Biodegradable Materials in RCC Construction – Case of Spider Silk in Ferro Cement for Crack Control in Buildings

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Abstract – Over the years, nature and animal world have provided abundant life upgradation techniques for mankind, utilizing them for co-existence ensuring a sustainable lifestyle. Spider silk has drawn much attention in the past 20 years for its toughness and elasticity. It is also known to be the strongest biomaterial existence in nature today. Spider silk is stronger than steel and more elastic than rubber. One can see the use of spider silk in bulletproof jackets, violin strings, medical bandages, optical fiber cables and so on. The proposed study describes combining spider silk with wire mesh for intricate distribution of concrete in ferro cement. Reduction of cracks in concrete will enhance durability, life span, making the structure impact resistance. The main objective is to indulge the use of a biomaterial like spider silk into the construction industry and utilize its physical properties like high tensile strength and remarkable low density. For many years, spider silk has been a point of debate due to its absorbent energy quality and for characteristics like, 10 times stronger than Kevlar. This paper is an effort to establish the same with outputs from some hands-on experiments and results. The paper further concludes with the possibilities of using spider silk as a regular mix in ferro cement to enhance concrete construction.

Backdrop and Inspirations –

In history, mankind has tried to harvest and create silk out of spider protein because of its noticeable physical properties. The first large scale weaving was done in late 1800s by French priest Jacob Paul Camboue. He, with a team, collected silk and had woven bed hangings which were displayed at Exposition Universals in Paris, in 1900s. The continuation got shelved till over a century later Simon Peers and Nicholas Godley chose to pursue Camboue's project and took over. Over a period of 5 years after collecting silk, these two Madagascar residents ended up creating a fabric from spider silk which was finished in 2008. The piece measured 11' x 4' but weighed only 2.6 pounds. The fabric travelled to museums all over the world. Eventually the outcome of the experiment became one of the most exciting products around.

Introduction -

Spiders are interesting models because they can produce silk fibers at room temperature using water as a solvent. Spider silk is a naturally produced proteinaceous fiber with exceptional mechanical properties, including high tensile strength and elasticity. It's five times stronger than steel on a weight-by-weight basis and can stretch to more than double its original length without breaking. In other words, spider silk is stronger than steel, tougher than Kevlar and can be more elastic than rubber. It's flexible and antimicrobial. It can be stretched several times before it breaks. Scientists have used silk to make bulletproof armor, violin strings, medical bandages, optical fiber cables and even extravagant clothing.

Fig. Spider silk and hand-woven bed hanging from spider silk.

The building industry consumes 40% of total energy and counts for 33% of greenhouse emissions. The buildings also have an estimated lifespan. Taking a cue, the use of spider silk in the building industry can always be experimented and expressed upon. Naturally available ingredients like spider silk, should be experimented upon to ensure sustainable and holistic global growth.

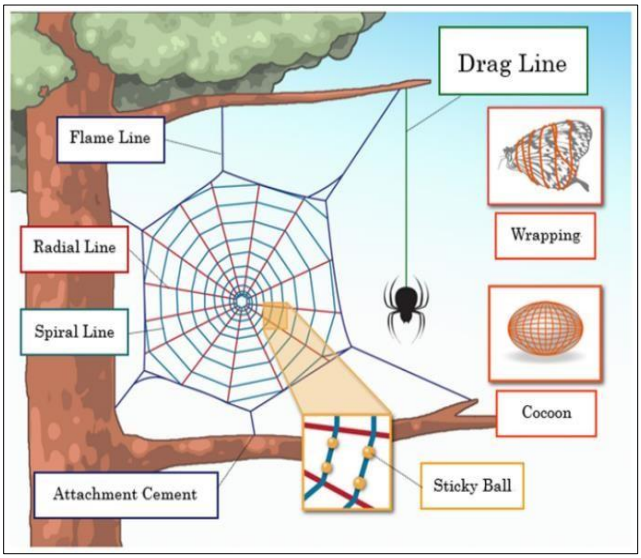

Fig. Orb web.

