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Sustainable mortar reinforced with recycled glass fiber derived from pyrolysis of wind turbine blade waste

Samy Yousef [a,*], Regina Kalpokaitė-Dičkuvienė [b]

[a] Department of Production Engineering, Faculty of Mechanical Engineering and Design, Kaunas University of Technology, LT-51424, Kaunas, Lithuania
[b] Laboratory of Materials Research and Testing, Lithuanian Energy Institute (LEI), Breslaujos 3, LT-44403, Kaunas, Lithuania

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ABSTRACT

Pyrolysis technology has recently made significant progress in recycling millions of tons of wind turbine waste (WTB). Short fibers represent its main product (~70 wt%), which needs further studies to explore its future applications. In this context, this work aims to the valorization of the recycled glass fiber (rGF) derived from pyrolysis of WTB (at 550 °C) in the production of rGF-reinforced mortar composite (rGF/M) for sustainable building applications. The research began by subjecting the derived rGF to sieving (rGFs), washing (rGFw), and oxidation (rGFo) pretreatments for purification and removing any impurities, organic residues, and char particles. Afterward, the chemical degradation of the treated rGF in a strong alkaline cement solution with pH = 14 was studied for up to 90 days. In parallel, the mortar composite samples were fabricated at 1 wt% of the treated rGF batches (rGFr, rGFw, and rGFo) to study the effect of different pretreatments on their microstructure, dispersion, compressive strength, flexural strength, and water absorption capabilities behavior after different curing periods (28 and 90 days). The results showed that rGFo (7.84%) showed a lower degradation rate versus rGFw (16.41%) and rGFr (30.76%). Meanwhile, the highest curing period (90 days) contributed to improving the properties of the mortar composites in general, especially in the case of using rGFo which led to improved compressive strength (15%) and reduced absorption coefficient (38%) and cumulative water content (32%) with a uniform distribution of short fibers in the matrices and a slight increase in flexural strength compared to control mortar sample (8.6 MPa). While rGFs provides better flexural strength (9.3 MPa) with a 12% improvement. Based on these results it can be concluded that rGFo has high potential in sustainable building materials with high competition with virgin glass fiber.

1. Introduction

In the past few years, wind turbine blade waste (WTB) has received significant global attention due to its large quantity (50,000 tonnes in 2020) and non-degradable composition consisting of fiber-reinforced resin composites [1,2], which in turn makes them difficult to recycle and dispose of in landfills that are accompanied by serious environmental burdens [3]. In order to valorise WTB and reduce its environmental burden, several effective management solutions have recently been proposed. These solutions can be divided into three main categories: mechanical, chemical, and thermal [4]. The mechanical solution using the shredding process is an industrial pre-treatment used to reduce size of WTB (around 1.5 m^2) to facilitate transportation from the wind farm to the recycling plant or landfill [5], thus this approach cannot be considered a major recycling process. While the chemical solution is classified as a main treatment that relies on the use of organic solvents to dissolve the resin under moderate heating conditions and thus release the fibers. In fact, this approach was developed to recycle waste printed circuit boards and fiber-reinforced polymer composites that have a similar composition to WTB [6,7]. However, this approach has not yet been generalized due to its several limitations including toxicity of organic solvents (e.g. dimethylformamide), consumes a lot of solvents, leaving large amounts of contaminated solvents in the form of chemical by-products that must be treated again, which requires additional cost [8,9] (see Table 1).

Pyrolysis is one of the most promising emerging thermal solutions used in WTB processing and several commercial plants are underway and will soon be opened across Europe [10]. Although pyrolysis technology consumes slightly higher energy compared to the chemical recycling approach which may lead to increased greenhouse gas

* Corresponding author.
E-mail address: ahmed.saed@ktu.lt (S. Yousef).

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Table 1
Diameter reduction of rGF after treatment in an alkaline solution.

Sample	Initial diameter (μm)	Final diameter (μm)	Fibers diameter reduction (%)
rGFs	15.15	10.49	30.76
rGFw	14.93	12.48	16.41
rGFo	14.54	13.40	7.84

