Volume 10, Issue 12, December – 2025 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25dec1121

# Master Report: ZnO, TAIC, and Zinc Acylate in EVA/POE Solar Encapsulants

Rahul Kumar[1]

[1]Ph.D. Researcher Vikrant University Gwalior

Publication Date: 2025/12/24

**Abstract: Zinc oxide (ZnO), triallyl isocyanate (TAIC), and zinc acylate form a complementary stabilizer–co-agent system that enhances the reliability of EVA and POE photovoltaic (PV) encapsulants under heat, moisture, and UV stress. ZnO provides broad-band UV absorption (UV-A/UV-B) and functions as an acid scavenger—neutralizing acetic acid generated by EVA hydrolysis—thereby mitigating silver grid/ribbon corrosion and preserving optical clarity when used in surface-modified (e.g., silane-treated) nanoparticulate form. TAIC acts as a multifunctional peroxide co-agent, increasing crosslink density and enabling lower peroxide levels, which reduces browning risk and improves dimensional stability. Zinc acylate contributes ionic/covalent interactions at interfaces, improving adhesion to glass/backsheet and promoting cure uniformity across film thickness. We outline the synergistic mechanism: ZnO stabilizes the matrix (UV protection + acid scavenging), TAIC builds tri-functional bridges that raise gel content, and zinc acylate enhances interfacial bonding—collectively delivering superior UV resistance, adhesion retention, and potential-induced degradation (PID) resilience. Comparative guidance for EVA vs POE (cure kinetics, lamination windows, moisture barrier, and electrical insulation) is provided, along with practical formulation ranges for ZnO/TAIC/zinc acylate packages and notes on dispersion and transparency control. A visual IEC 61215 test matrix (Damp Heat, UV preconditioning, Thermal Cycling, Humidity Freeze, PID) and illustrative performance charts (UV transmittance vs ZnO loading, gel content vs lamination time, corrosion index vs ZnO loading) demonstrate typical trends and trade-offs. This integrated approach helps module manufacturers balance throughput and long-term reliability, enabling publish-ready documentation and data-driven optimization of encapsulant systems for modern PV architectures.**

**How to Cite:** Rahul Kumar (2025) Master Report: ZnO, TAIC, and Zinc Acylate in EVA/POE Solar Encapsulants. *International Journal of Innovative Science and Research Technology*, 10(12), 1530-1534.
https://doi.org/10.38124/ijisrt/25dec1121

## I. INTRODUCTION

Photovoltaic (PV) modules rely on encapsulant materials to protect solar cells from environmental stressors such as ultraviolet (UV) radiation, heat, and moisture while maintaining optical clarity and electrical insulation over a 25–30 year service life. Ethylene–vinyl acetate (EVA) has historically dominated the encapsulant market due to its low cost and ease of lamination. However, EVA is prone to hydrolysis under damp heat conditions, generating acetic acid that accelerates corrosion of metallic components and contributes to potential-induced degradation (PID). Additionally, EVA can yellow under prolonged UV exposure, reducing module efficiency.

Polyolefin elastomers (POE) have emerged as an alternative encapsulant, offering superior moisture barrier properties, higher electrical resistivity, and improved PID resistance. Despite these advantages, POE typically requires longer lamination times and optimized co-agent packages to achieve target gel content and adhesion comparable to EVA.

To address these challenges, advanced additive systems are employed. Zinc oxide (ZnO) serves as a multifunctional stabilizer, providing UV shielding and acid scavenging capabilities. Triallyl isocyanurate (TAIC) acts as a peroxide co-agent, enhancing crosslink density and thermal stability. Zinc acylate improves adhesion to glass and backsheet interfaces and promotes uniform cure throughout the film thickness. When combined, these additives create a synergistic effect that enhances durability, optical stability, and electrical performance under IEC 61215 reliability tests, including Damp Heat, UV Preconditioning, Thermal Cycling, Humidity Freeze, and PID testing.

This report examines the roles of ZnO, TAIC, and zinc acylate individually and collectively, outlines surface modification strategies for ZnO to maintain transparency, and provides formulation guidance supported by mechanism diagrams, performance charts, and references from peer-reviewed literature and industry best practices.

## II. ZNO ROLE IN DETAIL

Zinc oxide (ZnO) is a multifunctional additive in EVA and POE solar encapsulants, providing several critical benefits for long-term module reliability:

➢ *UV Shielding*

- Mechanism: ZnO has a wide bandgap (~3.3 eV), enabling absorption of harmful UV-A and UV-B radiation.
- Effect: Converts UV energy into heat, preventing polymer chain scission and yellowing.
- Importance: Protects encapsulant and underlying solar cells from photodegradation.

