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FACULTY CIVIL ENGINEERING

Department of Concrete and Masonry

Textile Reinforced Concrete (TRC)

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ABSTRACT: Non-woven Polypropylene Textile Reinforced Concrete (PP TRC) can be used as thin coverage layer in concrete structures to decrease significantly the water and sulphate penetration to a structure and eliminate build-up. Despite this fact, the use of PP TRC coverage as mechanical protective surface has never been clearly understood and tested. In this thesis, a double layer of Non-Woven PP TRC has been used and tested on concrete samples, which were subjected to the compressive and tensile tests. Using the experimental data, further mathematical calculation has been provided to support the main task of this report, which was mechanical protection of a load-bearing structure. The result of this investigation revealed that textile reinforced concrete increases the stiffness of composite structure in both tension and compression, although the main problem occurs in the bond between the TRC protective cover and the already existing concrete structure. This bond was described in details based on laboratory data with the help of stress-strain diagrams. It was found out that the bond should be modified in order to increase the performance of the composite action.

Keywords: composite material, compression test, concrete, PP TRC, stress-strain diagram, tension test, textile.

Contents

1. Introduction

Today there are more and more concrete structures are built all around the world with a life period over 70 years and reconstruction of any built structure is essential not only for the framework, but also aesthetic point of view.

During the reconstruction it is commonly used to remove coverage layer with some extra load bearing part of an element in order to prepare the surface for attachment of a new one. For the reason that with damaged surface the main steel reinforcement is subjected to corrosion. Moreover, in parking garages walls and columns are subjected to being hit by cars, as a result new cracks appear, which allows the sulphate to penetrate with water and start to accumulate in the concrete.

For the listed above cases, it is highly desirable for strengthening or repairing of existing structures to have a thin coverage layer, which could hold several functions simultaneously for protection against mechanical damage, conservation of steel from corrosion and easy installation. This cannot be realized with typically used concrete cover, which is relatively heavy and massive due to density of the concrete. As an alternative Non-woven Polypropylene Textile Reinforced Concrete (PP TRC) could full-fill these conditions, because this canvas homogeneous material is 5-6 times more tensile than conventional steel for reinforcement, non-permeable and has light self-weight.

Since there is a lack of investigation and testing of this material as a protective layer. Thus, the proposed new textile cover within this thesis may contribute to innovation in Civil Engineering as it carries advantages opposed to typically used concrete cover as it is a durable method for the prevention of sulphate and water accumulation.

2. Textile Reinforced Concrete (TRC)

2.1. Application of TRC

Textile Reinforced Concrete (TRC) is a composite material which consists of fine-grained concrete and open-mesh textile structures or textile canvas laid in 1D plane. To compare with steel re-bars the textile fabric bears the tensile forces released by the cracking of the concrete structure. For attachment of the textile fabrics it is sufficient to have a minimal concrete cover around 2 cm as a consequence it makes a concrete structure with high durability and high-quality surface.

Hence, this technology in recent years, has been widely used for the production of ventilated facade systems. It allows to save in terms of material cost, transportation and anchorage of the facade elements. Meanwhile the design codes for an application of TRC façade elements (Figs. 1 and 2) are still not developed. Thus, the preparation requires individual approach for each construction or a general settled boundary conditions of the German building regulations (DIBt 2004) (Source: Grca.org.uk, 2019).

(Fig. 1: TRC tiles on the facade. Source: Grca.org.uk, 2019).

(Fig. 2: TRC tile composition. Source: Grca.org.uk, 2019).

Eco-buildings are usually made from Sandwich panels (Fig. 4) assembled from two facings and a core (rigid or flexible material) which function is to work as thermal insulation and increase the stiffness of the sandwich structure. Furthermore, they also offer extra properties in terms of acoustic insulation, non-flammability, easy assembly, cheap and simple manufacturing, time-saving installation, etc.

Currently there are two possible materials or approaches can be applied to create TRC facings in sandwich panels (Fig. 3). Materials such as glass fibre reinforced concrete (GFRC) and fibre reinforced polymer (FRP) are used as external layers. These panels with GFRC external surfaces are thick and reinforced additionally by steel frames in order to increase their load-bearing function, which makes them heavy structures. Meanwhile, FRP possess more efficient mechanical properties, but it carries toxic quantity due to the epoxy resin (Source: Mostostal.waw.pl, 2019).

(Fig. 3: Composition of Sandwich panels. Source: Mountainviewprecast.ca, 2019)

(Fig. 4: Installation of panels. Source: Mostostal.waw.pl, 2019).

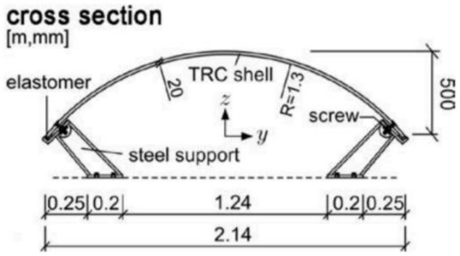
Reinforced Concrete frameworks are massive structures due to big cross-section of the load-bearing elements, which transfer large internal forces, because of enormous dead-load caused by high density of concrete. For these reasons, RC frameworks has limitations in dimensions.

While TRC simplifies the problem and provide a flawless opportunity to make prefabricated slender and light-weight structures with complicated and magnificent geometric shapes. The real-existing prototype of Rhombic Lattice-Grid (Fig. 5) is located in RWTH AACHEN UNIVERSITY in Germany and was built in February 2005. The TRC Arch was erected from 36 single rhombic elements with dimensions 1000 x 600 x 160 mm bolted together and connected in 3 parallel rows. This system has the total span of 10m with the height of 3m and the width is 3m. This light weight structure weights only 23kg (Source: Grca.org.uk, 2019)


(Fig. 5: Prototype of a diamond-shaped lattice grid. Source: Grca.org.uk, 2019).

The curved shapes often used for concrete shells, which are commonly used where a building interior needs to be free from intermediate walls or columns that might support a more conventional structures such as: railway terminals, bicycle or motorcycle roof stand and other various functions.

Barrel Shell TRC (see Fig.6) has cylindrical shape, domed, paraboloid or ellipsoid shape. The curvature of shell structures have the same distribution of internal forces as arches, which are pure compression forms with no tensile stresses. This property makes the textile-reinforced concrete structure extremely light-weight and the shell is rigid in both the longitudinal and lateral direction than conventional frames. As shown in Figure 6 (left side), the structure consists of four individual barrel shape shells supported on steel elements welded to the steel frame. Each shell has the thickness of 20mm, width of 2,14m and the length is 4,4m. It was produced by RWTH AACHEN UNIVERSITY (Source: Edisciplinas.usp.br, 2019)

(Fig. 6: Roof of the bicycle stand made of laminated TRC barrel vault shells. Source: Edisciplinas.usp.br, 2019)

Some RC Load-bearing elements, which are subjected to dynamic loading should be strengthened to prevent deterioration of their surfaces. Concrete bridges are loaded by non-static loading that is why the coverage layer of RC supports are destroyed (see Figure 7).