emissions, this deficiency can be addressed by using clean and renewable energy source (such as electricity, solar cells, solar panels, hydrogen, etc.) to avoid producing more greenhouse gas emissions [11]. The energy consumed in the pyrolysis process is still less than incineration and other heat treatments, which require temperatures of up to 1000 °C [12,13]. In addition, the cost of the energy consumed can be compensated by recovered energy products and recycled materials which have a high economic performance of up to 12000 $/ton [14]. Pyrolysis technology has succeeded in recycling all its components in the form of oil, gas, char, and short fiber products [15]. This emerging recycling practice contributes to making WTB a sustainable and renewable resource, very rich in fiber and resin, which can be used to replenish our reserves and preserve resources for future generations [16]. In addition to its significant contribution to reducing global warming, mineral resource scarcity, and other emissions, significantly up to 51% compared to landfill practices [14]. The pyrolysis process has also shown high performance in treating WTB with different fibers (glass and carbon) and resins (epoxy and unsaturated polyester) [17–19]. Studies also focused on optimizing its performance under different pyrolysis conditions such as temperatures, heating rates, and atmospheres [20,21]. Besides studying their catalytic pyrolysis behavior over various zeolite catalysts (ZSM-5 and Y-type) for producing more aromatic chemicals (benzene, toluene, and ethylbenzene) [22]. The results revealed that all these conditions have a significant impact on the composition of oil and gas products obtained from the degradation of resin, as epoxy can decompose into a phenol-rich oil versus a styrene-rich oil in the case of unsaturated polyester, which can be utilized in various applications related to energy and chemical industries [23,24]. Also, co-pyrolysis of WTB and biomass was studied to improve the quality of the pyrolysis oil [25]. While temperature was the main effective factor in the morphology of the recycled fibers, a temperature below 550 °C was the optimal value to ensure that the fibers did not decompose [26]. Some studies have also improved the morphology of recycled fibers (rFs) by subjecting them to an oxidation process at 450 °C for 30 min to remove any organic contamination [27]. Despite the high purity of rFs morphology, many of its properties are still missing and need to be explored for future commercialization and choosing its appropriate application, especially its mechanical behavior and chemical resistance to determine its competitiveness with virgin fiber [28].

One of the most widely used methodologies for this purpose is the use of rFs as fillers to enhance the mechanical properties of lightweight composites in general and cementitious matrix, concrete, and cement mortar composites in particular [29–31], hence, determining their performance compared to neat fibers under the same manufacturing and testing conditions, allowing their competitiveness to be determined. In this regard, several literature studies have been developed to study the effect of adding rFs on the mechanical behavior of cement matrices [32,33]. The results showed that the compressive strength, flexural strength, and elastic modulus of the cementitious matrices were enhanced by the incorporation of rFs as a result of the enhanced bridging effect between the fibers and the cement molecules. The addition of a small amount of rFs prevents crack propagation under the applied compressive load, contributes to delaying fracture, and improving its mechanical properties [34]. A higher addition ratio results in the production of relatively more voids in the matrices and weaker interfacial bonding between rFs and cement particles, which can help improve their impact performance and use in applications that require elevated temperature [35,36]. Although all these promising results and good economic benefits of rFs reinforced cementitious composite [37], the rFs used in these studies were shredded WTB called wet fiber (composed of short fibers mixed with resin) that has less compatibility with cement particles and provides non-uniform properties as a result of its random dispersion in the matrices compared to pure fibers [38]. On the contrary, short dry fiber (resin-free fibers) provide better bonding and compatibility compared to wet fibers and provides larger contact surface area and high cohesion with cement molecular. This contact surface can be increased by subjecting the recycled fibers to pretreatment such as chemical and thermal processes [39,40]. As shown in the literature, the performance of short dry fibers extracted from pyrolysis of WTB is still missing and needs to be known for future applications and generalizations. In this context, this work aims to study the performance of the rFs derived from pyrolysis of WTB in enhancing the properties of mortar composites and to study their competitiveness compared to virgin fibers. The experiments were conducted on recycled glass fiber (rGF) as the most widely used fiber in wind blades manufacturing [41]. The rGF was subjected to several subsequent pretreatments (sieving, washing, and oxidation) to further purify and achieve good bonding with the cement matrices. Also, the chemical resistance of the treated rGF was studied in a strong alkaline cement solution and was investigated for up to 90 days. Finally, the effect of these subsequent pretreatments on the morphology, mechanical strength, water absorption, and sorptivity coefficient of mortar composites was observed.

2. Experimental

2.1. Materials and chemicals

The WTB used in this research has a structure consisting of unsaturated polyester resin reinforced with glass fibers and was supplied by European Energy, Denmark. While the raw materials used in the manufacture of rGF-reinforced mortar composites, in particular, quartz sand particles in the ranges of 0.1–2.0 mm and ordinary Portland cement (CEM I 42.5R) were provided by JSC Akmenes Cementas Lithuania company. Whereas, the other chemical reagents were purchased from the supplier Sigma-Aldrich.

2.2. Research methodology

The methodology of the current research was designed as several stages as shown in Fig. (1). These stages are distributed in this way: A-C) the rGF received from pyrolysis treatment was purified using three different pretreatments (sieving, washing, and oxidation), D,E) study and characterize the chemical degradation of the treated rGF in cement alkaline solution up to 90 days, F,G) preparation and characterization of recycled glass fiber reinforced mortar (rGF/M) composites. All experimental procedures, characterization of all these stages, and their conditions are described in the following sections.

2.2.1. Preparation and purification of recycled glass fiber

The supplied WTB panels (1.5 m^2) were shredded into small pieces ranging in size from 5 to 25 mm using a Wittmann ML2201 granulator. Short rGF in the form of solid residue product was liberated from WTB using a small-scale pyrolysis setup at 550 °C (optimal temperature that can be used to produce the maximum yield of pyrolysis oil) and all other technical procedures for the thermal conversion process are described and published elsewhere [26]. After that, the solid residue was subjected to a sieving process to separate the fine particles (char) from rGF, thus obtaining char-free short rGF (rGFs) (Fig. (2A)).