➢ *Acid Scavenging*

- Reaction: EVA hydrolysis generates acetic acid under damp heat conditions:

EVA+H2O→Acetic Acid+Polyethylene segments\text{EVA} + \text{H}_2\text{O} \rightarrow \text{Acetic Acid} + \text{Polyethylene segments}EVA+H2O→Acetic Acid+Polyethylene segments

- *ZnO Neutralization:*

ZnO+2CH3COOH→Zn(CH3COO)2+H2O\text{ZnO} + 2 \text{CH}_3\text{COOH} \rightarrow \text{Zn(CH}_3\text{COO)}_2 + \text{H}_2\text{O}ZnO+2CH3COOH→Zn(CH3COO)2+H2O

- Impact: Reduces corrosion of silver grids and ribbons, stabilizes polymer matrix, and improves adhesion retention.

➢ *Optical Clarity*

- Challenge: Unmodified ZnO can catalyze photo-oxidation and cause haze.
- Solution: Surface modification (e.g., silane coupling agents like APTES, GPTMS) creates Si–O–Zn bonds, improving dispersion and compatibility with EVA/POE while preventing photocatalysis.

➢ *Synergy with TAIC and Zinc Acylate*

- ZnO: Stabilizes matrix and scavenges acids.
- TAIC: Enhances crosslink density for dimensional stability.
- Zinc Acylate: Improves adhesion and cure uniformity.
- Combined Effect: High gel content, UV resistance, and PID suppression.

➢ *Role of TAIC*

TAIC is a highly effective peroxide co-agent used in EVA and POE encapsulants to improve crosslinking efficiency and long-term durability. Here's its detailed role:

- *Crosslinking Enhancement*

✓ Mechanism: TAIC contains three allyl functional groups that react with free radicals generated by peroxide decomposition.
✓ Effect: Creates multi-functional bridges between polymer chains, significantly increasing crosslink density.
✓ Benefit: Higher gel content improves dimensional stability, mechanical strength, and resistance to thermal and UV degradation.

- *Cure Optimization*

✓ Synergy with Peroxide: TAIC accelerates curing, allowing lower peroxide levels, which reduces risk of browning and volatile organic compound (VOC) formation during lamination.
✓ Impact: Shorter lamination times and improved process control.

- *Thermal and UV Stability*

✓ Result: Crosslinked network resists creep and shrinkage under high temperatures and UV exposure, maintaining adhesion and optical clarity over time.

- *Compatibility with EVA and POE*

Works effectively in both EVA and POE systems:

✓ EVA: Enhances gel content quickly due to faster cure kinetics.
✓ POE: Compensates for slower cure rate, ensuring uniform crosslinking.

- *Synergy with ZnO and Zinc Acylate*

✓ ZnO: Stabilizes matrix and scavenges acids.
✓ TAIC: Builds robust network structure.
✓ Zinc Acylate: Improves adhesion and cure uniformity.
✓ Combined Effect: Superior performance under IEC 61215 tests (Damp Heat, UV, PID).

➢ *Role of Zinc Acylate*

Zinc acylate enhances adhesion to glass/backsheet and promotes uniform cure through film thickness via ionic/covalent interactions with radical sites; it can boost peel strength without compromising optical clarity when dosed appropriately.

➢ *Silane Types for ZnO & Reaction Mechanism*

- APTES (3-aminopropyltriethoxysilane) – amino functionality for bonding.
- GPTMS (3-glycidoxypropyltrimethoxysilane) – epoxy for adhesion.
- Vinyl/methacryloxy silanes – facilitate co-polymerization and crosslinking.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25dec1121

