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Alkylimidazolium Chloride Ionic Liquids as Green Additives in Rubber Composites: A Comprehensive Review

Anal D. Bhatt[1], Omprakash K. Mahadwad[2,*]

Abstract

The growing emphasis on sustainable and environmentally friendly materials has underscored the use of ionic liquids (ILs) as green additives in polymer science. Alkylimidazolium chloride ionic liquids (ACLs) have emerged as viable possibilities for improving the performance of rubber composites while minimizing the environmental impact of conventional processing aids. This research conducts a thorough examination of the function of ACls in rubber technology, focusing on their physicochemical features, interaction mechanisms with rubber matrices and curing chemicals, and their impact on the vulcanization process.Multiple preparation techniques for ACls-based rubber composites are examined, encompassing traditional two roll mill mixing, in situ polymerization using pre-dispersed ILs, solution mixing, and latex compounding. These methodologies provide adaptability in processing and facilitate the optimization of composite characteristics based on the specific rubber, filler, and ionic liquid employed. The choice of preparation process profoundly impacts ACls dispersion, filler interaction, and compatibility with the rubber matrix, hence affecting the performance of the finished material.Particular attention is placed on the capacity of ACls to facilitate uniform filler distribution, expedite curing kinetics, and improve the mechanical, thermal, and dynamic characteristics of rubber products. The environmental advantages of ACls, including low volatility, high thermal stability, and potential recyclability, are examined within the framework of green chemistry and sustainable manufacturing. This study consolidates previous achievements to highlight the promise of alkylimidazolium chloride ionic liquids as multifunctional, environmentally acceptable additives for the next generation of high-performance rubber composites.

Keywords: Alkylimidazolium chloride, green additive, ionic liquids, rubber composites, sustainable material

INTRODUCTION

Rubber composites' remarkable elasticity, durability, and chemical resistance make them indispensable in a wide range of industrial applications, such as tires, automotive parts, seals, footwear, and vibration dampers. To enhance their mechanical, thermal, and dynamic properties, these composites typically consist of an elastomeric matrix supplemented with functional fillers such as silica, carbon black, or nanofillers [1]. Ineffective crosslinking, poor interfacial adhesion, and suboptimal filler dispersion are common problems with conventional rubber systems [2] that affect their performance and dependability.

By incorporating ionic liquids (ILs), a class of organic salts that stay liquid at or close to room temperature, recent developments in materials science have opened up new avenues for

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overcoming these limitations. Ionic liquids have attracted a lot of interest as multipurpose additives in polymer composites [3], [4] because of their unique physicochemical characteristics [5], which include low volatility, significant thermal and chemical stability, and exceptional solvating capability [6]. Alkylimidazolium chloride ionic liquids have become one of the most intriguing choices for rubber composite applications among the several ionic liquid families. A wide range of performance enhancements are made possible by their ability to support strong interactions with polar and non-polar rubbers [7], as well as organic polymers and inorganic fillers, and by a structurally changeable framework.

Alkylimidazolium chloride (ACLIs) ILs have several functions in rubber compounding shown as per figure 1[8][7][9]. By serving as dispersing agents, they help fillers be evenly distributed throughout the rubber matrix, enhancing stress transmission and interfacial contact. By modifying cure kinetics and encouraging more effective crosslinking, they also significantly influence vulcanization behavior [10], [11]. Furthermore, Alkylimadozolium ionic liquids improve the processability and flexibility of compounds by acting as plasticizers or processing aids [12], [13]. Notably, because they are ionic, they can improve conductivity [14] and aid in the creation of rubber materials that are electrically sensitive or antistatic. Additionally, they are efficient viscosity adjusters due to their capacity to modify the compound's rheological behavior, which enhances mixing, flow control, and manufacturing [15].

The purpose of this article is to perform an extensive review of the current state of rubber composite technology's utilization of ionic liquids including alkylimidazolium chloride. Their influence on filler dispersion, crosslinking behavior, mechanical reinforcement, thermal stability, and dynamic characteristics are important considerations. This effort aims to direct future research and innovation in the creation of high-performance, sustainable rubber compounds by incorporating recent findings.