Afterward, the liberated rGFs were washed with deionized water to remove any fine char particles remaining on their surface (rGFw) (Fig. (2B)). The rGFw was subjected to an oxidation process at 450 °C for 30 min in a laboratory oven to remove any resin or organic particles remaining on their surfaces [14], thus, purified rGF (rGFo) is obtained

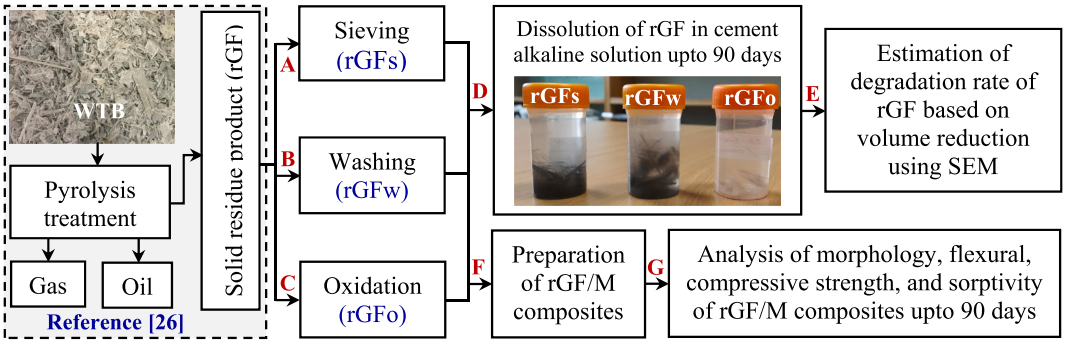

Figure (1). Flowchart of the current research experiments and characterizations.

Figure (2). Photos of A) rGFs, B) rGFw, and C) rGFo batches.

(Fig. (2AC)), which is characterized by its white colour without any entanglement between its threads, which helps to uniformly distribute in the mortar composites later. Finally, the size distribution of rGF batches was estimated in the ranges from 2 mm to 25 mm.

2.2.2. Dissolution experiments

The dissolved alkali solution with pH = 14 was prepared based on the concept of cement water extraction by mixing cement particles in water in a ratio of 1:4 (v/v), then the solution was left for 24 h to precipitate the cement particles, thus a strong alkaline cement solution is extracted with the help of the filtration process [42]. After that, the rGFs, rGFw, and rGFo were immersed in the prepared solution individually for 90 days, to simulate the same curing period of mortar composites. After the specific aging time, the rGF was taken out of the solutions and then dried at 40 °C for overnight, then observed their morphology and diameter size using a scanning electron microscope (SEM). Finally, the degradation rate of rGF in terms of diameter reduction was calculated using Eq [1,28]. In this formula, Δ D, D_o, and D_f are defined as rGF diameter reduction rate, initial rGF diameter, and diameter after treatment of rGF in alkaline solution, respectively.

$$\Delta D = \frac{D_o - D_f}{D_o} \quad (1)$$

2.3. Preparation of rGF-reinforced mortar composites

Firstly, a control mortar sample (M) was prepared using OPC, sand, and water in a weight ratio of 1:3:0.5 for comparison reasons. Subsequently, the rGF-reinforced mortar composite (rGF/M) samples were prepared with the same composition as mortar sample and a fixed amount of rGFs, rGFw, and rGFo (1 wt%) based on the optimal ratio obtained by Sami Al. (2023) that achieving the maximum mechanical strengthening of the matrices [43]. The rGF/M specimens were fabricated using these mixing proportions: 655 kg/m^3 (cement), 1765 kg/m^3

(sand), 111 kg/m^3 (water), and 0.5 (w/c). The mortar sample was prepared by adding OPC and sand to the bowl and then adding water during mixing using a planetary-type mixer for 5 min using the mentioned proportions above. In the case of rGF/M specimens, 1 wt% of rGF (rGFs, rGFw, and rGFo) filler material was added to the mortar mixture in small portions during continuous mixed for another 7 min at a low mixing speed to obtain a uniform dispersion of rGF in the matrices and avoid their breakage. The mixture of each batch was cast into cubic 20 × 20 mm and prismatic 20 × 20 × 100 mm metal molds for preparing compressive and flexural samples, respectively [44]. The mixture was shaken in the molds using a shaking table accompanied by blows on its sides, ending with levelling the surface using a trowel. The dry specimens were disassembled after 24 h from molds and then placed in a climate chamber at a temperature of ~20 °C and 95 ± 5% (relative humidity) for different curing periods: 28 and 90 days.

