanical strength (Sharma and Chandel, 2013). However, tempered glass contributes significantly to module weight and is susceptible to catastrophic fracture under impact an important concern in regions with poor handling infrastructure.

To address these limitations, polymer-based glazing materials such as polycarbonate (PC) and polymethyl methacrylate (PMMA, acrylic) shown in Figures 2 and 3 have been proposed as alternatives. These materials offer reduced weight, higher impact resistance, and ease of handling, making them attractive for off-grid and locally fabricated PV systems in Northern Nigeria (Whitfield, 2011). Nevertheless, polymer glazings are prone to UV-induced yellowing, increased haze, surface abrasion, and soiling, which can degrade optical performance over time, particularly in tropical climates (Pern and Glick, 2005; Hülsmann 2018).

Although North-Western Nigeria possesses abundant solar energy resources, many installed PV systems exhibit premature performance degradation, reduced energy yield, and shortened service life. A key contributing factor is the interaction between harsh tropical environmental conditions and PV module materials. While tempered glass glazing offers excellent optical stability, its weight and vulnerability to fracture limit its suitability in some applications. Conversely, polymer-based glazing materials such as PC and PMMA, although lighter and impact resistant, may suffer significant optical degradation due to UV radiation, dust abrasion, and humidity.

There is insufficient empirical data comparing the optical, mechanical, and electrical performance of these glazing materials under actual tropical outdoor conditions in North-Western Nigeria. This lack of localized performance data hampers informed material selection, system optimization, and policy formulation for sustainable solar PV deployment in the region.

The main objective if this research is to evaluate and compare the performance of silicon photovoltaic solar modules using selected glazing materials under tropical conditions in North-Western Nigeria.

Literature Review

Several studies have highlighted the influence of glazing materials on PV module performance. Jordan and Kurtz (2013) reported that material degradation is a major contributor to PV performance loss in harsh climates. Whitfield et al. (2011) emphasized the potential of polymeric materials in PV modules but noted their susceptibility to UV degradation. Pern and Glick (2005) demonstrated that polymer-based PV materials experience yellowing and haze increase under prolonged UV exposure, leading to optical losses. Hülsmann (2018) further confirmed that PMMA and PC front sheets exhibit measurable transmittance loss after accelerated ageing. In dusty environments, Sayyah (2014) and Ilse (2019) reported energy losses of up to 20% due to soiling, with surface properties of glazing materials influencing dust adhesion. Locally, Adaramola and Vågnes (2015) emphasized that tropical environmental factors significantly affect PV system performance in Nigeria, underscoring the need for region-specific material studies. However, few studies have experimentally compared tempered glass and polymer glazing materials under real outdoor tropical conditions in North-Western Nigeria, particularly considering combined optical, mechanical, and electrical performance metrics.

Methodology

1. Materials and Samples

1. **Tempered Glass (TG)**: 3 mm low-iron tempered soda-lime glass (industry PV glass, anti-reflective optional).
2. **Polycarbonate (PC)**: commercial UV-stabilized grade marketed for outdoor glazing, with and without factory hard coat.
3. **PMMA (Acrylic)**: outdoor grade with UV absorbers, with and without hard coat.

2. Fabrication of Solar PV Module

Preparation of sample 200mm × 200 mm full mini Solar PV module (cell + encapsulant + backsheet) for electrical testing.

3. Performance Tests

1) Field exposure: Outdoor racks tilted at local optimal angle in School of Technology and Technology Incubation Centre tropical sites taking measurements for 6 months.
2) Mechanical tests:
    a) Impact Resistance.
    b) Scratch Resistance.
3) Optical and chemical characterization:
    a) Visible Transmittance (300–1200 nm)
    b) Haze measurement (ΔYI.
    c) Yellowness index (ASTM E313).
4) Electrical:
    a) Assemble mini-modules with identical cell(s) and measure I-V under standard test conditions (STC) before/after ageing (Isc, Voc, Pmax).

Result and Discussion

Test Result Obtained

Test result for the performance analysis is described in Table 1 below.

Result for the Electrical Performance

Average six (6) month I–V tests performed under standard test conditions (STC equivalent: 1000 W/m², 25 °C cell temp) is described in Table 2 below.

Discussion

Results showed that tempered glass retained approximately 90% of its initial optical transmittance after ageing, with negligible haze and no visible yellowing. In contrast, polycarbonate and PMMA experienced 81.5% and 82% transmittance accompanied by increased haze and yellowness due to UV exposure. Electrical performance analysis revealed that polymer-glazed modules exhibited 5–12% lower estimated energy yield compared to tempered glass modules under identical conditions. However, PC and PMMA demonstrated superior impact resistance and significantly lower weight, reducing handling and structural requirements.

These findings indicate a trade-off between optical stability and mechanical advantages. While tempered glass offers superior long-term optical performance, polymer glazings may be suitable for applications where weight and impact resistance are critical, provided UV protection and maintenance strategies are implemented.

