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5 Conclusions

Tannic acid was modified in process of epoxidation with with epichlorohydrin / $POCl_3$ and glycidol in otder to make ETA / PGET respectively. ETA and PGET were used as a replacement of the epoxy resin component (A) – bisphenol A based epoxy in a ratio 25-100% as a reactive diluent to obtain test samples for thermal and mechanical experiments. The tensile test results indicate an increase in toughness with increase in the amount of PGET at 25% and a decrease in toughness with higher PGET amounts, a decrease in the modulus of elasticity, and an increase in relative deformation. Results of UL94 V test show an increase of flame retardant properties of PGET and ETA. PGET had shown much better thermal properties than ETA. Thermogravimetric analysis indicates that there is a slight improvement in the thermal stability of the material with an increase in PGET in the product, products with higher amounts of PGET would start degrading at higher temperatures and have more solid residue. In contrast to the above properties, a significant improvement was obtained in terms of reducing flammability: (PGET) material TA-epoks 100% has no practical significance due to poor mechanical properties. Optimal mechanical and thermal properties show TA-epoks 25% and TA-epoks 50%.

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PRIMENA KONCEPTA 3D ŠTAMPE BETONA U IZRADI VETROGENERATORA

APPLYING CONCEPT OF 3D PRINTING CONCRETE IN WIND TOWER CONSTRUCTION

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Iako je najčešće primenjivan materijal u savremenoj građevinskoj praksi zbog svojih očiglednih prednosti, beton poseduje izvestan broj nedostataka. Jedan od najvažnijih principa već decenijama je da se omogući masovna upotreba ovog materijala na gradilištima sa prihvatljivim svojstvima, neophodnim da bi on podneo specifične uslove. Koncept 3d štampe betona predstavlja obećavajuću osnovu za dalje poboljšanje ovog principa. Zadržavajući što veći broj preduslova i osnovnih svojstava da bi se zadovoljili konstruktivni zahtevi, ovaj materijal mora umnogome evoluirati da bi zadovoljio 3d concept, što bi, zauzvrat, popločalo put do sledećeg nivoa njegovog širokog obima primene u graditeljstvu. Cilj ovog rada je da sadrži osnovne principe 3d štampe betona, diskutujući glavne ciljeve I nedostatke koji se moraju sagledati i rešiti pre šire primene. Takođe, konstrukcija stuba vetrogeneratora, kao specifična konstrukcija biće diskutovana kao potencijalno obećavajuća osnova za ovaj stari građevinski materijal odeven u novo odelo.

Ključne reči: *beton; 3d štampa; concept projektovanja; zahtevi; nedostaci; specifična primena;*

Abstract: Although a most prominent material in contemporary construction practice due to its' obvious advantages, concrete incorporates a number of drawbacks. It is one of the most advantageous principles for decades to enable a large-scale on-site application of this materials with acceptable properties, needed to withstand specific conditions. A concept of 3d printing concrete presents a promising ground for further improvement of this principle. While maintaining as much as possible of the prerequisite and common properties to answer the construction demands, this material has to evolve as much as possible to fulfill the 3d concept, which would, in turn, pave a way for next level of its wide range of construction applications. This paper aims to contain main principles of 3d printing concrete, discussing the main goals and the drawbacks that have to be addressed and solved prior to wider application. Also, wind tower construction, as a specific construction will be discussed as a potentially promising ground for this old construction material dressed in a new suit.

Key words: *Concrete; 3d printing; design concepts; requests; drawbacks; specific application;*

1 Introduction

While the development of theory of building structures have been already highly developed, an obvious breakthrough effects of construction industry can be sought in the area of materials and technologies. Based on the never fully realized, but quite old, concept of concrete prefabrication, and provoked by the last decades achievements in many other industries (such as automotive, aerospace, food, pharmacy, biomedicine and others), additive manufacturing (AM) process is implemented in building industry. Some of the improvements that outcome from this technology are improved

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efficiency, safety and environmental benefits [1,2]. There is a wide range of different AM processes, varying in the materials used, or approaches based on

Additive manufacturing process is also known as 3d printing. The main philosophy of this process is to convert an existing digital design into a real structure by adding materials in layers, one above another. In the field of concrete production, this concept is identified with manufacturing technique in which linear fragments of cementitious composites are placed on top of each other in order to form objects without the use of formwork [3]. A wide range of AM techniques and materials is implemented in construction practice, but still there are several similarities in all of them including the following aspects: robotization in placement of the material, elimination of formwork use, substantially wider range of shapes and forms which can be produced, new functionalities, and tailored fabrication [4].The current development of this process is often characterized by the visible layers in the product appearance (Fig. 1).

Figure 1 – The appearance of 3d printed product [4]

There is a number of challenges that have to be addressed prior to the use of concrete in such a manner. Also, techniques and procedures have to be developed in order to make this process possible. The development of equipment is also expected, accompanied by the knowledge of the involved experts. All of the stated make 3d printing concrete one of the most dynamic fields in contemporary building industry. The thorough understanding of the relation between process parameters (ambient temperature, humidity, and their changes) and the mechanical properties of 3D printed concrete have to be reached.

2 Most significant advantages and disadvantages of 3d printing concrete

The main advantages of 3d printing involve the possibility to completely apply the digital design in the produced structure. The usual approach to generate a building starts with design, and then this design is realized by the contractor. This means that there is an obvious discontinuity in the process, which sometimes results in a structure which is quite different than the one that was designed. Different interpretations, errors, or personal selections of preferred materials and techniques are quite usual in the production phase of the building structure. Adding the fact that the contractor's approach is ultimately based on their experience, practice and motivations, and having in mind the occasional but omnipresent miscommunication between the designer and the contractor, the structure is never realized as designed, strictly put. The 3d printing process eliminates all the stated issues, but excluding at the same time the opportunity to rethink and optimize the structure once its' erection once started.