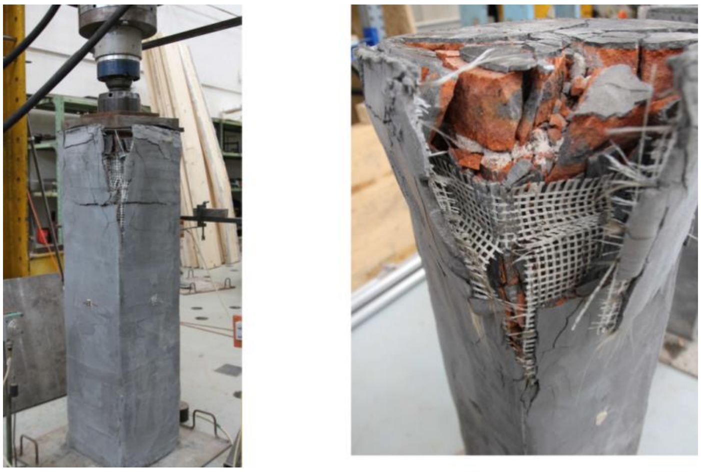
The near surface mounted fabrics technology could solve that problem. Due to ductility of carbon textile, the performance of this specific reinforcement could reach astonishing results and prevent the RC element from deterioration.

(Fig. 7: Damaged pillar of the bridge. Source: Roads & Bridges, 2019).

In recent decades brick was widely used in civil engineering. Partition walls, load-bearing walls and columns were erected by bricks and till nowadays this building material presents in modern construction.

Brick columns have multiple issues, which concern their load-bearing function. Temperature and humid influences the stiffness and bearing capacity of the bricks, but the main point is that mortar layers can destroy bricks, because mortar itself is softer and under the critical loading it transfers shear-forces. As a result of that behaviour mortar squeeze and damage bricks. To prevent this failure steel cages are welded around columns to increase rigidity of the whole structural element. Further alternative is placing steel mash in the mortal layers in horizontal projection. The mash transfer internal tensile forces from mortar thereby preventing from mortar expansion of mortar layer.

Modern approach of application TRC could solve these problems. Wrapping of Alkali-Resistant glass textile around the brick column (see Fig. 8) could benefit with achieving of maximum load up to 150% with respect to in-reinforced element. This unique technique is applicable also for reinforced concrete structures and can prolong the life period of these structures (Source: Holčapek, Vogel and Reiterman, 2019)



(Fig. 8: Collapsed pillar with TRC protective layer after testing. Source: Holčapek, Vogel and Reiterman, 2019).

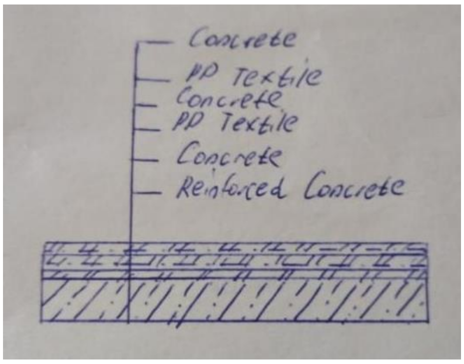
3. Research overview - Prevention from deterioration of concrete cover (under loading)

All above cases provide us with the knowledge about mechanical properties of textile reinforced concrete and usage of it in different fields of civil engineering. TRC can substitute the steel reinforcement or can be an additional strengthening element to the whole structure.

These days it is costly to build wide multi-storey parking garages with completely free internal space, for that reason owners use monolithic frame structures with the tight driveways inside of this construction. Due to these conditions millions of cars crash to the obstacle such as: wall, columns and corners. As a result of that, cars damage the concrete structure as a consequence destroyed coverage layer and opens main reinforcement of the reinforced concrete structure. In case of unprotected steel re-bars, the corrosion takes place and can cause cracking, delamination, and deterioration.

The motivation for this work was chosen according to these issues listed above. The main idea is to protect the already existed concrete structure by applying non-woven polypropylene textile on that (Fig. 9) to eliminate water penetration to the concrete, safe load-bearing part of the structure and transfer all internal forces, which occur on the top surface during car hit and the obstacle. Since PP textile is 5-6 times more tensile than conventional steel, also resists moisture, oils, and solvents. The composition of protective layer will consist of 2 layers of PP fully penetrated with cement paste and 1-2mm of fine-grained concrete between them (as shown in Fig. 10).

(Fig. 9: Non-woven polypropylene textile. Source: Author)



(Fig. 10: Schematic composition of tested TRC. Source: Author)

4. Concrete and RC samples manufacturing

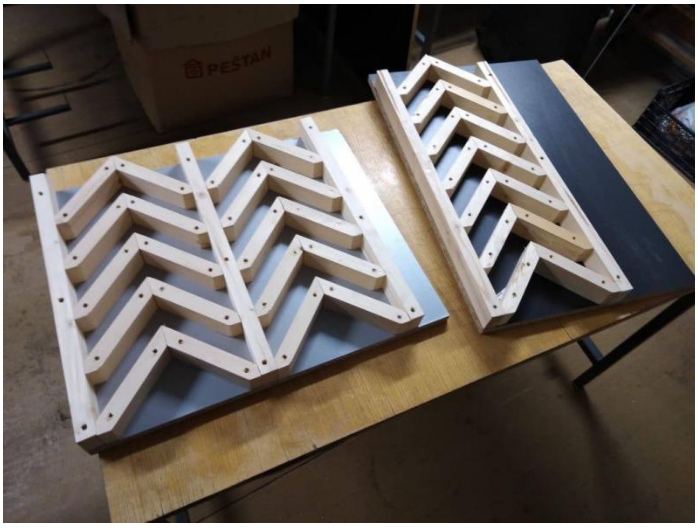
According to estimated goals; Concrete samples will be created before attaching protective layers from both sides (See Fig. 11) in order to monitor deformations and damage of composition under the loading.

(Fig. 11: Composition of TRC layer. Source: Author)

Twenty-four samples with the shape of a corner frame and the cross-section of 4 x 4 cm and the length of 15 cm from outer surface and 13 cm from the internal side was designed for this work (Fig. 12). Eleven of them are made of fine-grained concrete, meanwhile another part is made of reinforced concrete. The main point of making these samples is to measure all internal forces in samples and PP textile during the compression and tension tests.

(Fig. 12: Concrete samples. Source: Author)

The first step was making the wooden form-work for concrete samples (shown in Fig. 13). Wooden elements were attached to each other by 90 degrees and strengthened from both sides by wooden studs. All of these elements were screwed to the main plywood to where concrete will be poured.



