Possibility of Using Cotton Knitted Fabric Waste in Concrete

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Abstract. The use of waste and recycled materials in the construction industry, especially in concrete production, is becoming increasingly popular. The production of cotton underwear generates a certain amount of knitted fabric waste. This study was conducted to investigate the possibility of using cotton knitted fabric waste (CKFW) in concrete and to explore its potential application in the construction industry. The aim of the study is not only to reduce the waste but also to add positive properties to the concrete. A total of 4 mixes were prepared for testing purposes. CKFW were cut into small pieces of size about 6-8 cm x 2 cm. The addition of CKFW was a substitute for aggregates and replaced 0, 2.5, 5 and 10% of the total volume of aggregates in the concrete mix to make the concrete lighter. All mixes have the same amount of cement, water and superplasticizer. The knitted waste was saturated in water before mixing with other concrete components. The properties of the fresh mix were determined by slump method. The dynamic modulus of elasticity, flexural strength and compressive strength were tested on 28 days old concrete specimens. The σ-δ diagram is also presented. It was found that specimens with CKFW have better flexural strength and higher ductility but lower compressive strength than the reference concrete mix. The mix with the highest percentage of CKFW reduced the compressive strength by 28%, while the specimens with lower percentage of CKFW increased the flexural strength by 20% compared to the reference mix. The capillary water absorption capacity of concrete is closely related to its durability. The water absorption by capillarity was measured after 2, 4, 8, 15, 30, 45, 60 min, and 4 and 24 h. The increase in the amount of water absorbed was found to be higher than that of the reference mix. It was related to the percentage increase in the knitted waste and the values obtained ranged from 3.3 to 5.6% of the mass of the dry sample. The largest reduction in concrete density was 3.8% compared to the reference mix. Based on the obtained results, recommendations for further tests are given.

1. Introduction
The EU textile industry generates an estimated 16 million tonnes of production waste per year. Most of the waste is incinerated, mostly for energy recovery, or landfilled. Some of the production waste is upcycled or recycled if the process of recycling is profitable. An alternative that mitigates the constraints of waste management strategies is the use of textile waste as a secondary raw material in the construction industry. This method of waste reduction is in line with the EU Circular Economy Action Plan and can be studied as part of the industrial metabolism concept [1].

Most of the production waste from textile factories comes in the form of wastewater and textile waste. Although wastewater can be used for construction products [2, 3], the research focus is mainly on textile waste.
It is important to distinguish different types of textile waste and their specific properties. The material and structure of textile waste depends on the final product manufactured and the production process. Depending on the origin of the fibre, the waste can be divided into inorganic and organic waste. Depending on the structure, textile wastes can be divided into cuttings, pieces of fabric, knitted fabrics, canvases, felts, etc., which have the structure of the original textile, or wastes in the form of accumulated fibres, yarns, sponges, etc., produced during the manufacture of fabrics or fillings, which generally lack the structure of the original textile. These two types of waste are defined by Paiva et al. [4] as "textile waste" and "textile subwaste". Briga-Sá et al. [5] define them similarly, as "woven waste" and "subwaste". Subwaste can be obtained by further processing textile wastes that have the structure of the fabric from which they were cut or otherwise disposed.

The possibility of using textile waste in construction can be divided into two basic uses: pieces of fabric and fibres. The advantage of using recycled textile fibres, besides the environmental effect, is the lower processing cost compared to virgin fibres [6]. In general, fibres in composites increase strength, physical performance as well as durability by reducing cracking, and textile fibres have higher homogeneity compared to agro-based fibres [7]. Mar Barbero-Barrera et al. [8] analysed the use of textile fibre waste in boards and concluded that the physical and mechanical properties obtained are suitable for the use of the boards in existing and new buildings.

A review paper by Rubino et al. [9] shows that very different types of textile wastes can be used to produce a variety of textile composites suitable for numerous applications in the construction industry. These innovative materials include: textile waste composites made from different types of matrices [10, 11], sustainable thermal and acoustic insulators in the form of mats or panels [11,12,13,14], energy efficient bricks or lightweight bricks [15,16] and mortars [17]. Aspiras et al. [18] mixed textile cuttings (from disposed trimmings of a garments producer and a textile manufacturer) with Portland cement in textile to cement ratios of 1:3, 1:4 and 1:5 by weight for experimental blocks. The authors obtained a building material lighter than concrete and suggested a possible application for ceilings, walls, as a substitute for wooden boards or as an economic alternative to a concrete block. Binici et al. [19] studied the use of cotton waste, fly ash and epoxy resin in the production of chipboards and concluded that such a composition has a positive effect on the engineering properties of the resulting composite.

