Systematic Review of Natural Rubber Latex Modified Concrete for Eco efficient Construction Works

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Abstract

The paper presents a systematic review of the literatures on natural rubber latex modified concrete (NRLMC) which is a composite material that combines the benefits of both natural rubber latex (NRL) and concrete. The use of NRL in concrete mixtures can improve its workability, durability and microstructural properties and the concrete exhibits excellent mechanical properties such as high tensile and flexural strength, impact resistance and energy absorption capacity. Additionally, NRLMC can reduce the carbon footprint of the construction industry by incorporating NRL to substitute the quantity of cement in the concrete mix. The performance of NRLMC is influenced by various factors such as the type and dosage of NRL, curing conditions and mixing methods. This paper provides a review of the existing literatures on the use RLMC, including its properties, limitations and challenges, and also highlights its potentials by addressing sustainability and environmental concerns. Moreover, the review study of soft computing tool deployment such as adaptive neuro-fuzzy inference system (ANFIS) in the evaluation of NRLMC engineering properties was carried out in this research. The findings of this paper can guide the optimization of NRLMC for various applications and facilitate the adoption of this innovative material in the construction industry, also, the use of ANFIS can reduce the need for costly and time-consuming experimental testing, making the development of NRLMC more efficient and cost effective.

Keywords: Natural rubber latex, Ecofriendly concrete, Neuro fuzzy, artificial intelligence
Kulcsszavak: Természetes gumilatex, környezetbarát beton, Neuro fuzzy, mesterséges intelligencia

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1. Introduction

In the construction industry, there is growing interest in utilizing locally available and renewable resources to produce environmentally friendly and energy-efficient cement concrete. Natural rubber latex (NRL) is a natural polymer obtained from renewable sources, offering the potential for sustainable construction practices by effectively modifying cement composites [1]. NRL can be employed to modify cement composites, particularly concrete. Derived from the Hevea brasiliensis tree through a natural polymerization process, NRL is a milky white liquid consisting of a complex mixture of proteins, carbohydrates, and lipids [2, 3].

Incorporating NRL into concrete mixtures leads to the production of NRLMC, which can benefit from the unique properties of NRL. This approach promotes the use of renewable resources and supports sustainable construction practices [4]. The incorporation of NRL in concrete enhances workability by reducing water demand and increasing cohesion. Its long polymer chain structure improves binding properties, adhesion, and mechanical strength by forming a network of bonds [5]. NRL also contributes to a denser microstructure by creating a latex film that fills voids and microcracks, making the concrete impermeable. This improves durability by protecting against chemical attacks, freeze-thaw cycles, and water penetration [6, 7]. NRL modified concrete performs better in aggressive environments like marine areas, sewage plants, and acidic conditions compared to regular concrete [8]. However, it is important to consider the elastomeric effect and compositional stability of NRL at elevated temperatures, and coagulation can be mitigated by adding substances like ammonia-tetramethyl thiuram di-sulfide or zinc oxide. These considerations ensure the effective utilization of NRL in concrete applications [9].

Fig. 1 Natural Rubber Latex [5]
1. ábra Természetes gumi latex [5]

In addition, the use of NRL in the concrete mix can help to reduce the risk of segregation and bleeding, which are common problems in traditional concrete mixes. Segregation occurs when the aggregates in the concrete mix separate from the cement paste, resulting in a non-uniform mix that can weaken the final product. Bleeding occurs when water rises to the surface of the concrete and forms a layer of water on top, which can weaken the surface and reduce the durability of the concrete [10]. The addition of NRL can help to reduce these problems by improving the cohesion of the mix and reducing the water demand. Overall, NRLMC can offer improved workability compared to traditional concrete, which can make it a more attractive option for construction projects. The improved workability can result in a concrete that is easier to handle, place, and finish, with improved surface finish and appearance [11].

Polymer latex is commonly used in cementitious materials to enhance properties like durability, adhesion, mechanical strength, toughness, and crack resistance [12]. There is a growing interest in utilizing locally available and renewable resources, such as Natural Rubber Latex (NRL), to improve the mechanical strength and durability of concrete [13, 14]. NRL is a natural, renewable resource obtained from the Hevea Brasiliensis tree through a natural polymerization process. It mainly consists of cis-1,4-polyisoprene (94% hydrocarbon) along with non-rubber constituents (6%) and various mineral components like K, Na, Mg, Ca, Cu, and Fe [15, 16]. Studies have investigated the effects of incorporating NRL into cement mortar and high-performance concrete. Optimal proportions of NRL were determined to achieve waterproof concrete and enhance thermal insulation [17, 18]. Additionally, NRL was found to improve the durability of steel fiber-reinforced concrete, with a decrease in chloride ion permeability observed when NRL was added at a proportion of 0.5% by weight of cement. These findings demonstrate the potential of NRL as an effective additive for enhancing the properties and durability of concrete [19].

