Research Title

Optimization of braided structures for civil engineering application

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Abstract

Rebar is typically made of carbon steel and is used in reinforced concrete structures to provide strength and durability. They are designed to withstand forces applied to the concrete structure. However, conventional rebar has limitations such as susceptibility to corrosion, weight and handling issues, design limitations, thermal expansion, and electromagnetic interference. FRP rebar is presented as a promising alternative. They are non-metallic, corrosion-resistant, lightweight, and have a high strength-to-weight ratio. They are non-magnetic, and non-conductive, and offer thermal insulation and design flexibility.

The research report also describes the manufacturing process of FRP rebar, which involves the selection of fibers, impregnation with a polymer resin, alignment and arrangement of fibers, and a curing process to harden the polymer matrix. It introduces textile braiding, a fabric manufacturing technique used to create three-dimensional structures. Braided textiles are used in various applications due to their high flexibility, strength, and elasticity.

The study aims to develop a composite fiber reinforcement bar using the braiding technique with materials like basalt, Nylon, and polypropylene as reinforcement material and epoxy resin as the matrix material. The work covers both fundamental and applied research associated with Braided Composite Rebars (BCRs) and presents possible directions for

Technical textiles, designed for specific technical applications, offer high performance and functionality across various sectors such as protective clothing, medical textiles, automotive components, geotextiles, and building materials. These textiles, classified into 12 main application areas, provide advantages over conventional materials like steel or wood due to their flexibility, elasticity, strength, and design possibilities, making them suitable for

automotive, aerospace, civil, and mechanical engineering applications. It also explores the properties and applications of high-performance fibers known for their flame resistance, chemical resistance, electrical insulation, low creep, impact resistance, and durability. It also delves into the matrix materials in composites, focusing on polyester, vinyl ester, phenolic, polyurethane, and epoxy resins.

Braided composites, recognized for their strength, stiffness, impact resistance, and customization potential, find extensive use in aerospace, automotive, and sporting goods. In civil engineering, textile products like geotextiles, geogrids, geomembranes, and tensile structures offer lightweight, high-strength, cost-effective solutions for soil stabilization, drainage, erosion control, and innovative architectural designs.

The reinforcement bars (rebar) made from steel or fiber-reinforced polymers (FRP), essential for concrete structures. FRP bars, known for their corrosion resistance and lightweight, have been the focus of research in terms of their mechanical properties, durability, bond behavior, and environmental impact, with an emphasis on sustainability and cost-effectiveness.

The literature review compares steel rebar and FRP bars, highlighting the pros and cons of each. It discusses the work of various researchers who have contributed to the advancement of FRP technology in construction. Techniques like pultrusion, Resin Transfer Moulding (RTM), and Vacuum-Assisted Resin Infusion (VARI) are explored to improve quality and performance. Innovations in braided and woven fiber architectures, hybrid manufacturing techniques, and additive manufacturing expand design possibilities and offer tailored solutions. The use of bio-based resins and natural fibers for eco-friendly composites is also discussed.

The optimizing the bond strength between FRP bars and concrete is crucial for their effective use as a sustainable alternative to traditional steel reinforcements in construction. Detailed analysis also carried out during different stages of FRP rod manufacturing, including testing of the yarn, evaluation of the rope, analysis of the prepared rods, and preparation of cemented blocks and beams for checking the performance of the prepared rods inside the cement structure in terms of bonding and flexural strength. The literature review highlights the advancements in FRP bars for civil engineering applications, emphasizing the need for research on their long-term behavior and durability under extreme conditions. Various experts have contributed to the development of FRP bars with enhanced mechanical properties, durability, and production efficiency. The document concludes with a call for further research in this area.

The existing biaxial braiding machine was modified to facilitate an additional third axial yarn during braiding, known as Tri-axial braiding. The take-up mechanism was also modified to achieve different take-up rates. The modifications made the machine versatile for manufacturing both biaxial and triaxial braided products. High tenacity and high denier yarns of three different variants like Polypropylene, Nylon & Basalt were procured. These basic yarns and their combination blends i.e. Basalt - Nylon and Basalt - Polypropylene were used for rope preparation. The aim was to make a braided composite rod to be used for civil engineering applications and the strength and diameter requirement of these rods should be comparable with the existing steel rods. The high-tenacity yarns procured were used as raw material for the manufacturing of triaxial braided ropes. Circular braided ropes are manufactured on a B&B braiding machine. The diameter of the manufactured ropes was increased by the braid over braid technique. These desired diameter ropes are used as a reinforcement material and were further converted into rods.