ALKYLIMIDAZOLIUM CHLORIDE IONIC LIQUIDS' CHEMICAL STRUCTURE AND CHARACTERISTICS (AIC)

Figure 2[15] depicts the imidazole ring, a flexible ionic liquid scaffold. Due to their non-volatile nature and capacity to coordinate with metal atoms, imidazole-based ionic liquids have found usage in a wide range of applications, including as possible water treatment agents. They can also be utilized as organic solvents that are green [16]. Furthermore, the imidazolium ionic liquid's characteristics can be altered to suit the needs of diverse applications thanks to the special combination of distinct alkyl substituents. The adjustable structure, thermal stability, relatively high ionic conductivity, broad electrochemical window, and amphoteric behaviour in solution are some of the main reasons imidazolium ionic liquids have garnered attention.

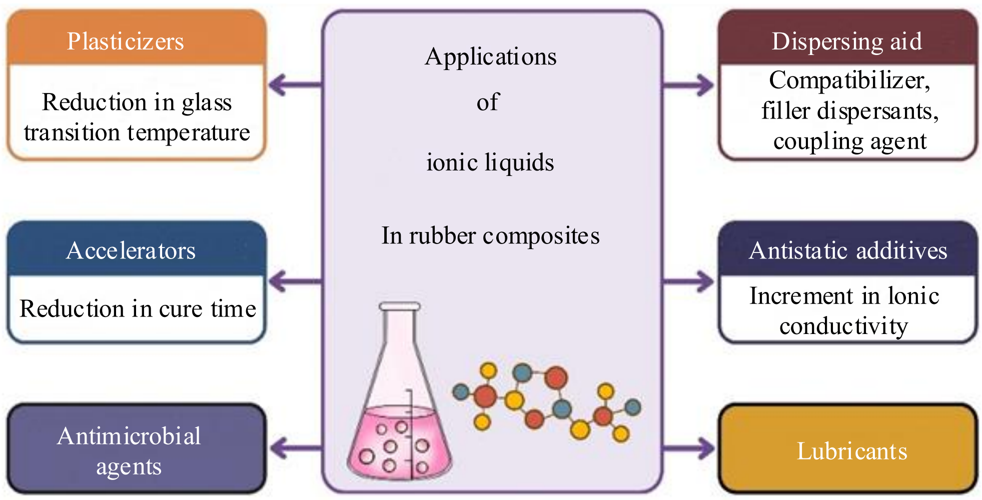

Figure 1. Role of Ionic liquid in rubber composites[8],[7], [9].

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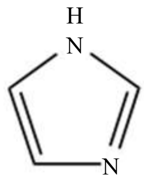

Figure 2. The imidazole ring structure [15].

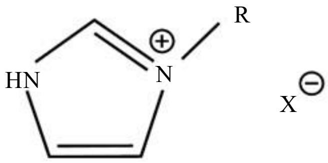

Figure 3. Ionic liquids of monosubstituted imidazolium [16].

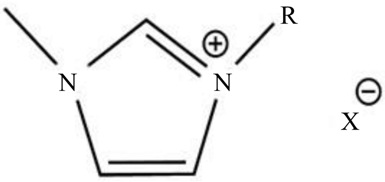

Figure 4. The structure of disubstituted imidazolium ionic liquids [16].

Monosubstituted imidazolium ionic liquids, disubstituted imidazolium ionic liquids, trisubstituted imidazolium ionic liquids, and benzimidazole ionic liquids are the four general categories into which imidazolium ionic liquids fall.

Ionic liquids of Monosubstituted Imidazolium

Imidazole monosubstituted ionic liquids as shown in figure 3[16] typically have a structure where the R group takes the place of the N atom on the imidazole ring. One of the typical compounds that can be utilized in biochemistry is N-alkylimidazolium chloride. Ionic solutions of imidazolium have varying degrees of effectiveness and efficiency when employed as refolding enhancers [17].

Ionic Liquid of Disubstituted Imidazolium

When both of the nitrogen atoms as per figure 4[16] in the imidazole ring are replaced with an alkyl group, the result is typically an ionic liquid. Disubstituted imidazole ionic liquids have so been extensively studied. Whether or whether an ionic imidazole molecule produces an ionic liquid depends on the kind or length of its substituents [17].