Artificial intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think and learn like humans. AI technologies enable machines to learn from experience, adjust to new inputs, and perform tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and language translation [20, 21]. The potential benefits of AI include increased efficiency, improved decision-making, and enhanced quality of life. However, there are also concerns about the potential risks and ethical implications of AI, such as job displacement, bias, and privacy violations [22]. AI tool such as neuro-fuzzy hybrid smart intelligent models have the potential to revolutionize many industries, including civil engineering and building construction. One area where AI can be applied is in the development and use of NRLMC [23]. Overall, the application of AI in NRLMC has the potential to improve the durability and cost-effectiveness of this innovative construction material, making it more widely adopted in the industry [24]. AI techniques can be adapted in various ways to optimize the production and use of NRLMC such as;

i. Predictive modeling: AI with supervised learning algorithm such as adaptive neuro fuzzy inference system can be used to develop predictive models that can accurately estimate the strength and durability of NRLMC based on its mix design and environmental conditions. This can help engineers, project managers and architects to optimize the mix design of concrete and reduce the amount of trial-and-error required in the development process and also material wastage [25].
ii. Quality control: AI can be used to monitor the quality of NRLMC during production and construction. By analyzing real-time data from sensors and cameras, AI can detect defects and anomalies, such as cracks or air pockets, and alert workers to take corrective actions in order to optimize the quality of the final product [26].
iii. Material optimization: AI tools can be used to optimize the use of natural rubber latex in the mix design of NRLMC. By analyzing data on the properties of natural rubber latex and its interactions with other materials, AI can help to identify optimal materials and formulations to reduce the amount of latex needed while still maintaining the desired properties of NRLMC [27].
iv. Cost optimization: AI can be used to optimize the cost of producing NRLMC. By analyzing data on the prices of raw materials, energy costs, and other factors, AI can help to identify the most cost-effective mix design and production process for NRLMC [28].

In the following sections of this paper, the methodology deployed for this systematic review exercise from essential database expertly selected to relevant literatures is described thus. The next section is critical assessment of mixture design protocols, chemistry and reaction mechanism and rheological properties of the natural rubber latex modified concrete. The subsequent section involves the mechanical properties and morphological assessment of the NRLMC blend and application of neuro-fuzzy models to optimize the NRLMC properties. This section is followed by Gaps in Literatures, conclusion and recommendations for future works in NRLMC.

2. Methodology

In order to achieve the review process in this study, PRISMA which denotes preferred reporting items for systematic reviews and meta-analyses were deployed for this investigative study. PRISMA provides a structured approach to searching for and selecting relevant studies extracting data and synthesizing the findings [29]. The essence is to clearly identify or define the review aims and problems to be addressed, develop detailed protocol and outlining the search strategy in terms of inclusion and exclusion criteria and data extraction methods [30]. Also, the approach of conducting comprehensive search of multiple databases to identify relevant studies in a reproduceable and systematic manner and screening of the identified studies based on predefined inclusion and exclusion criteria from the abstract, titles, keyword and full-text. In this study, databases such as PubMed, Science Direct, Scopus, and Web of Science were deployed and also, keywords with synonyms such as 'natural rubber latex', 'rubber latex modified concrete', rubber latex concrete reaction mechanism', 'microstructural assessment', 'concrete workability', and 'rubber latex concrete structural properties' combined Boolean logic operators like 'AND' and 'OR'. Using a standardized data extraction procedure, the relevant data were extracted from the included study, the quality assessed using predefined set of biases and synthesize the findings using appropriate statistical methods so as to provide a robust and reliable summary of the available evidence [31]. The overview of the article search strategy and methodology flowchart is presented in *Fig. 2*. Taking into account the aforementioned factors, 6490 pertinent and related published literature authored in English language obtained from scholarly research database and indexing systems were considered with 2354 based on titles and abstract, 2158 based on keyword and 1973 based on full-text. After the screening process, 153 relevant literatures were finally selected for this research which involves 45 review articles and 108 technical papers.

