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1. Trace a history of how TRC has globally come into use in the construction segment with special focus on India.

The development of the innovative composite material Textile Reinforced Concrete (TRC) provides a new way of construction with non-corrosive reinforced elements, such as alkali-resistant glass (AR-Glass) or carbon. Consequently the necessary concrete cover can be reduced significantly. Only a few millimeters are required to guarantee a good bond-behavior between the concrete and the textile reinforcement. As a result, thin construction-elements can be realized, which are impressive due to their little weight and slenderness. Also, the use of fine-concrete with a maximum grain size of 8 mm allows sharp edged parts and architectural high-quality surfaces.

Textile Reinforced Concrete (TRC) is a composite material consisting of high-strength fine grained concrete and textile reinforcement which is mainly fabricated of AR-glass or carbon fibres. Since 1998, the Collaborative Research Center 532 (called SFB 532) at RWTH Aachen University has been investigating the basic principles of TRC. The application of TRC allows economic savings in terms of material, transport and anchorage costs and thus has been severally used for thin-walled and light-weight ventilated façade systems in recent years. After the initial 12 years of research in TRC, the material was open for application in various application fields. Public Private Partnership Projects have been undertaken and Pilot Buildings set up for applications ranging from foot-over- bridges to Sandwich and ventilated facades. The material has proven itself and has the necessary permissions as well. The development of the material has been shown in the Figure below. TRC currently faces a tremendous market pull in the Indian sub-continent due to its manifold advantages. Since pilot projects have successfully been employed and have been awarded, the material and the production technology possesses a readiness level of about Technology Readiness Level (TRL) 7.

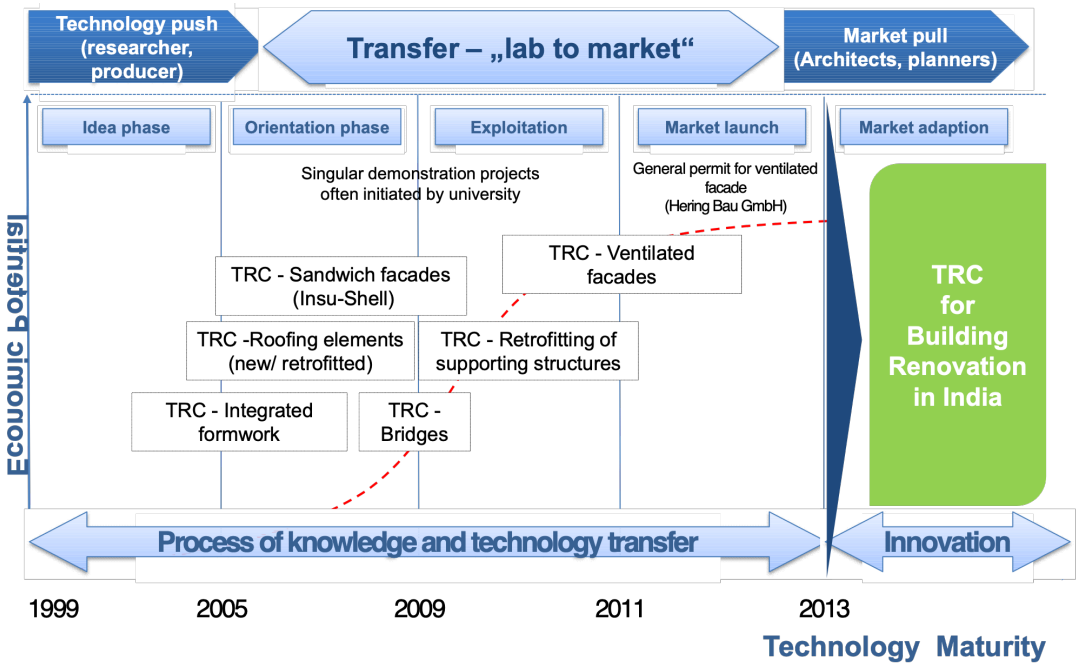


Figure : Development of TRC

2. What are the properties and composition of the material? Introduce us to its manufacturing process.

Textile-reinforced concrete (TRC) is an innovative composite material which uses mesh-like textile reinforcements and a fine-grained concrete as basic materials. Unlike steel, textiles are not susceptible to corrosion, thus it is possible to minimize the concrete cover to only a few millimetres. As a result, slender concrete constructions can be built, meeting the needs of modern architecture with both economic and environmental advantages.
Textile Reinforced Concrete (TRC) is a composite material consisting of high-strength fine grained concrete and textile reinforcement which is mainly fabricated of AR-glass or carbon fibres. Since 1998, the Collaborative Research Centre 532 (called SFB 532) at RWTH Aachen University has been investigating the basic principles of TRC. The application of TRC allows economic savings in terms of material, transport and anchorage costs and thus has been severally used for thin-walled and light-weight ventilated façade systems in recent years. At present, small panel sizes of 0.5-3.0 m² are state-of-the-art in the application of TRC in Germany. Panel sizes of up to 7 m² can only be realized in combination with bracing stud-frame systems.

