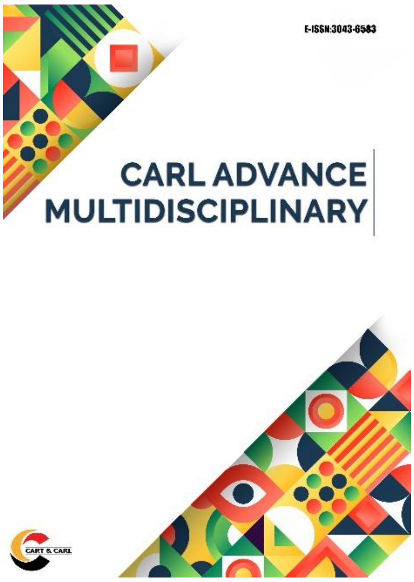
Original Article

CARL ADVANCE MULTIDISCIPLINARY
https://cartcarl.com/journal/carl-advance-multidisciplinary

Remote Automatic High Energy Flare (RAHEF) Ignition System Cable and Composite Wall Insulated Cable Solution

E-ISSN: 3043-6583



Authors
Nwokorie, F. O., Ossia, C. V., Big-Alabo, A.

Department of Mechanical Engineering, University of Port-Harcourt, Rivers State, Nigeria

Corresponding Author
Nwokorie, F. O.
(elyxxon@yahoo.com)

Received: 02 August 2025
Accepted: 25 August 2025
Published: 30 August 2025

Citation
Nwokorie, F. O., Ossia, C. V., Big-Alabo, A. (2025). Remote Automatic High Energy Flare (RAHEF) Ignition System Cable and Composite Wall Insulated Cable Solution. *Carl Advance Multidisciplinary*, 2(1), 32-41. https://doi.org/10.70726/cam.2025.213241

Abstract

The reliability of ignition system performance is directly influenced by the quality of high-voltage cables that deliver electrical pulses to spark plugs and other ignition components. Conventional ignition cables, typically constructed with single-layer polymeric insulation, are limited by thermal degradation, partial discharge susceptibility, and reduced electromagnetic compatibility. The RAHEF Ignition System introduces a composite wall insulated cable solution, designed to address these limitations through multilayer insulation architecture that combines high dielectric strength, thermal stability, and enhanced mechanical endurance. This study investigates the design principles, material composition, and performance characteristics of RAHEF composite ignition cables, with emphasis on dielectric behavior, partial discharge inception, mechanical robustness, thermal aging, and electromagnetic interference suppression. Comparative analysis with conventional single-insulated cables highlights the superior breakdown voltage, durability under harsh automotive conditions, and reduced spark-plug wear offered by composite insulation systems. The findings demonstrate that RAHEF composite wall cables significantly improve ignition reliability, reduce maintenance requirements, and extend service life, thereby providing a cost-effective and technologically viable solution for modern automotive and industrial ignition systems. The study concludes that composite insulation technologies, as applied in the RAHEF ignition system, present a strategic advancement in ignition cable design. Further research is recommended to optimize material combinations, ensure large-scale manufacturability, and establish standardized performance benchmarks for industry adoption.

Keywords: Flare Ignition, Ignition System Performance, RAHEF Ignition System, Ignition Cable Design

Introduction

The predominant reliance on outdated manual or semi-automatic flare ignition procedures across many Nigerian oil and gas facilities raises grave safety concerns. These outdated methods expose personnel to hazardous conditions during ignition attempts, significantly elevating the risk of accidents, injuries, and even tragic fatalities. The human element involved in these ignition processes introduces potential errors and delays, underscoring the critical need to address this safety hazard promptly. Ignition-system cables (commonly called spark-plug wires or high-tension leads) transfer very high-voltage pulses from the ignition coil or distributor to spark plugs, making them critical for reliable combustion in internal combustion engines and for the safe operation of many industrial ignition devices. These cables must withstand high peak voltages, rapid voltage slew rates, high temperatures, mechanical flexing, oil/chemical exposure, and must limit electromagnetic interference (EMI) that can disturb nearby electronics (Kumru & Kocatepe, 2023). Traditional ignition-cable constructions use metallic conductors with polymeric insulations (silicone, EPDM, ETFE, XL-ETFE and similar) and various EMI-suppressing cores or coatings. While these materials perform adequately in many service conditions, modern applications lighter and more compact engine bays, tighter electronic integration, higher operating temperatures, and stricter electromagnetic compatibility (EMC) requirements — expose limitations in single-material insulations: thermal/oxidative ageing, partial-discharge susceptibility, mechanical abrasion, and compromises between thermal conductivity and dielectric strength. These performance tradeoffs motivate exploration of advanced insulating systems (Islam & Arbab, 2023).

