Investigation of the Mechanical Stability and Deformation Mechanisms of Flame-Retardant PVC Compositions for Fire-Resistant Cable Sheaths

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UDC: 678.743.22:620.17:614.841

Publication Date: 2026/08/30

Abstract: This study experimentally investigates the mechanical stability and deformation mechanisms of flame-retardant polyvinyl chloride (PVC) compositions developed for fire-resistant cable sheaths. The mechanical properties of Germetik-35 and Germetik-45 compositions under tensile and compressive loading were evaluated using a universal testing machine according to a methodology closely aligned with ISO 527 and ASTM D638 standards. Force-elongation and stress-strain relationships, together with maximum load, maximum stress, relative deformation, and elastic modulus, were determined to characterize the structural behavior of the compositions. The results demonstrated that the Germetik-45 composition exhibits higher mechanical strength and greater resistance to deformation, whereas Germetik-35 possesses relatively higher elasticity. The effective interaction between flame retardants and the PVC matrix promotes a more uniform stress distribution, thereby improving the mechanical integrity and operational reliability of cable sheaths under fire conditions.

Keywords: *Flame Retardant, Polyvinyl Chloride (PVC), Fire-Resistant Cable Sheath, PVC Composition, Germetik-35, Germetik-45, Mechanical Stability, Deformation Mechanism, Tensile Test, Compression Test, Stress-Strain, Elastic Modulus, Mechanical Strength, Universal Testing Machine, Fire Safety.*

How to Cite: O'. D. Khakimov (2026) Investigation of the Mechanical Stability and Deformation Mechanisms of Flame-Retardant PVC Compositions for Fire-Resistant Cable Sheaths. *International Journal of Innovative Science and Research Technology*,11(8), 2006-2014. https://doi.org/10.38124/ijisrt/26aug607

I. INTRODUCTION

In recent years, approximately 60% of structural fires globally have originated from electrical short circuits and catastrophic failures within cable networks, rendering residential and commercial buildings entirely unserviceable. To mitigate these fire hazards, polyvinyl chloride (PVC) polymers, which constitute the core component of electrical cable insulation, are systematically treated with flame retardants. Notably, the utilization of such protective treatments for PVC-based cable insulation materials experienced a 5.7% growth in 2022. Consequently, substantial scientific focus has shifted toward the synthesis of oligomeric flame retardants capable of suppressing polymer flammability while simultaneously optimizing their rheological, physical, and mechanical characteristics. Worldwide research initiatives are increasingly directed at developing advanced synthesis pathways for oligomeric flame retardants to curb the flammability of vinyl-based cable networks. Within this context, establishing the optimal chemical formulation and physicochemical attributes of metal-containing oligomeric flame retardants, alongside elucidating their specific structural modification and interaction mechanisms within the polymer matrix, remains of paramount academic and industrial significance.

II. LITERATURE REVIEW

The synthesis of polyvinyl chloride (PVC) compositions and the systematic optimization of their physical and mechanical properties represent a foundational domain within modern polymer materials science. B.P. Shtarkman established the theoretical frameworks for processing thermoplastic vinyl polymer configurations, demonstrating that structural formulations and technological processing variables directly dictate the subsequent mechanical durability and operational lifecycle of the material [1].

In the field of polymer waste recycling and the development of secondary functional materials, research conducted by J.P. Zhang, C.C. Zhang, and F.S. Zhang highlighted the environmental benefits and processing

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

efficiency of fabricating novel composites using recycled PVC matrices [2]. Concurrently, X. Chen and X. Bai verified the chemical feasibility of co-processing PVC and lignocellulose biomass to simultaneously yield high-quality solid fuels and refined chemical feed stocks [3].

Regarding the quantitative evaluation of mechanical efficiency in structural polymers, M. Meyer, S. Dietrich, H. Schulz, and A. Mondschein evaluated alternative coating substrates, determining that chemical composition fundamentally governs tensile strength and yield behavior [4]. H. Cao, R. Wool, E. Sidoriak, and Q. Dan investigated the tensile characteristics of eco-friendly polymer configurations, noting that structural optimization significantly enhances long-term mechanical stability [5]. Furthermore, investigations into unplasticized PVC modifications by K. Lewandowski, K. Skórczewska, K. Piszczek, and M. Manikowski confirmed that specialized modifier additives substantially improve mechanical endurance, thereby extending its application scope within demanding industrial pipelines [6].

Refining PVC sorting and reclamation methodologies, S.R. Mallampati, C.H. Lee, M.H. Park, and B.K. Lee explored microwave-assisted surface modification paired with froth flotation, proving that polymer surface chemistry can be managed to achieve clean phase separation [7]. In subsequent research, S.R. Mallampati, B.H. Lee, Y. Mitoma, and C. Simion proposed an advanced separation protocol for recovering high-purity PVC from automotive and electronic shredder residues via hybrid nano-Fe/Ca/CaO ozonisation processes, markedly improving recycling throughput [8].