Ionic liquids known as alkylimidazolium chloride have an anion of chloride and a cation based on an imidazolium ring with a lengthy alkyl chain attached. These ILs have a range of qualities, including as antibacterial activity, solvent capacity, and diffusion characteristics, and they are liquid at room temperature. Structure of commonly used alkylimidazolium chlorides ionic liquids are given in figure 5[18][19][20][21][22][23].

Preparation Techniques for Rubber Composites Based on Alkylimidazolium Chloride Ionic Liquids

The technique of integrating AILs into the rubber matrix as shown in figure 6 [8][9][24] is crucial in ascertaining their efficacy. Various processes have been established to manufacture AIL-based rubber composites, each presenting unique benefits for processing simplicity, filler distribution, and compatibility with rubber components.

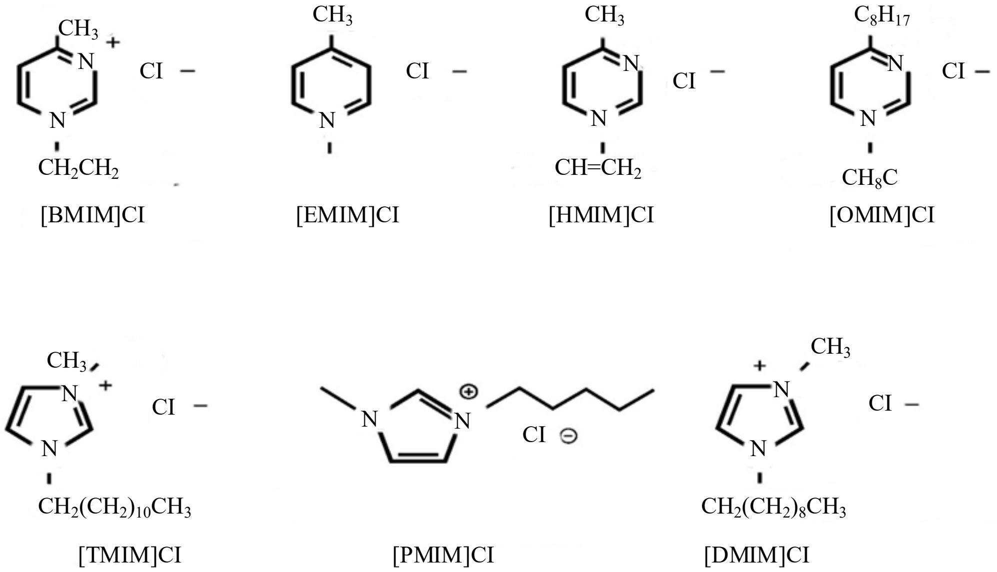

Figure 5. Structure of different Alkylimidazolium chloride ionic Liquids [18], [19], [20], [21], [22], [23].

Traditional Rubber Mixing

Alkylimidazolium chloride ionic liquids (ACl) must be successfully incorporated into rubber composites by careful preparation technique selection to guarantee even dispersion, robust filler–matrix interactions, and efficient vulcanization. The literature has examined a number of approaches to add ACl to rubber systems, each with unique benefits and drawbacks. ACl is usually added during compounding, either with the filler or before vulcanization agents. Mixing of IL on two roll mill is a simple, scalable, and compatible rubber manufacturing process that promotes good dispersion, but may degrade at high temperatures and requires optimization.

Solution Blending

Rubber and ACl are dissolved in an appropriate solvent as part of the solution blending process, which is then followed by solvent evaporation The process involves dissolving rubber in a solvent, combining ACl separately or together, and then blending, casting, and drying the mixture to remove the solvent. The study of ACl rubber interactions is facilitated by excellent molecular-level dispersion, but faces challenges such as solvent use, cost, and environmental concerns.

Latex Compounding

Method of Latex Compounding he aqueous-phase approach involves adding AIL-Cl to latex dispersions before coagulation, followed by introducing acid or salt solutions. This process offers good dispersion in polar systems and is environmentally friendly when water is used, but requires care to prevent premature coagulation or incompatibility with other ingredients [9].

In-Situ formation of Alkylimidazolium Chloride in Rubber Matrix

In some research, imidazole derivatives and alkyl halides react in the rubber matrix to generate ACl. Precursor compounds mixed with rubber during compounding form AIL-Cl, eliminating separate synthesis and improving interfacial activity. Challenges include strict reaction conditions and potential by-products or curing effects .