2.4. Characterizations of rGF-reinforced mortar composites

The morphology of the untreated and treated and treated rGF was observed using SEM. Also, the dispersion of rGF in the matrices and the morphology of the fracture surfaces were examined using SEM at high voltage (20 kV) after coating with a thin gold layer. The mechanical strength of the manufactured rGF/M composites was performed using the Zwick Roell universal tester according to the European standard EN 196-1. Capillary water absorption measurements of the broken prismatic mortar and rGF/M samples were performed according to EN 1015-18 standard procedure [45], by monitoring the growth in a mass change in the mortar and rGF/M specimens for certain periods of time, thus estimating the amount of absorbed water in terms of cumulative water content (mm). A sorptivity (A) parameter was calculated from the slope of the linear relationship between the cumulative water content (i) parameter and fourth root of time ($t^{0.25}$) [46]. All measurements were performed on five batches of mortar and its composites at specific curing time intervals from 28 to 90 days, then take the average to achieve repeatability and increase the accuracy of the results.

3. Results and discussion

3.1. Effect of alkaline solution on morphology and diameter reduction of rGF

Figure (3A-F) shows the SEM photos of the rGF samples before and after the pretrements and before the dissolution process. The observation process showed that the fibers thread in the rGFs sample was densely covered with agglomerates representing undecomposed resin, where the applied temperature (550 °C) and reaction time (1 h) were not sufficient to decompose all components of the resin and break of the chemical bonds and friction between the fibers and the resin [47]. It was also observed that there was some debris remaining on the fiber surfaces representing char particles and associated with a weak mechanical bond with the fibers. In the case of the rGFw batch, the sample became smoother and the undecomposed resin appeared in the form of a thin

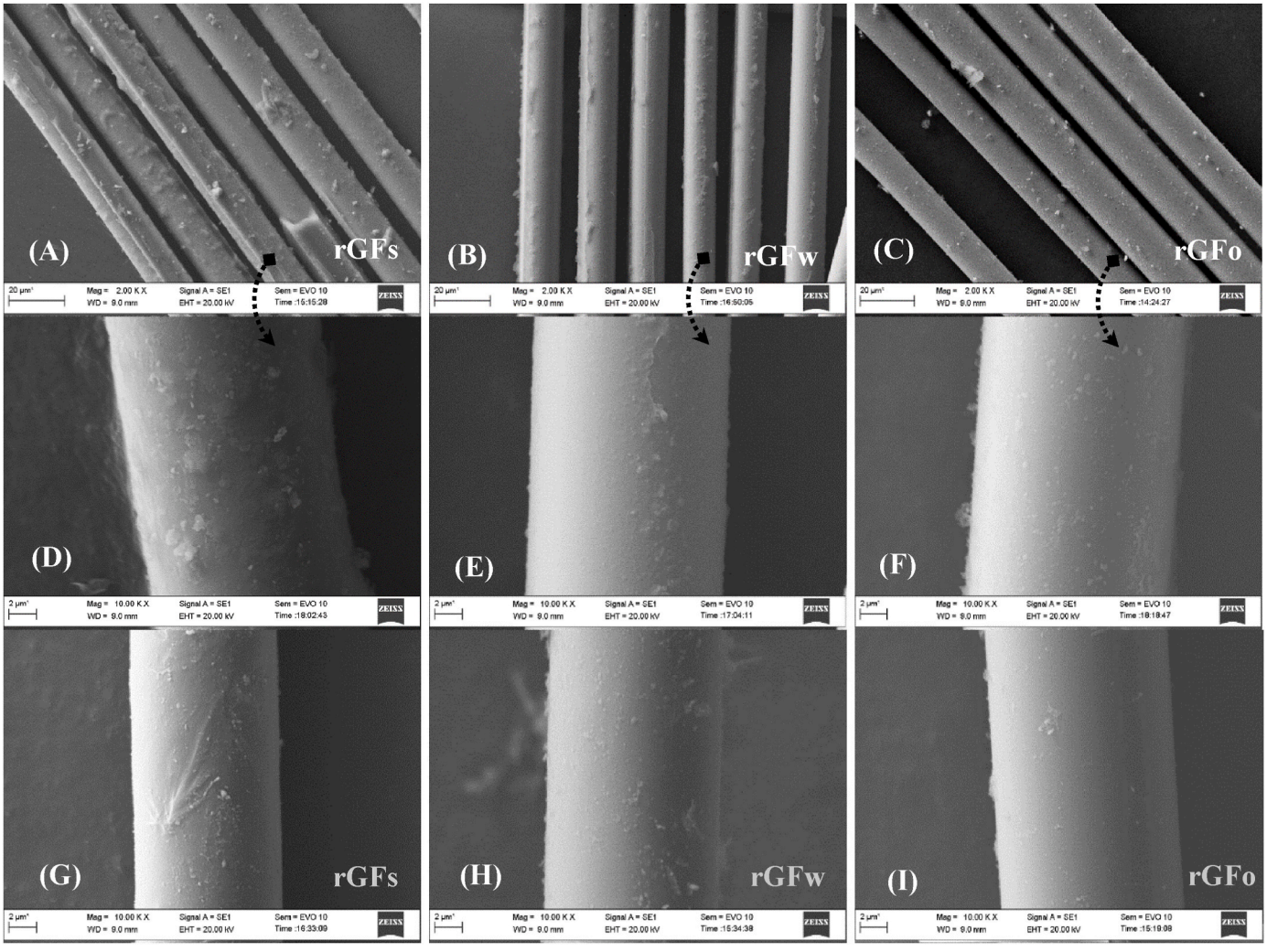

Figure (3). SEM images of rGF A-F) before degeneration and G-I) after degeneration in an alkaline solution.