➢ *Performance Charts*

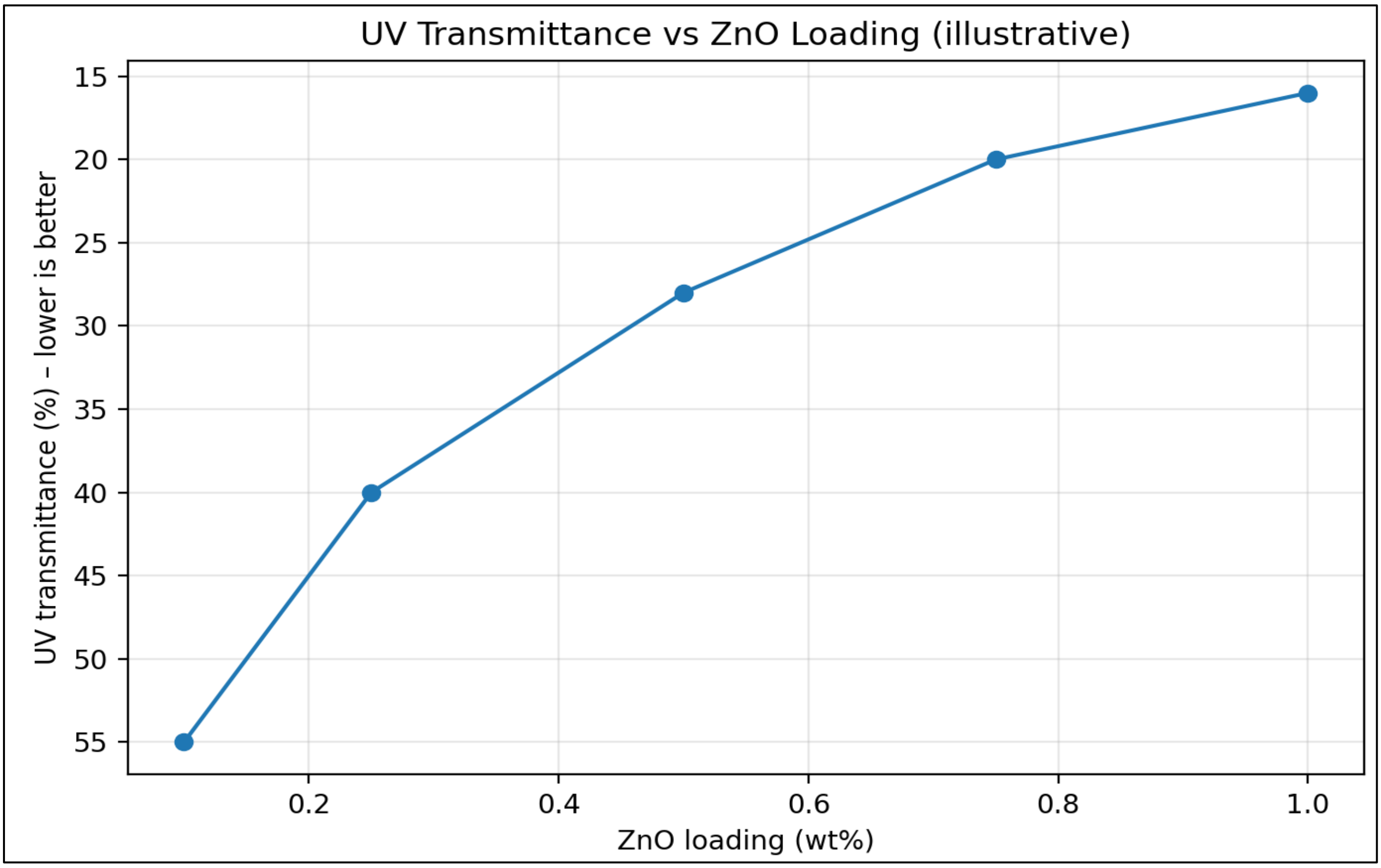


Fig 1 UV Transmittance vs ZnO Loading (Illustrative).