Filler Grafting or Immobilization on Fillers

Before mixing, ACl can also be chemically grafted onto fillers like carbon black or silica. Unfunctionalized filler surfaces are functionalized with silanes or coupling agents, containing ACl or precursors. This creates a strong, permanent interface, preventing migration or blooming, but may reduce ionic mobility [25].

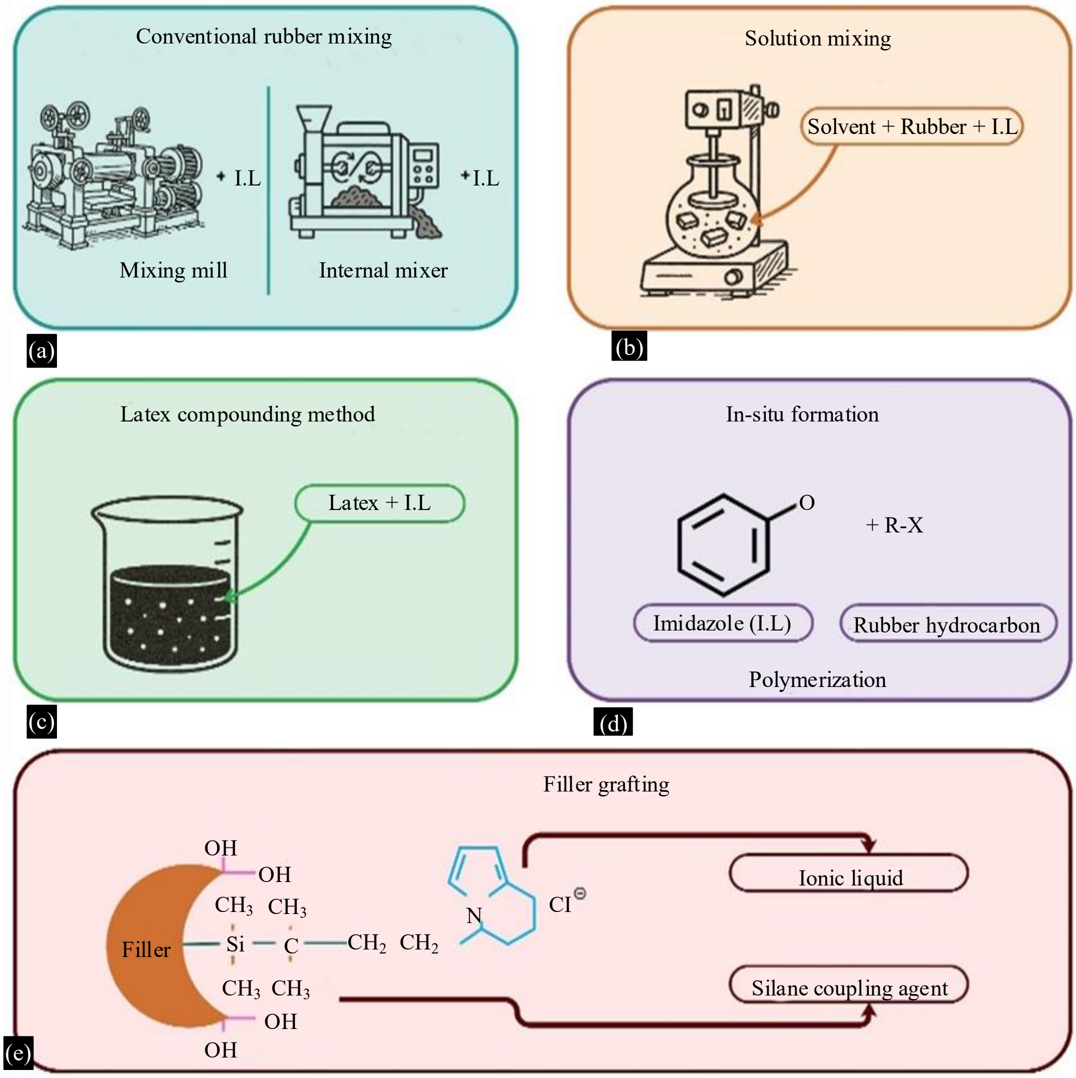

Figure 6. Methods used to prepare IL based Rubber Composites: (a) Traditional Rubber Mixing on Two Roll Mill/Internal Mixer (b) Preparation of Rubber Solution with IL, (c) Latex Compounding, (d) Addition of IL during Polymerization, (e) Treating Filler Surface with IL before [8], [26], [27].