laminated layer covering the entire surface of the fiber thread, while all char particles and debris were removed. After the oxidation process, the rGFo sample of the fiber thread became quite clear with only a few undecomposed resin particles present, and the fiber thread rGFo sample became completely clear with only a few particles (scratched fibers). After the dissolution process in the alkaline solution for 90 days, the rGF showed different features as displayed in Fig. (3G-I). As shown, the alkaline solution contributed greatly to the decomposition of the remaining resin on the surface of rGFs and rGBw. Where this long degradation time allowed an alkaline solution to penetrate between rGFs and rGFw components until reached resin thin film or its debris then breaking their van der Waals' bonds until achieving the full dissolution thus obtained bare fibers [48,49]. However, rGFo produced better morphology with smooth surfaces compared to the other samples, while rGFs showed smoother surfaces. This variation in the morphology of rGF is due to the change in its composition and type of pre-treatment. Based on the SEM analysis, the diameter size of the untreated fibers and the treated fibers were measured, then the diameter reduction was calculated and all values are summarized in Table **[1]** . It is clear that the diameter size of the recycled fibers decreased gradually after being exposed to successive pre-treatments due to the significant effect of pre-treatments in the breakdown of van der Waals' bonds and dissolve it [50,51]. Where, rGFs (30.76%) showed the highest degradation rate, followed by rGBw (16.41%) and rGFo (7.84%) with an almost linearly correlated relationship due to the corrosive behaviour of rGF. No significant etching was observed on rGFo or torn by alkali corrosion, which demonstrate the recycled fibers have a high resistance to corrosive and alkaline degradation media even after dissolving the resin thin layer. Although results in the literature have shown that an alkaline environment as in cementitious composite can lead to increased surface roughness and create some micro-cracks on the fiber surfaces [28], these features were not observed in the current research and SEM images of rGF/M matrices Because the alkaline environment used was not strong and without adding any heat source like the one used in these studies [52,53]. Also, the treatment time (90 days) used in the current research was not sufficient to dissolve rGF, as degradation of fiber requires longer periods up to 5000 h under heating condition (95 °C) [54].

3.2. Morphology and dispersion of fibers in the matrices

The morphology of the fracture surfaces (cross-section) of the mortar composites (after 90 days of curing time) and the dispersion of rGF in the matrices was observed using SEM at different scales. The observation process of rGF/M samples at the bond and interfacial region between the rGF and mortar are shown in Fig. (4). The mortar fraction (cement and quartz particles) in all matrices showed a rough surface consisting of soluble grains of OPC-C2S (pelite) and C3S (alite) interspersed with very fine pores and uniformly distributed inert quartz particles [55]. The homogeneity and good dispersion of rGF in the mortar composites was observed by reducing scanning magnification, but due to the large variation in fiber lengths (2–25 mm), it was difficult to see the heavy density of rGF together in one image, and this difficulty was