Due to all the above applications, textile waste needs to be further explored as a novel secondary raw material. Concrete is one of the most commonly used construction materials that requires immense amounts of raw materials such as aggregates. Replacing part of the aggregates in concrete with textile waste would reduce the amount of aggregates used from non-renewable sources as well as the amount of textile waste that is disposed of in landfills. The aim of this study is to further explore the possibility of using textile production waste by investigating the possibility of using cotton knitted fabric waste (CKFW) in concrete and exploring its potential application in the construction industry.

2. Experimental program

2.1. Materials and mix design proportions
In this study, a total of 4 mixes were prepared: one reference mix and three mixes in which 2.5%, 5% and 10% of the total volume of aggregate in the concrete was replaced by cotton knitted fabric waste. The same amount of CEM I 42.5 cement, water and superplasticizer (SP) was used in all four mixes. Crushed limestone aggregates were used in three different grading fractions: 0-4, 4-8- and 8-16 mm. The grading curves of the aggregate fractions and concrete are shown in Figure 1. The grading curve of the concrete follows the Fuller curve with a maximum grain size D = 16 mm. The replacement of aggregate with textiles was based on the total percentage of aggregate volume, and the remaining amount of aggregate in all mixes was distributed according to the grading curve shown in Figure 1.
Figure 1. Grain size distribution curves of aggregate fractions and concrete

The replacement of the aggregates by volume was chosen because the density of the aggregates (2.67 kg/dm$^3$) is about 12 times higher than the density of the textiles (0.22 kg/dm$^3$), all for the purpose of lightening the concrete. The textile waste was supplied by a local factory whose main activity is the production of clothing items such as underwear. The products are made from natural cotton fibre yarns. Cotton knitted fabric waste was cut into small pieces of about 2 x 6 - 8 cm (Figure 2), weighed and saturated in water. Before the material was added to the mixer, it was well-drained and brought to a saturated surface dry condition. The composition and designations of the mixtures are given in Table 1.

Figure 2. Cotton knitted fabric waste in the laboratory concrete mixer

Table 1. The mixture designs and labels for tested mixtures, mass for 1 m$^3$.

|       | Cement kg | w/c | CKFW kg | 0-4 mm kg | 4-8 mm kg | 8-16 mm kg | SP kg |
|-------|-----------|-----|---------|-----------|-----------|------------|-------|
| T0    | 350       | 0.5 | -       | 968.7     | 279.4     | 614.8      | 2.1   |
| T2.5  | 350       | 0.5 | 3.8     | 944.5     | 272.5     | 599.4      | 2.1   |
| T5    | 350       | 0.5 | 7.7     | 920.3     | 265.5     | 584.0      | 2.1   |
| T10   | 350       | 0.5 | 15.3    | 871.8     | 251.5     | 553.3      | 2.1   |

2.2. Preparation of test specimens
All concrete components were weighed and added to the laboratory concrete mixer. The dry components were mixed for 1 minute, and another 5 minutes with the addition of water and superplasticizer. The concrete specimens were poured into 15 cm cubes and 10x10x50 cm prisms and vibrated during pouring.
The cubes were prepared for testing density, sorptivity, water absorption, compressive strength and dynamic modulus of elasticity. The prisms were prepared for flexural strength testing. The specimens were removed from the moulds after 24 h and then cured in a water tank at a temperature of 20 ± 2 °C for up to 28 days, according to HRN EN 12390-2 [20].

2.3. Experimental tests on fresh concrete

The temperature of concrete mixtures was determined according to HRN U.M1.032:1981 [21] using a digital thermometer. A thermometer needle is inserted into the freshly mixed concrete, taking care to measure the temperature in the middle of the mix and not touching the mixer drum. The temperatures measured are given in Table 2. The temperature of the higher percentage of CKFW in the mixes is slightly higher than that of the reference mix. The workability of the concrete was tested using the slump method (Figure 3) according to HRN EN 12350-2 [22] and classified into the slump class, which is shown in Table 2. As can be seen in Table 2, the workability of the concrete is affected by the amount of CKFW. To test the pore content according to HRN EN 12350-7 [23], a porometar was used to measure the porosity according to the principle of Boyle-Marriott law. The obtained test results are presented in Table 2. The influence of the CKFW on the air content is not evident.