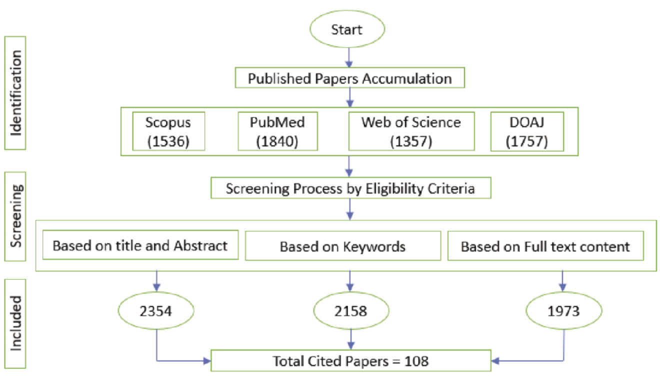

Fig. 2 Relevant Articles selection Strategy and Methodology Flowchart
2. ábra A vonatkozó cikkek kiválasztásának stratégiai és módszertani folyamatábrája

3. Findings of the Surveyed Articles

3.1 Chemistry and Reaction Mechanism of NRL mixture in concrete

The chemistry and reaction mechanism of natural rubber latex (NRL) modified concrete involve several processes that occur at different stages of the mixing and curing process. The addition of NRL to concrete affects the physicochemical behavior of the mixture, resulting to improved mechanical and durability properties [32, 33]. At mixing stage, the NRL particles are dispersed in water and then added to the concrete mix. The NRL particles contain a mixture of proteins, lipids, and carbohydrates that can interact with the cement particles and the water in the mixture. The NRL particles can act as a plasticizer, reducing the water demand of the mixture and improving its workability [34, 35].

During the curing process, interactions occur between NRL particles and Ca^{2+} in cement hydrate, resulting in the formation of a complex that improves the mechanical and durability properties of concrete [34]. Although the exact reaction mechanism is not fully understood, it is believed that NRL reacts with calcium hydroxide produced during cement hydration, forming additional calcium silicate hydrate (C-S-H) gel that contributes to strength enhancement [36, 37]. NRL also acts as a protective barrier around cement particles, reducing water ingress and the entry of aggressive agents into the concrete. The chemical and physical properties of NRL modified concrete are influenced by factors such as NRL type, quantity, mix design, and curing conditions [38]. Further research is needed to fully comprehend the complex chemistry and reaction mechanisms of NRL modified concrete and optimize its performance [39, 40]. The physicochemical characterization of NRLMC involves the study of various properties of the material, including essential factors such as;

- Chemical composition: NRLMC contains a complex mixture of components, including natural rubber latex, cement, aggregates, and water. The chemical composition of the NRL can affect the physical and chemical properties of the concrete [41].
- Rheology: The rheological properties of NRLMC affect its workability and flow behavior. The addition of NRL can modify the rheological properties of the concrete, resulting in a more cohesive and flowable mix [35].
- Hydration kinetics: The addition of NRL to the concrete mix can affect the kinetics of cement hydration. NRL can interact with the cement particles, which can modify the rate of hydration and the formation of hydrates [42]. NRL can interact with other components of the concrete mix, such as the cement and aggregates. These chemical interactions can affect the properties of the NRLMC, including its strength, durability, and resistance to chemical attack [43].

Overall, the physicochemical characterization of NRLMC is essential to understand its properties and behavior in different applications. The characterization of NRLMC can provide insights into the mechanisms that govern its performance, which can be useful for optimizing the mix design and improving the durability and sustainability of the material [44].

Characteristics	Results
Color	White
Total solid content (% by Mass)	50-61.5
Dry Rubber content (% by Mass)	>60
Non-Rubber solid content (% by Mass)	1.35-1.5
KOH (% by Mass)	0.35-0.55
Ammonia content NH_3 (% by Mass)	0.45-0.70
Mechanical stability time (Seconds)	600-1310
Volatile Fatty acid (% by Mass)	0.015-0.1
Magnesium content (% by Mass)	6.5-8
pH	10.05-13.5
Coagulum content (% by Mass)	0.005-0.01
Sludge content (% by Mass)	0.005-0.01
Cu content (PPM)	3.5-6
Fe content (PPM)	5.5-8
Rubber Latex Particle size ()	0.2
Rubber latex specific gravity	0.82-0.98

Table 1 Physicochemical analysis of Natural Rubber Latex Concentrate [36, 37]
1. táblázat Természetes gumi latex koncentrátum fizikai-kémiai elemzése [36, 37]

