



TEXTILE WASTE–DERIVED FABRIC FORMWORK FOR CONCRETE AND MORTAR: ENABLING GEOMETRIC FLEXIBILITY

Scientific paper
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ABSTRACT: Fashion and textile industry generate substantial volume of waste, during the production phase, as well as in the consuming phase. This waste is disposed in the landfills or incinerated significantly affecting the environment. At the same time, construction industry faces its own demands to reduce carbon dioxide emissions, to reconsider, among other things, the approach to the conventional formwork systems, being resource intensive and disposed after the use. This paper explores the feasibility of the usage of the textile waste in the form of the flexible formwork, for the casting of the elements made of concrete and mortar. The properties of textile, such as deformability and tensile capacity are used to make the formwork of non-standardized geometry while minimizing the material consumption. This paper shows performances, adaptability and the consequences of the application of textile waste fabric formwork in non-structural architectural products. The results obtained show that the recycled textile waste can be used as efficient and low-cost alternative to traditional formwork, while providing flexible geometrical shapes of the products and the reducing the environmental impact. This paper can be seen as a contribution to the development of the circular economy strategy in the cement-based construction industry, while introducing the new sustainable practices in architectural engineering.

Keywords: textile waste, material reuse, fabric formwork, concrete and mortar, sustainability, geometric flexibility.

OPLATA ZA BETONE I MALTERE OD TEKSTILNOG OTPADA: OMOGUĆAVANJE FLEKSIBILNIH GEOMETRIJA

APSTRAKT: Modna i tekstilna industrija generišu značajnu količinu otpada, kako tokom proizvodnje, tako i tokom upotrebe. Ovaj otpad se odlaže na deponije ili spaljuje, što



značajno utiče na životnu sredinu. Istovremeno, građevinska industrija se suočava sa zahtevima za smanjenje emisije ugljen-dioksida, i za preispitivanjem, između ostalog, korišćenja konvencionalnih sistema oplata, koji intenzivno koriste resurse i postaju otpad nakon upotrebe. Ovaj rad istražuje mogućnost upotrebe tekstilnog otpada u obliku fleksibilne oplata za livenje elemenata od betona i maltera. Svojstva tekstila, kao što su deformabilnost i zatezna nominalna čvrstoća, koriste se za izradu oplata nestandardizovane geometrije uz minimiziranje potrošnje materijala. Ovaj rad prikazuje svojstva, prilagodljivost i uticaje primene oplata od tekstilnog otpada u nekonstruktivnim arhitektonskim proizvodima. Dobijeni rezultati pokazuju da se reciklirani tekstilni otpad može koristiti kao efikasna i jeftina alternativa tradicionalnoj oplati, uz istovremeno obezbeđivanje fleksibilnih geometrijskih oblika proizvoda i smanjenje uticaja na životnu sredinu. Ovaj rad se može posmatrati kao doprinos razvoju strategije cirkularne ekonomije u industriji proizvodnje betona, uz uvođenje novih održivih praksi u arhitektonsko inženjerstvo.

Ključne reči: tekstilni otpad, reciklaža materijala, tekstilna oplata, malter i beton, održivost, fleksibilne geometrija.

1. INTRODUCTION

The construction industry is one of the biggest causes of change and often degradation of the environment. Global urbanization became rapid, contributing to the construction of the necessary new infrastructural facilities, along with simultaneous removal and adaptation of the those that exist, while consuming large amounts of natural resources and leaving a significant amount of construction waste. According to some sources, the construction industry is responsible for almost a third of all waste in the world [1][2][3]. The largest portion of the generated waste comes from the demolition of existing structures, and the rest (approximately 10%) is generated during the construction of new ones [4].

Another significant part of municipal waste is textile waste, which in most cases is incinerated or disposed of in landfills. During recent years, researches paid a lot of attention to the new methods of textile recycling [5][6][7]. The focus is shifted from basic mechanical recycling to more advance chemical [8] and recycling using biodegradation [9]. Still, many recycling procedures used sometimes harm the environment more than the waste itself [10]. Despite all efforts, large increase of the textile production volume affects the environment, so the recycling of used textiles remains an open challenge [11].