Table 2. Results of the slump test, temperature and air content

|     | Air % | Temperature °C | Slump mm | Consistency class |
|-----|-------|----------------|----------|------------------|
| T0  | 2.2   | 18.6           | 170      | S4               |
| T2.5| 1.5   | 18.5           | 135      | S3               |
| T5  | 1.2   | 19.1           | 70       | S2               |
| T10 | 2.7   | 20.3           | 15       | S1               |

Figure 3. Measuring slump on mixtures T2.5, T5 and T10

2.4. Experimental tests on hardened concrete

The flexural tensile strength was tested on 28-day prismatic specimens using a hydraulic device with a load capacity of 300 kN according to the standard EN 12390-5 [24]. The load was applied with a single concentrated force at the midspan of the prism. During the test, the load and midpoint displacements of the specimens were recorded. The displacement was measured using two LVDT devices, with a maximum measurement offset of 10 mm and a nominal sensitivity of 165 mV/mm. The LVDT sensors were mounted below the midspan of the front and back of the prism on a magnetic mount, Figure 4a.
Figure 4. a) Experimental set-up for load-displacement diagram, b) measurement of the ultrasonic pulse velocity through the samples, c) compression testing machine

Hardened concrete density according to HRN EN 12390-7 standard [25], ultrasonic pulse velocity through the specimens according to HRN EN 12504-4 standard [26], (Figure 4b) and compressive strength according to EN 12390-3 [27] were tested on 28-day cube-shaped specimens. The compressive strength was tested at a constant loading rate of 0.50MPa/s, Figure 4c.

The dynamic modulus of elasticity was calculated from the ultrasonic pulse velocity (v) assuming a Poisson’s ratio (µ) of 0.22 and using the hardened concrete density (ρ) according to the formula:

\[
E_{dyn} = \frac{v^2 \rho (1+\mu)(1-2\mu)}{1-\mu}
\]  

(1)

Sorptivity and saturated water absorption were tested on cube specimens according to [28, 29]. After curing for 28 days, the specimens were dried in an oven at 105 ± 5 °C for 24 h until a constant mass was reached. Then, the specimens were cooled at room temperature to determine the mass \(M_1\). The specimens were immersed in water for 24 h until a constant mass \(M_2\) was obtained and weighed. The saturated water absorption (Wₐ) was calculated using (2):

\[
W_a = \frac{M_2-M_1}{M_1} \cdot 100\%
\]  

(2)

where \(M_1\) is a mass of oven-dried sample in air and \(M_2\) is mass of surface dry specimen in the air after immersion.

The capillary water absorption (sorptivity) test was carried out according to the ASTM C1585 [28, 30]. The specimens were first dried in the drying oven at 105 ± 5 °C for 24 h until constant mass \(M_0\). Then the specimens were cooled at room temperature, weighted and only one surface of the specimen was exposed to water. The cubes rested on small supports in water, such that only < 5 mm of the cubes were submerged. The amount of absorbed water was determined at different times, after 0, 2, 4, 8, 15, 30, 45 and 60 min, 4 and 24 h, by weighing the cubes:

\[
\Delta W = M_t - M_0
\]  

(3)

\(\Delta W\) represents the mass increase (g) of water absorbed by the surface 150 x 150mm, at t (min) is a time at which the mass is determined.

Sorptivity in mm/min⁰.⁵ can be calculated from expressions (4):

\[
S = \frac{\Delta W}{t^{0.5}}
\]  

(4)
where $\Delta W/A$ is an increase in mass due to the access of water in mm, (1 g of water is equivalent to 1 mm$^3$, so g/mm$^3$ = mm$^3$/mm$^2$ = mm, [28]), A is a cross-section of the cube (150x150 mm) and t is time measured in minutes ($t = 1440$ min). Lower values are preferable.