A promising solution is the composite-wall insulated cable: a multilayer cable insulation that combines two or more materials (for example, a thin high-dielectric polymer layer, a nanofiller-enhanced thermally conductive layer, and an outer tough protective jacket) to deliver a combination of excellent dielectric performance, improved thermal management, mechanical robustness, and reduced weight/volume. Composite (or hybrid) cable concepts are already used in aerospace, security, and industrial cabling where weight, space, and multifunctionality matter and recent polymer-nanocomposite and core-sheath research demonstrates routes to improve breakdown strength, reduce dielectric loss and increase thermal conductivity without sacrificing flexibility. Applying these composite insulation concepts to ignition cables can reduce EMI, lower peak insulation stress, improve spark-plug life, and increase service lifetime in harsh environments (Bahrim F. S. et al., 2018).

This study investigates the design, materials, and performance of a composite-wall insulated ignition cable solution (hereafter "the composite solution") compared with conventional single-material ignition cables. Objectives include: (1) characterizing dielectric and partial-discharge behavior under engine-relevant voltages and temperatures; (2) assessing EMI suppression and influence on nearby electronics; (3) measuring mechanical durability and chemical resistance; and (4) evaluating effects on spark-plug wear and ignition performance. Filling these gaps will help manufacturers and engineers select insulation architectures that meet increasing demands for reliability, miniaturization, and EMC in modern powertrain and industrial ignition systems. Prior studies on ignition-cable effects on spark-plug durability and on polymer composite insulation guide the experimental design and establish relevant test metrics. (Kumru & Kocatepe, 2023).

Literature Review

Table 1 shows some studies and resources that are relevant, which can inform material selection, test methodology, and expected performance benchmarks:

Table 1: Highlighted Studies and the relevant to the Study

Authors/Title/Year	Key Points Relevant to the Study
Islam, S., & Arbab, M. N. "Celite and Unsaturated Polyester Resin Composite for High-Voltage Automotive Ignition Coil Insulation-Based Applications." *Transactions of the Indian Institute of Metals*, 2023.	Investigates a composite resin + mineral (Celite) insulation in the automotive ignition-coil context, including dielectric strength, resistivity, suitable for high voltage, which is analogous to composite wall insulation.
Dung, Nguyen Van & Truong, Le Vinh. "Breakdown Characteristics of Composite Insulation for High Temperature Superconducting Cable." *VNU Journal of Science: Mathematics - Physics*, 2021.	Studies multi-layer insulation (composite) under AC and impulse voltages; useful for understanding how composite walls behave under high stress, and the effect of layer structure on breakdown and lifetime.
Effects of Electrical Insulation Breakdown Voltage And Partial Discharge (Bahrim F. S. et al.), IOP Conference Series, Materials Science and Engineering, 2018.	Compares XLPE and XLPE-polypropylene-fibreglass composites; shows how composite materials affect breakdown strength and partial discharge behavior.
An Experimental Study on Dielectric Parameters of XLPE Insulated High Voltage Cables under Different Operating Conditions (Kumru & Kocatepe), 2023.	Examines how temperature, voltage and frequency affect dielectric constant, dielectric loss, etc., for XLPE insulation. This helps in setting baseline comparisons for composite wall designs.
Thermal Aging Effects on Fire Performance of the Cross-Linked Polyethylene Insulated Cable (Materials Science Forum), 2017.	Evaluates how thermal aging influences ignition time, heat release, and insulation failure in standard cab materials; useful for flammability/safety baseline.
Composite Insulated Conductor, NASA / Langley Research Center ("TBMG-27033: Composite Insulated Conductor")	Describes development of composite insulation materials (e.g. polyimides, layered systems) that have high fire resistance and maintain electrical integrity under extreme conditions. Provides insight into high-performance insulation design.

Materials and Methods

Real Time Flare Stack-Diameter and Temperature Survey

The operating temperature of the flares that were sampled in this study, ranges from 611 ^{0}C to 754 ^{0}C, while the flare stack sizes, included 16-inch diameter to 24-inch diameter Flare stack. The location of the sampled flare oil fields are, OML17 at Agbada Flow Station, being operated by Heirs Energies Limited, OML 124, being operated by NNPC-Antan Producing Limited, at Izombe Flow Station, and OML11, Imo River Flow station Owaza, being operated by Heirs Energies Limited. Table 2 shows the real time flare stack diameter and temperature survey report for the sampled flow stations in this study.