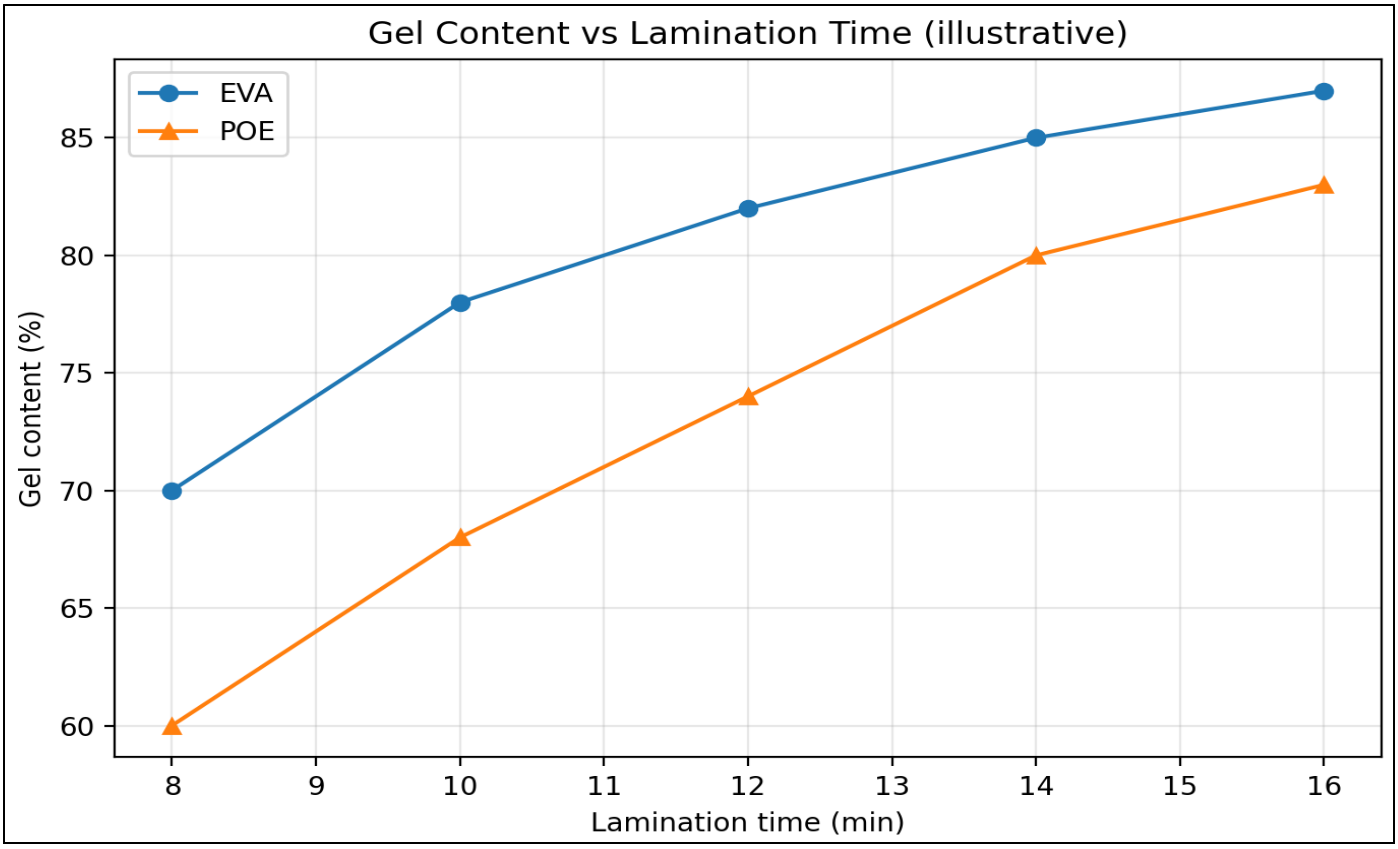


Fig 2 Gel Content vs Lamination Time for EVA and POE (Illustrative).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25dec1121