About spider silk –

Spider silk is a protein fiber spun by spiders. They use their silk to make webs or other structures, which function as sticky nets to catch other animals, or as nests or cocoons to protect their offspring, or to wrap up prey. They can also use their silk to suspend themselves, to float through the air, or to glide away from predators. Most spiders vary the

thickness and stickiness of their silk for different uses. All spiders produce silk, and even in non-web building spiders, silk is intimately tied to courtship and mating. A spider can produce seven different types of silk. The most common among these webs are orb web as shown in Figure.

Objectives –

The objective of the proposed study is to determine, that spider silk if procured and harvested methodically, then can be combined with building materials like wire mesh in a Ferro cement structure. The process here is mostly an experimental effort -

1. Studies and synthesis – About effective procurement and harvesting of spider silk.
2. Experiments and execution - Moul spider silk into wire mesh with predesigned openings.
3. Description and delineations – Infer upon the results and propose future possibilities.

Methodology -

The proposed study is covered in three parts:

- *Part I – Stepwise harvesting and Procuring methods of spider silk.*
- *Part II – Ferro cement integration and methods of execution.*
- *Part III – Spider silk and wire mesh combined in ferro cement.*

Part I – Harvesting and Procuring methods of spider silk

Scientists like Carles Lalueza Fox, (Institute of Evolutionary Biology, Spain) wrote about his carried-out experiments to procure spider silk. He focused on a particular species Malagasy Darwin's bark spider (Caerostris darwini) - also known as the toughest biomaterial. Gist of his experiments and citation -

- Adult females were collected and transported to a green house.
- Some were simply released to spin on the plants.
- Others were placed within individual frames.
- Web building took place within two months after release in greenhouse frames.
- Some spiders-built webs immediately, others were fed live crickets every other day.
- Most spiders accepted the prey offered and eventually built a web.

Proposed Method to acquire spider silk –

- Single structure web collection.
- Procuring from the world market.

Single structure web collection –

This proposed method is inspired by the experiments and articles carried out by Scientist Carles Lalueza Fox and is more effective as it doesn't incur any loss during its collection process.

Step 1: Creating a poly house with local shrubs and flowering plants to attract prey for spiders.

Step 2: Creating frames whose measurements will depend on the size of the poly house. The frames will also depend on the number of local spiders they can accommodate because spiders are not known to be group workers.

Step 3: Reporting observation after a maximum of 5 days on web in each frame; and providing natural support in enhancing the system of web building. For example, if in a frame a spider is spinning web faster than others but unable to acquire prey then inducing prey artificially into frame is necessary so that it doesn't leave its own frame.

Step 4: Collecting the web. Strands of webs are easy to collect but not by bare hands for a handful of collection. Any cylindrical object like a tree trunk or metal rod can be used to roll out the webs around it.

Fig. Collection of the spider web.

Step 5: Cleaning the silk of the twigs and dirt and untangling. Untangling is not mandatory, but it removes the dirt better. Blow drying also removes the excess of the dirt from the webs after placing the silk on a horizontal surface.

Fig. Cleaning and stretching.

Step 6: Soaking the silk in ethanol/methanol after cleaning for removal of the water or any moisture.

Step 7: Winding spider silk into a spool like a thin wire or thread is spanned into. This gives it a firm look and easier to handle for the next job.

Fig Spool of spider.

Procuring it from the world market - A town is south-east Australia; Victoria's Gippsland has found itself completely covered in spider sheet webs after several days of rain and flood. These spiders weaved the web to save themselves from flood water. And after procuring it, using single structure web collection method to harvest and store the silks for later use.

Fig. Spider web sheets in Australia.

Part II – *Ferro cement integration and methods of execution –*

The intermediate part of the process deals with the experimental phases where in situ experiments are carried out with the main objective of molding welded wire mesh and concrete in ferro cement. Then the need to adopt one of the different methods to apply cement mortar in a ferro cement.