The possibility to fabricate a concrete element prior to its placement has been one of the development directions concerning concrete structures. There is a number of prefabrication companies in the world, as well as in the region, that produce concrete elements, such as columns, beams, plates and others, which are then transported to the building site and placed. The main advantages of this

approach include the usually high quality of the produced elements, which have been made from concrete properly produced, installed, vibrated, and cured, unlike the concrete which was transported and applied in the building site under, often harsh, environmental conditions, and sometimes with untrained personnel. Unlike on-site erected structures, and unlike steel structures also, concrete structures made of prefabricated elements incorporate a disadvantage regarding the joints between elements. Namely, these details were often identified as weak spots, being the cause of structure collapse under earthquakes. This serious drawback, which caused the limitation of concrete prefabrication, may not be an issue when 3d printing is taking place, because of the layered design, where elements are monolithized layer wise. In 3d printing, this sensitive question is transferred on the compatibility of layers. Due to the nature of cement composites such as concrete and mortar, the consecutive layers are more likely to be better connected, especially when executed one after another, and including chemical admixtures improving adhesion. Nevertheless, a statement has to be made that both prefabricated and on-site 3d printed structures are being produced, resulting with a variety of differences in equipment, material and cure of the 3d printed structures.

Several inherited drawbacks of conventional concrete can be found in 3d printed concrete. One of the main is the brittleness of concrete, and its' low performance under tensile, bending and shear loadings. Therefore, a steel reinforcement is always introduced in traditional concrete structures. In the sphere of 3d printing, introducing the reinforcement, although not uncommon, seriously compromises the whole principle, because usually the reinforcement presence makes it impossible to 3d print concrete in one phase. This is an issue which has to be addressed because divided in several phases (3d printing concrete, placing the reinforcement and then 3d printing concrete) such an enterprise often loses the intended purpose and potential [4]. On the other hand, the solution is often found in fiber reinforcement [5,6], Figure 2.

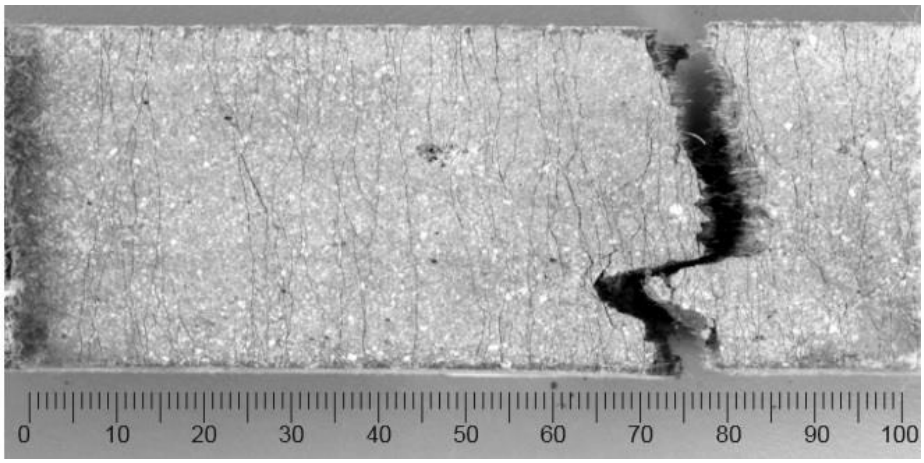

Figure 2 – The fiber reinforced specimen cut from the 3d printed concrete element [5]

3 Possibility of applying concept of 3d printing concrete in wind tower production

The 3d printing process is often thought of as one of the promising innovations, that could solve problems in many areas of industry, including onshore wind tower erections. One of the main potentials of this idea is to be able to construct higher wind towers, which is made harder due to the difficulties in transport of such elements. The transport of the 3d printing device and the component materials would be economically and environmentally (due to lower gas emissions) advanced in comparison to the transport of elements, and the dimensions of 3d printed elements could be substantially larger. This would, in turn, enable different constructions of concrete bases for steel towers of wind generators, as well as the construction of towers made entirely of concrete. Also, the amount of time and labor for building a wind tower would be also reduced.

The main challenges of this enterprise lay in the development of the material of satisfactory properties, and the on-site 3d printer with the serious requirements and high energy consumption. Also, there is little knowledge gathered regarding the behavior of such developing materials, and

structures through erection and exploitation. Finally, the stresses which can be expected to occur in such cylindrically shaped structures are expected to reach substantial tension in certain parts of the structure, based on membrane theory.

4 Conclusion

Additive manufacturing process (also known as 3d printing) presents a promising technology innovation offering the opportunity to convert an existing digital design into a real structure by adding materials in layers, one above another. Although found to be applicable in some industries, it still embeds several difficulties in the field of construction. Key challenges in this field lay in inovative materials and new procedures which have to be studied, developed and applied prior to the wider application of this process.

Onshore wind towers can be regarded as less complicated structures, from the structural engineer point of view. In the past year there have been attempts to apply 3d printing concrete technology for erection of wind towers. This concept offers several benefits if proved, environmental and economic being the main. Hopefully, the proper solutions will be reached by the involved engineers worldwide, which would pave a way to a more intense wind energy harvesting and consequently to our common better future.

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