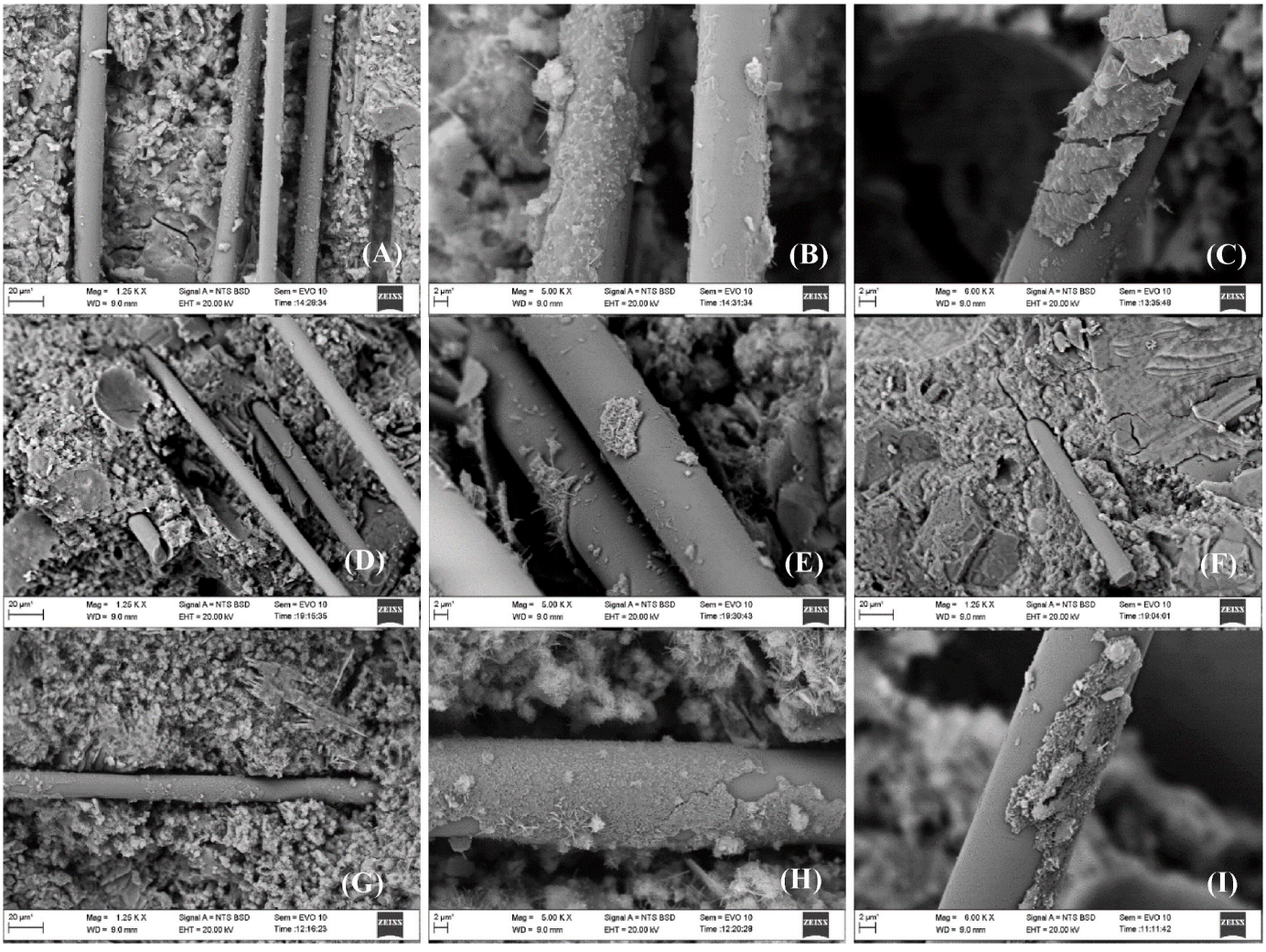

Figure (4). SEM images of the fracture surfaces of A-C) rGFs/M, D-F) rGFw/M, and G-I) rGFo/M samples.

compounded by the fact that the fibers were not always distributed in one direction. Although the fibers are very small in size, they do not wrinkle, but are distributed separately from each other. Also, SEM has been used to monitor the growth and formation of hydration products on rGF. The monitoring process showed complete incorporation between rGF and cement hydration products (hydrate and calcium hydroxide) [56]. However, the hydration products were not able to cover all rGFs and grow up regularly due to rGFs irregular shape and composition that consisting of entangled fibers mixed with some resin particles and fine char (Fig. (4A-C)).

All these features impede an incursion of the hydration products inside and cover the internal fibers and develop a new strong bonding [57,58]. However, in many areas, wetting products are ideally developed due to the dissolution effect which successfully breaks down the remaining resin layers as described above. Also, after this long curing period, the fine char particles can be separated from the resin layers and diffused into the pores of the cement to reduce its porosity. After the washing process, the fibers become free (rGFw) with a high surface area which provides more contact surface between the fibers and hydration products through improving the bonding (Fig. (4D-F)). However, the remaining resin prevents the hydration products from reaching the bare fibers and bonding with them. After the oxidation process (Fig. (4G-I)), the fibers become completely bare (rGFo) which allows to cover all their surfaces and create strong bonds with them which leads to enhancement of properties as shown in the following sections [59].

3.3. Flexural strength

Figure (5A) shows the flexural force and deformation curves of mortar composites (rGF/M) after 90 days curing period, while Fig. (5B) shows the effect of adding rGF and their pretreated fibers (rGFs, rGFw, rGFo) on the flexural strength of the mortar composites at different curing periods (28 and 90 days). As shown, the flexural strength of the mortar sample doesn't change a lot by adding rGF and their pretreatment at the lower curing time (28 days), where the flexural strength was estimated at 8.1 MPa (M), 8.2 MPa (rGFs/M), 8.1 MPa (rGFw/M), and 7.8 MPa (rGFo/M). By increasing the curing periods up to 90 days, the strength of the control sample almost doesn't change unlike in the case of mortar composites the flexural strength increased significantly especially in the case of incorporating of rGFs (9.3 MPa) with 12% improvement. This is due to the fact that rGF can delay the propagation of carcks [60]. Besides that the highest curing period helps to break down the chemical and mechanical bonds between fibers and the remaining resin which allowed the hydration products to penetrate deeper and develop more coherence between the rGF and cement molecular [61,62]. In addition, the rGFs are considered as wet fiber (as still continuing resin) with high flexibility (elasticity) contributing to increasing the flexural strength of the matrices [63,64]. This flexibility was lost in the case of rGFo (dry fiber) after the resin was removed by washing and oxidation.