Welded wire mesh - The welded wire mesh is a metal wire screen that is made up of low carbon steel wire or stainless steel. Weld mesh is manufactured in square, rectangular or rhombus shaped mesh from steel wire, welded at each intersection. Welded wire mesh exhibits greater flexural strength for ferro cement structure. The ideal mesh is 13mm x 13mm x 19 gauge (1mm) welded mesh to BS 4482 for the use in a ferro cement structure.

Concrete - Concrete is strong in compression as the aggregate efficiently carries the compressive load. However, it is weak in tensile as the cement holding the aggregate in place can crack and the whole structure may fail.

A Ferro cement structure - is a system of construction using reinforced cement applied over an 'armature' of welded wire mesh and closely spaced thin steel rods. The cement is typically a rich mix of sand and cement in 3:1. Ferro Cement increases tensile strength and ductility of concrete due to the use wire mesh of small diameter. But the concrete made up of Portland cement lacks tensile strength and is susceptible to cracks. Application of cement mortar in ferro cement depends on need and situations.

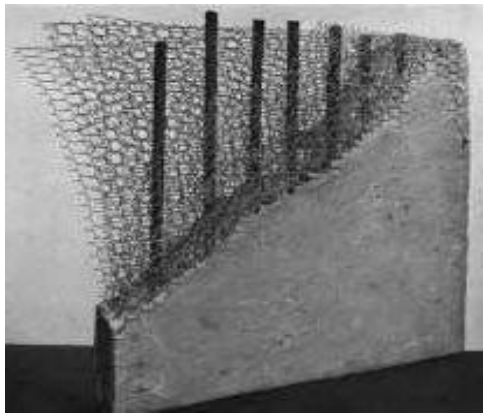

Fig. Ferro cement wall.

In this case - **Skeletal Armature method** is preferred - In the skeletal armature method, several layers of wire mesh are tied on either side of the reinforcing bars (skeleton steel). This entire framework is then welded to attain the desired shape. Following which, the mortar is applied from one side by forcing it to penetrate through the mesh layers until the excess mortar appears on the other side. This excess quantity is then pressed back, and the remaining mortar is struck off to give a good finish.

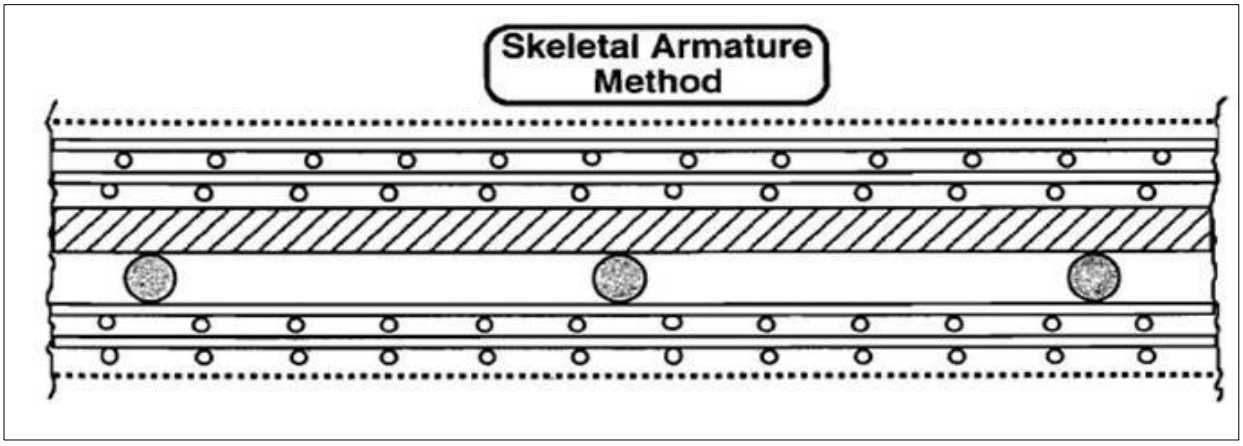

Fig. Typical section of ferro cement wall of skeletal armature.