Key Features of Different Alkylimidazolium Chloride Ionic Liquids

Alkylimidazolium chloride ionic liquids constitute an extensively researched category of room-temperature ionic liquids, characterized by a substituted imidazolium cation and a chloride anion. The difference in alkyl chain length connected to the imidazolium ring considerably affects their physicochemical properties, hence customizing them for certain purposes are given in table 1[28], [29], [30], [31], [32].

APPLICATION OF ALKYLIMIDAZOLIUM CHLORIDE IONIC LIQUIDS IN RUBBER COMPOSITES

Dispersing Agent

Creating a uniform dispersion of the filler particles in the elastomeric matrix that promotes strong interphase adhesion is the fundamental prerequisite for the reinforcement effect [33]. However, a homogenous dispersion in the elastomer is technically challenging due to the high degree of agglomeration exhibited by the majority of fillers. Furthermore, interactions between filler and elastomer may alter the elastomeric network's structure, creating more cross-links [34]. The interactions between the filler's particles, which lead to the creation of a filler network inside the elastomeric matrix, are equally significant. This network affects the mechanical properties of vulcanizates under static conditions and substantially alters the dynamic properties of the rubber. The mechanical performance of the final elastomeric composite is contingent upon both filler-filler and filler-elastomer interactions. The primary parameters influencing the filler–elastomer interaction are the dispersion of filler particles inside the elastomer matrix and the adhesion between these two phases. Coupling agents are typically employed to enhance compatibility and, subsequently, the interaction between elastomer chains and filler surfaces. Silanes are among the most prevalent and efficacious coupling agents utilized in rubber technology [35], [36]. Recent literature analysis reveals that ionic liquids are increasingly utilized in elastomeric composites as a novel class of dispersion agents for fillers. Owing to their minimal vapor pressure, non-flammability, and thermal stability within the processing temperature range of elastomeric composites, ionic liquids can be effectively utilized in elastomer technology [37]. Alkylimidazolium ILs are frequently employed to enhance the dispersion of carbon fillers, including graphene and graphene oxide [38] carbon black [39] and multi-walled carbon nanotubes [40].

Table 1. The key features of different AIL.

Key features	**BMIMCl**	**EMIMCl**	**HMIMCl**	**OMIMCl**	**DMIMCl**	**PMIMCl**	**TMIMCl**
Cation Structure	Butyl group (C_4H_9) attached to imidazolium ring	Ethyl group (C_2H_5) attached to imidazolium ring	Hexyl group (C_6H_{13}) attached to imidazolium ring	Octyl group (C_8H_{17}) attached to imidazolium ring	Decyl group ($C_{10}H_{21}$) attached to imidazolium ring	Pentyl group (C_5H_{11}) attached to imidazolium ring	Dodecyl group ($C_{12}H_{25}$) attached to imidazolium ring
Melting Point	~65°C (liquid at room temperature)	~50–60°C (liquid at room temperature	~50–55°C (liquid at room temperature	~50–60°C (liquid at room temperature	~55–65°C (liquid at room temperature	~60°C (liquid at room temperature	~60–70°C (liquid at room temperature
Viscosity	High viscosity (more viscous than EMIMCl)	Moderate viscosity	Higher viscosity than EMIMCl	High viscosity	Very high viscosity	Moderate viscosity	Very high viscosity
Solubility in Water	Moderate solubility in water	High solubility in water	Moderate solubility in water	Low solubility in water	Very low solubility in water	Moderate solubility in water	Very low solubility in water
Thermal Stability	Stable up to ~200°C	Stable up to ~200°C	Stable up to ~200°C	Stable up to ~200°C	Stable up to ~200°C	Stable up to ~200°C	Stable up to ~200°C
Density	~1.05–1.10 g/cm³	~1.05 g/cm³	~1.05–1.10 g/cm³	~1.10–1.15 g/cm³	~1.10–1.15 g/cm³	~1.05 g/cm³	~1.05 g/cm³
Conductivity	Moderate conductivity	Moderate conductivity	Moderate conductivity	Moderate conductivity	Moderate conductivity	Moderate conductivity	Moderate conductivity
Hydrophobicity	Moderate hydrophobicity	Moderate hydrophobicity	High hydrophobicity	Very high hydrophobicity	Extremely high hydrophobicity	High hydrophobicity	Extremely high hydrophobicity
Viscosity Trend	More viscous than EMIMCl	Lower viscosity than BMIMCl	More viscous than EMIMCl	Higher viscosity than BMIMCl and EMIMCl	Very high viscosity	Lower viscosity than BMIMCl but higher than EMIMCl	Very high viscosity
Application	Solvent, plasticizer, vulcanization modifier	Solvent, plasticizer, polymerization medium	Solvent, surfactant, lubricant	Solvent, surfactant, lubricant, non-aqueous applications	Solvent, non-aqueous reactions, surfactant	Solvent, surfactant, non-aqueous applications	Solvent, non-polar applications, surfactant