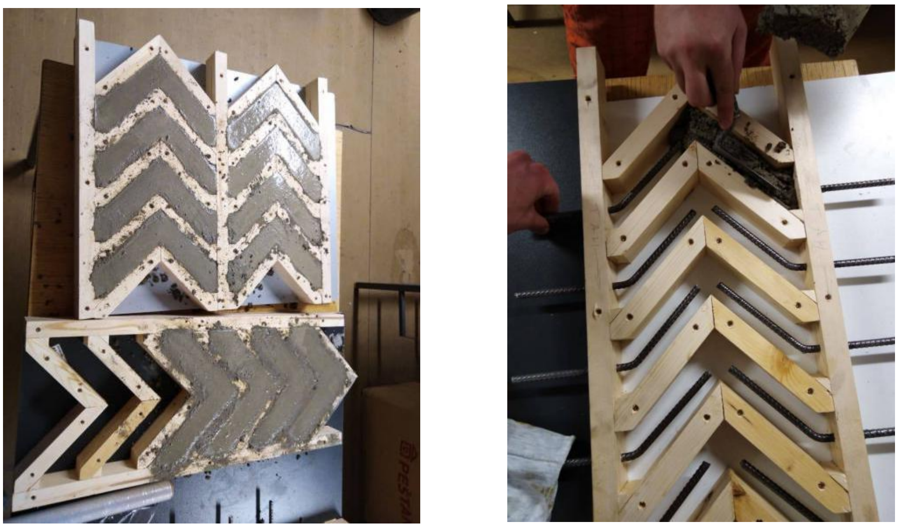
(Fig. 13: Wooden form-work for compression test. Source: Author)

The second step was creating another type of form-work (Fig. 14) for reinforced concrete samples. The modification was made by drilling holes in wooden studs with diameters of 8mm for inserting bent steel re-bars with diameter 8mm.

(Fig. 14: Wooden form-work for tension test. Source: Author)

After building up form-works all drilled holes and joints between wooden elements were sealed in order to avoid any leakages of fresh concrete and keep all samples homogeneous and identical.

Further step was making concrete mixture for samples. Based on laboratory testing equipment the maximum sizes of samples are deducted. According to these maximum sizes it is possible to reflect the maximum size of aggregate components for creation of concrete and reinforced concrete samples. For this reason, a mixture consists of fine-grained sand (0-0.4mm), cement (CEM I 42.5 R), plasticizer and water with the w/c of 0.37. After creation of fresh concrete, it was poured into the forms. Fresh concrete was manually compacted and mixed directly in the forms with the help of a spatula. Justification for this process is to avoid cavities below reinforcement and reach homogeneity of the specimens (See Fig. 15). During production 2 samples were broken due to shrinkage of the wooden formwork and to an extent, the concrete samples.



(Fig. 15: Pouring concrete into the form-works. Source: Author)

4.1. Penetration of PP Textile with cement paste

After 24 samples were concreted and left for hardening, simultaneously tests for preparation of textile layers were held. The main issue of PP textile is penetration of concrete through this particular material. Two mixtures were chosen for penetration of canvas textile. First mixture was fine-grained concrete with sand 0-0.25 mm, water to cement ratio (w/c) is equal to 0.35, and plasticizer to cement ratio (P/C) is 0.013. Another mixture was cement paste consisted of w/c is equal to

0.3 and P/C is 0.02. The reason for using low w/c ratio and applying plasticizer is to prevent textile from over saturating with water and avoid water disposal between textile and concrete layers. Moreover, excess of water will oppose to cement penetration as it will appear on the surface of the PP material.

Three PP textile were tested (See Fig. 16). Textile number 1 and 2 were concreted with fine-grained concrete, while the canvas number 3 was penetrated with cement paste. Moreover, PP textile 1 was fully submerged to the water, meanwhile other samples were dry before the test.

(Fig. 16: PP textile penetration. Source: Author)

Due to non-permeability of PP textile the concrete stays on the surface of the material (Fig. 16 left side). In order to penetrate material, it should be gently rubbed with a spatula. In case of intensive rubbing, the concrete becomes crumbly, that is why it has to be applied gently to achieve full penetration of concrete through the canvas.

After hardening of the concrete mixtures, a judgment was settled. Observation of samples (Fig. 17) revealed that textile number 1 had an issue with oversaturation, which influenced the final composition of the hardened concrete. In the result of that, sand disposed on the outer surface of the textile, while only cement penetrated and stayed in the PP canvas. Moreover, during concreting the cement, the paste flowed out from the material, for that reason less concrete would have to be used for that specific textile than in in others. Meanwhile, specimen number 2 with the same concrete mixture was applied on the dry canvas. During the manufacturing difficulties were encountered as the amount of plasticizer was relatively low for penetration of the material, which lead to an extension of time for the preparation and poor quality of the final composition. The concluding inspection revealed, that concrete did not penetrate PP textile entirely, simultaneously sand remained on the upper surface and partly penetrated the material, but not fully. For the third specimen the cement paste was tested. Big amount of plasticizer was used, that is why hand application was the most successful approach, because the mixture was fluid, whilst the spatula method resulted in a more rigid outcome. Furthermore, the arragment of the cement paste was homoginious along the whole specimen, for that reason the decision was made to apply this mixture for futher work.

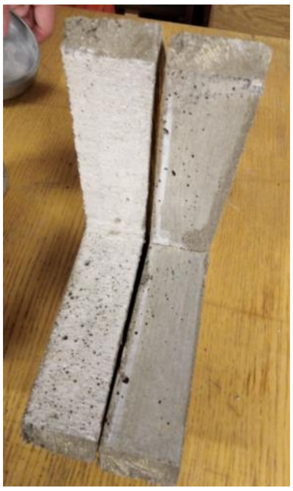
(Fig. 17: Hardened PP textiles. Source: Author)

4.2. Bond and overlay

Based on experience with penetration of textile the second mixture was chosen for bonding of 2 individual PP textiles penetrated with cement paste. Due to non-permeability of textiles, the water used in the concrete mixture will not evaporate during manufacturing. For that reason, shrinkage of concrete in the core of TRC protective coverage layer will be prevented.

The outer layer of composition consists of the same concrete type. It has to stick to the textile canvas and makes 1-2 mm protective layer. Fresh concrete will be covered with foil in order to prevent the whole composition being affected by shrinkage.

The bond between concrete/RC and TRC was decided to be done in two ways. The reason being that it is a reconstruction of damaged surfaces of load-bearing elements, two scenarios were selected (Fig. 18). First one considered to be with smooth external surface of the structure, where TRC will be attached on fresh concrete poured onto a smooth surface. The concrete for attaching the TRC will be identical as concrete used in bonding of PP textile. Another scenario is to apply TRC coverage layer of damaged surface of a structure. The technology of manufacturing will be the same as in the case mentioned above.

