Sieving Analysis Classification of Mechanically Treated Recycled Glass Powder

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Abstract. Factors considering the introduction of a Circular Economy Action Plan from the EU, the possible negative effects that arise from the continuous disposal of waste materials in landfills and not recovered/recycled or reused, has led researchers into finding ways of exploiting those materials. Waste glass from households or industrial sectors in Cyprus was either not recovered as targeted or limited data exists. Methods or applications for the valorization of recycled glass had been proposed over the past decade that initially begins by crushing the waste glass into fine-grade particles. However, in literature there are inadequate data on the effect of the applied treatment method, regarding parameters such as number of rotation cycles, quantities treated etc. The aim of this research was to process waste glass in a Los Angeles abrasion machine for different rotation cycles and with two quantities of materials (10 and 20 kg), where the particle size distribution was examined. It was observed that the optimum treatment rotation was for 10 thousand cycles and 10 kg of recycled glass. Furthermore, treatment in the Los Angeles apparatus for wine bottles showed that the removal of labels had no significant effect on the particle size distribution especially on smaller sieves.

Keywords: Glass Powder, Recycled Glass, Los Angeles, Abrasion Test, Sieving Analysis, Cycles, Particle Size Distribution

1 Introduction

The Management of Construction and Demolition Waste (CDW) and Manufacturing Waste (MW) has become an utmost importance for the EU, since they constitute almost half the annual waste generation [1]. Concerns arise regarding the possible presence of hazardous and toxic substances that may lead to irreversible effects on the environment and human health, if they continue end up in the landfill. Also, the establishment of the Circular Economy Action Plan from the EU, sets a climate neutrality target by 2050. Furthermore, it includes the Strategy for Sustainable Built Environment, where the revision of material recovery targets in EU legislation for CDW and Recycled Content Requirements for Certain Products will be discussed [2]. In Cyprus CDW and MW constitutes 62% of total waste generation, 10% higher than the annual average, while the corresponding recovery rates remain significantly low [1]. Even though, efforts and proposals for applying the requirements of a circular economy plan in Cyprus began to be promoted, the conversion from a linear to a circular economy will be long-term [3]. Therefore, researchers have got into continuous efforts in finding new ways of exploitation and valorization of waste materials, such as glass. The annual production of glass fluctuates in high levels, since it has numerous applications in many economic sectors. In the EU, waste glass packaging had a recovery rate of 73% in 2020 [4], while in Cyprus the recovery target was not achieved (8852 tones target, 6433 tones collected) [5]. Limited to no data exist for waste glass which generates from the construction or the manufacturing sector. Transportation of waste glass through EU or neighboring countries is difficult, considering the geographic restrains of Cyprus and also the high weight of glass which rises significantly the cost [6].

Several studies were dealt with the valorization of waste glass in structural and non-structural applications. The implementation of recycled glass as a partial replacement of fine aggregates in cementitious mixtures was successfully investigated through numerous of researches [7-13]. Also, the inclusion of waste glass in geopolymerisation composites was thoroughly examined. Geopolymerisation is a process based on a heterogeneous chemical reaction that occurs between solid materials rich in alumino-silicate oxides and highly alkaline silicate solutions, producing high thermal and fire resistance materials. In general, the addition of waste glass in this process improves rheological properties, affects the compressive strength regarding the Silicate/Alkaline ratio and increases durability [14-19]. For non-structural applications, recycled glass was implemented into pre-cast specimens [20], asphalt mixtures mostly as a mineral powder filler [21-26] and insulation materials (glass foam) [27].

The majority of the aforementioned studies, waste glass was produced by crushing (mainly mechanically), sieved through a pre-defined sieve and then added into the investigated composite. Limited data regarding of how the chosen parameters (cycles, quantities etc.) in the mechanical treatment method, affects the fineness of produced glass. Therefore, the aim of this study was to determine the particle size distribution of industrial waste glass, with the differentiation of treatment parameters and optimum percentage passing through a 75 μm sieve with the aim of producing as fine-grained material as possible. This was needed since further investigation research in geopolymerisation composites, will be conducted by the authors and in literature it was observed that the particle size distribution, effects the durability and the fine-graded waste glass enhances a complete geopolymerization process [28]. Also, the effect of removing labels in commercially produced wine bottles was examined.