3.2 Principles of Latex Modification and Mixture design Methodology

When latex is incorporated into mixes with Portland cement, aggregates, and water, the resulting fresh concrete exhibits similar consistency and workability to conventional concrete. After the curing process, the latex-modified concrete (LMC) consists of hydrated cement and aggregate interconnected by a continuous latex film [45, 46]. This film contributes to the superior physical and chemical properties of LMC. According to Ohama [47], the internal responses of latex systems in cement paste and concrete can be divided into three stages. In the first stage, the small polymer latex particles uniformly mix with the fresh cement paste, partially coating the cement grains and early hydration products. In the second stage, as cement hydration progresses and water content reduces, the remaining polymer particles flocculate and form close-packed layers on available surfaces. In the third stage, as water further depletes, the close-packed layers of polymer particles condense to form continuous films or membranes that interpenetrate throughout the cement hydration products [48]. These films transform the fine cement paste matrix into a cement-polymer film matrix. While the details and timeframes of these processes remain speculative, the effect of latex on the transition zone surrounding aggregates in concrete or mortar has not been addressed by Ohama, though it is likely modified [49].

The mix design of NRLMC is an important aspect of its production, as it can considerably influence the behavior and performance of the material [50]. The mix design for NRL modified concrete is typically based on the same principles as conventional concrete, but with modifications to account for the presence of NRL. The mix design for NRL modified concrete typically involves the following steps:

Selection of materials: The materials used in NRLMC are similar to those used in conventional concrete, including cement, aggregates, water, and NRL. The type and properties of these materials can affect the performance of the NRL modified concrete, so careful selection is important [51].

Proportioning of materials: The proportions of the materials used in NRLMC are typically determined based on the desired properties and performance of the material. The amount of NRL added to the mixture can vary depending on the application and the desired performance characteristics [52].

Mixing: The mixing of NRL modified concrete is similar to that of conventional concrete, but care must be taken to ensure that the NRL is evenly dispersed throughout the mixture. NRL can act as a plasticizer, reducing the water demand of the mixture and improving its workability [53].

Curing: The curing of NRL modified concrete is typically done in a similar manner as conventional concrete, but with modifications to account for the presence of NRL. Proper curing is important to ensure the development of the desired mechanical and durability properties [54].

The mix design for NRL modified concrete can vary depending on the specific application and performance requirements. Careful consideration should be given to the selection and proportioning of materials to ensure that the NRL modified concrete meets the desired performance characteristics [55].

3.3 Rheological Characteristics of NRLMC

Rheology investigates the flow and deformation characteristics of materials, including NRLMC. Incorporating NRL into concrete has implications for its rheological properties, such as workability, viscosity, and yield stress [56]. Various techniques, such as slump tests, flow table tests, and rheometer measurements, have been employed to study the rheology of NRLMC [57, 58]. Slump tests assess concrete workability, and NRL addition can enhance it by acting as a lubricant, reducing particle friction and improving flow [59]. However, excessive NRL addition can reduce workability due to increased viscosity and particle friction. Flow table tests measure workability too, and NRL incorporation can increase the spread diameter, indicating improved flow. Yet, excessive NRL can reduce the spread diameter and hinder flowability [60, 61]. Rheometer measurements offer detailed rheological insights. NRL addition can elevate viscosity, signifying enhanced resistance to deformation. It can also elevate the yield stress, improving stability and mitigating segregation and bleeding risks [62]. While NRL inclusion influences the rheological properties of concrete, the optimal NRL dosage depends on specific mix designs and application requirements, as excessive NRL can negatively impact rheology [63].

3.3.1 Workability Property

NRLMC offers numerous advantages over traditional concrete and holds promise for various applications, including building and infrastructure construction. NRL, obtained from renewable sources, renders NRLMC an environmentally friendly choice [64]. The incorporation of NRL enhances the workability of concrete, a crucial attribute in the construction sector. Good workability facilitates easier handling, placement, and finishing of the concrete mix, reducing the required effort [65, 66]. NRL enhances concrete workability by reducing water demand and increasing mix cohesion, leading to easier placement and improved surface finish [67]. It also improves flowability and pumpability, particularly useful for transporting concrete over long distances or through narrow spaces [68]. NRLMC's workability is a key property improved by adding NRL, reducing water demand and achieving a more cohesive mix [69]. Multiple studies confirm the superior workability of NRLMC compared to traditional concrete. For instance, adding 10% NRL increased workability by around 21% while reducing the water-cement ratio by approximately 18% [70]. NRL effectively enhances concrete workability, offering advantages in placement, finishing, and transportation. The improved workability of NRLMC can result in several benefits for construction projects [70]. A more workable mix can be easier to place and finish, which can reduce the amount of labor required for concrete placement. It can also result in a more uniform and consistent concrete surface, with fewer defects or imperfections [70]. However, it is important to note that the workability of NRLMC can be affected by several factors, including the type and dosage of NRL used, the mix design, and the environmental conditions. Therefore, it is essential to carefully design and test the mix to achieve the desired workability properties [71].

