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INSULATION RELATED RELIABILITY PROBLEMS OF ELECTRICAL VEHICLE SUPPLY EQUIPMENT PLUGS AND PROPOSED SOLUTIONS

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Abstract: Recent studies show that Electric Vehicle Supply Equipment (EVSE) is out of service 30% of the time, often due to plug failures. The authors reviewed the IEC 62196-1-2022 standard and found that it tests humidity and thermal ageing separately, which may not reflect real conditions. They suggest using the IEC 60068-2-38 method to test both factors together. Simple polyamides like PA6 and PA66 degrade under combined conditions, so High-Performance Polyamides (HPPA) are recommended for better reliability and safety.

Keywords: Electric Vehicle Supply Equipment (EVSE), Reliability, IEC 60068-2-38, High-Performance Polyamides (HPPA), Humidity and Temperature Ageing

INTRODUCTION

Electric Vehicle Supply Equipment (EVSE) plays a pivotal role in the electrification of the transport sector. However, the reliability and operational efficiency of these systems are often compromised due to plug failures—30% of EVSE downtime can be attributed to such issues. This downtime is largely due to the insufficient resilience of polyamides used in plug manufacture against the combined effects of humidity and thermal ageing.

The existing standard for evaluating plug materials, IEC 62196-1-2022, has limitations in its separate assessment of humidity and thermal effects. Such a dichotomy fails to replicate the synergistic environmental stresses encountered during actual operation. Thus, advanced materials like High-Performance Polyamides (HPPA) are necessary to mitigate these vulnerabilities.

This paper seeks to address the shortcomings of conventional polyamides and present a robust alternative through the use of HPPA, specifically focusing on Omnix 6030. We aim to substantiate the use of the IEC 60068-2-38 testing standard for a comprehensive assessment of material performance under realistic conditions.

1. PROBLEMS WITH CURRENT INSULATION MATERIALS

1.1. Selection of Materials

Conventional polyamides, notably PA6 and PA66, have been widely used for EVSE plugs due to their cost-effectiveness and ease of manufacturing. However, these materials display suboptimal performance under combined thermal and humidity stress, leading to deterioration in dielectric properties.

1.2. Testing Limitations

The current IEC 62196-1-2022 fails to simulate real environmental conditions that plugs endure. The individual testing of thermal and humidity ageing may overlook critical interactions leading to material failure. This paper argues for the application of the IEC 60068-2-38 standard, which provides a more holistic evaluation by considering composite temperature/humidity cyclic stress-tests.

2. PROPOSED SOLUTIONS

2.1. Adoption of High-Performance Polyamides (HPPA)

Omnix 6030, a High-Performance Polyamide, emerges as a formidable alternative, offering enhanced resistance to thermal-humidity ageing. Its formulation includes 30% glass fiber which improves mechanical stability and dielectric strength.

2.2. Comparative Testing and Validation

Using Omnix 6030, experimental characterizations were carried out, showing significant retention of mechanical and dielectric integrity post-ageing. The same tests were applied to 4 conventional polyamide samples, namely, two injection moulding grade PA6 samples (PA6 and PA6-REC

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"recycled content"), and two glass fiber-filled samples of PA6 (PA6-GF) and PA66 (PA66-GF). These four conventional polyamide samples exhibited notable performance declines after ageing, in contrast with Omnix 6030 HPPA. The comprehensive study incorporated simulations to predict impact performance, reflecting superior outcomes for HPPA when subjected to cyclical thermal-humidity stresses according to the IEC 60068-2-38 standard.

3. RESULTS

The experimental data highlighted in the technical development (Figure 1) underscore Omnix 6030's proficiency. Before and after exposure to the IEC 60068-2-38 test conditions, Omnix 6030 maintained its mechanical and electrical properties significantly better than conventionally used polyamides (PA6-GF, PA66-GF, PA6, and PA6-REC).

The HPPA exhibited a dielectric strength reduction from 26.8 kV/mm to 24.8 kV/mm, whereas PA6-GF and PA66-GF saw reductions from 28.3 kV/mm to 11.5 kV/mm and 35.8 kV/mm to 12.4 kV/mm, respectively. Additionally, Omnix 6030 maintained a higher comparative tracking index (CTI) exceeding 600V, signifying superior electrical resistance compared to the 550 V of PA66-GF, PA6-GF, and PA6, as well as the 525 V of PA6-REC. These findings reveal the advancing degradation patterns of conventional polyamides under combined stresses.