III. RESEARCH METHODOLOGY

The mechanical performance of flame-retardant-modified PVC compositions, designated as Germetik-35 and Germetik-45, was evaluated via controlled laboratory testing. Tensile and compressive properties were characterized using a calibrated universal testing machine (UTM) following an experimental protocol structured around the baseline mandates of ISO 527 and ASTM D638. Quantitative parameters-including peak failure load, ultimate tensile strength, relative elongation, rupture characteristics, and Young's modulus-were derived from real-time force-elongation and stress-strain trajectories. The resulting experimental datasets were statistically analyzed to evaluate structural stability, deformation dynamics, and the suitability of these compounds for protective cable insulation.

IV. RESULTS AND DISCUSSION

➢ *Mechanical Characterization of Flame-Retardant-Modified PVC Compositions via Uniaxial Tensile Testing*

The quasi-static mechanical response of the flame-retardant-modified polyvinyl chloride (PVC) formulations developed for fire-resistant cable sheaths was evaluated comprehensively. Tensile testing was executed on a high-precision Universal Testing Machine (UTM) to capture the constitutive behavior of the polymeric compounds under controlled uniaxial stress. The experimental apparatus applied an increasing mechanical load at a precise crosshead displacement rate, continuously tracking parameters such as instantaneous force (F), absolute elongation (ΔL), and elapsed time (t) via digital sensors calibrated to the International System of Units (SI).

Tensile profiles were gathered using flat, die-cut specimens at a constant deformation rate of 1 mm/min, establishing a strictly quasi-static loading regime to simulate structural service strains. The experimental boundary conditions were selected to align closely with the core criteria of ISO 527 and ASTM D638, ensuring reproducible and reliable data extraction across all sample sets.

The sequential testing phases and macro-structural failure profiles of the flame-retardant-modified PVC variants (Germetik-35 and Germetik-45) are presented chronologically in Figure 1. The first and third frames illustrate the primary test zone of the Shimadzu UTM, detailing the vertical alignment of the dogbone specimens (fabricated according to GOST/ISO structural geometry) within the pneumatic gripping jaws. This symmetrical alignment prevents parasitic bending moments, ensuring pure axial force transmission along the principal gauge length.

Fig 1. Chronological Tensile Testing Sequence and Post-Failure Profiles of Flame-Retardant-Modified Germetik-35 and Germetik-45 PVC Composites.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

The second frame displays the physical specimens after complete tensile rupture. The failure zone is localized within the narrow parallel gauge region, confirming appropriate sample geometry and validating that stress concentration remained confined to the designated gauge boundaries. The Germetik-45 variant exhibited greater total elongation before ultimate rupture, indicating superior plastic compliance and deformation capacity compared to the Germetik-35 formulation.

Overall, these photographic records verify the technical accuracy of the experimental setup and the dimensional consistency of specimen execution. They confirm that the recorded values reflect the true, uncorrupted constitutive properties of these modified vinyl configurations. This visual evidence supports the structural reliability of the engineered compounds, confirming their viability for deployment as fire-resistant electrical insulation barriers.

The experimental engineering stress-strain paths for both the Germetik-35 and Germetik-45 systems are presented in Figure 2. The initial linear slope of these trajectories reflects a rapid accumulation of stress relative to applied strain, defining the classic elastic deformation regime. This trend indicates that the bulk polymer matrix retains a robust elastic modulus. Beyond this initial linear region, the slope transitions into a less steep trajectory, representing the onset of segment mobility across the vinyl polymer chains and the activation of internal viscoelastic relaxation mechanisms. The Germetik-45 specimen achieved a peak ultimate tensile stress of approximately 6.9 MPa, remaining structurally stable up to a relative strain value of 3.3%. In contrast, the Germetik-35 compound reached its ultimate tensile strength threshold at approximately 6.47 MPa before undergoing structural failure at a lower strain value. This performance variance demonstrates that the flame-retardant additives achieve superior interfacial bonding and more effective structural integration within the PVC matrix of the Germetik-45 variant.

The recorded mean relative deformation of approximately 2.6% indicates that the synthesized composites avoid catastrophic brittle fracturing, displaying instead a controlled elasto-plastic deformation profile. This moderate ductility is highly beneficial for cable sheathing applications; it minimizes the risk of macro-cracking during installation stresses and helps preserve structural integrity when subjected to mechanical vibration or thermal expansion during service. Retaining mechanical stability under high thermal loads is essential for ensuring the functional reliability of cable protection layers. A comprehensive review of these mechanical parameters shows a balanced relationship between ultimate strength and structural ductility within the flame-retardant-modified PVC matrix. This balanced performance allows the insulation layer to preserve its physical geometry and barrier performance during normal operations and under direct fire exposure. Combining flame-retardant chemistry with stable mechanical properties minimizes severe structural distortion, splitting, or sudden mechanical failure when the cable sheaths are subjected to intense thermal stress.