3. Results and discussion

Test results for the density, compressive and flexural tensile strengths, dynamic modulus of elasticity, sorptivity and saturated water absorption are shown in Table 3.

|                  | Flexural strength MPa | Compressive strength MPa | Dynamic modulus of elasticity GPa | Density kg/m$^3$ | Sorptivity x 10$^4$ mm/min$^{0.5}$ | Saturated water absorption % |
|------------------|------------------------|---------------------------|----------------------------------|------------------|-------------------------------------|-----------------------------|
| T0               | 7.0                    | 66.4                      | 52.6                             | 2421.5           | 0.79                                | 3.3                         |
| T2.5             | 8.5                    | 59.5                      | 50.6                             | 2399.8           | 0.91                                | 4.2                         |
| T5               | 8.3                    | 53.4                      | 47.5                             | 2378.8           | 0.99                                | 4.4                         |
| T10              | 7.3                    | 47.9                      | 46.3                             | 2335.5           | 1.30                                | 5.6                         |

The effect of replacing part of aggregate with CKFW on the properties of concrete was evaluated by the ratio of the properties of the referent mixture and the mixtures with CKFW, Figure 5.

From Table 3 and Figure 5, it can be seen that the mixes with CKFW improve the flexural strength of the concrete. The improvement is in the range of 4 to 21% compared to reference mix. Replacing 2.5 and 5% vol. % of aggregate with cotton knitted fabric waste gave the best results. Selvaraj [31] obtained much greater improvement in flexural strength in his study, but he also used a larger amount of textile waste in the concrete. Manishankar and Sathiyaraj [32] tested concretes with textile wastes with different textile to cement ratio with respect to cement weight. The authors found that textile waste in concrete generally increases the strength of concrete and up to 3% textile waste gives better flexural strength compared to control concrete.
A load-displacement diagram was recorded at the same time as the flexural strength test. A $\sigma - \delta$ diagram was created from the load-displacement curves and shown in Figure 6.

![Figure 6. $\sigma - \delta$ diagram](image)

From the $\sigma - \delta$ curves in Figure 6, it can be seen that the performance of the CKFW concrete is improved. The reference mix breaks immediately while the CKFW specimens are still carrying the load. According to Figure 6, cotton knitted fabric waste acts as micro reinforcement in concrete. Selvaraj [31] came to the same conclusion that the inclusion of fabric waste increases the tensile properties of concrete due to the reinforcing effect of fabric fibres in concrete.

According to the results in Table 3 and Figure 5, the compressive strength of CKFW concrete was reduced proportionally to the percentage of aggregate replacement by cotton knitted fabric. This result was expected since it is known that the different properties of aggregate have a significant effect on the strength of concrete. The dynamic modulus of elasticity has a similar trend as the compressive strength. The decreases in compressive strength and dynamic modulus of elasticity are in the range of 10-28% and 4-12%, respectively. Selvaraj [31] obtained a strength reduction of almost 50% for the largest amount of textile waste in concrete. In this study, textile waste was added at 0 - 5% by weight of cement and the best compressive strength result (1 % replacement) is lower than the lowest value in this study. The reference mix [31] and the reference mix in this test differ only by 3 MPa. The author considered that the decrease in strength is due to the loss of cohesion and that calcium silicate hydrate formation does not occur completely around the aggregate grains. Anglade et al. in [33] concluded that the compressive strength decreases because the fibres increase the air bubbles and voids in the concrete when polyester textile waste is added. Voids in the concrete are visible in the cross-section of sample T10 in Figure 7, which probably contributed to the reduction in strength.

![Figure 7. Cross-section of specimen T10](image)
Larger amounts of CKFW make it difficult to place the concrete, although they are evenly distributed across the cross-section according to Figure 7. For mesh cuts, it is very important in which direction the mesh is torn, as it behaves anisotropically to the weave. In one direction it stretches more than in the other weaving direction, Figure 8.

Figure 8. Two ways of knitting deformation

The appearance of the last piece of knitted fabric in Figure 8 confirms that the knitted fabric behaves like a thick fibre in the concrete, helping to increase the flexural strength and ductility of the concrete.

For all mix proportions, Table 3 and Figure 5, the sorption values range from $0.79 \times 10^{-4}$ to $1.30 \times 10^{-4}$ mm/min$^{0.5}$. These values indicate that water penetration is very slow, although the T10 value is 65% higher than the reference mix. The water absorption is in the range of 3.3 to 5.6%. Selvaraj [31] determined water absorption in the range of 2.67 to 28.74% and concluded that these values are due to the absorption of water by the cloths themselves. Although the values obtained in this study are within acceptable limits, a higher percentage of CKFW may reduce the durability of the concrete.