3.4 Mechanical Behavior of NRLMC

The addition is NRL to concrete can improve its mechanical properties, such as compressive strength, flexural strength, and durability by increased toughness behavior of the concrete whereby NRL act as crack inhibitors by absorbing energy during deformation [72]. Also, NRL can act as adhesive agent to improving the bond strength between the cement paste and the aggregates, and increase the ductility property of the concrete making it more resistant to brittle fracture [73]. Moreover, addition of NRL enhances the abrasion resistance capacity of the concrete and lower the permeability property by reducing ingress of water and other harmful substances which can lead to deterioration and premature failure of the structure [74].

3.4.1 Compressive Strength Properties of NRLMC

The compressive strength of concrete is a critical mechanical property that reflects its ability to withstand compressive loads. Research indicates that incorporating NRL can enhance the compressive strength, particularly in early stages, owing to improved concrete microstructure and enhanced cement hydration [75]. However, excessive NRL addition can reduce compressive strength due to the high viscosity of NRL hindering particle movement and mix compaction. Notably, Subash et al. demonstrated that the addition of 5% NRL resulted in a 20% increase in compressive strength at 40MPa. These findings highlight the positive impact of NRL on concrete's compressive strength, attributing it to improved microstructure and cement hydration. Particles can fill the voids between cement particles, resulting in a denser and more compact concrete matrix [72]. The improvement in compressive strength is mainly attributed to the following mechanisms:

i. Pozzolanic reaction: NRL can react with the calcium hydroxide produced during cement hydration, forming additional (C-S-H) gel that can contribute to the strength and durability of the concrete.
ii. Latex film formation: NRL can form a film around the cement particles, which can improve the adhesion and cohesion between the particles, resulting in a stronger and more stable matrix.

Excessive NRL addition can decrease compressive strength due to NRL's high viscosity impeding particle movement and mix compaction. The optimal NRL dosage relies on factors like NRL type, quantity, mix design, and curing conditions. Typically, adding NRL at 5-10% by weight of cement achieves substantial enhancement in compressive strength while preserving workability and other concrete properties [76].

3.4.2 Flexural Strength Properties of NRLMC

The flexural strength of concrete is crucial as it demonstrates its resistance to bending and tension loads. Research indicates that adding NRL can enhance the flexural strength, particularly in early stages, owing to improved microstructure and the formation of NRL-cement complexes that provide a stable and cohesive matrix [77]. However, excessive NRL addition, similar to compressive strength, can diminish flexural strength. NRL's presence fills voids between cement particles, resulting in a more compact and homogeneous matrix, enhancing adhesion and cohesion and consequently leading to a stronger and more stable structure [78]. The improvement in flexural strength is mainly attributed to the following mechanisms:

i. Increased tensile strength: NRL can improve the tensile strength of the concrete, which is a key factor in determining its flexural strength.
ii. Increased interparticle bonding: NRL can form a film around the cement particles, improving the interparticle bonding and resulting in a stronger and more stable matrix.
iii. Enhanced microstructure: The addition of NRL can result in a more homogeneous and compact microstructure, which can improve the load transfer and reduce the risk of cracking and failure.

The optimal fraction of NRL to be incorporated in the matrix to improve the flexural strength of concrete varies depending on various factors, such as the nature and quantity of NRL, the mix design, and the curing conditions [79]. Similar to compressive strength behavior, the inclusion of NRL at a measure limit of 5-10% by cement mass can result in a substantial enhancement in flexural strength properties to about 5.27 N/mm2 while preserving other concrete's characteristics which is in consonance with the findings of Grinys et al [56].

3.4.3 Durability Properties of NRLMC

Durability is a significant mechanical property of concrete, representing its ability to withstand environmental factors like freeze-thaw cycles, chloride ion penetration, and carbonation. Research has demonstrated that incorporating NRL can enhance concrete durability by improving microstructure and forming NRL-cement complexes that create a protective layer on the concrete surface [80]. Adding NRL to concrete improves its ability to resist deterioration caused by moisture, freeze-thaw cycles, chemical attack, and abrasion. Additionally, NRL incorporation influences other mechanical properties such as elastic modulus, Poisson's ratio, fatigue resistance, and fracture toughness, resulting in a more resilient material less prone to cracking or spalling [76]. Notably, studies have confirmed that NRL addition enhances concrete durability, particularly in harsh environments, as NRL acts as a protective barrier against aggressive agents like water and chemicals that can penetrate and deteriorate the concrete [71].