3.4. Compressive strength

Figure (6A) shows the compressive strength and deformation curves of rGF/M samples after 90 days curing period, while their compressive strength values are shown in Fig. (6B). It was observed that after 28 days, the adding of rGF to the matrices has a significant effect on their compressive strength, where the compressive strength of mortar sample (25.9 MPa) gradually increased by subjecting the recycled fibers to different pretreatments with the following trends: 30.1 MPa (rGFs/M) < 37.3 MPa (rGFw/M) < 37.7 MPa (rGFs/M). After 90 days, the compressive of all samples increased by it was very clear in the case of mortar (37.8 MPa), rGFw/M (40.7 MPa), and rGFo/M (43.6 MPa) due to low cohesion [65]. Whereas, in the case of rGFo/M provides a high contact surface ratio leading to better bonding and hydration products as mentioned above. The same features can be noted in case of rGFw/M, but the remaining resin can obstruct the coherence between cement and fiber a little that why we got lower strength. Based on that, rGFw has a high potential in increasing the compressive strength of mortar.

3.5. Sorptivity

Figure (7) shows the estimated sorptivity values of mortar and rGF/M samples. As shown, the mortar sample showed the highest sorptivity after 28 days (0.3006 mg/mm^{2}s$^{0.25}$), this sorptivity decreased significantly after adding rGF to the matrices by 26% (rGFs), 40% (rGFw), and 32% (rGFo). After 90 days curing time, the sorptivity of all samples decreased with almost the similar trendency, where the sorptivity of mortar was estimated at 0.2528 mm/s$^{0.25}$ that decreased by 36% with the addition of rGFs, and by 38% with the addition of rGFw and rGFo. As shown, the addition of rGF generally has a significant effect on reducing mortar sorptivity, especially with increasing the curing time. This means that rGF/M samples have a high resistance to fluid penetration, which also contributes to enhancing their durability [51].

3.6. Resistance to water absorption

In general, the rate of water absorption by capillary suction of cement mortar and its composites depends on the expansion of the deforming (CSH) and non-deforming phases [42]. The capillary absorption curves of mortar and its composites as a function of the fourth root of time are presented in Fig. (8). The cured samples for 28 days (Fig. (8A)) showed that the mortar sample has a higher water ingress rate that increases linearly with increasing fourth root of time. In the case of rGFw/M and rGFo/M samples, it was observed that the water ingress rate gradually decreased by 23% and 27%, respectively due to the filler effect that reduces the continuity of mortar pores and closes its larger porosity [46]. Also, rGF/M blended has higher compositions

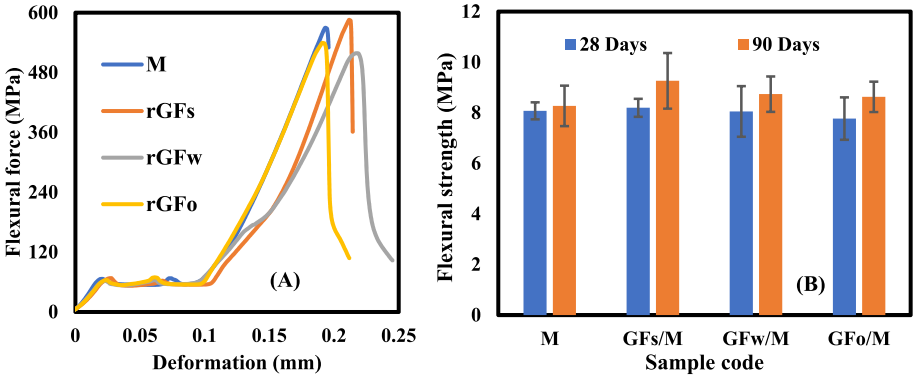

Figure (5). Flexural strength of the recycled glass fiber-reinforced mortar composites.

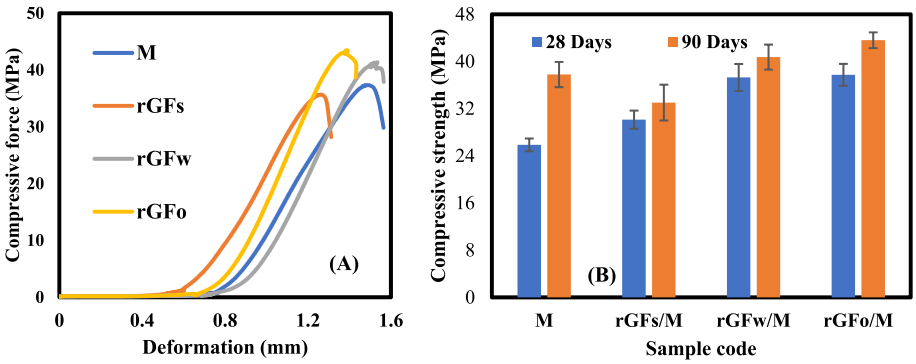

Figure (6). Compressive strength of the recycled glass fiber reinforced mortar composites.