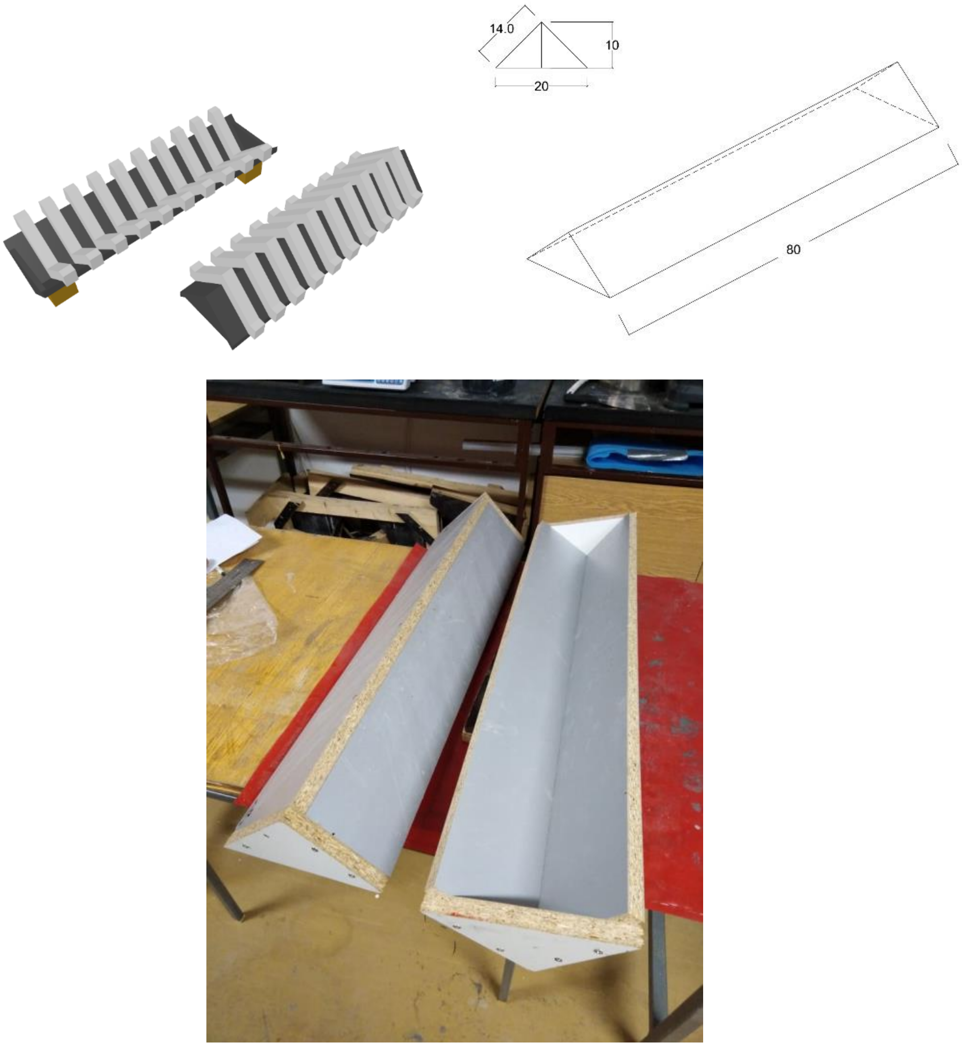


(Fig. 18: Rubbed and smooth surfaces. Source: Author)

For these conditions 11 hardened RC and 11 concrete samples were prepared. 11 of all samples were rubbed by a grinding tool (7 for compression, 7 with reinforcement for tension) see Fig. 19. All internal and external sides were grinded for application of TRC layers from both sides. Other 11 samples were left as they are (3 compression,5 tension), because of smooth surfaces of the samples.

(Fig. 19: Rubbing of samples. Source: Author)

Further step was to create a new formwork for creation and attachment of TRC to already existed RC samples. New wooden formwork had a shape of a uniform triangular prism (shown in the Fig. 20) following the dimensions: 80 cm in a longitudinal direction, 20 cm in horizontal and 10 cm in vertical direction with the inclined 14 cm plywood. All wooden elements were screwed together and independent wooden V- shape support was designed for supporting the entire formwork. Two forms were designed for concreting of 11 samples on each formwork simultaneously. The structure has special mobility in the way of supporting samples, as it can be used from both sides, which makes the process of manufacturing much faster and comfortable.



(Fig. 20: Formwork for TRC. Source: Author)

Before creation of a sample set on the new formwork, which was covered with foil, the concrete mixture was tasted on it. The reason for application of a foil is to prevent the TRC adhering to the wood and making the un-forming process complicated (See Fig.21). Test revealed that during the placement of fresh concrete on foil the substance should be poured on the top edge in a small amount and intensely applied with a spatula. That special treatment makes concrete spread uniformly along the inclined surface in order to reach the thickness of the concrete layer in the range of 1-2 mm. Greater than that the thickness is barely impossible to achieve with the given mixture, because of the self-weight of the substance, which pushes the entire mass down the slope (Fig. 22) and due to the high inclination of the surface (45 degrees) on the slip surface. Probable solution for creating a thicker layer is to use less plasticizer amount in the concrete mixture that will result in less fluidity.

(Fig. 21: Concrete mixture on foil. Source: Author)

(Fig. 22: Sliding of fresh concrete layer. Source: Author)

4.3. TRC manufacturing

Firstly, the foil covered the formwork for an easy detachment of the concrete samples (Fig. 23). Right after that, the concrete mixture was created to make the first and outer layer of TRC composition. The concrete was poured in small portions on top of the edge and gently applied with a spatula for making the concrete flow from top to bottom of the inclined wooden desk with homogeneous layer along the whole slope.

(Fig. 23: Concreting of the outer layer. Source: Author)

Secondly, the preparation of the first textile layer has begun. Canvas material was cut and in the meantime the cement paste was mixed. Before inserting the mixture, the PP textile was sprayed with water in small portions, because the PP canvas absorbs the water and as a result, it reduces dramatically water to cement ratio of the concrete substance. As the technology of penetration of the canvas was mentioned in section 3.2, it was applied during concreting, but it was made on a small scale of material to compare with a real one. For that reason, the decision was made to apply new technology, which requires manual inserting of the cement paste (shown in Fig. 24).

This method revealed that bigger area of canvas applied by hand produced a more uniform surface with less excess portions with ease.

(Fig. 24: Manual rubbing of cement paste to PP Textile. Source: Author)

Third step was to attach the penetrated canvas to fresh concrete, which was poured on the inclined formwork. There were no special conditions for laying the canvas. The approximate amount of cement paste, which was inserted to the textile was 1 kilogram that is why the material was prestressed to the concrete mixture by its own self-weight. The next step was to place interlayer of concrete between PP textile layers (Fig. 25). Only one complication was observed during the process and it was the oversaturation of already placed PP textile on the formwork with water. That specific condition made fresh concrete flow down the slope. The problem raised after spraying some extra water on the canvas, because concrete started to harden. That problem was solved by inclination of the formwork. In 30 minutes after new concreting, the old PP layer became marginally harder resulting in excess of water and concrete flowing out of the formwork.

(Fig. 25: Concreting of interlayer. Source: Author)

Further step was to repeat the process of textile penetration. The technology was exactly the same as it was during production of the first layer of PP textile, however concrete interlayer was not sprayed with water to prevent the PP textile from oversaturation. Subsequently it was laid on the concrete layer (shown in Fig. 26).