3.4.4 Strength Development Properties

The incorporation of NRL into concrete can influence its strength development characteristics. Generally, NRL addition enhances early-age strength, while the impact on long-term strength varies depending on factors like mix design, NRL dosage, and curing conditions [81]. Research indicates that NRL incorporation can increase the compressive strength of concrete, particularly in the early curing stages. This improvement stems from enhanced bonding between cement and NRL particles, as well as improved workability, leading to better compaction and reduced voids in the concrete [82]. The effect of NRL on flexural strength is less conclusive and subject to specific application and performance requirements. Some studies show an increase in flexural strength with NRL addition, while others report no significant effect or even a decrease. It is crucial to consider multiple factors, including curing conditions, water-cement ratio, cement type, and mix design, as they can influence the strength development properties of NRL-modified concrete. Therefore, careful control of these factors and appropriate testing are necessary to determine the optimal mix design and curing conditions for a given application [83].

3.5 Microstructural Behaviors Assessments

The microstructural assessment of NRLMC involves the study of the concrete at the microscopic level, focusing on the interaction between the different components' mix and their effect on the microstructure of the hardened concrete [84]. Some of the key aspects of the microstructure of NRLMC are:

i. Cement matrix: The cement matrix is the primary component of the NRLMC microstructure, and it is responsible for providing the strength and durability of the concrete. The addition of NRL to the mix can modify the microstructure of the cement matrix, resulting in a more compact and homogeneous structure [85].

ii. Aggregates: The aggregates in NRLMC can affect the microstructure of the concrete by providing mechanical interlocking and improving the strength of the concrete. The addition of NRL can also improve the bonding between the aggregates and the cement matrix, resulting in a stronger and more durable concrete [65].

iii. NRL: The addition of NRL to the mix can modify the microstructure of the concrete by forming a thin film around the cement particles. This film can improve the bonding between the cement and aggregates and result in a more cohesive and compact microstructure [58].

iv. Porosity: The porosity of the NRLMC microstructure can affect the durability and strength of the concrete. The addition of NRL can reduce the porosity of the concrete by improving the packing of the cement matrix and reducing the amount of water needed for the mix [71].

Overall, the microstructural assessment of NRLMC is important to understand the interaction between the different components of the mix and how they affect the properties of the concrete. This knowledge can be used to optimize the mix design and improve the durability and sustainability of the concrete. Techniques such as SEM and XRD can be used to study the microstructure of NRLMC in detail [33].

3.5.1 Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM) is a highly effective technique for examining the microstructure of NRLMC. It enables high-resolution imaging of the concrete's surface and cross-section, offering detailed insights into the morphology and structure of its various components [86]. In SEM analysis of NRLMC, a small section of the concrete sample is typically prepared, coated with a conductive material like gold or carbon, and placed in the SEM chamber. A beam of electrons is then scanned over the sample's surface, generating secondary electrons that are detected by a sensor to produce an image of the concrete's surface [87]. SEM analysis is a valuable tool for understanding the microstructure of NRLMC and its impact on properties. This information can be used to optimize mix design and enhance concrete's strength, durability, and sustainability [88]. In *Fig. 3*, the concrete sample without NRL displayed irregular-shaped aggregates, micro cracks, and pores. In contrast, the NRL-modified concrete exhibited needle-like ettringite and calcium hydroxide crystals near the aggregate interface. NRL particles were observed as lumps deposited on hydrated products, forming a dense microstructure that filled capillary pores and created a membranous film [89].