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According to reports, the imidazolium cation of these ILs and the p-electrons on the filler surface form favourable interactions that enhance the compatibility between the filler and the elastomer matrix and, as a result, the degree of dispersion in the elastomer. Interfacial modifiers for silica-filled polymer composites are ILs with particular architectures [41], [42]. Styrene-butadiene rubber (SBR) can be modified with 1-methylimidazolium methacrylate to enhance silica dispersion and boost interfacial contacts between SBR and the filler [42]. However, hydrophobic ILs containing bis(trifluoromethanesulfonyl)imide anions are used to enhance the dispersion of multilayer fillers such hydrotalcite [43] or montmorillonite (MMT) [44]. The filler layers, which are necessary to improve the functional qualities of the composites, were exfoliated and distributed uniformly throughout the polymer matrix.

Lubricant

A lubricant is a material employed to diminish friction between surfaces. They are additionally referred to as processing aids. They facilitate the efficient processing of polymers. Lubricants in rubber function to reduce frictional forces between rubber-rubber surfaces, rubber-metal surfaces, and rubber-filler surfaces. In the rubber composite, the molecular structure of ILs influences their wettability to fillers [45], [46] and interactions with the rubber matrix [47].

Table 2. Summary of Role of Imidazolium Chloride based Ionic Liquids in Preparation of Rubber Composites

Rubber type	IL Used	Role of IL	Key effects
Natural Rubber (NR) + Silica	[BMIM]Cl, [EMIM]Cl	Enhancer of Vulcanization, Filler Dispersant	Increased Crosslink Density, Quicker Eure, and enhanced Mechanical Strength [29]
Nitrile Butadiene Rubber (NBR) + Silica	[BMIM]Cl	Dispersant, Conductivity Improver	Improved Silica Dispersion, Transparency, Increased Ionic Conductivity [54]
Nitrile Butadiene Rubber (NBR) + Aramid Pulp	[CMIM]Cl, [AVIM]Cl	Filler compatibilizer with the Rubbe Matrix	Better wear characteristics and increased tensile and tear strength [62]
Hydrogenated Acrylonitrile Butadiene Rubber (HNBR)	[BMIM]Cl, other ILs	Coagent, Dispersant	Improved Mechanical Properties and Cure Features [30]
Styrene-Butadiene Rubber (SBR) + Graphene Oxide (GO)	[AMIM]Cl	Functionalized Filler	Improved GO Dispersion and Solvent, Thermal, and Mechanical Resistance [38]
Methylvinylsilicone Rubber	[BMIM]Cl, others	Vulcanization Accelerator	Better Elasticity, Energy Dissipation, and Shorter Cure Time [64]
Acrylonitrile Butadiene Rubber (NBR)	Hydrophilic/ hydrophobic [BMIM]Cl	Crosslinking Agent, conductivity enhancer	Faster Curing, Enhanced Mechanical and Electrical Performance [32]
Fluorinated Rubber+Metal Fillers	BMIM]Cl, [OMIM]Cl	Moderator for Reinforcing Agents	Stronger and more thermally Stable than Carbon Black [65]
S-SBR (Solution Polymerized-Styrene Butadiene Rubber) + Multiwall Carbon Nanotubes (MWCNTs)	[AMIM]Cl	Filler Dispersant	High degree of MWCNT dispersion and reinforcing
S-SBR (Solution Polymerized-Styrene Butadiene Rubber) + Polybutadiene Rubber (S-SBR/BR Blend) + Carbon Black	[AMIM]Cl	Plasticizer for Carbon Black	A modest increase in elongation at break and enhanced conductivity
Ethylene Propylene Diene Ter Copolymer (EPDM) + Carbon Black	[AMIM]Cl	Plasticizer and Crosslink Modifier	Significant Drop in Crosslink Density and Rise in Elongation at Break [63]

