RECYCLED CARBON FIBERS FROM WIND TURBINE BLADES: ADVANCING THE MECHANICAL PERFORMANCE OF CONCRETE

Julita KRASSOWSKA*, Andrzej KAZBERUK**

*Faculty of Civil and Environmental Engineering, Bialystok University of Technology, ul. Wiejska 45A, 15-351 Bialystok, Poland
** Faculty of Mechanical Engineering, Bialystok University of Technology, ul. Wiejska 45A, 15-351 Bialystok, Poland

j.krassowska@pb.edu.pl, a.kazberuk@pb.edu.pl

received 26 December 2024, revised 27 December 2024, accepted 27 December 2024

Abstract: Recycled carbon fibers from wind turbine blades offer a sustainable approach to enhancing concrete's mechanical properties. This study investigates the preliminary performance of concrete reinforced with fibers recovered via pyrolysis. Experimental results demonstrate improvements in flexural strength (up to 30%) and fracture mechanics parameters (e.g., KIc and CTODc). Planned research will focus on optimizing mix designs and exploring deformation criteria for quasi-brittle materials, paving the way for environmentally friendly construction solutions.

Key words: recycled carbon fibers, fiber-reinforced concrete, fracture properties, sustainable construction

1. INTRODUCTION

Wind turbine blades have a service life of approximately 20–25 years, after which they constitute significant waste that is difficult to dispose of in landfills. Due to the large number of turbines installed around the world, the amount of waste generated is constantly increasing. Recycling alleviates environmental pressure by minimizing waste accumulation. Turbine blades are made of high-quality materials, such as carbon fibers, which are energy-intensive in production. Recycling allows these raw materials to be recovered and reused in various industries, which reduces the need for mining new raw materials [1-3]. Recovered materials, such as carbon fibers, can be used in construction, automotive, and aviation, giving them new life and increasing their economic value. The use of fibers in concrete structural elements increases their crack resistance, counteracts the development of shrinkage cracks, and prevents brittle cracking of concrete.

Currently, various types of non-metallic fibers are used in construction: carbon, basalt, glass, plastic as well as organic fibers. Fibers used as concrete additives differ in origin, thickness, length, tensile strength, and modulus of longitudinal elasticity. Thus, they significantly change the mechanical properties of resulting concrete in different ways. Therefore, their effective use requires in-depth analysis that goes beyond simple assessment of compressive and flexural strength. We need to conduct systematic tests of fibrous cement composites and modify existing methods for assessing mechanical properties of fiber-reinforced concrete.

The growing interest in the use of recycled fibers is confirmed by numerous recent publications [4–7]. Recycled tyre cords, feather fibers, steel chips, wood fibers from paper waste and high density polyethylene from PET bottles and woven bags and woven plastic bags are used as additives in concrete [7]. Recycled textile carpet fibers have been shown to increase the tensile and flexural strength of concrete elements [9,10] and the addition of recycled steel fibers (RSF) to concrete can be a cheaper substitute for steel reinforcement [11,12].

2. PRELIMINARY EXPERIMENTAL INVESTIGATION

In our own preliminary research, carbon fibers obtained from recycling wind turbine blades made of carbon composite were used. The fiber recovery process was carried out by Anmet using the pyrolysis method using their own technology. The recovered carbon fibers, characterized by (according to the manufacturer) tensile strength of 1.17 GPa and Young's modulus of 317 GPa. High fiber strength and especially a very high longitudinal elasticity modulus predispose these fibers as good dispersed reinforcement for structural concrete.

A total of 32 series of concrete samples with different types of cement, water to cement ratio (w/c = 0.4 and 0.5) and fiber content (0, 2, 4 and 8 kg/m³) were tested. The tests revealed a beneficial impact of the recovered carbon fibers on the compressive strength of concrete. Compared to the reference concrete made of CEM I 42.5R cement, with water to cement ratio (w/c) of 0.5 and 0.4, a decrease in this strength of about 17% was observed. In the case of concrete with CEM II 42.5 R/B-M (S-V) cement, with a w/c of 0.5 and a fiber content of 4 kg/m³, the compressive strength increased by a maximum of 30%. Young's modulus tests showed that the addition of fibers has a minimal effect on the secant modulus of elasticity of concrete, which confirms general observations in this field. The use of recycled dispersed reinforcement in concrete significantly improved its flexural strength compared to the reference concrete. The largest increase, up to 30%, was observed in the series with CEM I 42.5R cement at w/c equal to 0.4 and fiber content of 4 and 8 kg/m³, as well as in the series with CEM II 42.5 R/B-M (S-V) cement at w/c equal to 0.4 and fiber content of 8 kg/m³.

The residual tensile strength of recycled carbon fiber concrete (recC) increased with increasing fiber content from 2 kg/m³ to 8 kg/m³, reaching a maximum increase of 40% for concrete with CEM I 42.5R cement, w/c ratio 0.4 and fiber content 8 kg/m³. Concrete containing recC exhibited enhanced fracture mechanics parameters, such as increased stress intensity factor (KIc) and larger critical crack opening displacement (CTODc).