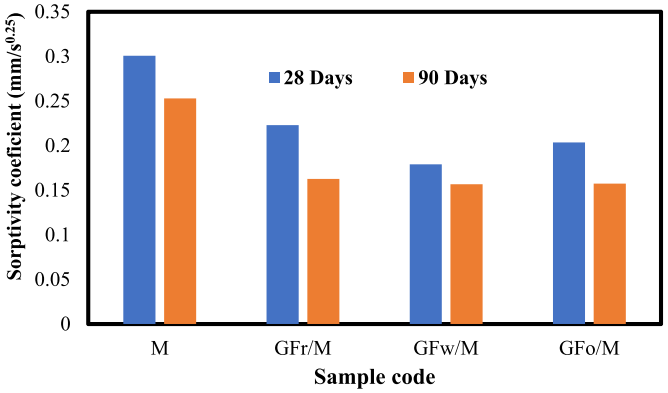

Figure (7). Sorptivity values of mortar and its composites samples.

compared to mortar that contributes to develop more deforming phases in the blends that led to reduced porosity and pore interconnection of the matrices as an increases the degree of restraint in the rGF/M matrices and pore tortuosity increment [62]. In the case rGFo/M sample, the rate was increased significantly by 36% due to the reasons mentioned above coupled with their smaller size allowing them to close smaller porosity and pores as well [46]. Besides its effect in an arrangement of hydrates phases and their contents in the capillary pores that affect some specific changes in the microstructure of the matrix (as shown in SEM observation) their ability to close the pore space helps to the continuity of pores in the rGF/M composites and results in varying absorption capacities of formulations [46,66]. With increased hydration time of up to 90 days (Fig. (8B)), the water ingress rate of all samples decreased again in the ranges of 6.002 mm (mortar) - 4.088 mm (rGFo/M) with a reduction rate estimated at 28% (rGFs/M), 31% (rGFw/M), and 32% (rGFo/M) compared with mortar sample. This can be explained that the organic components (resin and char) of rGFs and rGFw started to decompose under the highly harsh environment of cement [67,68], thus separating against fibers that act as rGFo that's why all rGF provide similar performance after long curing time. As shown, the rGF/M samples demonstrated the lowest water absorption rate, especially rGFo/M, which means the recycled fibers have a high potential in applications that need high water resistance.

Finally, since wind energy and its components are classified as a sustainable and green resource [69], the materials extracted from it, including fibres, can also be called sustainable fibres. The recycled fibers can also be classified as eco-friendly material as the recycling process used in this proposal (pyrolysis) is classified as eco-friendly [70]. However, it is highly recommended to verify this using life cycle assessment as a common approach for such analyzes and has been adapted in several cementitious composites studies to determine the burdens and their contribution to the environment [71,72].

4. Conclusions

In this research, the recycled glass fiber (rGF: in the form of solid resuise product) derived from wind turbine waste pyrolysis (WTB) was treated using sieving (rGFs), washing (rGFw), and oxidation (rGFo) processes, followed by study their chemical degradation in alkaline cement solutions, and then reuse them as fillers to enhance the properties of mortar. The following results and conclusions were obtained.

a) the dissolution results showed that after 90 days, rGFO has higher degradation resistance (92%) in alkaline solutions compared to other rGF samples.

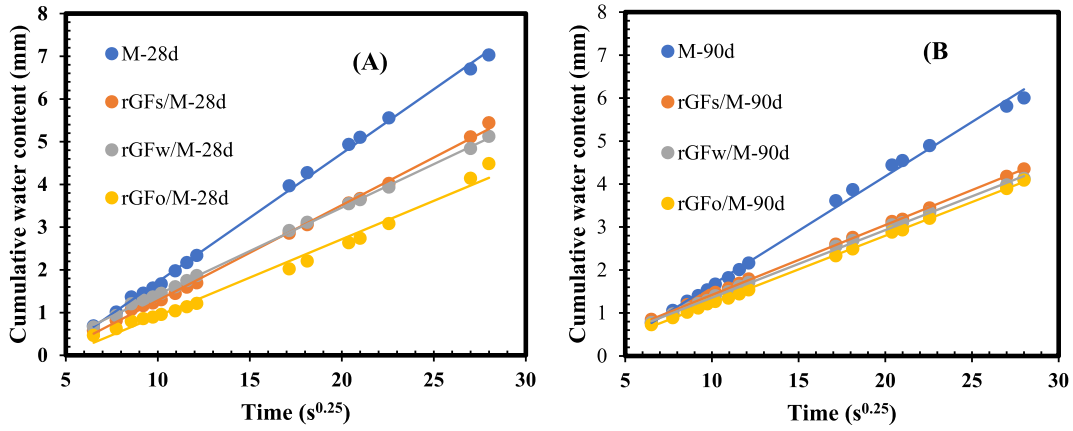

Figure (8). Capillary absorption of mortar and its composites samples hydrated for A) 28 days and B) 90 days.

b) after a short curing time (28 days), the performance of rGF/M composite samples doesn't change a lot compared to mortar sample.
c) after a long curing period (90 days), the rGF/M composite samples showed a noticeable improvement in their performance compared to mortar sample, especially in the case of rGFo/M sample, estimated at 15% (compressive strength), 38% (absorption coefficient), 32% (cumulative water content), and stable flexural strength (8.6 MPa).

Based on the reported results, the recycled glass fiber from WTB can be used as a cheap and competitive source for short fiber production.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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