The main objective of this study was to reduce the density of concrete. According to Table 3 and Figure 5, the density values are in the range of 2335.5 to 2421.5 kg/m$^3$ and the reduction of concrete density is within the limits of 1.2 - 3.8% to the reference mix. The replacement of part of aggregate with CKFW in the ratio of 2.5%, 5% and 10% of volume of aggregate to volume of concrete was 1.7%, 3.5% and 7%, respectively. However, by replacing part of aggregate with CKFW, 47 to 186 kg of aggregate per 1 m$^3$ of concrete was saved compared to the control concrete. The replacement of aggregate with cotton knitted fabric waste is an environmentally friendly alternative due to the storage of non-renewable sources.

Based on the obtained results, several possibilities of using concrete mixtures with CKFW in construction industry are apparent. According to its properties, primarily of density, compressive and flexural tensile strengths, there is a potential for application in floor screed elements, also as partitioning elements, pavements, wall and ceiling finishing. Recommendations for further tests include more detailed examination of detected properties. Sorptivity and saturated water absorption suggest that application of water sealant materials should be investigated. Also, elements made of concrete mixtures with CKFW should be tested for durability and stability in water-saturated conditions. Compressive and flexural tensile strengths suggest that the combination with additional materials (steel, polymer etc.) can open possibilities of structural applications.

4. Conclusions
One way to deal with textile waste is to use it in concrete. This method can help in solving two problems. First, by eliminating environmental pollution by reducing the cost of storage and the amount of waste in landfills and the amount of CO$_2$ released into the atmosphere by recycling textile waste for energy; and by providing a secondary raw material for the construction industry.
Based on the test results, it can be concluded:

- Textile waste can be used as a partial substitute for aggregate in concrete, with the effect of reducing the overall weight of CKFW concrete.
- The compressive strength of CKFW concrete was reduced proportionally to the percentage of aggregate replaced by cotton knitted fabrics.
- The inclusion of waste cloth increases the tensile properties and ductility of CKFW concrete due to the reinforcing effect of the cloth fibres in the concrete.
- Mixtures with higher CKFW contents are more difficult to pour and therefore have a greater number of voids, which contributes to the reduction in strength.
- The workability of CKFW concrete depends on the percentage of textile waste.
- Mixtures with a higher percentage of CKFW have higher values of sorptivity and water absorption, which may affect the durability of the concrete.