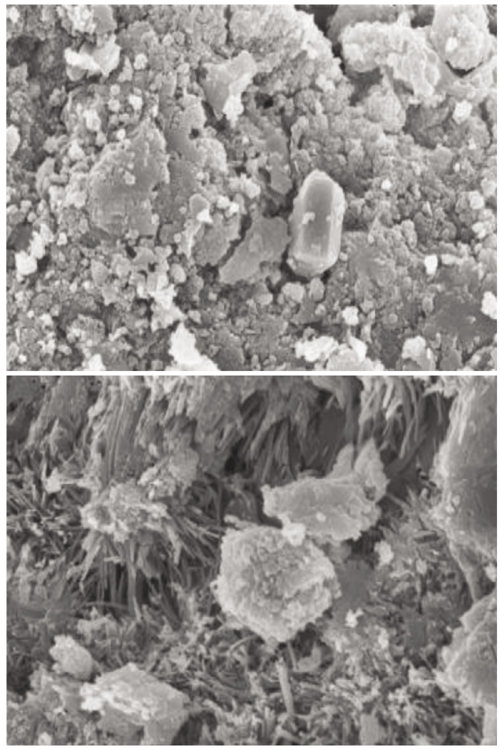

Fig. 3 SEM image of a) Control Specimen (CS) b) 5% Latex [87]
3. ábra A (CS) kontrollminta (a) és az 5% Latex tartalmú minta SEM felvétele [87]

3.5.2 X-ray diffraction (XRD)

XRD is a valuable technique for analyzing the microstructure of NRLMC. It provides information about the crystallographic structure and phase composition of the materials in the mix. XRD can identify the phases present, such as calcium silicate hydrates (C-S-H) and calcium hydroxide ($Ca(OH)_2$), and quantify their relative amounts and crystallographic properties [90]. The addition of NRL can result in new peaks or modifications to existing peaks in the XRD pattern, indicating changes in the mix's crystallographic structure [91]. XRD analysis can be used to optimize the mix design and enhance the concrete's strength, durability, and sustainability. XRD can track the formation and evolution of hydrated products, revealing that NRL modifies the crystallographic structure of the C-S-H phase, resulting in a more compact and ordered microstructure [92]. The XRD spectra of hydrated NRLMC specimens display peaks representing $Ca(OH)_2$, $CaCO_3$, calcium silicate (Ca_2SiO_4), and quartz. The presence of quartz as the main crystalline phase and traces of un-hydrated Ca_2SiO_4 are observed. These findings highlight the impact of NRL on the crystalline phases during the hydration curing process [93].

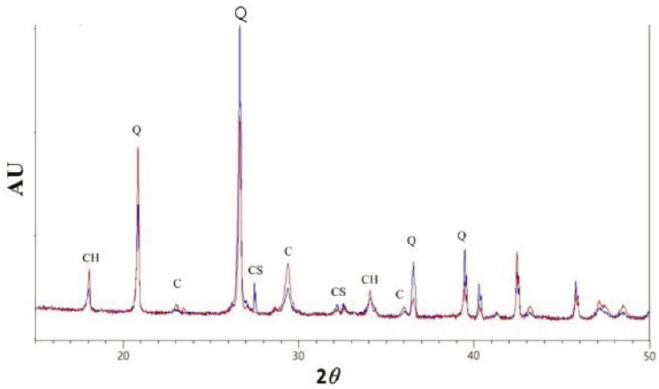

Fig. 4 X-ray diffraction pattern of NRL modified concrete specimen [54]
4. ábra Az NRL módosított betonminta röntgendiffraktogramja [54]

4. Optimization and Modeling of the Mechanical Properties of NRMLC

4.1 Adaptive Neuro Fuzzy Inference System (ANFIS)

The Adaptive Neuro Fuzzy Inference System (ANFIS) is an AI approach that combines neural networks and fuzzy logic to create a hybrid system capable of learning and decision-making. Introduced by Jang in 1993, ANFIS has found applications in control, classification, and prediction [93]. It comprises two key components: a fuzzy inference system and a neural network. The fuzzy inference system utilizes fuzzy rules and membership functions to map inputs to outputs, while the neural network fine-tunes the fuzzy system's parameters for optimal performance [94]. ANFIS is a supervised learning method that trains on input/output data. By adjusting parameters, it minimizes prediction errors. Trained ANFIS models can then forecast outputs for new data [95]. ANFIS boasts benefits such as handling complex relationships and adapting to changing input data. Its versatility extends to fields like engineering, finance, and medicine [96, 97]. ANFIS finds extensive application in engineering for modeling and control, including in the case of NRLMC. For NRLMC mix design optimization, ANFIS develops a model that correlates input parameters (e.g., NRL amount, cement, water, aggregate) to output properties (e.g., compressive strength, flexural strength, durability). This model helps determine optimal mix designs for desired NRLMC properties [98]. Additionally, ANFIS can predict mechanical properties of NRLMC based on input mix design parameters, avoiding costly and time-consuming lab tests. This significantly reduces NRLMC research and development costs and time. Employing ANFIS in NRLMC enables efficient mix design optimization and accurate mechanical property prediction, leading to superior performance in construction applications [99, 100].