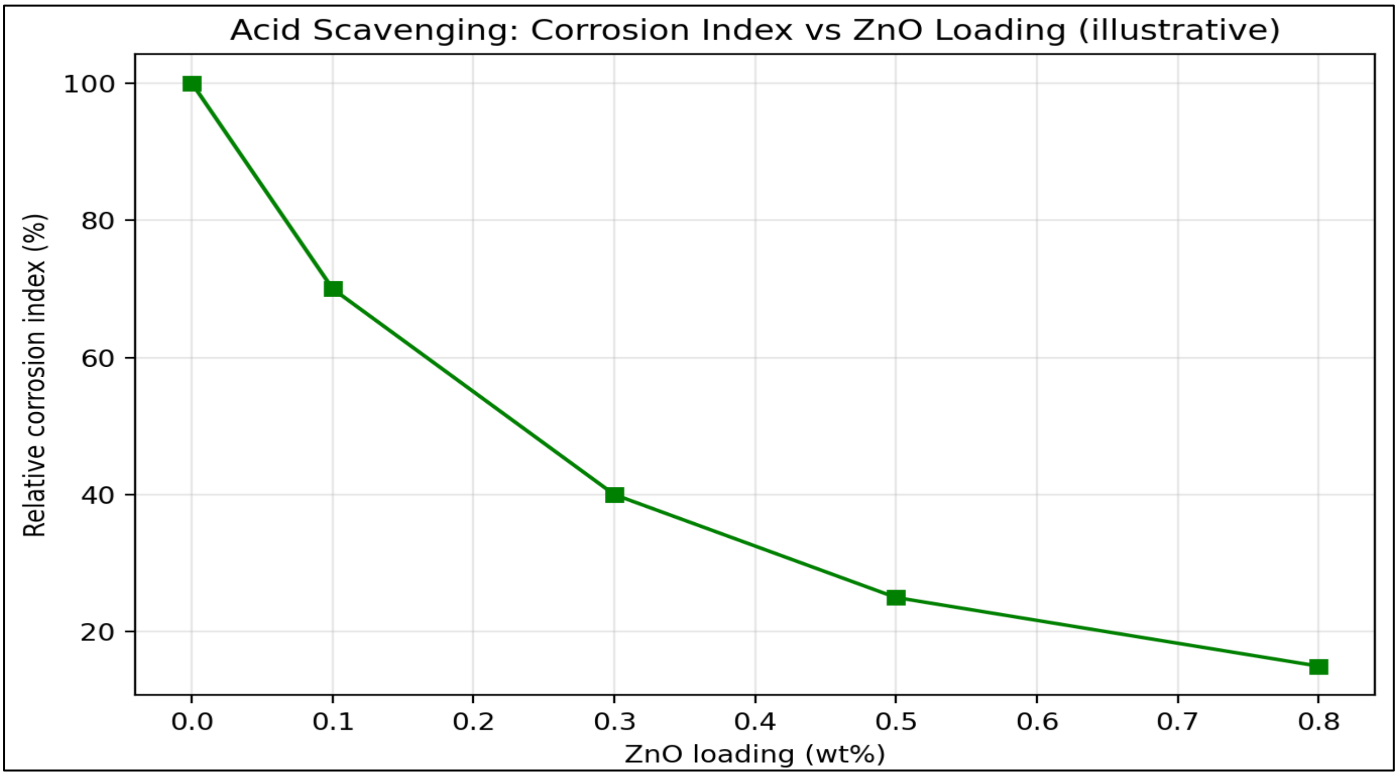

Fig 3 Acid Scavenging Effect of ZnO (Relative Corrosion Index).

**IEC Reliability Tests Relevant to EVA/POE Encapsulants with ZnO, TAIC, Zinc Acylate**

| Test | Description |
|---|---|
| Damp Heat | Samples are exposed to 85% relative humidity at 85²C for a predetermined period, assessing moisture resistance, delamination, and electrical insulation. |
| UV Preconditioning | Encapsulants are subjected to UV radiation to evaluate resistance to UV-induced discolorian degradation. |
| Thermal Cycling | Samples undergo repeated cycles of high and low temperatures to simulate thermal stresses and evaluate mechanical and electrical stability. |
| Humidity Freeze | Samples are subjected to a combination of high humidity and sub-zero temperatures to assess performance under freeze-thaw conditions. |
| Potential-Induced Degradation (PID) | Evaluates susceptibility to degradation of electrical performance under high voltage stress. |

Fig 4 IEC Reliability Tests Relevant to EVA/POE Encapsulants with ZnO, TAIC, Zinc Acylate.

## III. CONCLUSION

The combined use of ZnO, TAIC, and zinc acylate in EVA and POE encapsulants creates a synergistic stabilizer–coagent system that significantly enhances module reliability under IEC 61215 stress conditions. ZnO provides UV shielding and acid scavenging, TAIC optimizes crosslinking for dimensional stability, and zinc acylate improves adhesion and cure uniformity. This integrated approach addresses EVA's hydrolysis and UV yellowing issues while compensating for POE's slower cure kinetics, enabling superior optical clarity, adhesion retention, and PID resistance. For manufacturers, adopting this additive package—along with surface-modified ZnO and optimized lamination parameters—offers a practical pathway to balance throughput, cost, and long-term durability in next-generation PV modules.

## REFERENCES

[1]. Wallner et al., Polymers (2022): EVA vs POE crosslinking kinetics. https://doi.org/10.3390/polym14071441
[2]. Wendt et al., Progress in Photovoltaics (2024): TBEC & TAIC interactions; gel content & browning. https://onlinelibrary.wiley.com/doi/10.1002/pip.3849
[3]. Fiandra et al., Polymer Degradation and Stability (2024): UV aging of EVA/TPO/POE films. https://doi.org/10.1016/j.polymdegradstab.2023.110643
[4]. Oreski et al., Progress in Photovoltaics (2020): Polyolefin encapsulants vs EVA under damp heat. https://doi.org/10.1002/pip.3323
[5]. Ghaffar et al., Sustainability (2024): ZnO nanocomposite coatings; UV blocking & durability. https://doi.org/10.3390/su16156538