Thermal Stability Tests

a. *Differential Scanning Calorimetry DSC;*

Differential Scanning Calorimetry Tests were conducted to determine the thermal conductivity of the components of the proposed (fire resistant), Composite wall insulated cable, and the Control cable. Because of their different chemical compositions, and thermophysical properties, these component materials, displayed different behaviors, when subjected to various degrees of thermal energy. Differential Scanning Calorimetry tests were carried out at a heating of rate of 10 0C per minute on all the individual materials that forms the insulating composite wall for the Cable, in order to determine the suitability of the selected (specified) materials.

The method uses thermal energy measurements to track the needed heat for both substance and reference material to reach equal temperatures while running at a controlled heating or cooling rate throughout the procedure. DSC tests to ASTM D3418, were carried out on the components of the cable conduit composite wall, namely the stainless steel AISI 316L, the mixture of castable refractory cement and refractory clay, the castable refractory cement alone, and a mixture of Portland cement, and sharp sand. These component material samples, were prepared in specified test-piece dimensions, before the test was conducted

b. Thermogravimetric Analysis (TGA)

Thermogravimetric Analysis (Figure 1) tests were conducted on the composite and control specimens, in order to determine their thermal stability for the proposed Composite wall insulated, and Control cables. Thermogravimetric Analysis TGA is a thermal analytic technique where the change in weight of the specimen sample, in an environment, heated or cooled at a controlled rate is recorded as a function of time or temperature. The result of thermogravimetric test is represented by plotting of change in weight change, against temperature or time, which is known as Thermogravimetric Curve (TG-curve). The weight is usually plotted on Y-axis, while the temperature or time is plotted on the X-axis, in ascending order from left to right.

c. Differential Thermal Analysis Test (DTA)

Differential Thermal Analysis tests (Figure 2) were carried out on the Insulating Composite wall component materials: With this approach, the temperature difference between a substance (sample or specimen) and the source material is recorded against time or temperature when the two specimens are exposed to the same temperature change in an isolated setting.

Recording of DTA results:

The difference between the test and reference temperatures displayed against time, or the test temperature, reference temperature, makes up the DTA chart.

Information from DTA curve:

On the DTA curve, there are exothermic and endothermic peaks. The shape and size of these peaks furnished good information about the nature of test sample. Endothermic peaks are frequently produced by physical changes, whereas exothermic peaks are produced by chemical changes. Until the sample experiences a physical or chemical change of state, the DTA curve would typically be parallel to the temperature axis.

Table 2: Selected Flow Stations in the Niger delta and their operating temperatures and flare stack sizes

S/N	Flow Station	Oilfield Location	Measured Flare Temperature (^{0} C)	Flare Stack Diameter (inches)	Oilfield Operator
1	Izombe Flow Station	Oguta Imo State OML 124	611	16	NNPC-Antan Producing Limited
2	Imo River 1 Flow Station	Owaza, Ukwa East LGA Abia State	704	20	Heirs Energies Limited
3	Agbada 2 Flow Station	Rukpokwu OML 17	754	24	Heirs Energies Limited
4	Imo River 2 Flow Station	Owaza, Ukwa East LGA Abia State	678	20	Heirs Energies Limited

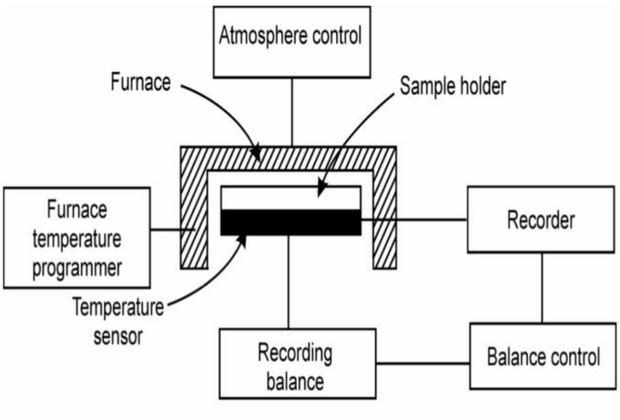


Figure 1:Thermogravimetric Analysis TGA Test Outlay (Dronacharya, 2019)

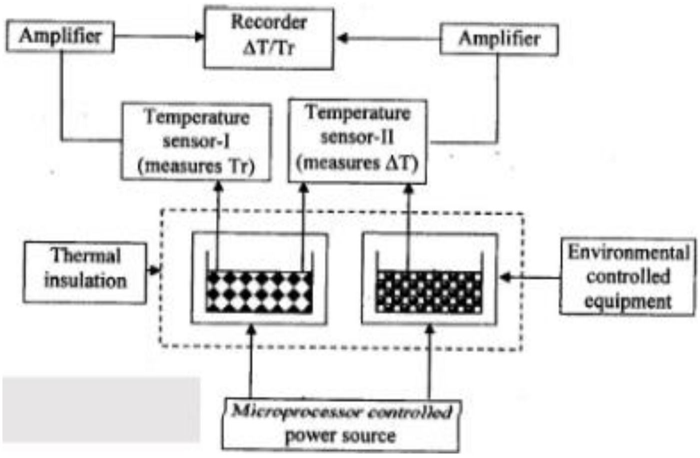


Figure 2:Differential Thermal Analysis Test Outlay (Dronacharya, 2019)