2 Materials and Methods

The requirement of obligatory process before use, has resulted into sourcing the waste glass through numerous of industrial glass processing factories in Cyprus. Then, the waste glass was crushed into finer particles through mechanical treatment. Los Angeles abrasion apparatus (EN 1097-2:2020) [29] was used for reducing the waste glass. Quantities of 10 kg and 20 kg of recycled were left rotating inside the machine along with 10 metallic spheres (438 g each) for different number of cycles (500, 1500, 3500, 10000 and 20000). Subsequently, after the treatment each batch was sieved through pre-defined sieves (5, 1, 0.5, 0.25, 0.125, 0.075 and 0.063 mm) for the evaluation of particle size distribution and the remaining mass in each sieve. For the wine bottle experiment, two different batches of 10 kg were tested (one with labels and one with labels removed) and were mechanically treated through a Los Angeles machine for 500 cycles and 4.38 kg metallic spheres.

3 Results and Discussion

Table 1 and Figure 1 demonstrates the particle size distribution of the mechanical treatment method applied into the waste glass for the aforementioned examined parameters.

Table 1. Particle size distribution (passing mass %) on each examined sieve

Sieve size, mm	Passing Mass (%)							
	500 cycles - 10kg	500 cycles - 20kg	1500 cycles - 20kg	3500 cycles - 10kg	3500 cycles - 20kg	10000 cycles - 10kg	20000 cycles - 10kg	20000 cycles - 20kg
5.000	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
1.000	19.61%	18.25%	31.89%	100.00%	49.69%	98.54%	99.83%	95.89%
0.500	10.75%	14.06%	24.92%	51.12%	37.79%	83.82%	95.50%	75.49%
0.250	4.33%	10.42%	18.82%	34.49%	28.25%	62.98%	78.57%	55.21%
0.125	0.00%	7.38%	13.34%	21.97%	19.68%	44.11%	60.73%	39.76%
0.075	0.00%	3.12%	8.98%	14.54%	14.27%	30.88%	46.27%	27.87%
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

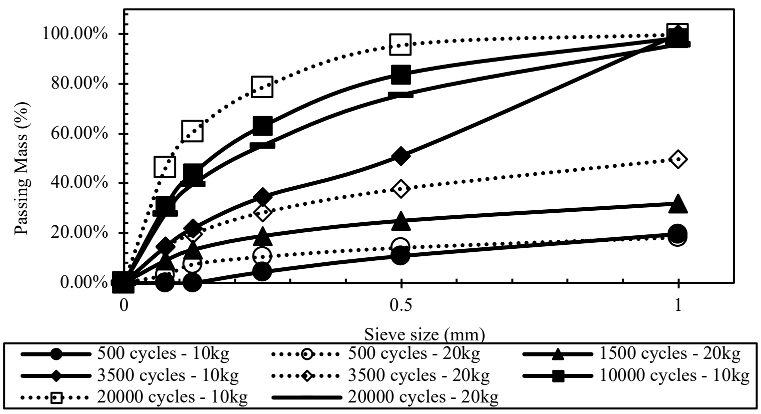

Fig. 1. Passing mass of waste glass on each sieve for each treatment duration

It is noteworthy that the particle size distribution consists an important tool for the design of structural or non-structural applications, since it can affect rheological characteristics, mechanical properties and matrix cohesiveness. Initially, we can observe that after applying the abrasion method on waste glass and without considering the number of rotation cycles and glass quantity, the entire amount of treated material passed the 5 mm sieve. Therefore, a fairly fine-graded material can be achieved with a minimum number of treatment cycles for applications without requiring less fine material. At 500 cycles, the mass passing the remaining sieves was observed as significantly low, where especially for 10 kg of recycled glass, the passing mass below the 0.125 sieve was zero. This might indicate that the number of rotation cycles were not high enough to sufficiently treat the examined material for producing fine-grade glass. For 20 kg of waste glass and 500 cycles of treatment, we can notice that increasing the treatment quantity, increased the passing mass in smaller sieves. Thus, 1500 rotation cycles for treating 20 kg of recycled glass were tested, where a similar behavior as with the 1500 rotation cycles was detected. The passing mass of waste glass below the 1 mm sieve was increased compared to the quantities passing after 500 cycles of treatment (31.89% and 18.25% respectively). Afterwards, treatment rotations were increased from 1500 to 3500 cycles, were the particle size distribution differentiated according with the amount of material tested. For 10 kg of waste material, the percentage mass passing between the 1 mm and 0.125 sieve was higher, however as demonstrated in Figure 2, the amount passing through the 75 μm sieve remains similar compared to 20 kg of material treated (14.54% and 14.27%, respectively). This may imply, that as the rotation cycles were increased, the effect of the quantity of the added material decreases.