Literature indicates that silica can adsorb imidazolium-based ionic liquids (ILs) depending on their alkyl chain length, offering a straightforward pre adsorption technique for altering silica. This study employed two ionic liquids with distinct alkyl chain lengths, 1-Allyl-3-Methylimidazolium Chloride (AMIC) and 1-Decyl-3-methylimidazolium Chloride (DMICl), to change hydrophilic silica through physical adsorption. The effects of the two ionic liquids on the glass transition and rheological properties of silica-filled isoprene rubber compounds were examined. Both ionic liquids at low concentrations do not affect the segmental dynamics of isoprene rubber chains; nevertheless, they inhibit the formation of a glassy fraction and reduce the bound rubber content. In low-filled compounds, ionic liquids may diminish the reinforcing effect of silica by functioning as a lubricant that enhances macromolecular mobility and reduces intermolecular friction. Conversely, in densely packed compounds, ionic liquids (ILs) may enhance the reinforcing effect while concurrently exacerbating the weak strain overshoot (WSO) associated with the Payne effect [48], [49], [50], [51], [52].

Plasticizer

A broad class of compounding additives used primarily to improve the processability, moulding and flexibility of rubber materials Their presence modifies the physical processing of rubber compounds, including flex life, antistatic qualities, low temperature performance, hardness, and elongation. In addition, plasticizers are known to enhance polymer processing by reducing viscosity, making it simple to incorporate fillers, facilitating the smooth dispersion of recipe ingredients, and improving flow properties [53]. Additionally, they lower the rubber compounds' glass transition temperature. Plasticizing effect of imidazolium IL(BMIMCl) is studied on NBR/SiO2/IL system. The authors have concluded that chosen IL can work as plasticizer [54].

Crosslinker

When used as accelerators in the sulfur vulcanization of unsaturated elastomers, ILs with the right structure could be effective [55], [56], [57]. ILs can also be used as part of innovative systems that allow unsaturated elastomers (SBR, NBR, and EPDM) to undergo sulfur vulcanization. The foundation of these systems is the usage of ILs with various cations and anions in conjunction with nanosized ZnO. It is very challenging to achieve a uniform dispersion of zinc oxide nanoparticles in an elastomer. The problem of choosing the right dispersing agents has not been solved. ILs might be helpful in this capacity. Moreover, ILs may also improve the crosslinking effectiveness and shorten the vulcanization time and temperature because of their catalytic activity in interfacial processes [58], [59], [60].

Antistatic Agent

When creating conductive rubber composites, alkylimidazolium chloride ionic liquids (ILs), such as 1-Butyl-3-Methylimidazolium Chloride (BMIMCl) and 1-Ethyl-3-Methylimidazolium Chloride (EMIMCl), have a variety of uses. Epoxidized natural rubber (ENR) and 1-ethyl-3-methylimidazolium chloride (EMIMCl) as the ionic liquid are used to create composites with enhanced electrical conductivity. The mobility of cations and anions in the EMIMCl, which acted as extra charge carriers, enhanced the electrical conductivity of ENR composites [61].

Alkylimidazolium chloride ionic liquids (ILs), demonstrate exceptional efficacy in rubber composites by serving as environmentally friendly processing aids, improving filler dispersion, facilitating interfacial bonding, and expediting vulcanization, resulting in enhanced mechanical strength, thermal stability, and dynamic properties as summarize in table 2[29][62][63][64][65][38].