(Fig. 26: Layering of PP textile. Source: Author)

The final step was placing concrete and RC samples on TRC coverage layer. After attaching second layer of PP textile the last concrete layer was poured. A few minutes later, when the concrete marginally hardened it was necessary to place the other portion of mixtures directly on concrete and RC samples (as shown in the Fig. 27). It was done to increase the bond between PP textile with outer concrete surface and RC sample, also to eliminate any chances for cavities between these layers.

(Fig. 27: Placing extra concrete on RC samples. Source: Author)

Due to some imperfections in the formwork and other unexpected issues the decision was made to place the samples on fresh TRC protective layer and load each individual sample by the other one (Fig. 28). Then it was left for hardening in the laboratory, moreover all samples were covered with foil to prevent the freshly poured concrete from the shrinkage.

(Fig. 28: Inserting RC sample. Source: Author)

Further manufacturing of TRC coverage layer was performed. The technology of application is identical. Firstly, TRC was placed on the formwork (shown in the Fig. 29)

(Fig. 29: Creating TRC coverage layer. Source: Author)

Subsequently, the set of samples was placed directly into the formwork (see Fig.30). And prestressed by previous already concrete set of samples in order to achieve better bond between TRC and concrete/RC.

(Fig. 30: Inserting samples into the formwork. Source: Author)

5. Tensile and compressive stress test preparation

Before the test two sets of samples were cut into individual elements. To be able to cut concrete material special equipment is required. A diamond grinder was used to cut TRC coverage layer from both sides of the samples (as shown in the Fig. 31)

(Fig. 31: Cutting TRC layer. Source: Author)

For this specific test - two apparatus were selected. One of them is for axial compression test and another for axial tensile test. Both of these machines have immovable lower pad/plate, which records data, in the meantime the upper part loads a sample.

5.1. Composite action under loading

Visually, the rubbed and non-rubbed samples are impossible to recognise one from another, only the final data reveals the real difference in performance of each type of element. Thus, we can neglect the description of behaviour of samples individually.

Firstly, the axial compression test (see Fig. 32) was conducted, where samples with rubbed and smooth surfaces between TRC and concrete/RC were tested until complete collapse. The reason for full destruction of the samples is to obtain the entire data for analysis of each individual element of composition, because both internal and external TRC layers have distinct roles.

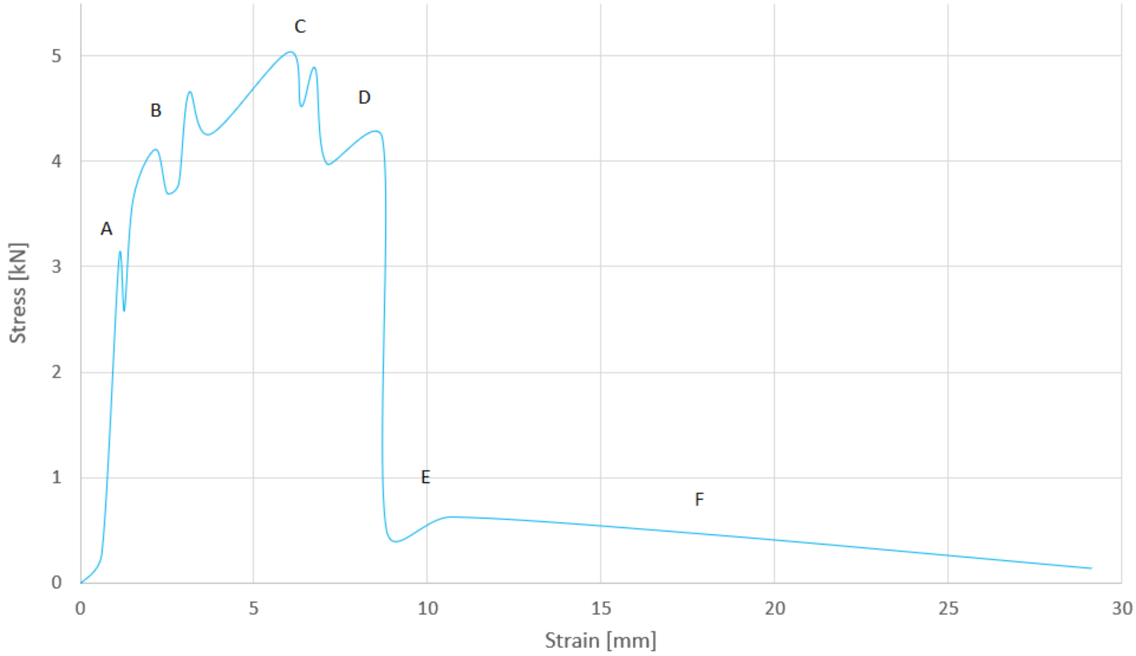
(Fig. 32: Compression test. Source: Author)

The final measurement for tensile strength was carried out by axial tensile test (represented on Fig.33). Identically, samples with the rubbed and smooth surfaces were tested. The duration of this test was twice as long, because PP textile is a very ductile material and loading has to be done carefully with maximum precision. The machine applies some force and halts for a result of deformation, when the material starts to tear, the applied force stays at the same level or decreases to some extent. The is the result of linear sections of the graphs, where strain continues to enlarge, while the stress stays at the same level.

(Fig. 33: Tensile test. Source: Author)

5.2. Compression test results

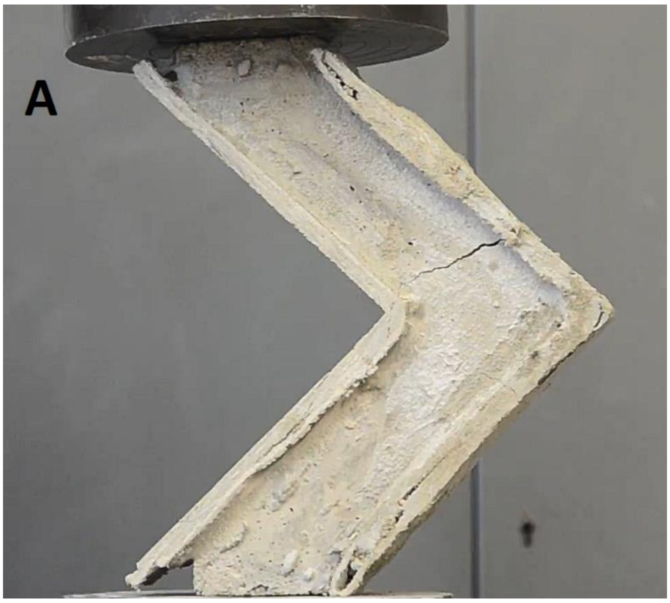
According to the given data from testing equipment, the stress-strain graphs can be plotted. The first graph represents the rubbed samples (see Fig.34).