The majority of methods used for textile recycling rely on conversion of the fabric into fibers that are then reused [12]. New methods for automated separation of textiles according to the fiber type and origin are rapidly being developed [13]. Although a lot of work and energy is invested in the production of textiles, a limited number of studies deal with ways to recover the invested energy and material in the most efficient way [14].

The application of textiles in construction and concrete constructions is in two ways: as specially produced fibers or meshes made of glass, polyethylene, or carbon that are embedded in concrete and mortar as reinforcement, in order to increase the tensile strength



of the base material [15][16], or it is used as a textile flexible formwork for pouring concrete and mortar in a special deformable mold, in order to obtain unusual curved shapes that cannot be formed using the usual wooden and metal formwork [17].

2. FABRIC FORMWORK FOR CONCRETE

The first industrial applications and patents for the use of textiles as formwork for concrete date back to the 19th century [18], and historical traces date back to the beginnings of the use of concrete in the Roman era [19]; however, the textile formwork usage wasn't significant in the concrete production industry and in concrete structures' construction [20]. Textile formwork is fundamentally different from conventional wooden or metal formwork. Conventional formwork made by usage of the rigid flat wooden or metal sheets are used to produce rectangular flat concrete forms. Achieving curved shapes of the product made of concrete using this type of formwork is more expensive and technically demanding. On the other side, soft, stretchable and easily deformable textile materials provide free and curved forms much more easily and affordably. Free and diverse form of the elements is enabled using tailoring the textile fabric and the hydrostatic pressure of the fresh concrete mixture. This free approach to the formation of the geometry of concrete elements is not easy to reconcile with the completely deterministic way in which concrete structures are calculated and constructed.

On the other hand, the freedom and flexibility that textile formwork along with the variety of concrete surface textures that faithfully replicate textile formwork, have attracted the attention of numerous artists, architects, architectural and structural engineers. Work of many authors (Mark West, at the University of Manitoba, C.A.S.T projects, Anne-Mette Manelius at the Royal Danish Academy of Fine Arts, John J. Orr and Will Hawkins, at the University of Bath, etc.), have explored the numerous possibilities offered by this type of formwork in the fields of art, architecture, construction, optimization, topology, etc. [21][22]. According to the typology and the nature of the load, formwork can be divided into two categories [22]: formwork that changes shape when filled with concrete (filled molds), and formwork that preserves its shape (surface molds).

According to the textile recycling procedures, the most common methods of textile recycling are mechanical (fiber shredding), chemical and biochemical (chemical decomposition of fibers), energy production (incinerating) and re-usage, upcycling and creative reusing (reuse of textiles or parts in a different way) [24][25][26].

The use of recycled textile waste in the form of fibers for reinforcing concrete and cement mortars creates some problems due to the accumulation of dirt and their uncontrolled distribution on the composite material, and is not suitable for the production of textile formwork. The best method for the production of textile formwork from used or waste textile is the reuse method where the textile waste, after being sorted, is connected into a whole. For the production of formwork that changes its shape, parts of textile waste can be sewn, while for the production of pre-formed textile formwork that preserves the given shape, parts of textile waste can be glued. When the textile parts are glued, the durability and load-bearing capacity of such textile formwork depends on the load-bearing capacity

of the joints. This paper will present the testing of textile waste joints for the production of preformed formwork made from textile waste glued using a polymer-cement binder.



Figure 1: Research into various applications of textile formwork (Mark West (CAST), according to [22])

3. EXPERIMENTAL RESULTS AND DISCUSSION

The objective of this experiment was to test whether it is possible to use cement-based and polymer-based binders to create a bond between two pieces of textile. Cement is the basic binder in cement mortars and concretes. When mixed with water, it begins to harden and forms cement paste and cement matrix, which includes fillers, most often stone aggregate, and forms a hardened material known as concrete. In reinforced concrete, cement paste is sufficient to transfer tensile and compressive forces from one steel bar to the next one.

Waste material from the production of T-shirts, made by of organic cotton, was selected for the experiment. In contrast to cement mortar and concrete, this material is very elastic in both directions, so one of the intentions was to test to what extent the stiffness of the cement binder will affect the elasticity of the composite material.