The mechanical performance of these flame-retardant PVC configurations was evaluated through tensile profiling, analyzing their structural performance for fire-rated cable insulation applications. The experimental data consisted of detailed stress–strain and force-elongation curves, complemented by comprehensive datasets documenting individual and average mechanical properties. The engineering stress–strain curves illustrate the constitutive response of the modified vinyl polymers under continuous tensile loading. As shown in the plots, both formulations demonstrate a smooth, continuous increase in stress as deformation progresses, illustrating a classic transition from initial elastic resistance to a subsequent plastic yielding phase.

The initial steep slope of these trajectories indicates a robust elastic modulus within the bulk polymer matrix. The subsequent flattening of the stress–strain path reflects the movement of polymer chain segments and the initiation of internal molecular relaxation processes. This type of mechanical behavior is well-suited for fire-resistant cable sheaths because it helps prevent sudden, brittle cracking under coupled mechanical and thermal stresses. The higher stress threshold achieved by the Germetik-45 curve ($\sigma_{max} \approx$ 6.9 MPa) and its extended strain capacity ($\varepsilon \approx 3.3$ %) confirm superior mechanical stability compared to the Germetik-35 formulation. This performance enhancement is attributed to the effective dispersion of the flame-retardant phase within the PVC matrix, which facilitates more uniform internal stress distribution across the bulk material.

The sharp drop at the termination point of the curves marks ultimate specimen rupture. This failure occurs after controlled plastic deformation rather than via sudden, brittle cleavage. This ductile behavior helps cable sheaths maintain their structural shape when subjected to thermal expansion and mechanical loads during fire outbreaks.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

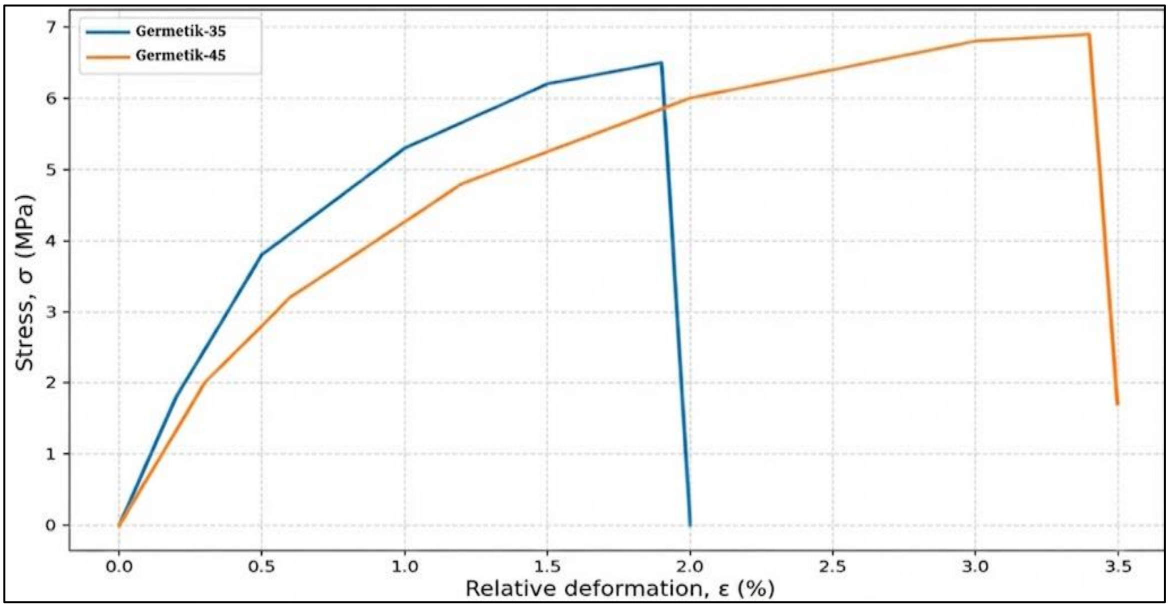

Fig 2. Engineering Stress-Strain Trajectories of Flame-Retardant-Modified Germetik-35 and Germetik-45 PVC Composites.

The force-elongation profiles directly illustrate the structural response of the flame-retardant-modified PVC compounds under continuous mechanical loading. As shown in the plots, both formulations exhibit a smooth, steady increase in applied force relative to continuous displacement, indicating a stable elastic deformation phase and high initial structural resistance. The Germetik-35 specimen reached its peak force capacity at a lower displacement threshold before undergoing structural failure, demonstrating limited deformation capacity. In contrast, the Germetik-45 composite sustained applied loads across a wider displacement range (≈0.85 mm) and achieved a higher peak load (≈870 N). This performance enhancement indicates that the flame-retardant additives achieved stronger interfacial integration within the PVC matrix of the Germetik-45 variant, promoting a more uniform distribution of internal stresses under load.