Resin is also a very important component of the composite material. It's bonding with the material defines the product's application. Various types of resin and hardener combinations are available in the market. After a few initial trials with a couple of epoxy resins as well as a polyester base resin, the researchers chose to go with the epoxy resin CTE556 and the hardener material CTAH951. The solution of resin CTE556 (Epoxy resin) and hardener CTAH951 were used in the braided ropes by keeping the ratio of at 10:1. Curing of this resin into the braided rope is again an important factor. It needs to be a straight rod-like structure. Curing takes place at room temperature. For this, arrangements were made to hang these resin-applied ropes vertically and it was hanged in such a manner that its self-weight made it almost straight. Ropes were kept in this position for about 24 hrs. to cure. This curing process will harden the rope and will convert it into the rod-like structure.

The yarn procured was tested for its linear density and tensile properties. The rope prepared from the material was also evaluated for its linear density, braid geometry, and tensile properties. The prepared rods were further analyzed for their diameter, fiber volume fraction, and tensile properties. The prepared rods were also subjected to the preparation of cemented blocks and beams, for checking the performance of prepared rods inside the cement structure in terms of bonding and flexural strength respectively.

The research design is outlines the materials, combinations, sample numbers, and tests conducted. A total of 235 tests were performed on 25 different combinations of ropes and rods.

The study presents tensile test results for braided ropes and rods made of various materials, including Polypropylene (PP), Nylon, Basalt, and their blends. The results indicate that integrating Basalt fibers into PP and Nylon ropes enhances tensile properties, providing a balance between strength and elasticity. The tensile behavior of the fifth layer of braided ropes shows distinct performance profiles for each material, with Basalt ropes exhibiting exceptional tensile strength and minimal elongation, beneficial for high load-bearing applications with minimal stretch.

The study presents a comprehensive analysis of the mechanical properties and bond strength of braided composite rods made from various materials, including Polypropylene (PP), Nylon, Basalt, and their composites with different layer configurations. The tensile test results across different layers show that Nylon and its composite with Basalt exhibit the highest strength, while Basalt is the stiffest material, and PP displays the most elasticity. The composites offer a balance between elasticity and stiffness, with improved strength compared to individual materials.

The study presents a comprehensive analysis of the flexural strength of concrete beams reinforced with various braided Fiber Reinforced Polymer (FRP) rebars compared to unreinforced beams. The results indicate that FRP rebars, including those made of polypropylene, nylon, basalt, and hybrid materials like PP + Basalt and Nylon + Basalt, significantly enhance the flexural strength of concrete beams. The addition of FRP rebars leads to substantial increases in strength, with basalt rebars showing the highest improvement, followed by the hybrid combinations.

The study also uses a mathematical model to predict the tensile strength of these materials based on parameters like yarn strength and braiding configuration. The model utilizes machine learning techniques, including a multi-layer perceptron (MLP) regressor, for this purpose.

The study also explores the use of Artificial Neural Networks (ANN) to predict tensile strength, highlighting ANN's advantages such as nonlinearity, adaptability, and parallel processing. The Levenberg-Marquardt algorithm is used for optimization, and the study emphasizes the importance of selecting the optimal ANN architecture for accurate predictions in textile engineering.

The research report is divided into six chapters, each dedicated to a specific aspect of the work. The chapters cover the introduction, literature survey, selection of raw materials and methods, observations, mathematical modeling, and concluding remarks. The findings indicate that nylon ropes exhibit the highest tensile strength, suggesting material choice is crucial for rope performance. The model demonstrates potential for optimizing braided rope design for civil engineering applications by enabling accurate strength predictions based on material and construction parameters.

The data suggests that the number of layers and the combination of materials in the FRP rebars play a crucial role in determining the extent of the strength enhancement. The study highlights the potential of FRP rebars as a robust alternative to traditional reinforcement materials, offering improved structural performance and longevity for concrete beams in construction applications.

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