(Fig. 34: Stress-strain diagram of rubbed samples. Source: Author)

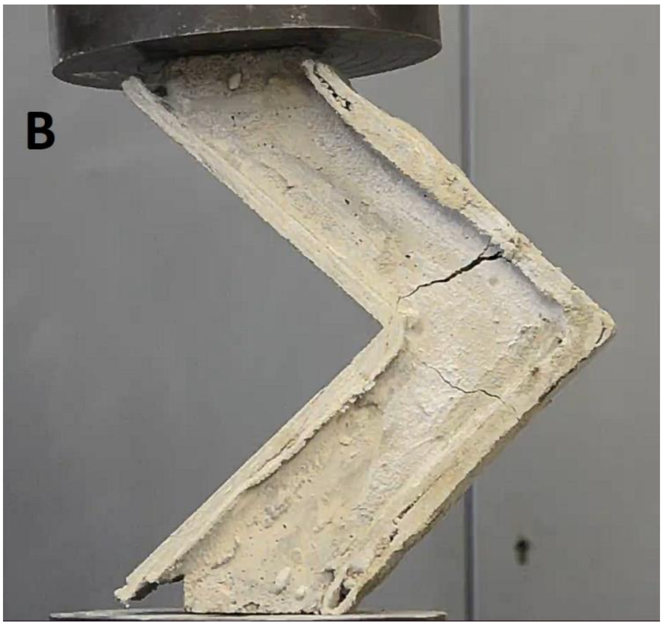
On this graph the average curve is derived, where all samples with any imperfections were taken into account. For this reason, only common features will be presented and described in this work.

Point A (in the picture 34) represents first crack on a sample (showed in the Fig. 35). Due to internal bending moment in the corner of the sample, which is caused by applied force from the testing equipment the load-bearing part of composition starts to crack. It means that strength of the bond between TRC layer and RC element was weakened and transferred its load during the release of the bond onto the concrete element. However, the whole element does not collapse due to ductile TRC cover, which is engaged locally and is stretched more.



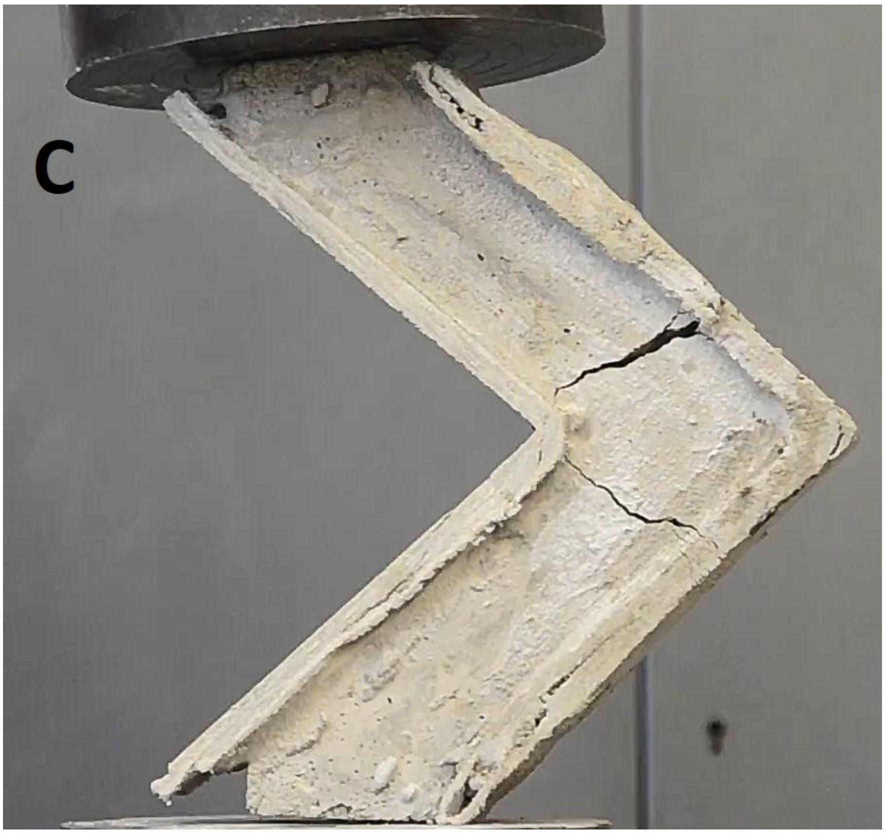
(Fig. 35: First crack during compression. Source: Author)

Point B represents the second crack during the test (Fig. 36). The static scheme of all samples as a fixed corner meaning that the internal bending moment in the corner is equal to each other from both sides of the samples. After the first crack the corner becomes weaker in the area of the initial deformation and in the symmetrical region shear stress rises, which leads to the second crack. Simultaneously TRC cover above the new fracture reaches its plastic deformation, while the protective layer above the initial opening starts to tear.



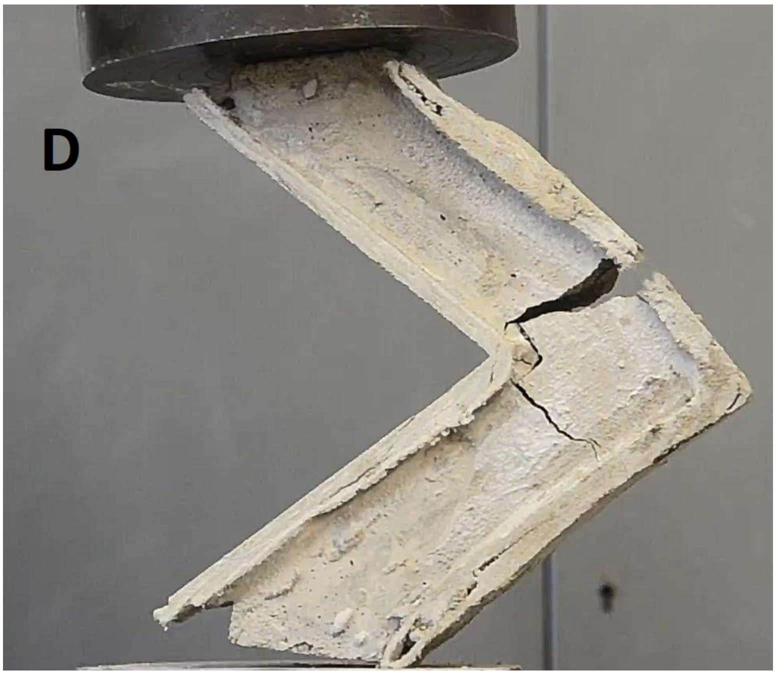
(Fig. 36: Second crack during compression. Source: Author)

From the peak point C, the judgement can be settled surely. After the second fracture the TRC layer from both sides begins to tear (cracks on coverage layer represent it) by exceeding its own plastic limit. Consequently, tensile PP material in tension withstands enormous loading compared with conventional concrete, that is why the graph reached its maximum (see Fig. 37). Moreover, right angle became to be acute, because of the stiffness of the whole sample subjected to buckle and beginning to obtain the final shape of a semicircle, that is the reason of bending and tension on upper surfaces, where cracks appeared.