The steep drop in force at the end of each trajectory indicates complete specimen failure. However, the measurable displacement recorded prior to ultimate rupture confirms that both compounds exhibit ductile elasto-plastic behavior rather than sudden, brittle fracture. This performance characteristic is highly beneficial for cable insulation applications, as it significantly reduces the risk of sudden sheathing rupture when components are subjected to mechanical impacts, operational vibrations, or thermal expansion.

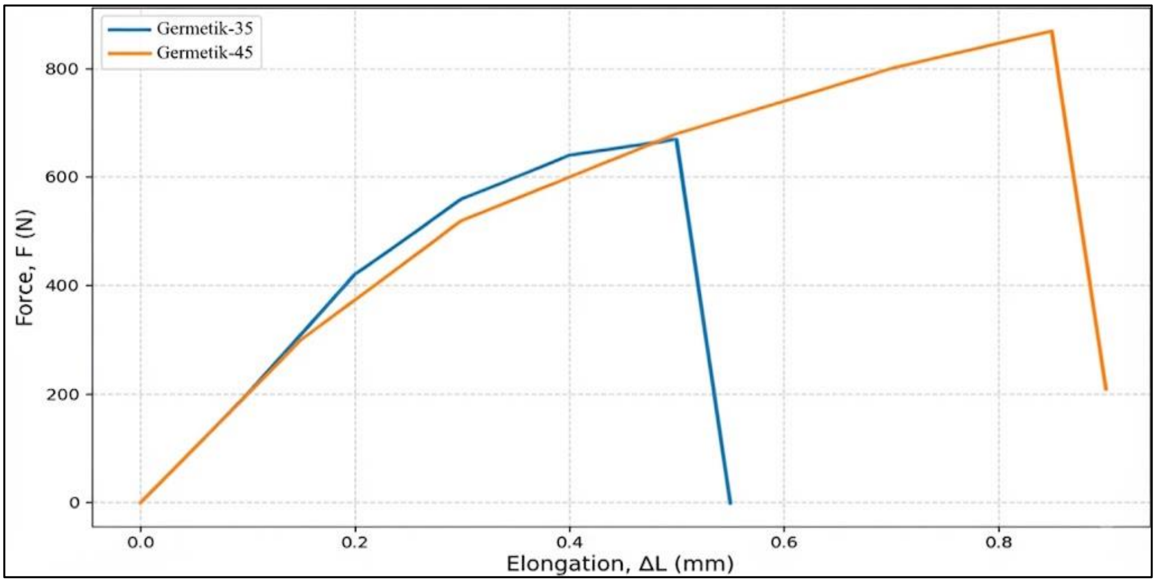

Fig 3. Force-Elongation Curves of Flame-Retardant-Modified Germetik-35 and Germetik-45 PVC Composites.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

As illustrated by the load-displacement relations in Figure 3, both formulations demonstrate a continuous and stable increase in resisting force as elongation progresses. The Germetik-35 compound reached its peak ultimate force (≈673 N) at a relatively small displacement threshold before undergoing rapid structural separation. Conversely, the Germetik-45 composite sustained its load-bearing capacity across a significantly broader displacement range (≈0.85 mm), achieving a higher peak load (≈872 N). This variation confirms the superior structural stability and deformation resistance of the Germetik-45 configuration under uniaxial tension.

Based on the individual experimental testing series, the composite materials exhibited an average peak failure load of 772 N, an ultimate tensile strength of 6.69 MPa, and a breaking stress of 6.68 MPa. The exceptionally close alignment between the ultimate tensile strength and the breaking stress indicates that the structural network effectively resists severe localized stress concentrations and catastrophic brittle fracture, distributing internal stresses uniformly across the material volume instead. This performance characteristic substantially enhances the mechanical reliability and functional durability of the electrical cable sheaths during assembly operations, standard service lifecycles, and high-temperature emergency conditions.

The recorded mean relative strain values, which fall within the 2.6-2.7% range, confirm that these flame-retardant PVC systems exhibit ductile elasto-plastic behavior rather than a brittle response. Maintaining this specific level of structural ductility significantly reduces the risk of micro-cracking, macro-sheathing rupture, or the subsequent loss of protective insulation performance. This capacity to absorb moderate deformation is highly critical during active fire outbreaks, as it allows the cable insulation layers to preserve their functional stability when subjected to concurrent thermal expansion and external mechanical loads. The integrated mechanical datasets confirm a highly stable balance between ultimate tensile strength and strain capacity within the flame-retardant-modified PVC matrix. This balanced performance ensures that the material can retain its physical geometry, cross-sectional profile, and protective performance as a functional barrier under elevated thermal exposure.

According to the quantitative metrics summarized in Table 1, the flame-retardant PVC configurations demonstrated an average peak failure load of 772 N, a mean maximum tensile stress of 6.69 MPa, and a rupture stress threshold of 6.68 MPa. The exceptionally minimal variance between the maximum stress and the rupture stress values mathematically confirms a stable, controlled failure mechanism rather than sudden, unpredictable cleavage fracturing.