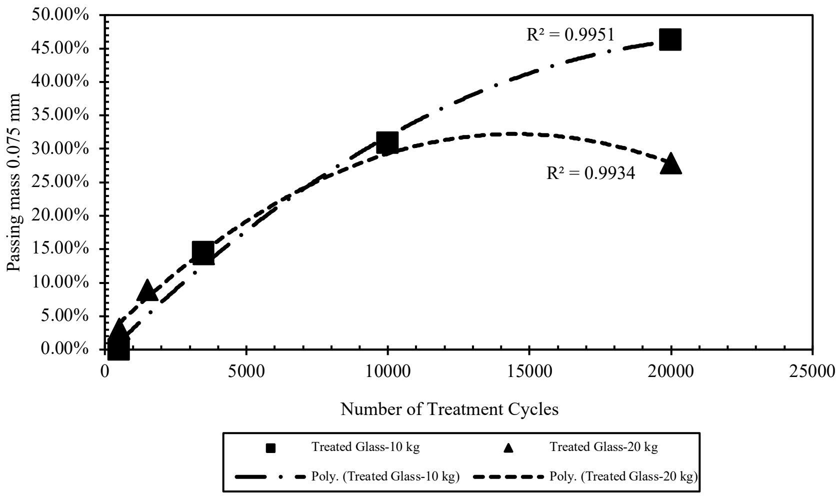

Fig. 2. Passing mass of treated glass on the 75 μm sieve at each treatment cycle

Treatment for 10000 cycles and 10 kg of waste material, increased significantly the passing mass in all examined sieves, compared to previous treatment with less applied rotations. Specifically, for 3500 rotation cycles, even though a similar passing mass was achieved for the 1 mm sieve, the percentage passing in the 0.500 mm sieve was increased from 51.15% to 83.82% and in the 75 μm from 14.54% to 30.88%, respectively. After 20000 cycles of treatment, a similar behavior on the particle size distribution was observed in relation with 10000 rotation cycles, however the passing mass on each sieve was increased and an amount of 46.27% recycled glass passed through the 75 μm sieve. Nevertheless, applying 20000 cycles for 20 kg of the examined material produced a less fine-graded glass, as noted in the declined tradeline in Figure 2. This indicates the presence of a local maximum where after that specific point, increasing the rotation cycles and/or the amount of added material, cannot produce higher amounts of a fine-graded waste glass. Also, the tradeline for 10 kg of recycled glass, implies that after 20000 cycles, increasing the number of treatment cycles will only slightly increase the 75 μm passing mass, which does not justify the corresponding increase in energy consumption and cost. As a result, the optimal mechanical treatment (considering fine material) was chosen for introducing 10kg of recycled glass to the abrasion machine for 20000 cycles.

Table 2 and Figure 3 presents the mechanical treatment results regarding the investigation on the removal of wine bottle labels. The target was to examine whether the presence of labels affects the treatment method on the particle size distribution and the quantities of fine material produced. It was observed that as the sieve size was decreased the passing mass between batches with labels on and labels off were approaching. However, comparing the two batches and considering that the passing mass for all the examined sieves were slightly different between them, the time and cost required for the removal of labels cannot be substantiated.