The influence of combined thermal/humidity (T/H) aging cycles on mechanical properties, specifically stress at break, strain at break, and elastic modulus, exhibited comparable trends for Omnix 6030, PA66-GF, and PA6-GF glass-filled polyamide grades. Omnix 6030 demonstrated an elastic modulus comparable to the PA66-GF grade (approximately 10,900 MPa before aging and 5,940 MPa after aging) and slightly higher than PA6-GF (approximately 9,800 MPa before aging and 4,940 MPa after aging). Notably, T/H aging significantly reduced the elastic modulus by more than 40%, with reductions of approximately 45% for Omnix 6030, 41% for PA66-GF, and 49.5% for PA6-GF. Stress at break followed a similar trend, with reductions of approximately 37% for PA66-GF (143 MPa to 88.8 MPa), around 51% for Omnix 6030 (189 MPa to 92.1 MPa), and approximately 53% for PA6-GF (107 MPa to 50.1 MPa). Additionally, unfilled PA6 grades such as PA6 and PA6-REC exhibited substantial reductions in both elastic modulus and stress at break (Figure 2a).

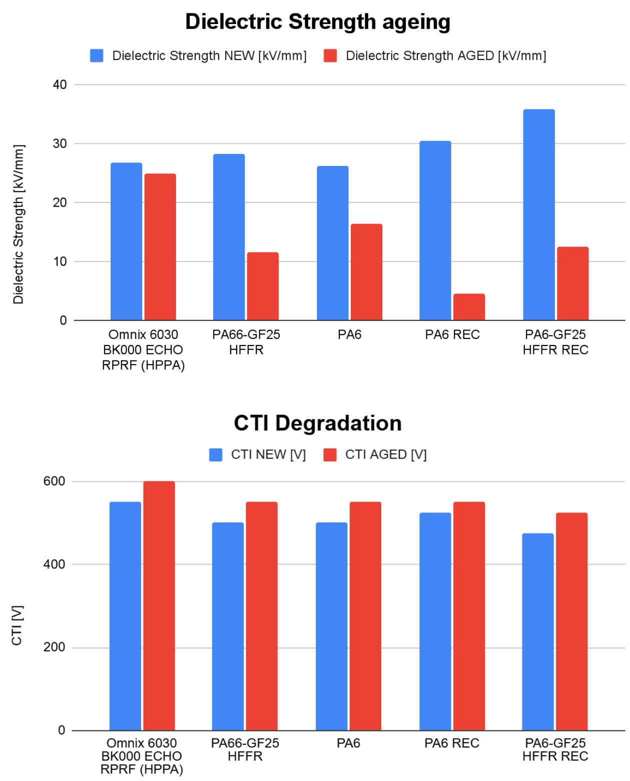
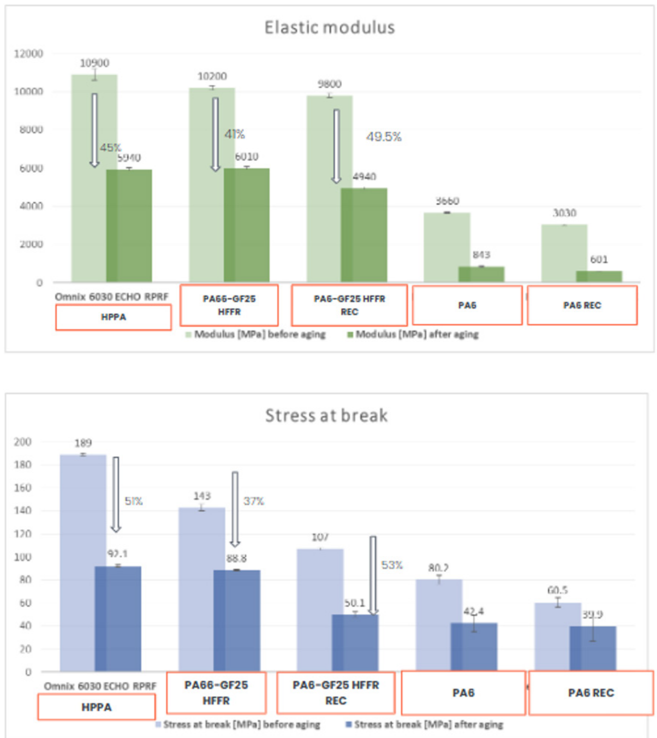


Figure 1: Important deterioration of Dielectric Strength due to moisture absorption and temperature ageing. Considering the same shape, this means a deterioration of electric permittivity and electrical conductivity of the materials. CTI is below PLC0 for all aged grades apart from Omnix 6030 HPPA



a)