3. PLANNED EXPERIMENTAL AND THEORETICAL RESEARCH

The planned own research aims to determine the effect of carbon fibers recovered from the renewable energy sector on the properties of cement concretes. This includes examining both fresh and hardened states of concrete, such as workability, setting time, and early-age strength. Additionally, long-term durability properties like freeze-thaw resistance, chloride ion penetration, and carbonation depth will be investigated to assess the material's suitability for harsh environmental conditions.

The main goal of the first stage of the research will be to develop recipes for concretes with the addition of carbon fibers, taking into account the desired features of the concrete mix and the mechanical properties of the designed concrete, i.e.: compressive strength, tensile strength during shearing, tensile strength during splitting, and Young's modulus. Special attention will be given to optimizing fiber dispersion within the matrix to ensure uniform reinforcement and to minimize potential clustering.

The fracture mechanics parameters of concrete will be tested in accordance with the RILEM TC89 procedure and the general guidelines of the fib Model Code. These tests will include determining stress intensity factors, energy dissipation during cracking, and crack propagation patterns under various loading conditions. An important part of the planned research will be to conduct the necessary theoretical analyses and experimental studies, further developing our own deformation criterion for fracture of quasi-brittle materials. The research will also involve comparative studies to benchmark the performance of recycled carbon fibers against other commonly used reinforcement materials.

4. CONCLUSIONS

The incorporation of recycled carbon fibers (recC) into concrete is an innovative approach that significantly improves its mechanical properties, such as compressive strength, flexural strength and fracture toughness. Despite technological challenges, such as uniform fiber distribution or mixture optimization, recC offers significant environmental and economic benefits, supporting sustainable development. Further research in this area is crucial to fully exploit the potential of this material in construction.

REFERENCES

1. Global Wind Energy Council (GWEC). Decommissioning and Recycling of Wind Turbine Blades. 2021.
2. WindEurope. Accelerating Wind Turbine Blade Circularity. 2020.
3. European Commission European Union. Recycling Wind Turbine Blades to Support Circular Economy Goals. 2021.
4. Merli R, Preziosi M, Acampora A, Lucchetti MC, Petrucci E. Recycled fibers in reinforced concrete: A systematic literature review. J Clean Prod. 2020;248:119207. https://doi.org/10.1016/j.jclepro.2019.119207.
5. Wang Y, Wu HC, Li VC. Concrete Reinforcement with Recycled Fibers. J Mater Civ Eng. 2000;12(4):314–9. https://doi.org/10.1061/(ASCE)0899-1561(2000)12:4(314).
6. Xie J, Kou S, Ma H, Long W-J, Wang Y, Ye T-H. Advances on properties of fiber reinforced recycled aggregate concrete: Experiments and models. Constr Build Mater. 2021;277:122345. https://doi.org/10.1016/j.conbuildmat.2021.122345.
7. Bui NK, Satomi T, Takahashi H. Recycling woven plastic sack waste and PET bottle waste as fiber in recycled aggregate concrete: An experimental study. Waste Manag. 2018;78:79–93. https://doi.org/10.1016/j.wasman.2018.05.035.
8. Ahmed HU, Faraj RH, Hilal N, Mohammed AA, Sherwani AFH. Use of recycled fibers in concrete composites: A systematic comprehensive review. Compos Part B Eng. 2021;215:108769. https://doi.org/10.1016/j.compositesb.2021.108769.
9. Meesala CR. Influence of different types of fiber on the properties of recycled aggregate concrete. Struct Concr. 2019;20(6):1656–69. https://doi.org/10.1002/suco.201900052.
10. Tran NP, Gunasekara C, Law DW, Houshyar S, Setunge S, Cwirzen A. Comprehensive review on sustainable fiber reinforced concrete incorporating recycled textile waste. J Sustain Cem Based Mater. 2022;11(1):28–42. https://doi.org/10.1080/21650373.2021.1875273.
11. Grzymski M, Musiał M, Trapko T. Mechanical properties of fibre reinforced concrete with recycled fibres. Constr Build Mater. 2019;198:323–31. https://doi.org/10.1016/j.conbuildmat.2018.11.183.
12. Savruk MP, Kazberuk A. Stress Concentration at Notches. Springer International Publishing Switzerland; 2017.
13. Kosior-Kazberuk M, Kazberuk A, Bernatowicz A. Estimation of Cement Composites Fracture Parameters Using Deformation Criterion. Mater. 2019;12(24).
14. Kazberuk A. Application of the Deformation Fracture Criterion to Cracking of Disc Specimens with a Central Narrow Slot. Acta Mech Autom. 2022;16(4).
15. Kazberuk A. Slip bands at the tips of narrow slot in Brazilian notched disk — plane deformation. Acta Mech Autom. 2024;18(4):737-742. https://doi.org/10.2478/ama-2024-0080

The work has been accomplished under the research projects LIDER14/0206/2023 and WZ/WM-IIM/3/2020.

Julita Krassowska: https://orcid.org/0000-0001-9209-1285

Andrzej Kazberuk: https://orcid.org/0000-0003-4179-0312