Mechanical Properties Tests

a. Tensile Test:

Tensile Test was carried out on the Stainless-steel material, 316L, which forms the outer shell of the cable conduit composite wall. A tensile test, is a mechanical test that measures a material's response to pulling stress. It's a fundamental test used by engineers to evaluate a material's mechanical properties. The test procedure involves; placing a material sample between two jaw-grips, followed by application of load (weight) to one end of the material, and then, measuring the material's change in length. The process of load application, continued incrementally, until the material (test piece) got broken (stretch). The results of the tensile test are displayed on a graph that plots load (weight) versus displacement (stretch) (Plate 1). The test provides information about the material's tensile strength, yield strength, and ductility. Materials may be subjected to mechanical forces over brief or extended periods of time, through recurrent or cyclical use, and under a wide range of climatic and temperature conditions. Tensile testing gives engineers information about a material's mechanical characteristics and helps them decide how, when, and where to employ a particular material.

Tensile test specimen preparation:

Tensile Test (Figure 3), was carried out on the outer shell metallic component of the cable conduit wall, namely, Stainless steel material AISI 316L. The Tensile specimens was machined in the shape of a dog-bone, of specified dimensions, before the test (Plate 1). The 'shoulders' of this dog-bone shaped sample/specimen, was intended to be gripped by clamping jaws, of the testing machine and the 'gage length' is used for measuring the tensile properties. The entire geometry, and dimensions of the specimen were prescribed by the testing standard. The dimensions and texture of the specimens, were considered, in selecting the type of grips, and jaw face surfaces may be used for a testing operation, and also to ensure an effective gripping of the sample / specimen. To ensure that tensile load is applied in the right direction, different alignment devices were applied to guide operator while positioning the sample for test.

Among all determined material properties, the Ultimate Tensile Strength stands out as the most vital. A tensile strength test determines the highest stress value which a specimen sample can withstand. The UTS relates to material breaking strength differently based on specimen characteristics which determine if it is brittle or ductile or shows signs of both characteristics. The modulus of elasticity enables stiffness evaluation of materials within their linear portion at the beginning of the curve. During this initial straight-line phase of loading tensile testing the researcher can release the force applied to the specimen because it will return to its original state. Any deviation from the linear shape of the curve indicates that Hooke's Law becomes inapplicable while the specimen experiences permanent deformation. An elastic limit represents the point where testing occurs. Any additional rise of load or stress will lead the material to exhibit plastic responses past its current point in the tensile test. The material remains deformed even after removing the external forces since it cannot restore its original state as it was before the stress was imposed. Materials display plastic deformation after the yield strength point because this stress magnitude triggers the start of such deformation. Material plastic deformation starts when reaching this particular stress level. Tensile testing measures stretch deformation in the specimens known as strain. The metric exists as both absolute values for length change and relative ratios between measurements. Engineering strain serves as the most widespread as well as the simplest method to express strain values. The measurement relates the change in length to initial length dimensions.

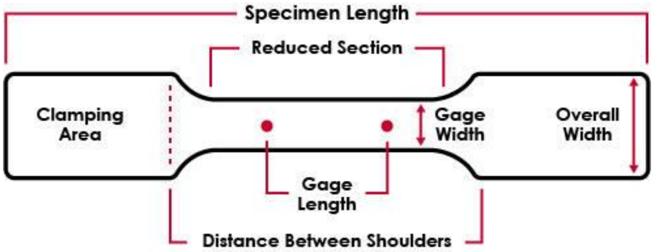


Figure 1: Sketch of a Typical Tensile Test Specimen sample (Instron, 2023)

Plate 1; specimen sample used for the Tensile test (Material: Stainless steel 316L)

b. Compression Tests

Reference Standards: ASTM Test Methods for the Compression Test, ASTM C39 (Plate 2). This is the standard tests for concrete cylinder compressive strength, and ASTM C1424: The assessment of compressive strength, including stress-strain behaviour, in advanced ceramics under monotonic uniaxial loading at room temperature is the special focus of this standard test procedure. Based on characteristics including hardness, yield strength, and compression strength, a compression test was used to evaluate the quality of the cable composite wall insulating materials. This mechanical test assessed the materials' behaviour, when subjected to a crush or compression force. Compression testing enables engineers to assess the integrity and safety of materials, components, and products during several phases of the manufacturing process. For a material to be selected for a particular application or product, there is need to establish, that the material can withstand whatever mechanical forces it will encounter in its end-use application.