Special attention was paid to the selection of the cement binder used for the connection and continuation of the textile pieces. As a cement binder, different proportions of the polymer-cement materials were selected for further testing, due to their greater elasticity and adhesion. The final choice was the polymer-cement mixture obtained from a manufacturer consisting of a liquid component based on acrylate latex and a powder component based on cement of quality CEM I 42.5. The polymer-cement material was tested on prismatic samples 40 mm × 40 mm × 160 mm. The properties of the polymer-cement material used as a binder for pieces of waste textiles are given in Table 1.

Table 1: Properties of the selected polymer-cement material

Property	MPa
Bending strength, after 7 days	7,0
Bending strength, after 28 days	9,0
Compressive strength, after 7 days	30,0
Compressive strength, after 28 days	41,0
Adhesion for concrete surface	2,4

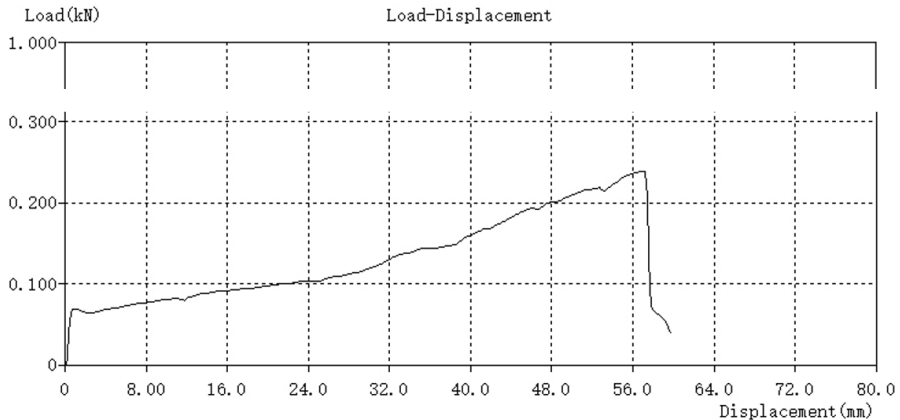
In order to test the effect of the polymer-cement coating on properties of waste textiles, as well as the capability of gluing textile pieces, tests were conducted on samples. The tests were carried out on a textile tearing machine on textile samples measuring 350 mm × 50 mm, with a thickness of $d = 0.5$ mm. The tensile strength of the textile was tested on control samples made of untreated textiles and those made of textiles coated with polymer-cement material. In order to test the overlap of textile pieces, samples were coated and overlapped using the layer of polymer-cement material. The overlap of two textile pieces was in the middle of the tested sample. Three different length of the overlap were tested: 25 mm, 37.5 mm and 50 mm, corresponding to the 50 d, 75 d and 100 d, where d is the thickness of the textile. The test results are shown in Table 2.

Table 2: Tensile forces and deformations on samples of whole and joined textile parts

Type of sample	Average Force (N)	Average dilatation (mm)
Referent uncut textile	182	148,0
P-C coated uncut textile	248	58,4
Double P-C coated uncut textile	576	80,6
P-C coated cut textile, overlap 25 mm	240	55,9
P-C coated cut textile, overlap 37,5 mm	256	47,8
P-C coated cut textile, overlap 50 mm	272	52,3

The test results showed that polymer-cement material coating of the textile increases the total tensile force during which the sample breaks (by 36%), while at the same time it significantly reduces the elongation of the composite sample (by 60%). This is expected, since the polymer-cement material, during the hardening process, fills the gaps between the threads of the knitting, thus preventing large elongations.

The test results justified the assumption that it is possible to provide the continuation of the waste pieces of textiles using polymer-cement material. The overlap length of 25 mm practically enables the same tearing force (97% compared to the unbroken pattern) to be achieved as with an unbroken textile. Longer overlaps, 37.5 mm and 50 mm, increase the tear force by 3% and 10%, respectively, while reducing sample elongation. A small increase in tearing force is probably due to a thicker layer of polymer-cement material around and at the place of the overlap. Load-displacement diagram (Figure 2) shows



increased stiffness of a composite material at the beginning, and further decrease in elastic modulus due to formation of cracks.