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References
[1] R.U. Ayres, “Industrial Metabolism: Theory and policy,” Industrial Metabolism: Restructuring for Sustainable Development, United Nations University Press, Tokyo, pp. 3–20, 1994.
[2] S. S. Jahagirdar, S. Shrihari, and B. Manu, “Utilization of Textile Mill Sludge in Burnt Clay Bricks,” Int. J. Environ. Prot., vol. 3, no. 5, pp. 6–13, 2013.
[3] S. Praveen et al., “Utilization of Textile Effluent Waste Sludge in,” Int. J. Sci. Basic Appl. Res., vol. 2, no. 12, pp. 3103–3107, 2015.
[4] A. Paiva, H. Varum, F. Caldeira, A. Sá, D. Nascimento, and N. Teixeira, “Textile subwaste as a thermal insulation building material,” ICPSD 2011 Int. Conf. Pet. Sustain. Dev., vol. 26, pp. 78–82, 2011.
[5] A. Briga-Sá et al., “Textile waste as an alternative thermal insulation building material solution,” Constr. Build. Mater., vol. 38, pp. 155–160, 2013., doi: 10.1016/j.conbuildmat.2012.08.037.
[6] I.H. Jayasinghe, B.F.A. Basnayake, K.S.P. Amarathunga and P.B.R. Dissanayake, “Environmental Conservation Efforts in Developing Textile Waste Incorporated Cement Blocks,” Tropical Agricultural Research Vol. 21(2): pp. 126 – 133, 2010.
[7] R.M. Rowell, J.S. Han and J.S. Rowell, Characterization and factors effecting fiber properties. Nat Polym Agrofibers Compos 115-34, 2000.
[8] M. del Mar Barbero-Barrera, O. Pombo, M. de los Angeles Navacerrada, Textile fibre waste bindered with natural hydraulic lime, Composites Part B 94 26-33, 2016.
[9] C. Rubino, S. Liuzzi, F. Martellotta, and P. Stefanizzi, “Textile wastes in building sector: A review,” Model. Meas. Control B, vol. 87, no. 3, pp. 172–179, 2018., doi: 10.18280/mmcb.870309.
[10] S. Ramamoorthy., A. Persson and M. Skrifvars, “Reusing Textile Waste as Reinforcements in Composites,” Journal of Applied Polymer Science, vol. 131, no. 17, pp. 1-16, 2014., doi: 10.1002/app.40687
[11] H. Binici, M. Eken, M. Dolaz, O. Aksogan and M. Kara, “An environmentally friendly thermal insulation material from sunflower.” Construction and Building Materials, vol. 51, pp-24-33, 2014., doi: 10.1016/j.conbuildmat.2013.10.038
[12] Y. Lee and C. Joo, “Sound absorption properties of recycled polyester fibrous assembly absorbers,” Autex Research Journal, vol. 3(2), pp. 78-84, 2003.
[13] A. Patnaik, M. Mvubu, S. Maniyanasamy, A. Botha and D. Anandjiwala, “Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies,” Energy and Buildings, vol. 92, pp. 161-169, 2015., doi: 10.1016/j.enbuild.2015.01.056
[14] A. Tiuc, H. Vermeșan, T. Gabor and O. Vasile, “Improved sound absorption properties of polyurethane foam mixed with textile waste,” Energy Procedia, vol. 85, pp. 559-565, 2016., doi: 10.1016/j.egypro.2015.12.245
[15] S. Agrawal, R. Wattile, P. Mohata and S. Makwana, “Utilization of textile apparel waste in clay brick,” International Journal of Advanced Research in Engineering & Technology, vol. 4, pp. 48-52, 2013.
[16] H. Algin and P. Turgut, “Cotton and limestone powder wastes as brick material,” Construction and Building Materials, vol. 22, pp. 1074-1080, 2008., doi: 10.1016/j.conbuildmat.2007.03.006
[17] S. Kalkan, L. Gündüz, “A study on the usage of denim waste as reinforcement element in composite mortars on exterior building application,” 12 International congress on advances in civil engineering, Istanbul, 2016.
[18] F. F. Aspiras and Manalo J. R. I., “Utilization of Textile Waste Cuttings as Building Material,” J. Mater. Process. Technol., vol. 1-4, no. 48, pp. 379–384, 1995.
[19] H. Binici, R. Gemci, A. Kucukonder and H. H. Solak, “Investigating sound insulation, thermal conductivity and radioactivity of chipboards produced with cotton waste, fly ash and barite,” Construction and Building Materials, vol. 30, pp. 826-832, 2012.
[20] HRN EN 12390-2:2019 Testing hardened concrete – Part 2: Making and curing specimens for strength tests
[21] HRN U.M1.032:1981 Temperature measuring of fresh concrete
[22] HRN EN 12350-2:2019 Testing fresh concrete – slump test
[23] HRN EN 12350-7:2019 Testing fresh concrete - Part 7: Air content - Pressure methods
[24] HRN EN 12390-5:2019 Testing hardened concrete – Part 5: Flexural strength of test specimens
[25] HRN EN 12390-7:2019 Testing hardened concrete - Part 7: Determination of density
[26] HRN EN 12504-4:2004Testing concrete - Part 4: Determination of ultrasonic pulse velocity
[27] HRN EN 12390-3:2019 Testing hardened concrete – Part 3: Compressive strength of test specimens
[28] S. Raju and B. D. B, “Durability characteristics of copper slag concrete with fly ash”, GRADEVINAR, vol. 69, pp. 1031-1040, 2017., doi: 10.14256/JCE.1229.2015
[29] Q. Gao, Z. Ma, J. Xiao and F. Li, "Effects of Imposed Damage on the Capillary Water Absorption of Recycled Aggregate Concrete", Advances in Materials Science and Engineering, vol. 2018., Article ID 2890931, 12 pages, 2018., doi: 10.1155/2018/2890931.
[30] ASTM C1585-13 Standard test method for Measurement of rate of Absorption of water by hydraulic cement concretes.
[31] R. Selvaraj and R. Priyanka, “Study on Recycled Waste Cloth in Concrete,” Int. J. Eng. Res., vol. 4, pp. 891-895, 2015, doi: 10.17577/ijertv4is04is090437.
[32] S. Manishankar and C. Sathiyanaray, “Experimental Investigation of Textile Wastes used in Concrete” IJSRD - International Journal for Scientific Research & Developmentl, vol. 7, pp. 659-660, 2019.
[33] J. Anglade, E. Benavente, J. Rodrígue and A. Hinostroza, “Use of Textile Waste as an Addition in the elaboration of an Ecological Concrete Block” IOP Conf. Ser.: Mater. Sci. Eng. 1054 012005, 2021, doi: 10.1088/1757-899X/1054/1/012005