Compression test machines measure material properties like; yield strength, ultimate strength, modulus of elasticity, compressive yield strength and stress-strain. Compression tests were carried out on the non-metallic components of the cable conduit composite wall, namely the mixture of castable refractory cement and refractory clay, the castable refractory cement alone, and a mixture of Portland cement, and sharp sand. These component materials were pre-casted into a rectangular beam of specified dimensions, as shown in figure below, before the compression test was conducted (Plate 4). The test aims at evaluating the compressive strength of ceramics by applying a compressive load and measuring the material's resistance to deformation and failure. It involves applying a compressive load to the test specimen with a standard shape and measuring the resulting stress and strain. The compressive strength data obtained from this test was used to assess the material's suitability for various applications, particularly those involving compressive stress.

Plate 2: Compression test system outlay (TestResources, 2021)

Plate 3: Compression test system outlay (TestResources, 2021)

Compression tests was used for the following;

i. Application of the compression test data, (material properties), to the engineering design process, in order to determine the suitability of the cable insulating material component, for the RAHEF ignition cable application.
ii. To improve the prototype building processes, by using the test data, to ensure that the selected insulating materials meet the optimum requirements.
iii. To provides valuable insights into material fracture phenomena, failure mechanisms, and helps to improve material design.
iv. Measurement of the insulating material's stiffness under compression.

c. Flexural Test

Reference Standard: ASTM D7264: For flexural testing of composite materials, which is a test method for determining the flexural properties (stiffness and strength) of polymer matrix composite materials These insulating component materials were pre-casted into a rectangular beam of specified dimensions, before the Flexural test was conducted (Plate 3). This test was used to assess the composite wall material's stiffness or resistance to bending by measuring the force needed to bend a beam made of brittle material. Flexural testing was carried out on the non-metallic components of the cable conduit wall, namely the mixture of castable refractory cement and refractory clay, the castable refractory cement alone, and a mixture of Portland cement, and sharp sand.

d. Thermal Expansion Coefficient

Reference Standard: ASTM E831-19: Being the Standard Test Method for Linear Thermal Expansion of Solid Materials using Thermomechanical Analysis (Plate 4). The Coefficient of Thermal Expansion Test, was carried out on the components of the cable conduit wall, namely the Stainless-Steel material AISI 316L, the mixture of castable refractory cement and refractory clay, the castable refractory cement alone, and a mixture of Portland cement, and sharp sand. These component materials were pre-casted into a rectangular beam of specified dimensions, before the test was conducted. The amount that a material expands or contracts in response to temperature variations is measured by its coefficient of thermal expansion. A material's rate of expansion as a function of temperature can be ascertained using the Thermal Expansion Test. This test can be used to assess the possibility of failure due to thermal stress and for design considerations. For an application to be successful, it can be crucial to comprehend the relative expansion/contraction properties of two materials in contact.

Optical Microscopy

Reference Standard: ASTM D8075-16: To guide and provide a framework for consistent description of microstructural and microtextural features visible in optical micrographs. The Optical microscopy test was carried out (for both the heated and unheated cable specimen /samples), on three different composite wall insulating samples, namely;

i. Mixture of refractory clay and castable refractory cement,
ii. Castable refractory cement alone, and,
iii. Mixture of sharp sand Portland cement.

The Optical microscopy test was also carried out on the Control Cable specimen / sample, with emphasis on the cable insulating material (layers), namely; the Fiberglass insulating sleeve (outer insulating layer), and the PVC material (inner insulating layer). Because of their different chemical compositions, and thermophysical properties, these component materials, displayed different behaviors, when subjected to various degrees of thermal energy.

Optical Micrographic examinations were carried out on both the heated and unheated test pieces (specimen/samples), and the results were recorded. Carrying out micrographic examinations on a prepared surface under an optical microscope makes it possible to determine the nature of the structure, grain size, the nature and the Micrographic Examination (Optical microscopy) was carried out on the different test-pieces of the insulated composite wall cable, and the control-cable, before and after subjecting the composite wall insulated cable, to a temperature of 1000 ^{0}C, and the results (resultant images) were recorded (Plate 5).

Thermal Analysis

Aluminum pans with lids were selected for both the sample and empty reference pans for DSC or platinum/ceramic pans for DTA 1600. They were placed in their respective positions in the heating cell (Plate 6). Experimental parameters; sample weight, sample name, operator name and instrument information (heating rate, start and end temperature etc.) were entered through the TA Instruments universal analysis 2000 software. By clicking START on the software Control program, the instrument automatically ran the experiment to completion. Realtime plot was generated simultaneously as the experiment ran. Both the experimental parameters and real time plot were automatically saved in the system for subsequent recall and analysis.