Table 1. Mechanical Strength and Deformation Parameters of Flame-Retardant-Modified Germetik-35 and Germetik-45 PVC Compositions

Specimen	**Max. force, F (N)**	**Max. stress, σ (MPa)**	**Max. elongation, ΔL (mm)**	**Max. strain, ε (%)**	**Elongation at rupture, ΔL (mm)**	**Strain at rupture, ε (%)**	**Stress at rupture, σ (MPa)**
Germetik-35	672.625	6.46755	0.50247	2.00987	0.50247	2.00987	6.46755
Germetik-45	872.075	6.92123	0.82677	3.30707	0.84347	3.37387	6.89707
Mean	772.350	6.69439	0.66462	2.65847	0.67297	2.69187	6.68231
Maximum	872.075	6.92123	0.82677	3.30707	0.84347	3.37387	6.89707
Minimum	672.625	6.46755	0.50247	2.00987	0.50247	2.00987	6.46755

Furthermore, the clustering of the mean relative elongation between 2.6% and 2.7% highlights the controlled elasto-plastic structural configuration of the material. The Germetik-45 variant consistently outperformed the Germetik-35 formulation in both peak load-bearing capacity and ultimate strain limits, demonstrating a more optimized and favorable synergy between mechanical strength and structural flexibility.

➢ *Comparative Evaluation of Germetik-35 and Germetik-45 Variants.*

The comparative analysis demonstrates that while the Germetik-35 formulation is characterized by relatively higher initial stiffness paired with a limited deformation threshold, the Germetik-45 composite exhibits higher peak structural loads, greater absolute elongation, and superior plastic compliance. This variance in mechanical behavior is attributed to the specific concentration of the flame-retardant additives and the corresponding efficiency of their interfacial bonding within the PVC matrix. In the Germetik-45 compound, the highly uniform distribution of internal stresses across the bulk material volume significantly enhances macroscopic structural stability, thereby providing the vital operational reliability required for protective cable sheathing systems.

Consequently, the empirical mechanical profiles derived from the stress–strain trajectories and quantitative datasets provide a rigorous scientific justification for utilizing these flame-retardant-modified PVC composites as reliable insulation barriers and structural sheaths for fire-resistant electrical cables. The robust tensile strength, highly predictable deformation mechanics, and stable post-yield failure characteristics classify this material as a dependable protective framework capable of maintaining its functional integrity under standard service lifecycles as well as extreme thermal exposure during active fire outbreaks. Ultimately, these systematic experimental findings establish a robust empirical foundation for future comprehensive optimization of flame-retardant vinyl configurations and the strategic engineering of next-generation wiring insulation materials for advanced fire-safety applications.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

➢ *Experimental Evaluation of the Compound Materials Under Compressive Loading.*

The mechanical behavior of the elastomer-based Germetik-35 and Germetik-45 compounds under compressive loading was evaluated experimentally. The load-displacement and engineering stress–strain relationships were systematically characterized to determine primary performance parameters, including ultimate compressive force, maximum compressive stress, peak strain limits, failure thresholds, and the compressive modulus of elasticity (Young's modulus).

The experimental results indicate that the Germetik-45 compound exhibits higher mechanical strength across all primary load metrics compared to the Germetik-35 formulation. Specifically, the Germetik-45 compound sustained a peak ultimate compressive force of 225.083 N, outperforming the Germetik-35 variant (167.548 N) by approximately 34%. This higher threshold demonstrates an enhanced structural load-bearing capacity under direct compressive stress, as documented in Table 2.

Table 2. Primary Mechanical Performance Metrics of the Compound Materials Derived from Compressive Configuration Testing

Compound Designation	Maximum Force (N)	Maximum Stress (MPa)	Maximum Strain (%)	Strain Rupture Limit (v=0.01) (%)	Stress Rupture Limit (v=0.01) (MPa)	Compressive Modulus (Young's Modulus) (3%) (MPa)	Rupture Load (N)
Germetik-35	167.548	2.19017	2.84300	2.91055	2.17855	67.9020	166.659
Germetik-45	225.083	2.38323	2.98661	2.99489	2.38280	61.0985	225.042
Mean	196.316	2.28670	2.91481	2.95272	2.28068	64.5003	195.851

The peak compressive stress values closely mirror this trend, with the Germetik-45 compound reaching 2.383 MPa, whereas the Germetik-35 variant recorded a lower limit of 2.190 MPa. However, a detailed analysis of the deformation mechanisms indicates that while the Germetik-45 matrix sustains higher stress thresholds, its structural elasticity exhibits a moderate reduction. This behavioral transition is clearly quantified by the Young's modulus metrics: the Germetik-35 compound exhibited a compressive modulus of 67.9 MPa, whereas the Germetik-45 configuration recorded 61.1 MPa. This variation demonstrates that the Germetik-35 formulation maintains a more compliant and highly elastic structural framework under continuous loading.