For the production of Textile Reinforced Concrete, various types of textiles and fibre materials are used. Alkaline resistant glass fibres (AR-glass) and carbon fibres are the most commonly used materials. The textile reinforcement structures have to be especially designed to take resulting strains in the building member. Hence it has to be ensured during manufacturing of the concrete building members that the textiles are positioned correctly. In that respect, choosing the correct textile structure facilitates the manufacturing process.

The textiles are produced using a warp knitting process with inserted reinforcement fibres. The advantage of warp-knit fabrics is the biaxially stretched position of the filaments. The fibres in warp- and weft direction are laying on each other – non-crimped – and are bonded with a knitting thread. Non-crimped fibres provide best results for reinforcement purposes. The warp knitting process allows variations in material and local additional reinforcement depending on variation in machine set ups. Textile reinforcement can be used in a coated or uncoated state. Coating allows for a higher load bearing capacity and an increased durability especially for glass fibre material.

The matrices used for TRC generally meet special demands regarding production techniques, mechanical properties and durability of the reinforcement material. In most cases a small maximum grain size (< 5 mm) is used. An essential aspect for TRC matrices is the full penetration of the technical textiles in order to guarantee a good bonding as well as loading behaviour. Hence, the consistency of the matrix has to be adjusted for the properties of the textile, geometry of the specimen and production technique.
Production techniques are casting (highly flowable consistencies are required), lamination, spraying or pultrusion (rather plastic consistencies are required).

3. Highlight its various uses and applications for the Indian construction industry.

In the Indian construction industry the material could be used to make different products such as
- Outer facades
- Partition walls in buildings
- Jaali structures
- Water Tanks etc.

Some of these examples are depicted in images below

4. Kindly share in detail the advantages of using TRC for India in the current scenario. Does this material contribute to green construction/sustainability? Also, if there are any shortcomings, please specify along with the ways/alternatives to overcome these?

Situation

The Indian construction industry employs 32 million people and its total market size is estimated at 35,640 Mio. € (₹ 2,48,000 crores). The construction industry contributes to 11 % of the Indian Gross Domestic Product (GDP). Much of the growth of construction industry is fuelled by the exponential rise of the middle class in India as well as the need to develop substantial infrastructure (such as roads, airports, railway tracks, ports, etc.). Currently extensive amounts of steel reinforced concrete are being used for building structures all across India. A major challenge

faced by steel reinforced concrete is the corrosion resistance of the steel in the coastal areas of India. India has a costal line of coastline of 7,517 km. The temperature in the coastal regions often exceeds 30 °C (86 °F), and is coupled with high levels of humidity. Annual rainfall in this region averages between 1,000 and 3,000 mm (39 and 120 in). These extreme climatic conditions have a great effect on the reinforced structures. Hence, the reinforced structures have to be replaced and restored after every couple of years. A sustainable material for solving this problem is not available in India.

Problem

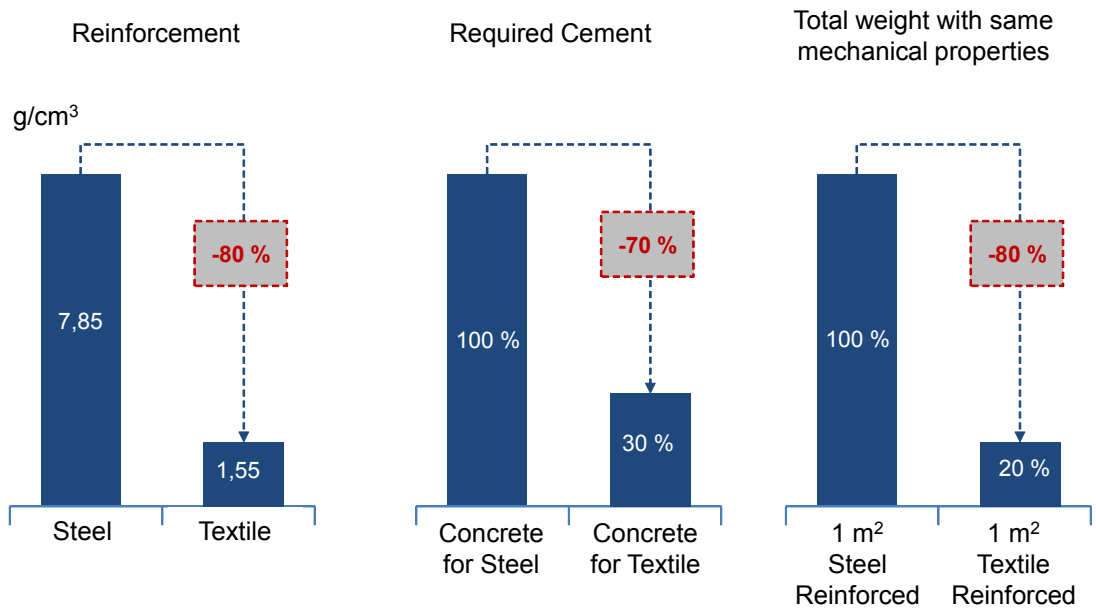
India and neighbouring countries face barriers to continue the construction industry growth at more than 10 %. A growth is restricted due certain deficits:

- Dearth of standardised building components in the building and construction sector
- The consumption of construction material in India consists majorly of conventional construction materials such as cement, steel, aggregates and sand
- The consistency in construction material quality is difficult to achieve in the sub-continent.
- There is a reluctance to integrate new products like textile reinforced concrete (TRC) which have established them in the western world
- Health and safety is still a major issue on sub-continental construction sites. This is mainly due to construction industry being a highly unorganised sector with dependence on cheap illiterate construction labour and less automation
- Majority of the construction in India is cast-insitu based. There has been a substantial rise in precasting applications in the last decade, but this forms only a small percentage of the total construction market
- The construction market is highly cost driven in the subcontinent
- Lack of supply chain developed due to the unorganised nature of the construction industry

Solution

In order to encounter the deficits new advanced sustainable materials have been developed in Germany over the past decade. In the field of precast concrete the concept of textile reinforced concrete (TRC) has been established in Germany. The TRC offers a solution which progresses beyond the state of the art short fibre reinforced concrete. This advanced material and the associated new manufacturing technologies have the following advantages:

- Reduction of concrete consumption by about 60 %
- Reduction in embodied energy of building component i.e. less cost of production, reduced transportation costs, reduced erection and application costs
- Reduction of End of Life waste by about 60 %
- The advanced TRC material can be used for new and retrofitting works
- The advanced TRC material offers the possibility of freedom in design



5. In India in the present day, how affordable is TRC in terms of its pricing and availability?

TRC vs Contemporary Solutions

● Best Solution
◉ Better Solution
○ Good Solution

Value	TRC Solution		Steel-Fibre Reinforced concrete		PP Fibre reinforced Concrete	
Material Consumption	Least (25 mm thick Facade)	●	Moderate (55 mm thick Facade)	◉	Maximum (90 mm thick Facade)	○
Material wastage with spray concrete	About 20% only concrete	●	About 20% concrete with expensive steel fibres	○	About 20% concrete with PP fibres	◉
Service Life/ Performance	Maximum due to continuous reinforcement	●	Average due to steel fibres that corrode with time	◉	Least due to cheap PP fibres with very low E-modulus.	○
Energy and Climate	Least CO2 consumption and embodied energy	●	Average CO2 consumption and embodied energy	◉	Maximum CO2 consumptiom and embodied energy	○
Health and Safety	Lightest element	●	Middle weight element	◉	Heaviest element	○
Social progress	Allows novel designs, faster construction, introduces new material to indian market, requires less maintenance	●	Expensive varient with still limitations related to corrosiveness of the elements	◉	Not an optimum solution, that increases the dead load of the building, while still not giving enough strength.	○
Cost	Most	○	Second Most	◉	Cheapest	●

The figure belw shows you the costs aspects of TRC Facades

6. How has the Indian market accepted the use of this material? In your opinion, does it need to be further popularised?

TRC as a material has barely been introduced to the Indian scenario. However the potential of this material is extremely high. The material needs to be marketed and popularized extensively. Among companies in India, Raina Industries Pvt. Ltd. has launched this product in India for the manufacture of facades and also street furniture.

7. Which existing material in India can it substitute? In terms of benefits, can you draw a comparison between both the materials?

TRC Concept with dead weight savings

Textile Reinforced Concrete	**Steel Fibre Reinforced Concrete***	**PP Fibre Reinforced Concrete***
▪ Density estimated: 2700 kg/m^3 ▪ Thickness: **0.025 m** ▪ Weight of 1 panel: **approx. 146 kg** ▪ Weight savings as compared to PP FRC benchmark: **68%** ▪ Total weight savings for the building approx.: **1300 tonnes** ▪ Easy to transport and erect	▪ Density estimated: 2450 kg/m^3 ▪ Thickness: 0.055 m ▪ Weight of 1 panel: approx. 291 kg ▪ Weight savings as compared to PP FRC benchmark: 37% ▪ Total weight savings for the building approx.: 700 tonnes ▪ Relatively hard to transport and erect	▪ Density estimated: 2400 kg/m^3 ▪ Thickness: 0.09 m ▪ Weight of 1 panel: approx. 467 kg ▪ Benchmark material ▪ Benchmark material ▪ Very hard to transport and erect

8. How does the use of TRC add to the life of a project? How can it add more value to a project (please cite examples here)? In case of any damage, can it be replaced or repaired?

TRC comprises of a “Textile” Reinforcement which does not corrode. This highly increases the life of the buildings and projects where this material is incorporated. Further the flexible textile reinforcement provides with enormous amount of design freedom.
Yes the material can be repaired and replaced as well. The textile reinforcement is also used as retrofitting and building renovation projects.