Table 2. Particle size distribution on wine bottles with or without labels

Sieve size (mm)	Wine Bottles - Labels On		Wine Bottles - Labels Off	
	Remaining mass (g)	Passing mass (%)	Remaining mass (g)	Passing mass (%)
5.000	0	100.00%	0	100.00%
1.000	3580.40	30.75%	3416.80	34.00%
0.500	606.20	19.03%	641.90	21.60%
0.250	411.40	11.07%	443.50	13.03%
0.125	244.60	6.34%	278.10	7.66%
0.075	134.80	3.73%	175.20	4.28%
0.063	39.00	2.98%	71.70	2.89%
0	154.10	0.00%	149.80	0.00%
Total Remaining Mass (g)	5.17	-	5.18	-

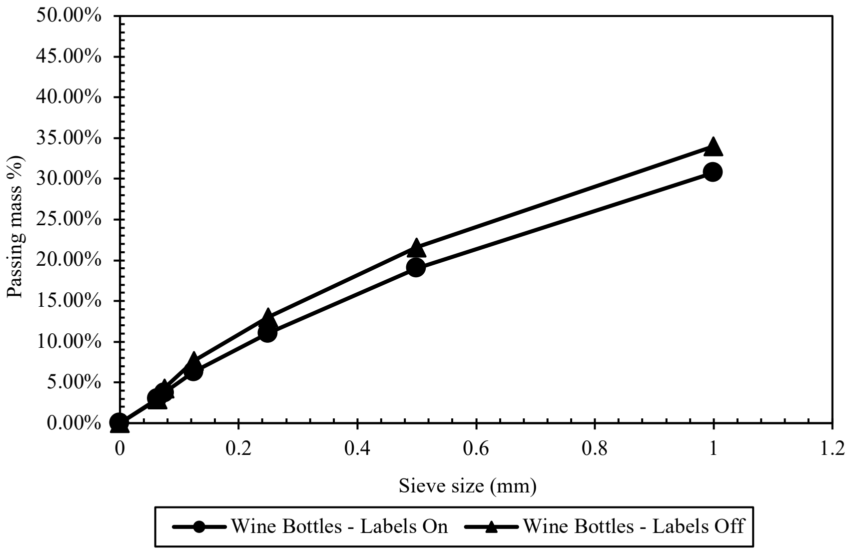

Fig. 3. Particle Size Distribution on wine bottles mechanical treatment

4 Conclusions

An optimal mechanical treatment method for recycled glass was investigated and determined after altering parameters considering the numbers of rotation cycles applied and the quantities of added material. The effect on the particle size distribution was studied after 10 kg and 20 kg of waste glass were treated through a Los Angeles abrasion machine for 500, 1500, 3500, 10000 and 20000 rotation cycles. Main conclusions are presented below:

- Regardless the number of rotation cycles and quantities of waste glass treated with the abrasion apparatus, the passing mass on the 5 mm sieve was 100%. This indicates a beneficial effect on the production of a fairly fine-graded material that possibly doesn't require less fine waste glass.
- It was observed that for 500 rotation cycles, the inclusion of higher quantities of recycled glass, increased the amount passing through the 0.250 mm sieve, however they remained at fairly low levels (4.33% for 10 kg and 10.42% for 20 kg of treated glass).
- A differentiation on the particle size distribution was noted when the number of rotation cycles increased from 1500 to 3500 cycles. Even though, the quantities of recycled glass passing the 75 μm were almost identical (14.54% for 10 kg and 12.27% for 20 kg of material), dissimilarities were observed for higher sieves sizes.
- Passing mass on smaller sieve sizes increased when the rotation cycles increased from 3500 to 10000 cycles (for 0.500 mm sieve was increased from 51.15% to 83.82% and for the 75 μm from 14.54% to 30.88%, respectively).

- For 10 kg of recycled glass an amount of 46.27% recycled glass passed through the 75 μm sieve for 20000 rotation cycles.
- A declined tradeline at the treatment of 20 kg recycled glass and 20000 applied cycles, indicates that after a certain number of rotations cycles the amount of fine-graded material does not continue to increase proportionally.
- The optimal mechanical treatment was chosen for 10kg of recycled glass and for 20000 rotation cycles.
- Since the particle size distribution was closely approaching for wine bottle batches with labels on and off, their removal can be considered as unnecessary due to the required excess cost and workhours.

Further investigation regarding the utilization of fine-graded waste glass through geopolymerisation will be conducted by the authors.

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