The strain rupture limits, evaluated at the designated v = 0.01 termination threshold, remain closely aligned for both systems, indicating comparable structural stability and deformation limits. Concurrently, the sharp drop in load observed immediately after the peak force threshold in the force–displacement curves signifies the initiation of structural cell failure or the breakdown of internal physical crosslinks. The integrated average parameters-consisting of a 196.316 N ultimate force, a 2.287 MPa peak stress, and a 2.915% maximum deformation capacity-confirm that these specialized compound formulations possess sufficient mechanical capacity to efficiently withstand compressive stresses encountered in demanding industrial and structural engineering applications.

The geometric relationship between the engineering stress (MPa) and the maximum compressive strain (%) for the Germetik-35 and Germetik-45 compounds during mechanical testing is fully characterized. The initial phase of each curve exhibits a nearly linear relationship between stress and strain, identifying a predominantly elastic material response. As compressive displacement increases, the curves transition to a non-linear trajectory, eventually achieving their maximum stress values. The subsequent reduction in stress beyond these peak thresholds indicates the onset of microstructural breakdown and the degradation of internal physical bonds. The overall trends confirm that while the Germetik-45 formulation achieves a higher ultimate compressive stress, the Germetik-35 compound provides more stable and predictable deformation behavior (Figure 4).

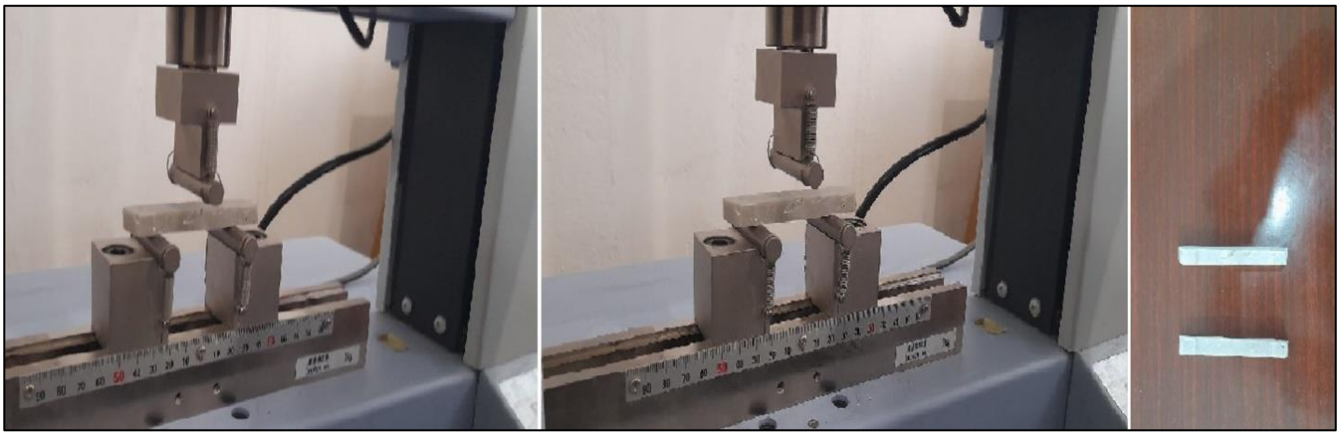

Fig 4. Experimental Compressive Performance Evaluation of Compound Specimens Using an Automated Universal Testing Machine.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

The compressive force (N) versus displacement (mm) curves for the Germetik-35 and Germetik-45 compounds during mechanical testing are structurally characterized. The initial portion of each plot features a shallow, nearly linear increase in force relative to displacement, demonstrating that both formulations remain within their elastic deformation limits during the early stages of testing (Figure 5). Within this linear region, the internal structural bonds remain intact, and the applied mechanical energy is absorbed primarily through elastic strain mechanisms.