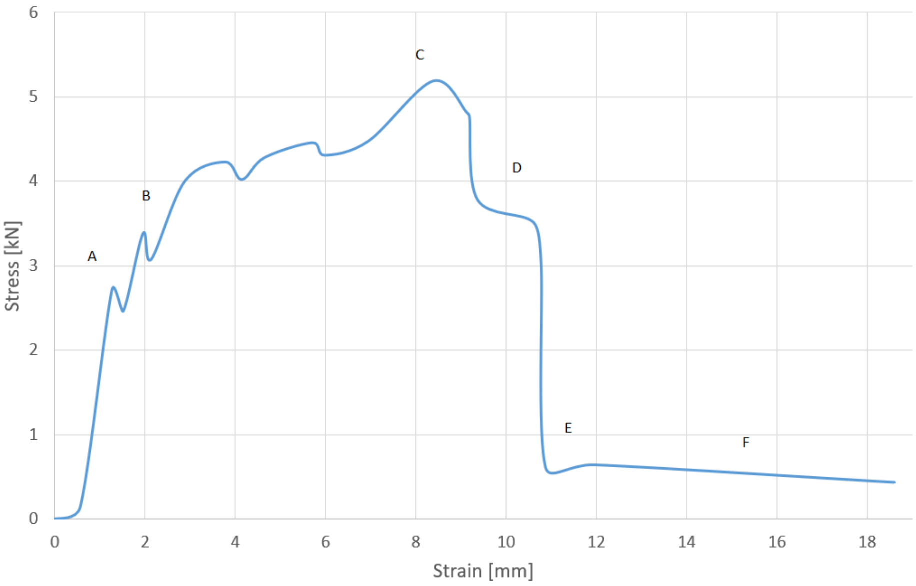
(Fig. 37: Ultimate strength of samples. Source: Author)

Point D shows failure point. In this specific case the failure caused by complete rupture of TRC layer above the first crack (Fig. 38). In the graph it is represented by a sudden drop to the lowest value on Stress Axis (point E). After complete opening of the sample the concrete stops to carry any load, only internal TRC layer continues to bear the external load (point F).



(Fig. 38: Failure of concrete specimen. Source: Author)

Another set of samples was with a smooth surface. The final data from axial compression test is shown on the Fig. 39. According to the given graphs the main difference between rubbed and smooth specimens is the appearance of first and second cracks in concrete samples. The reason for this behaviour is less friction between attached TRC cover and an old concrete specimen (see Fig.40).

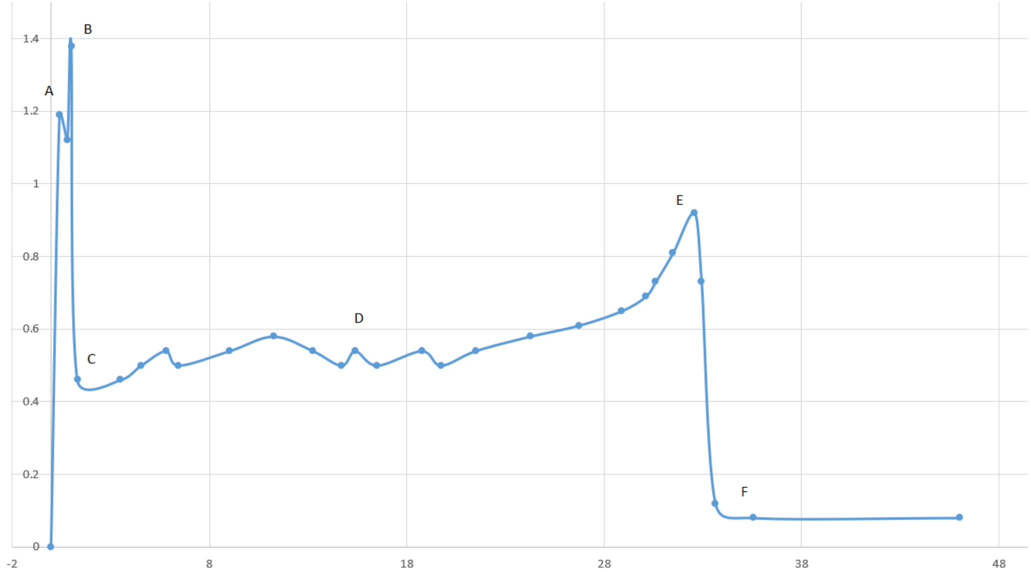


(Fig. 39: Compression Stress-strain diagram of samples with a smooth surface. Source: Author)

(Fig. 40: Poor bond between TRC and concrete sample. Source: Author)

5.3. Tension test results

Meanwhile the tensile test was carried out. The following average graph represents tensile strass-strain diagram of specimens with smooth surfaces (Fig. 41).



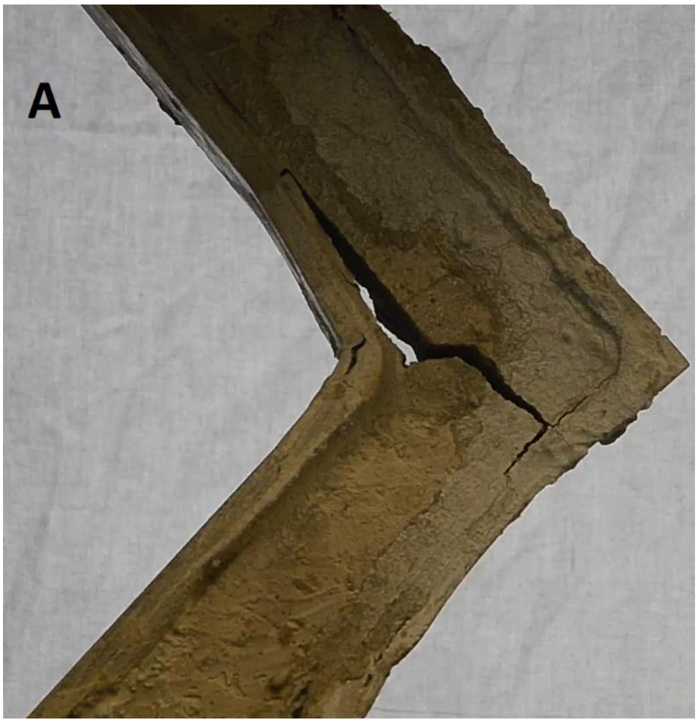
(Fig. 41: Tensile stress-strain diagram of samples with smooth surface. Source: Author)

For the reason that in this work only average diagrams are presented, small errors are not visible on the graphs. Before the point A the first crack appeared in the cavity between TRC layer and load-bearing concrete in the corner (Fig.42).

(Fig. 42: First crack during tension. Source: Author)

The applied force was approximately 0.8 kN. The reason for this opening is non-unity of material at that cavity, where all internal forces are not able to distribute equally through the whole concrete and reduce the resistance of the entire composition. Moreover, the concrete itself is a weak material in tension, that is why the applied load is especially low with respect to compression test, but PP textile works as reinforcement and carries a greater amount of all internal forces, which appears on internal and external surfaces of samples.