Part III – Placement of spider silk in ferro cement -

The idea of the proposed structural combination is to -

- Create a more intricate mesh structure by spider protein.
- Attach it with the welded wire mesh in the armature of the steel section.
- Apply the cement in skeletal armature method in a Ferro cement wall structure.

To achieve –

- More uniform bonding of concrete.
- Reduction of cracks in concrete.
- Expandability and higher tensile strength.
- Flexibility of the structure.

To theoretically understand and for maximum prediction, the mechanical properties of the combination of both the materials are necessary -

PROPERTIES	STEEL	SPIDER SILK
Tensile Strength (Gpa)	1.65	1.3
Density(g/cm^3)	7.75-8.05	1.097
Extensibility (%)	Steel will expand from 0.06% to 0.07% in length for each 100^0 Feh. rise.	5 times than relaxed strength
Contraction (in water/moisture)	-	Shrinking up to 50% in length- Super contraction.
Withhold to Temperature (^0C)	-25^0 to 540^0	-40^0 to 220^0

Table. Comparative mechanical properties of spider silk and steel.

Deduced vision from above physical properties –

- The physical properties of both the materials in a ferro cement structure will enhance the tensile strength to give support to the binding material i.e. concrete, whose tensile strength is 2.2 – 4.2 MPa, much lesser than steel and spider silk.
- If the experiment is conducted practically then the strength graph of materials could have been presented as load vs. deflection graphs.

Traditional method for ferro cement wall panel -

- The flexural loads at first crack load and ultimate loads depend on the type and specifications of reinforcing mesh used in ferro cement panels.
- Using the ideal mesh stated earlier and skeletal armature method of creating a ferro cement structure, the wall panel is constructed as shown in Figure.

Proposed experimentation method for Ferro cement wall panel –

The proposed combination is like the traditional method of construction using ideal mesh dimensions and skeletal armature method of constructing the wall panel. After the skeleton is prepared layers of spider mesh is rounded and attached to the wire mesh, where spider mesh is created by spinning the spider protein in mesh like structures as shown in Figure.

After the spider mesh is attached to the skeleton then the concrete is to be stuffed inside manually or mechanically for packing, as shown in Figure, the same way used in traditional method.

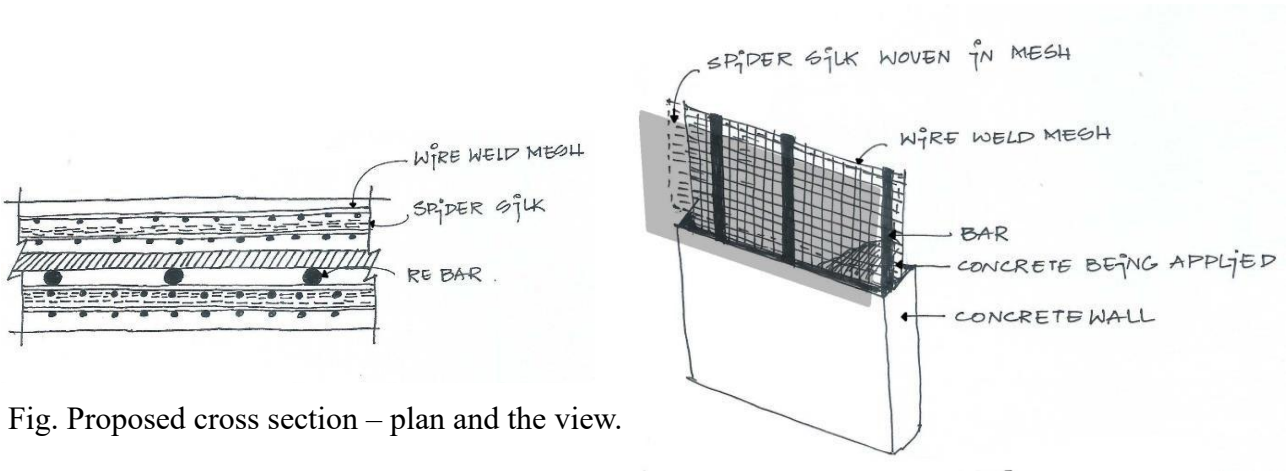

Fig. Proposed cross section – plan and the view.