Figure 2: a) HPPA and PA66 GF25 HFFR have a similar elastic behavior both aged and unaged. Tested recycled grade performs worse at Stress at break. PA6 grades perform worse, advancing potential failures against some of the harsher conditions in outdoors applications (vehicle run-away)

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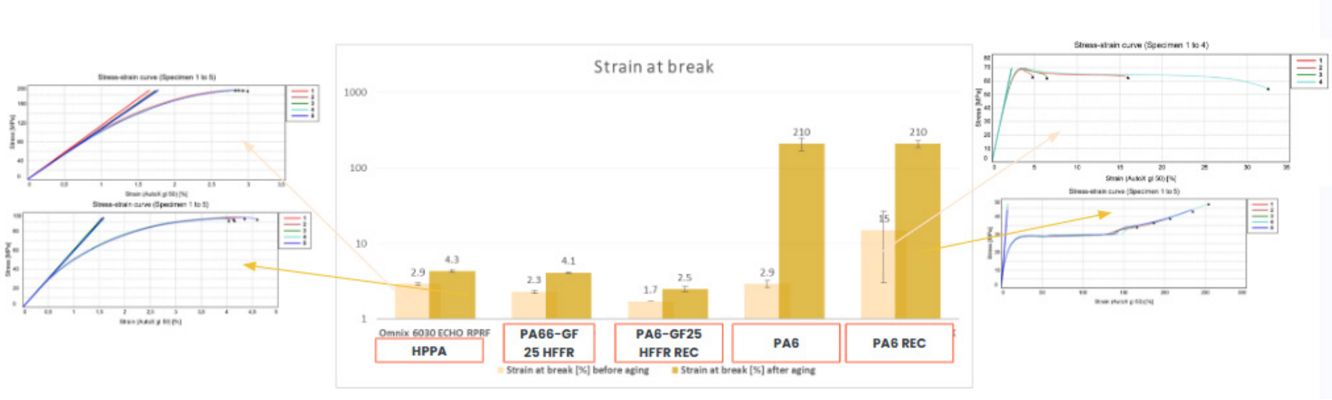


b)

Figure 2: b) Glass-fiber filled grades show a similar deformation behavior. Possible problems of pin deformation could appear when PA6 unfilled is aged, this could pose a safety concern especially if the lock mechanism gets compromised or the pins are deformed.

Strain at break values increased moderately after aging (Figure 2b), from 2.9% to 4.3% for Omnix 6030, from 2.3% to 4.1% for PA66-GF, and from 1.7% to 2.5% for PA6-GF. However, unfilled grades PA6 and PA6-REC showed significant increases, reaching up to 210%, reflecting the considerable effect of water absorption.

Tribological performance, assessed through disk-on-disk tests under pure linear sliding conditions, demonstrated superior wear resistance of Omnix 6030 compared to PA66-GF and PA6-GF grades. After aging, the wear rate increased notably for PA6-GF, exceeding 100 mm³/h, indicating greater susceptibility to wear under aged conditions compared to other grades. Omnix 6030 maintained relatively stable tribological performance before and after aging (approximately 20 mm³/h to 30 mm³/h), underscoring its superior wear characteristics (Figure 3).

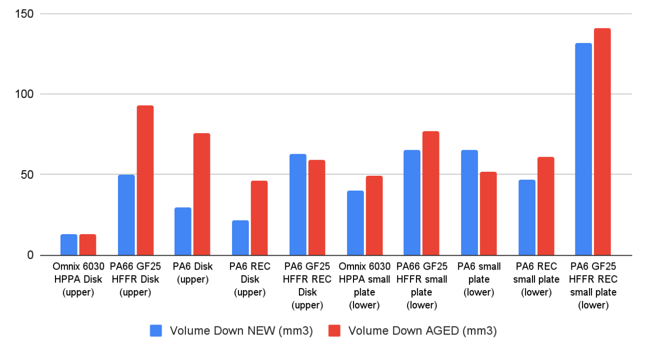


Figure 3: Omnix 6030 HPPA shows lower loss of volume due to friction compared to the rest of materials. It is worth mentioning the important loss of volume of PA66 grades and the effect of ageing in some of them. Higher volume reduction directly means loss of tight contact and reduction of insulating walls, advancing plug problems

Finite element simulations of rollover tests employing anisotropic elastoplastic modeling revealed slightly lower maximum local vertical deflection for Omnix 6030 (0.85 mm) compared to PA66-GF (1.0 mm) when performing wheel rotation on the charging gun handle (Figure 4a). Initial strain peaks during wheel movement were lower for Omnix 6030 (approximately 0.7%) than for PA66-GF (approximately 1.2%). Performing the rollover test on a central position (Figure 4b), both materials exhibited low failure indicator values (approximately 0.15-0.2), suggesting negligible static failure risk under simulated loading conditions. Furthermore, full-model simulations without symmetry constraints confirmed these observations, emphasizing the reliability of Omnix 6030 in realistic rollover scenarios.