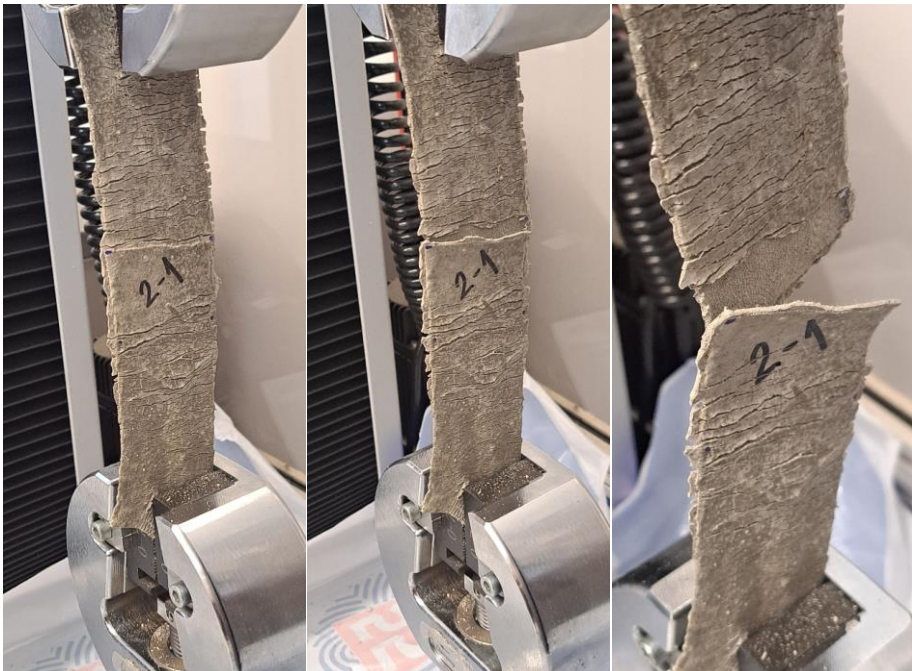


Figure 2: Tension test phases of overlapped joint (25 mm)

The distribution of cracks on the samples shows that they are formed evenly, which means that the waste textile enables uniform deformation of the sample. This is not the case in



plain polymer-cement materials, where the first crack propagates and leads to breakage (Figure 3). On the other hand, the total elongation reduction is the result of a longer length of the overlap, where the cracks do not appear, even when the overlap delaminates.

4. CONCLUSION

The construction industry has a major impact on the environment, both due to the significant use of resources and energy, and due to the large amount of waste it generates. At the same time, it also has great potential for the application and recycling of waste generated in other industries. The textile and fashion industries are major producers of used materials that end up as waste. Reusing this waste is a modern challenge.

Textile formwork has been present in construction for a long time. Textile formwork offers great opportunities for faster, more flexible and more affordable construction. Research has shown that it is possible to form textile formwork from parts of waste textiles in a simple way, by bonding them with a cement-polymer binder. Such formwork can be pre-formed into the required dimensions or shapes, and more importantly, simply continued on site. Preformed formwork from textile waste can be finished as a final texture, and thus become part of the structure.

The test showed that coating of the textile using polymer-cement material increases the tensile strength of the composite, while at the same time significantly reduce the elongation. The test also showed that pieces of the textile can be glued using the selected polymer-cement material simply by overlapping. It was shown that the overlap length of 25 mm practically achieve the same tearing force (97%) in the sample with overlapped pieces as in the sample made by continuous textile pieces (100%). Overlaps of 37.5 mm and 50 mm increase the tearing force by 3% and 10% respectively, with a decrease in elongation. The small increase in tearing force originates from the thicker layer of polymer-cement material at the overlap, while the decrease in elongation is the result of the longer overlap length, where cracks do not occur.

In order to fully realize the potential of preformed formwork from waste textiles, further research is necessary, not only to determine the characteristics of the formwork itself, but also to expand the field and methods of its application. We are facing the challenges of testing the applicability and durability of such materials. In this process, engineers from all professions (architects, technologists, civil engineers, mechanical engineers) must work closely and collaborate.

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