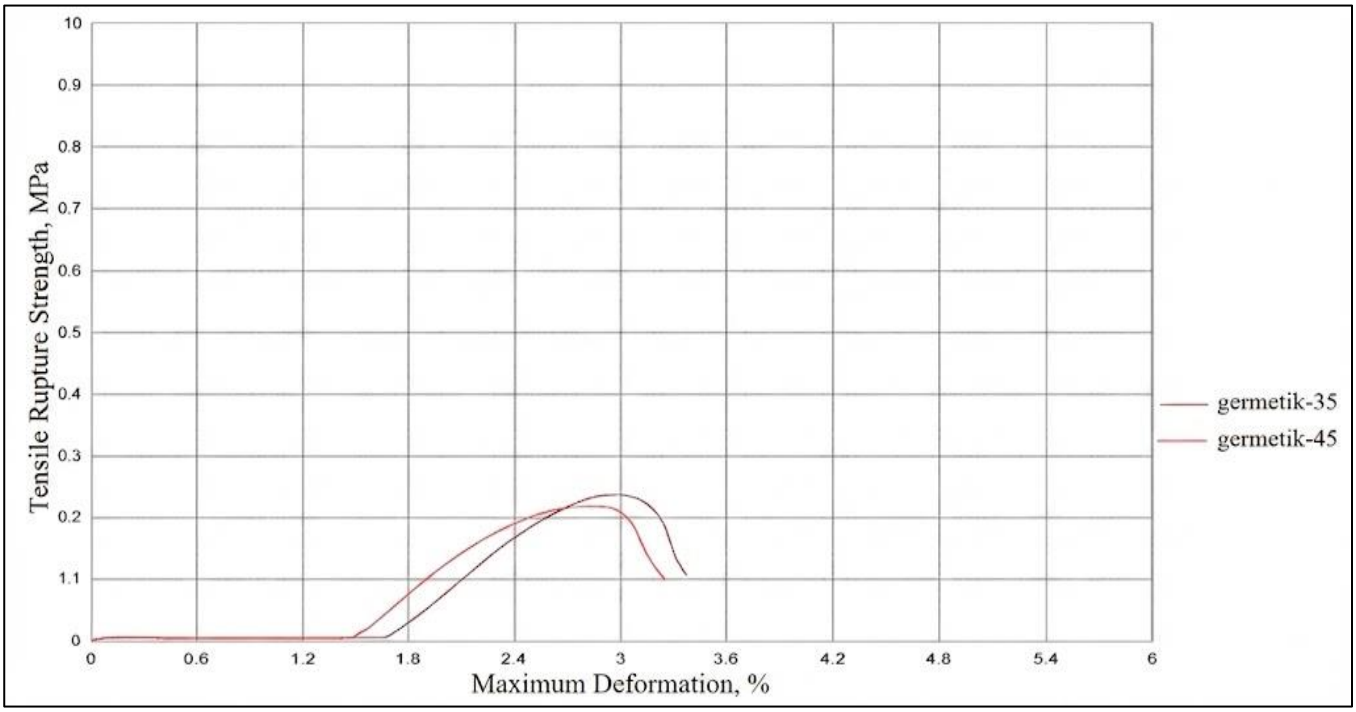

Fig 5. Compressive Stress Versus Maximum Strain Profiles of the Compound Materials During Mechanical Compression.

As displacement values increase, the rate of force development accelerates significantly, causing the curves to adopt a non-linear trajectory. This transition marks the onset of internal stress redistribution, microstructural phase shifts, and the formation of localized deformation zones within the specimens. The Germetik-45 compound achieved consistently higher force values across this region, reaching a peak compressive load of approximately 225 N, which confirms its superior structural load-bearing capacity.

Beyond the peak force threshold, both formulations exhibited a rapid decline in resisting force. This sharp drop reflects the transition of the material past its structural stability limit, indicating the failure of internal physical crosslinks and localized crushing. While the Germetik-35 formulation demonstrated a lower peak force capacity, it maintained a smoother and more progressive deformation path throughout the displacement range. In summary, the experimental data plotted in Figure 5 clarify the compressive performance of these compounds, confirming higher ultimate strength in the Germetik-45 formulation and superior deformation flexibility in the Germetik-35 variant (Figure 6).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