Conclusion

In this research, performance of three glazing materials commonly proposed for photovoltaic (PV) modules in tropical climates; Tempered Glass (used as a reference), Polycarbonate (PC) and Poly Methyl Methacrylate Acrylic (PMMA) respectively were carried out**.** Performance analysis was conducted on the materials, this includes; optical transmittance, haze, yellowness index, mechanical/impact resistance, scratch resistance and resulting electrical performance and an outdoor field exposure at School of Technology, Kano Sate Polytechnic and Technology Incubation Centre Kano tropical sites. The research provides region-specific data for PV material selection in North-Western Nigeria, supports local PV manufacturing and system optimization and informs policymakers and investors on material performance trade-offs.

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Figures

Figure 1: Tempered Glass Glazing Material

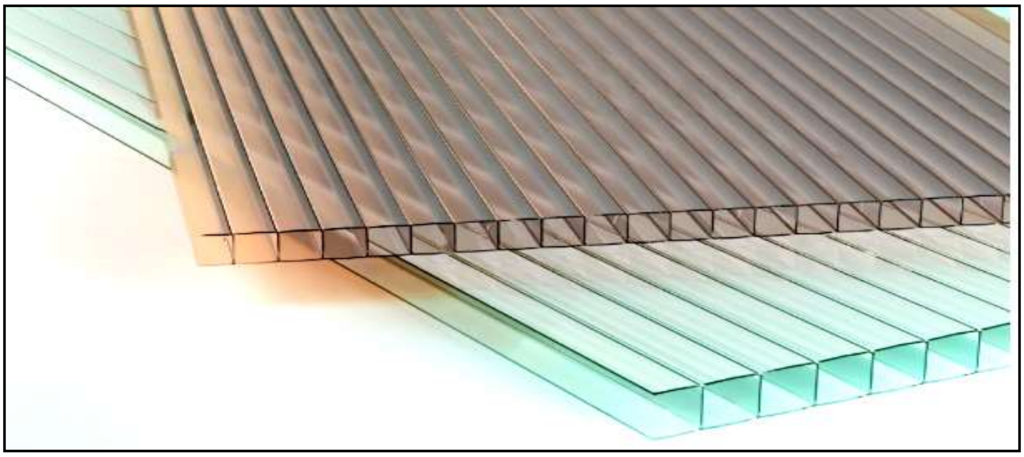

Figure 2: Polycarbonate (PC) Glazing Material

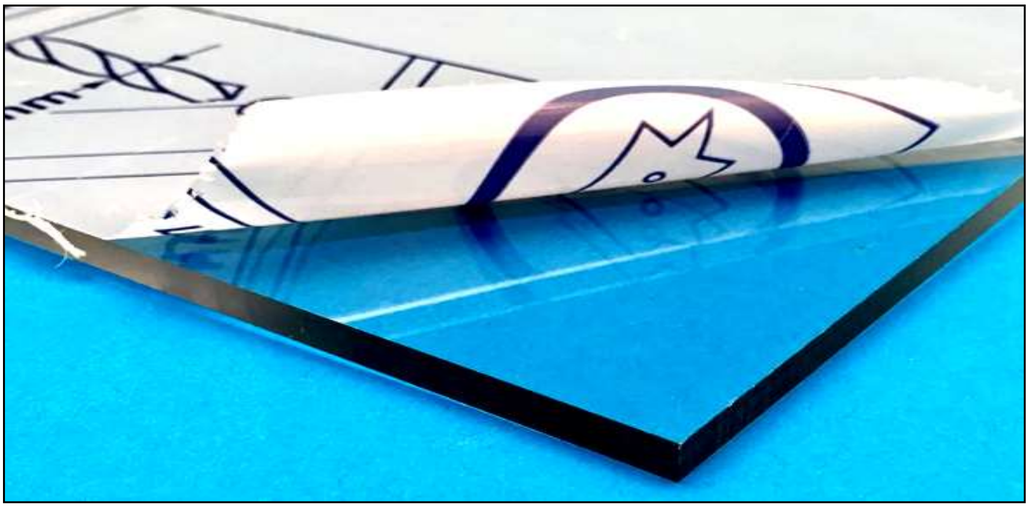

Figure 3: Poly Methyl Methacrylate Acrylic Glazing Material

Tables

Table 1: Test Result

Standard Test Methods	TG	PC	PMMA
Visible transmittance (380 –780 nm)	90.0%	81.5%	82.0%
Haze (ASTM D1003)	1.5%	6.5%	5.8%
Yellowness index (ΔYI)	0.5	10	8
Scratch resistance / abrasion	Excellent	Moderate (surface craze, scratches)	Moderate (scratches, surface microcracks)
Impact resistance	Moderate (tempered resists)	Excellent (high)	Good (but brittle if aged)

Table 2: I-V Test Result

Month	TG	PC	PMMA
0	100.0	98.0	99.0
6	99.6	95.8	97.1