Plate 4: Coefficient of Thermal Expansion Test for the composite wall materials (conducted at an Engineering Laboratory at PGI Resources Nigeria Limited)

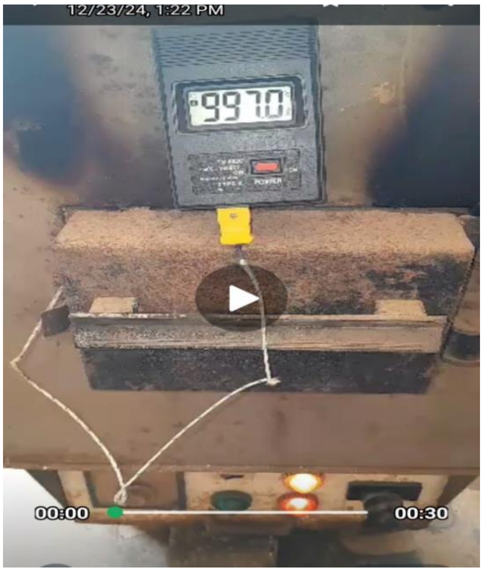


Plate 5: Furnace Heating of the Cable specimen samples to 1000 ^{0}C, to test for their thermal stability

The selected platinum or ceramic pan was placed on the sample platform and tarred by clicking TARE on the instrument panel. Experimental parameters; sample name, operator name and instrument information (heating rate, start and end temperature etc.) were entered through the TA Instruments universal analysis 2000 software. The pan with sample was placed on the sample platform. Prior to this, nitrogen purge gas was set at 60 ml/minute and 40 ml/minute for the furnace and balance chambers respectively. By clicking START on the software Control program, the instrument automatically loaded, weighed and ran the experiment to completion (Plate 7). Realtime plot was generated simultaneously as the experiment ran. Both the experimental parameters and Realtime plot were automatically saved in the system for subsequent recall and analysis.

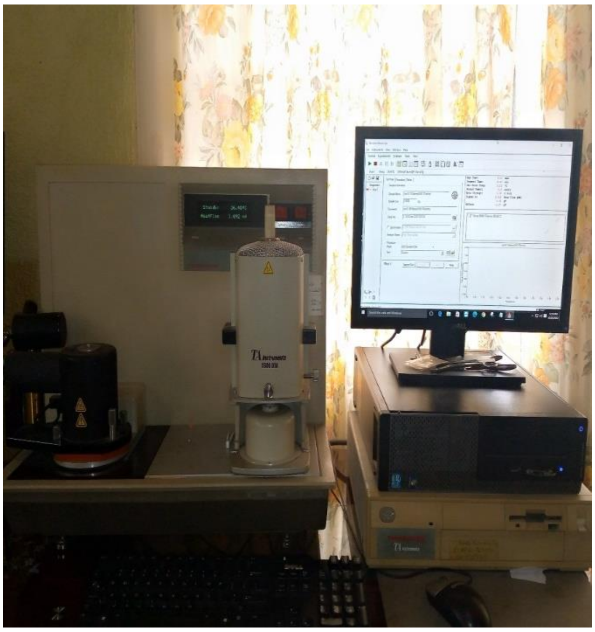


Plate 6: TA Instruments Modulated Differential Scanning Calorimeter MDSC 2920/DTA 1600

Plate 7: TA Instruments Thermogravimetric Analyzer TGA 2950

e. Performance Evaluation of Developed RAHEF Ignition System Cable Sheathing

RAHEF Ignition System Prototype Test Rig Layout and Cable Sheathing

Within the production operation process, a hazardous and unsafe practice prevails, wherein gas flares are ignited through risky methods. These methods involve the throwing of fireballs and the use of improvised burning fabrics across the flare tip during a flare light-up operation (Figure 2). This practice not only endangers the safety of personnel involved in production operations but also poses a significant risk to the critical production facilities within the process plants. The unsafe practice also results in prolonged facility downtime, due to the reliance on a trial-and-error approach, exacerbating challenges in production operations. The extended facility downtime translates into substantial revenue losses for organizations within the industry. The inefficiencies inherent in the existing flare ignition systems leads to increased emissions of unburned hydrocarbons into the atmosphere, which exacerbates environmental degradation and climate change concerns. The environmental impact of this practice is undesirable and places Nigeria under international scrutiny, potentially resulting in regulatory actions that could further affect her economic interests.