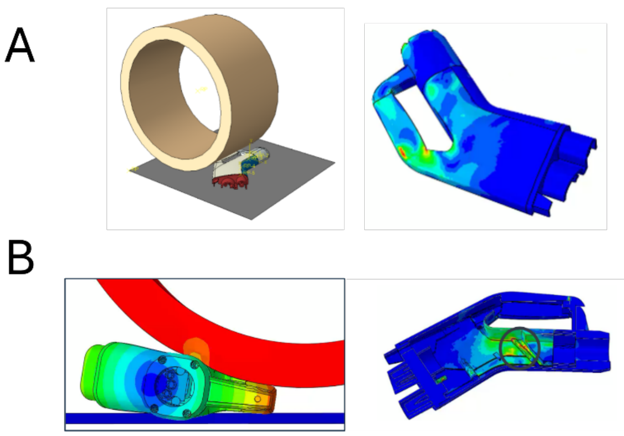
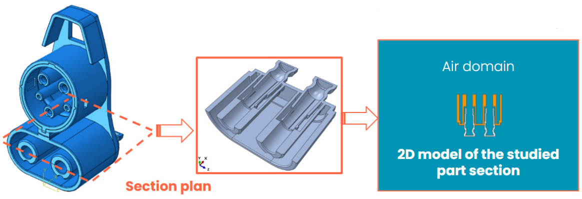
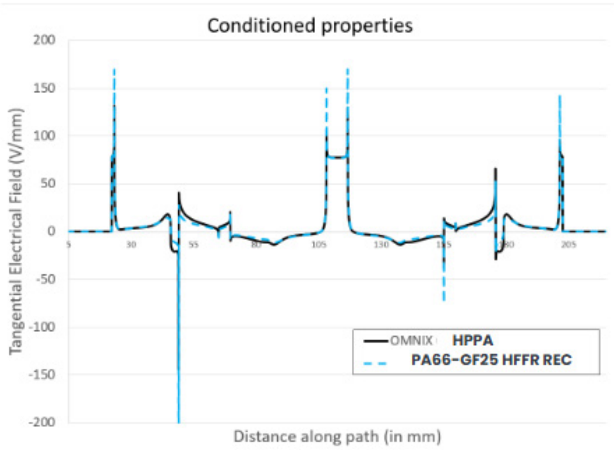


Figure 4: Scheme of the rollover test simulations on a) handle-oriented position b) central position.

Finite element analyses of electric field distributions between pins in EV-charging plugs (Figure 5) indicated comparable permittivity for Omnix 6030 and PA66-GF in the dry-as-molded state. However, aged PA66-GF exhibited significantly higher local electric field spikes around hotspots, suggesting reduced electrical insulation performance post T/H aging. This highlighted Omnix 6030's robustness in maintaining stable electrical insulation properties after aging cycles, making it particularly suitable for EV-charging plug applications.



a)



b)

Figure 5: a) Scheme of the electric field simulation studied part. b) Comparison of Electrical field simulation of Conditioned plugs in Omnix 6030 HPPA and PA66-GF25

4. IMPLICATIONS AND RECOMMENDATIONS

The findings suggest a strong rationale for transitioning to High-Performance Polyamides in the manufacture of EVSE plugs. Moreover, the integration of the IEC 60068-2-38 standard into material testing protocols would better simulate operational environments, reducing downtime and enhancing reliability.

The projected adoption timeline suggests anticipated market penetration by 2026. Implementing these advanced materials is slated to significantly boost user satisfaction and system safety.

5. CONCLUSION

The study confirms that Omnix 6030 HPPA offers substantial improvements over traditional polyamides under realistic operational stresses, verified by the IEC 60068-2-38 testing. Its performance presents a pathway towards more reliable and resilient EVSE installations, reaching exceptional electrical properties while maintaining a high mechanical stability after ageing paving the way for robust infrastructure support in the burgeoning electric vehicle industry.

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