4.1.1 ANFIS Network Architecture

The ANFIS architecture employs a training process to adjust the parameters of the fuzzy sets and neural network, learning the relationships between input and output variables. This is achieved through backpropagation, a gradient descent algorithm that minimizes prediction errors [101]. ANFIS combines artificial neural networks and fuzzy logic, consisting of five layers: input, fuzzification, normalization, defuzzification, and output [102, 103]. The input layer receives system input variables and passes them to the next layer. The fuzzification layer converts crisp inputs to fuzzy values using membership functions. Each node in this layer represents a fuzzy set and applies a membership function [104]. The normalization layer evaluates fuzzy rules derived from expert knowledge or data, ensuring equal importance among nodes in the subsequent layer [105, 106]. The defuzzification layer converts fuzzy sets back to crisp values, representing the system output. Each node represents a rule, computing its strength based on inputs and membership functions. The output layer combines rule strengths and computes the final output [107, 108].

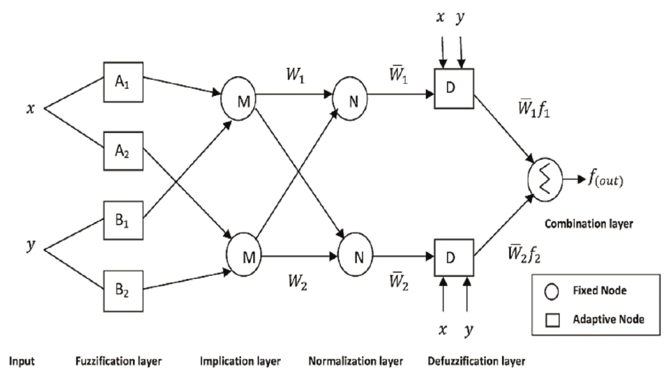

Fig. 5 ANFIS basic architecture [105]
5. ábra ANFIS alap architektúra [105]

5. Identified Gaps in Reviewed Literatures

While there has been significant researches on natural rubber latex modified concrete, there are still some gaps in the literature that require further investigation. Some of the major gaps include:

i. Long-term durability: Although some studies have investigated the durability of natural rubber latex modified concrete, more research is needed to assess its long-term performance under different environmental conditions.

ii. Optimization of mix design: There is a need for more research to optimize the mix design of natural rubber latex modified concrete, particularly with respect to the proportion of natural rubber latex, cement, and aggregate to achieve the desired properties.

iii. Mechanical properties: While some studies have investigated the compressive and flexural strength of natural rubber latex modified concrete, more research is needed to assess its other mechanical properties, such as tensile strength, modulus of elasticity, and impact resistance.

iv. Rheological properties: More research is needed to investigate the rheological properties of natural rubber latex modified concrete, including its workability, flowability, and setting time.

v. Cost-benefit analysis: While the use of natural rubber latex modified concrete has many potential benefits, such as improved durability and reduced environmental impact, there is a need for more research to assess its overall cost-effectiveness compared to traditional concrete.

Addressing these gaps in the literature will help to further advance the development and application of natural rubber latex modified concrete in various construction projects. Furthermore, considering the application of soft computing techniques deployed in the optimization of structural properties of NRLMC, while there have been some studies on the application of artificial intelligence, specifically the ANFIS, in the optimization of NRLMC, there are still some gaps in the literature, such as:

i. Lack of studies comparing the performance of ANFIS with other machine learning techniques in the optimization of NRLMC.

ii. Limited studies on the use of ANFIS in the optimization of other properties of NRLMC, such as durability and workability.

iii. Limited studies on the use of ANFIS in the optimization of NRLMC using different types and grades of natural rubber latex.

iv. Lack of studies on the optimization of NRLMC using ANFIS with the consideration of sustainability factors, such as the use of recycled materials or reducing the carbon footprint.

v. Lack of studies on the application of ANFIS in the optimization of NRLMC in different environmental conditions, such as high temperatures or exposure to chemicals.

Addressing these gaps could provide a better understanding of the capabilities and limitations of ANFIS in the optimization of NRLMC, and could contribute to the development of more efficient and sustainable construction materials.

6. Conclusion

To summarize, natural rubber latex modified concrete offers improved mechanical, durability, and workability properties due to enhanced bonding and microstructure. Optimizing mix design, curing conditions, and compaction factor is crucial. ANFIS have shown promise in optimizing mix design and predicting mechanical properties. However, further research is needed to understand the long-term durability and behavior of the material under different environmental conditions. Exploring the use of additional additives alongside natural rubber latex could further enhance the material's properties.

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