Results and Discussion

Proposed Cable Sheathe and control-cable sheathe Mechanical Properties.

Tensile Test: Tensile test was carried out in accordance with ASTM E8, in order to determine the tensile properties of the cable conduit shell material SS316L the test result, is as shown in Plate 8. The Tensile test being conducted at an Engineering Laboratory at PGI Applied Resources (Nigeria) Limited. The test results obtained during the test, were documented as shown in Table 3.

Compression Tests: Compression tests were carried out in accordance with ASTM C39, on the non-metallic components of the cable conduit composite wall, namely the mixture of castable refractory cement and refractory clay, the castable refractory cement alone, and a mixture of Portland cement, and sharp sand. The test results obtained, were documented as shown in Table 4.

Flexural Testing: Flexural testing of composite materials was carried out in accordance with ASTM D7264. The test results obtained, were documented as shown in Table 5.

Coefficient of Thermal Expansion Test: The Coefficient of Thermal Expansion Test, was carried out in accordance with ASTM E831-19, on the components of the cable conduit wall, namely the Stainless-Steel material AISI 316L, the mixture of castable refractory cement and refractory clay, the castable refractory cement alone, and a mixture of Portland cement, and sharp sand. The Coefficient of Linear Thermal Expansion test was carried out in conformance with the following applicable codes and standards; ASTM E831, ISO 11359. The test results obtained, were documented as shown in the Table 6.

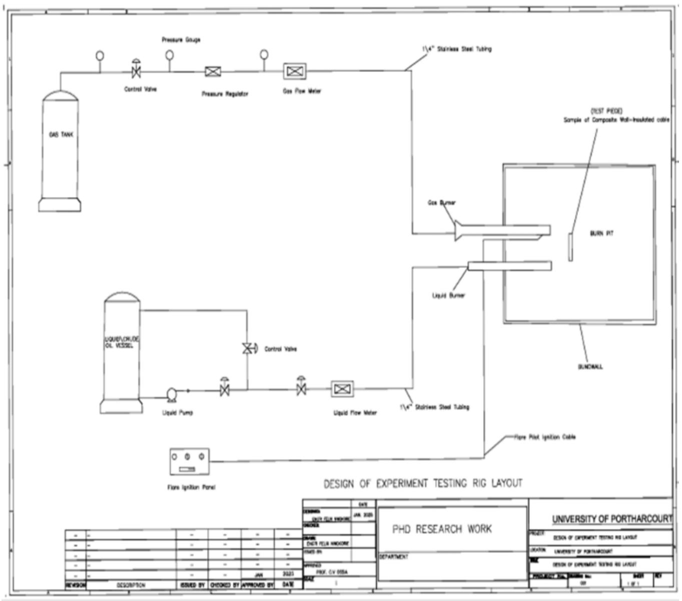


Figure 2: The layout Plan for the Design of Experiment Testing

Plate 8: The Tensile test being conducted at an Engineering Laboratory at PGI Applied Resources (Nigeria) Limited

Table 3: Tensile test result for the outer shell of the RAHEF ignition system cable conduit Stainless steel SST-316L

Strain (mm/mm)	Stress (MPa)
0.038	121.2595
0.058	181.8892
0.0728	212.2041
0.0796	242.519
0.082	272.8338
0.0944	378.9359
0.1056	454.7231
0.1336	485.0379
0.2044	515.3528
0.2816	485.0379
0.2856	454.7231

UTS, MPa	515.3528
Yield strength, MPa	212.2041
Young's Modulus MPa	2914.891
% elongation	28.56
Extension mm	7.14

Stainless steel test piece dimension: Lx W x T= 25mm x 4.75mm x 1.61mm, Strain: mm/mm, Stress: Mpa

Table 4: Test result for the Compression Test

S/N	Sample ID	Width (mm)	Thickness (mm)	Peak force F, (N)	Compression strength, (Mpa)
1	Castable and clay	13	7	153	1.681319
2	Castable alone	11.6	10	163	1.405172
3	Cement and sand	13.5	9	116	0.954733

Table 5: Flexural test result for the insulating components of the RAHEF ignition cable composite wall

S/N	Sample ID	Constant	Peak force F, (N)	Span L, (mm)	Constant	Width b, (mm)	Thickness d, (mm)	Flexural Strength, (MPa)
1	Castable and clay	3	8.15	30	2	13	7	0.575746
2	Castable alone	3	14	30	2	11.6	10	0.543103
3	Cement and sand	3	9.02	30	2	12.8	9.02	0,.389759