Benefits of the proposed method –

- Longer life span of concrete
- Impact resistance
- Crack control
- Durability in structure
- Flexibility in structure

Concluding Discussions –

Ferrocement is a composite material used in construction, that combines thin layers of cement mortar with wire mesh reinforcements. It's known for its high strength-to-weight ratio, durability, and ability to form complex shapes, making it suitable for various structural applications. By incorporating spider silk fibers into the ferro cement matrix, it potentially enhances the material's overall strength, durability, flexibility and crack resistance capacity. While the idea of combining spider silk with ferro cement is promising, research is needed to determine the optimal way to integrate spider silk into the ferro cement matrix and assess the resulting material's performance under various conditions.

The study shows that spider silk, known for its exceptional strength and toughness, is being explored as a potential reinforcement material in ferro-cement for improved crack control in buildings. Ferrocement, a composite material using a cement mortar reinforced with layers of wire mesh or steel, is found here to have excellent crack control properties in buildings. Ferro-cement, which uses multiple layers of mesh and diameter rods infiltrated with mortar, and incorporating

spider silk could enhance its resistance to cracking. The paper shows that the close spacing of the reinforcement mesh can effectively act as crack arrests preventive.

A few reasons as spider silk application adds specifically to increase the strength for ferro cement control in buildings -

- **Strength and Toughness:** Combination of strength and toughness, make the spider silk fiber superior reinforcement material compared to traditional steel fibers.
- **Versatility and Durability:** The natural fibers can be used in mechanical engineering fields and are known for their flamboyancy and robustness.
- **Tangible and Lightweight:** Spider silk composites can reduce the weight of structures as they don’t weigh much - without compromising on their performance.
- **Crack Width and Spacing:** Adding silk fibers to ferro-cement can help reduce the width and spacing of cracks that may develop in the structure in due course
- **Flexibility and Flexural Strength:** Incorporating spider silk into ferro-cement panels can lead to a significant increase in the ability to bend, fold, or flex strength.
- **Sustainable and Eco-Friendly:** Spider silk is a natural and biodegradable material, making it a more sustainable option than traditional plastic-based fibers.

While spider silk holds immense promises for enhancing ferrocement's properties, further research and development are necessary to address the challenges associated with its cost, availability, and integration into cementitious materials. The potential benefits of incorporating spider silk, including improved mechanical performance, enhanced durability, and a more sustainable approach to construction, are significant and warrant continued exploration.

Ferrocement's Strengths advantages in terms of cost, ease of fabrication, and high tensile strength, makes it suitable for various applications while **Spider Silk's Benefits** in terms of its exceptional tensile strength and elasticity, rivaling that of high-strength steel makes it withstand significant stress and elongation without breaking. This makes it a desirable reinforcement material for controlling cracks in building construction.

To conclude, spider silk mixed with ferro cement can be used in support of all regular structural portions of a building. Special implications can be seen in shell structures, wall panels, drain covers, pergolas, precast elements and so on. Implications with proper proportions and forming a

performance related outcome of the material – it can also be used in further ways to strengthen the building construction technology for the future.

Limitations in terms of high cost and limited availability of spider silk are significant challenges to its widespread adoption. Integration and Processing with efficient methods for incorporating into ferrocement composites without compromising its strength and durability is crucial. Further research is needed to evaluate the long-term performance of spider silk-reinforced ferrocement under various environmental conditions.

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