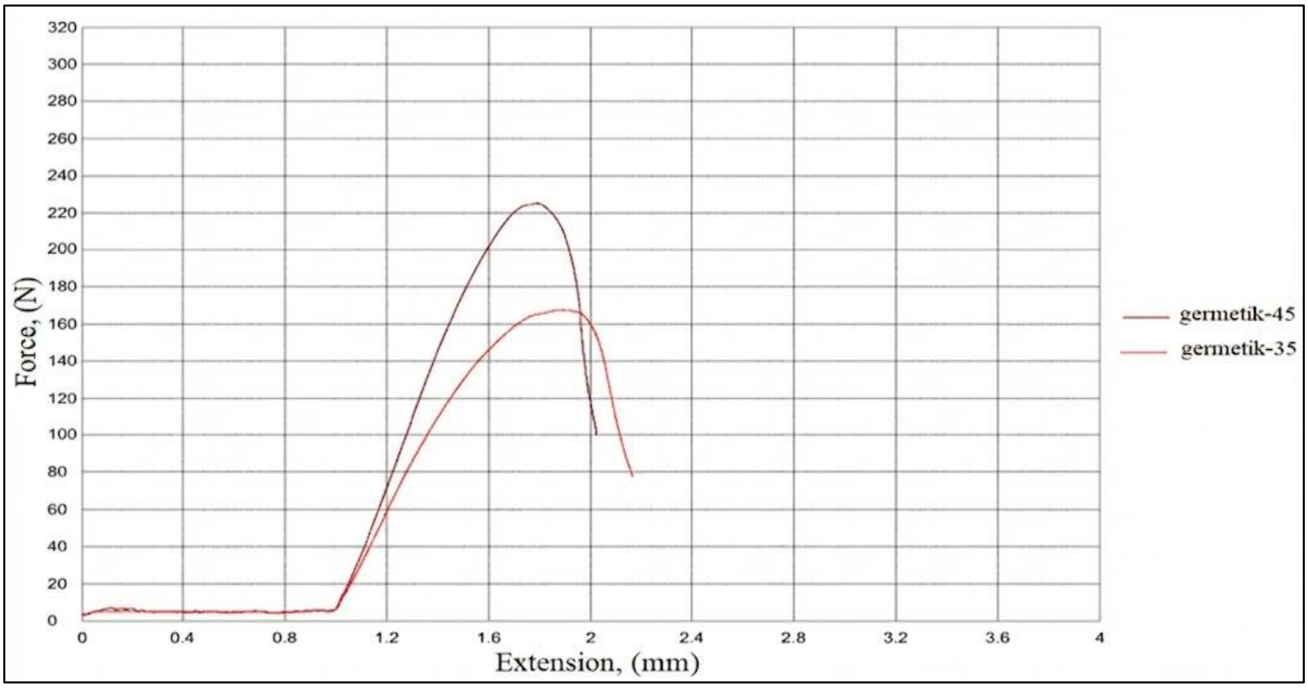

Fig 6. Compressive Force Versus Displacement Curves of the Compound Materials During Mechanical Testing.

The mechanical performance of the elastomer-based Germetik-35 and Germetik-45 compounds under compressive loading was evaluated experimentally. Force-displacement and engineering stress-strain relationships were derived from compression tests to calculate and compare the primary mechanical parameters of each formulation.

The experimental data indicate that the Germetik-45 formulation achieves higher maximum force and peak compressive stress values than the Germetik-35 variant. Under direct compression, the Germetik-45 compound sustained a peak load of 225.083 N, demonstrating approximately 34% higher load-bearing capacity than the Germetik-35 specimen. This higher strength threshold indicates that the Germetik-45 compound is well-suited for structural and engineering applications requiring enhanced resistance to compressive loads.

Concurrently, analysis of the elastic modulus metrics reveals that the Germetik-35 formulation maintains a more compliant and ductile response under load. The Germetik-35 compound exhibited a Young's modulus of 67.9 MPa, whereas the Germetik-45 variant recorded a lower threshold of 61.1 MPa. This variation confirms the superior strain adaptation and more progressive, predictable deformation mechanics of the Germetik-35 configuration.

The experimental stress-strain and force-displacement trajectories demonstrate a distinct two-phase mechanical response: a predominantly linear elastic phase during the initial loading cycle, followed by pronounced non-linear deformation prior to peak stress, and eventual microstructural breakdown beyond these ultimate thresholds. The rapid reduction in load capacity observed past the peak force limit signifies the sudden degradation of internal physical bonds and the subsequent loss of structural stability.

The integrated average performance metrics indicate that these specialized elastomer-based compound formulations possess sufficient mechanical capacity to efficiently withstand compressive stresses in challenging industrial and structural engineering applications. Ultimately, these systematic experimental findings justify the necessity of balancing ultimate strength with structural compliance when choosing sealing materials, and they establish a reliable empirical foundation for subsequent formulation optimization studies.

V. CONCLUSIONS

In this study, the mechanical stability and deformation characteristics of flame-retardant-modified Germetik-35 and Germetik-45 PVC composites were systematically evaluated using comprehensive experimental configurations. The quantitative data derived from both uniaxial tensile and compression testing confirm that the incorporation of functional flame-retardant additives not only enhances the inherent fire resistance of the vinyl matrix but also substantially improves its macroscopic mechanical strength and long-term operational reliability.

The experimental findings reveal that the Germetik-45 composite exhibits superior structural strength and deformation resistance during tensile deformation, achieving a peak ultimate force of 872.075 N and a maximum engineering stress of 6.921 MPa, thereby outperforming the Germetik-35 configuration. Mechanical compression tests closely mirrored this trend, confirming an enhanced load-bearing threshold for the Germetik-45 formulation. Concurrently, the Germetik-35 compound successfully retained a higher compressive elastic modulus alongside superior strain adaptation compliance.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug607

Detailed assessments of the force-elongation and engineering stress-strain trajectories verify that efficient interfacial bonding between the flame-retardant particles and the bulk PVC matrix facilitates a highly uniform internal stress distribution across the material volume. This crosslinked structural integrity successfully mitigates the risk of catastrophic brittle fracture, acting as a critical factor in preserving the geometric stability and isolating performance of protective cable sheaths when subjected to severe mechanical loads and extreme thermal exposure during active fire outbreaks.

Consequently, these flame-retardant-modified PVC compositions can be highly recommended as a promising class of structural insulation barriers for fire-resistant electrical wiring applications. The structural insights and empirical datasets established in this research provide a rigorous scientific and practical foundation for subsequent optimization of vinyl compound formulations, further enhancement of synergistic mechanical-thermal performance, and the strategic design of advanced next-generation electrical cable products.

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