Table 6: Determination of Coefficient of Thermal expansion test

S/N	Sample ID	Lo (mm)	ΔL (mm)	To (°C)	T_1 (°C)	α, per degree. Celsius
1	Castable and clay	52	0.02	30.5	107	5.02765E-06
2	Castable alone	60	0.02	28.9	70.8	7,95545E-06
3	Cement and sand	46	0.01	34.6	179	1.50548E-06
4	Stainless Steel	43.6	0.07	30.8	130.3	1.81357E-05

Conclusion

The growing complexity of modern ignition systems requires cables that can withstand higher voltages, harsher environments, and stricter electromagnetic compatibility standards. Conventional single-layer insulated cables, while functional, often present limitations in terms of thermal aging, dielectric strength, and long-term reliability. The introduction of composite-wall insulated ignition cables, as proposed in the RAHEF system, offers a promising pathway to address these challenges. By integrating multiple insulation layers with complementary properties—such as high dielectric strength, thermal stability, mechanical toughness, and fire resistance—the composite-wall approach enhances the overall performance of ignition cables. This not only ensures efficient energy transfer and reduced partial discharge but also improves electromagnetic shielding, spark plug durability, and safety margins.

The findings from prior research on polymer composites, hybrid insulation systems, and high-voltage cable behavior support the feasibility of this solution. Adopting composite-wall insulated cables in ignition systems can therefore extend service life, reduce maintenance needs, and improve operational reliability in both automotive and industrial applications. Ultimately, the RAHEF ignition cable solution demonstrates how material innovation and layered insulation design can provide a robust response to the evolving demands of high-performance ignition technologies. Future studies should focus on optimizing material combinations, cost-effectiveness, and large-scale manufacturability to accelerate adoption in real-world applications.

Based on the findings and discussions of this study, the following recommendations are made:

1. Adoption of Composite-Wall Insulation in Ignition Cables: Manufacturers of ignition systems should prioritize the transition from conventional single-layer insulated cables to composite-wall insulated designs. This will improve dielectric performance, thermal resistance, and durability, particularly in modern high-performance engines.

2. Material Optimization: Future development should focus on identifying the most effective material combinations (e.g., nanofiller-enhanced polymers, fire-retardant outer sheaths, and mechanically robust protective layers) to balance performance, flexibility, and cost-effectiveness.

3. Standardized Testing Protocols: Industry stakeholders should establish standardized testing regimes (dielectric breakdown, partial discharge inception voltage, thermal aging, vibration, chemical resistance, and EMI suppression) to benchmark composite ignition cables against traditional designs.

4. Integration of EMI Shielding Layers: Considering the increasing presence of sensitive electronic control units (ECUs) in vehicles and industrial machines, composite ignition cables should incorporate EMI-shielding layers to minimize electromagnetic interference.

5. Lifecycle and Cost Analysis: A comprehensive cost-benefit analysis should be conducted to assess the long-term economic advantages of composite-wall ignition cables, considering reduced maintenance, extended service life, and improved reliability.

6. Collaboration with Automotive OEMs and Standards Bodies: To facilitate large-scale adoption, partnerships between cable manufacturers, automotive original equipment manufacturers (OEMs), and regulatory agencies should be pursued to establish certification, compliance, and safety standards for composite-wall ignition cables.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Nwokorie F.O.: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Ossia, C.V.** and **Big-Alabo, A.**: Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

References

Bahrim, F. S., Abidin, I. Z., Abid, A., & Baharudin, H. (2018). *Effects of Electrical Insulation Breakdown Voltage and Partial Discharge of XLPE/PPGF Composites.* IOP Conference Series: Materials Science and Engineering, 341(1), 012020. Available at: https://iopscience.iop.org/article/10.1088/1757-899X/341/1/012020

Dung, N. V., & Truong, L. V. (2021). *Breakdown Characteristics of Composite Insulation for High Temperature Superconducting Cable.* VNU Journal of Science: Mathematics – Physics, 37(1), 26–35. Available at: https://js.vnu.edu.vn/MaP/article/view/4624

Islam, S., & Arbab, M. N. (2023). *Celite and Unsaturated Polyester Resin Composite for High-Voltage Automotive Ignition Coil Insulation-Based Applications.* Transactions of the Indian Institute of Metals. Springer. Available at: https://link.springer.com/article/10.1007/s12666-023-02914-4

Liu, J., & Wu, Z. (2017). *Thermal Aging Effects on Fire Performance of the Cross-Linked Polyethylene Insulated Cable.* Materials Science Forum, 898, 2399–2404. Available at: https://www.scientific.net/MSF.898.2399

NASA Langley Research Center. (2000). *Composite Insulated Conductor (TBMG-27033).* NASA Tech Briefs. Available at: https://saemobilus.sae.org/articles/composite-insulated-conductor-tbmg-27033