Point A represents the appearance of the first crack (see Fig. 43). At that time the concrete element stopped resisting to tensile force, because it was fragmented. In spite of that, bond between TRC and concrete prevent the sample from sudden failure, because it continues to bear internal forces, at the mean time the specimen progresses to open more the initial crack.

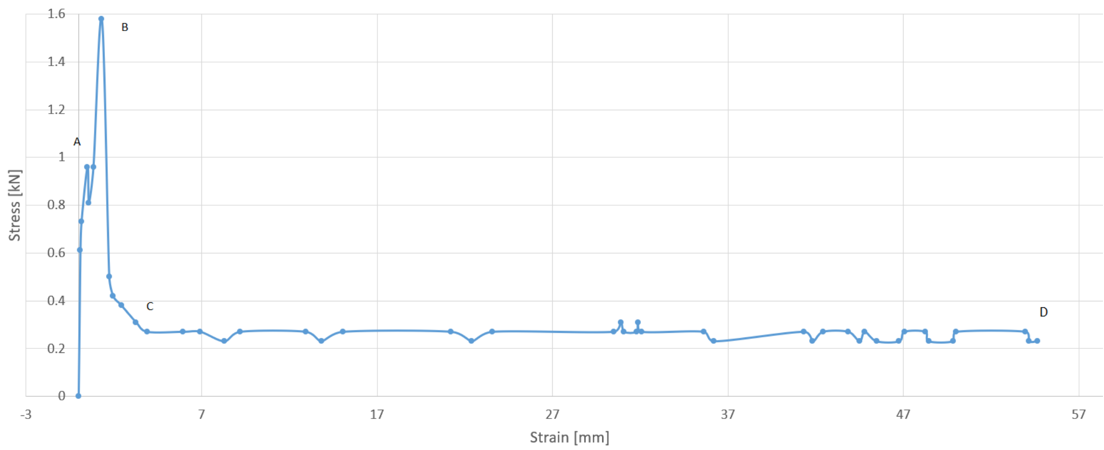


(Fig. 43: Delamination of TRC layer. Source: Author)

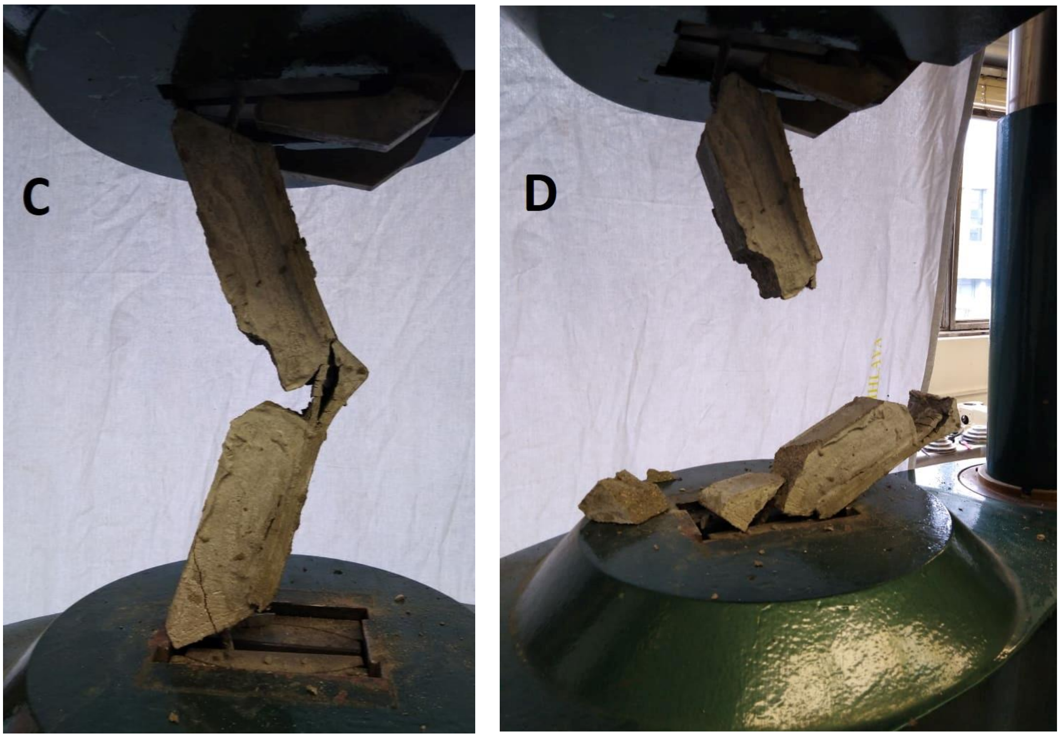
When the bond reached its own tensile limit (point B) and completely delaminated from the concrete element (Fig. 44) the sharp drop in the graph was recorded as point C. Before that critical point the outer TRC layer engaged and another fragmentation can be visible there. For that reason, the specimens reach their second peak point.

(Fig. 44: Failure of TRC specimen under tension. Source: Author)

From point C to D the concrete part of composite element was completely destroyed and did not play any role in the load-bearing function identically in the tensile stress-strain diagram of the rubbed samples (Fig.45). Only internal and external TRC layers were loaded. Point E represent the final rupture of outer TRC layer (as shown in the Fig. 46).



(Fig. 45: Tensile stress-strain diagram of rubbed sample. Source: Author)



(Fig. 46: Final rapture of TRC layer. Source: Author)

6. Conclusions

In this work, a composite action of textile reinforced concrete made of Non-woven Polypropylene material and concrete has been presented. This composite is produced by the attachment of TRC in layers to the concrete surface of load-bearing elements. In order to accomplish this bond, the following mixtures were used: the mixture for penetration of PP canvas was cement paste consisting of w/c is equal to 0.3, the P/C is 0.02, meanwhile another mixture for bonding concrete element with TRC and both layers of textile material was fine-grained concrete with sand 0-0.25 mm, water to cement ratio (w/c) is equal to 0.35, plasticizer to cement ratio (P/C) is 0.013. Textile reinforced concrete with polypropylene fabric has the density between 1200-1500 kg/m^3.

The main issue in this experimental work was poor technology of manufacturing the TRC protective cover and attaching to the already existing concrete surface. During the creation of the bond between these surfaces, large cavities were formed, as a result it led to poor quality of the bond. Possible reasons for that behaviour are imperfections within the formwork, absence of vibration of freshly poured concrete on the already existing structure or inappropriate consistency of the bonding material. As it was described in the previous section of this work, bond is the key parameter to a successful composite action of the given materials.

Possible solutions for improving the bond conditions might be application of steel studs, use of a different textile material (carbon mesh/ glass fibres and etc.) or creating rougher surface on the already existing structure.

Nevertheless, the results from the laboratory testing reveals the excellent performance of PP textile in tension. In the future, this material may substitute the conventional steel reinforcement in proper cases, because it is a several times more ductile than steel and a corrosion resistant material. The material has a high potential to be used in the near future as a composite material.

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