CONCLUSION

Ionic liquids of alkylimidazolium chloride (ACl) offer multifunctionality that surpasses that of traditional additives, marking a substantial breakthrough in the creation of high-performance rubber composites. Stronger interfacial adhesion between the rubber matrix and filler particles, enhanced dispersion of fillers like carbon black, and accelerated vulcanization kinetics are all actively facilitated by their high heat stability, adjustable polarity, and intrinsic ionic conductivity. Comprehensive experimental evidence supports these interactions, showing that ACl plays a dual role in changing the filler's surface properties and actively promoting crosslinking within the rubber matrix.

In contrast to other classes of ionic liquids and conventional processing aids, ACl compounds specifically aid in the creation of more homogeneous and tightly crosslinked networks, resulting in improved thermal resistance, increased mechanical strength, and more stable dynamic mechanical behavior under operating conditions. Additionally, ACl's ionic nature offers an extra energy-dissipating mechanism that can be used in applications that call for better fatigue resistance or damping.

Even though there are still issues with synthesis cost, material recovery, and ecological effect, these can be resolved more and more thanks to developments in green chemistry, recycling techniques, and scalable production processes. Even at modest loadings, ACl's excellent efficiency and versatility make it worth including since they provide a cost-performance balance that is challenging to attain with traditional systems.

To sum up, adding ACl to rubber composites is not just an additive; it is a revolutionary process that makes it possible to move toward next-generation elastomeric materials that satisfy the increasing demands for sustainability, performance, and durability. To fully achieve the industrial potential of ACl-based systems, more research into lifecycle analysis and structure–function linkages will be necessary.

SCOPE OF WORK

To fully exploit the potential of alkylimidazolium chloride ionic liquids (ACls) in rubber composite technology, next research should concentrate on many important domains. The development of task-specific AILs that can partially or entirely replace existing hazardous accelerators and vulcanizing agents is a particularly appealing direction. By structurally modifying the imidazolium cation and chloride anion, it may be feasible to engineer ionic liquids that improve crosslinking efficiency while concurrently mitigating the environmental and health risks linked to conventional curing methods.

A crucial research focus is the optimization of filler dispersion to provide a decrease in filler dosage. AILs have shown the capacity to alter filler–rubber interactions, enhancing dispersion and interfacial bonding, especially with polar fillers like silica or carbon nanotubes. This not only reduces material consumption and expenses but also enhances the flexibility, dynamic performance, and energy efficiency of rubber materials. Advanced characterization approaches must be utilized to comprehend the molecular interaction mechanisms and inform formulation strategies.

Moreover, there is increasing interest in utilizing AILs for the advancement of electrically conductive rubber composites. Owing to their intrinsic ionic conductivity, AILs can function as both dispersants and conductive agents when integrated with conductive fillers such as carbon black, carbon nanotubes, or graphene. Future study should investigate the function of ACls in improving electrical conductivity while preserving mechanical integrity, facilitating their application in flexible sensors, antistatic materials, electromagnetic shielding, and smart wearable devices. Modifying the ionic structure to enhance charge transfer inside the rubber matrix may create new possibilities in advanced functional materials.

ABBREVIATIONS

IL:	Ionic Liquid
ACl:	Alkylimidazolium Chloride Ionic Liquids
BMIMCl:	1- Butyl-3-Methyl Imidazolium Chloride
EMIMCl:	1-Ethyl-3-Methyl Imidazolium Chloride
HMIMCl:	1-Hexyl-3-Methyl Imidazolium Chloride
OMIMCl:	1-Octyl-3-methyl Imidazolium Chloride
DMIMCl:	1-Decyl-3-Methyl Imidazolium Chloride
PMIMCl:	1-Pentyl-3-Methyl Imidazolium Chloride
TMIMCl:	1-Dodecyl-3-Methylimidazolium Chloride
NR:	Natural Rubber

SBR:	Styrene Butadiene Rubber
NBR:	Acrylonitrile Butadiene Rubber
EPDM:	Ethylene Propylene Diene Monomer
ENR:	Epoxidized Natural Rubber
HNBR:	Hydrogenated Acrylonitrile Butadiene Rubber
S-SBR:	Solution Polymerised Styrene Butadiene Rubber
BR:	Polybutadiene Rubber
GO:	Graphene Oxide
MWCNT:	Multiwall Carbon Nanotube
MMT:	Montmorillonite

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