III Convegno Internazionale “Refuse, Reduce, Repair, Reuse, Recycle”

IL RICICLAGGIO DI SCARTI E RIFIUTI IN EDILIZIA

Dal downcycling all’upcycling verso gli obiettivi di economia circolare

a cura di

Adolfo F. L. Baratta

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RECYCLING
OF WASTES AND DROSSES IN BUILDINGS
from downcycling to upcycling towards
the objectives of circular economy

Premessa / *Foreward*

Saggi / *Essays*

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Architetture e Paesaggi / Architectures and Landscapes

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Fresh and hardened properties of cement mortars with waste glass fine aggregate

Cement mortar, Waste glass, Workability, Hardened density, Water absorption

Abstract

Waste glass residue after recycling procedures is increasingly becoming an environmental problem, as it cannot be reinserted into the process and has to be disposed in landfills.
In the last decades, research is pushing towards finding new environmental-friendly approaches to recycle industrial and urban waste. Cementitious materials are a very interesting alternative to common disposing practices, as the extraction and processing of raw materials (e.g. sand, cement) cause environmental damages and high pollutant emissions.
Several studies have shown the possibility of partially replacing sand with crushed glass aggregate obtaining mortars meeting the Standard's requirements.
This paper presents the results of experimental tests assessing fresh and hardened properties of mortars made using glass cullet to replace sand aggregate in different percentages.
Obtained results show that glass mortars are equally or less workable (depending on the substitution rate), slightly lighter and absorb more or as much water than traditional sand mortars do.

Introduction

Cementitious materials, such as concrete and mortars, are among the most used building materials, thanks to their features of low cost, wide availability of raw components, ease to make and flexible use. However, environmental damages caused by the extraction of raw materials and the high CO_2 emissions related to the manufacturing process, are pushing the research towards finding environmental-friendly materials to partially replace cement and aggregates [Mollo et al., 2012]. Glass is widely used in daily life and has short lifecycle, so its cullet is increasingly becoming a huge environmental problem [Axinte, 2011 and Edwards et al., 2013]. Many efforts are being made by both research groups and industries to find sustainable alternatives to recycle waste glass (WG); one of the most promising is to use it in cementitious building materials production [Paul et al., 2018]. Glass can be used to partially replace binder [Patel et al., 2019 and Abdollahnejad et al., 2017] or fine aggregate [Ling et al., 2017] to produce concrete [Pavlů et al., 2018 and Ling and Poon, 2014] and cement mortars [Lu et al., 2017 and Degirmenci et al., 2011]. Many kinds of waste glass have been tested, such as heavyweight [Kim et al., 2018], ground [Afshinnia and Rangaraju, 2016 and Corinaldesi et al., 2005], Cathode Ray Tubes

Chemical Composition	Sand [%]	Glass [%]
SiO_2	89.37	71.68
Al_2O_3	1.27	1.81
Fe_2O_3	0.82	0.30
CaO	5.86	11.02
MgO	0.48	1.21
K_2O	0.39	0.60
Na_2O	0.41	12.93
Cr_2O_3	-	0.18
SO_3	-	0.11

1. Chemical compositions of fine aggregates.

(CRT) [Ling and Poon, 2014, Ling et al., 2017, Hui and and Sun, 2017 and Zhao et al., 2013], crushed beverage glass [Ling and Poon, 2012] and glass cullet [Lu et al., 2017 and Agliata et al., 2015]. Focusing our attention on the research field investigating aggregate replacement, different substitution percentages have been tested obtaining encouraging results in terms of workability [Lu et al., 2017,Ling et al., 2011 and Zhao et al., 2013], hardened density and water absorption [Ling and Poon, 2012], drying shrinkage and expansion [Ling et al., 2011, Hui and Sun, 2011, Zhao et al., 2013 and Idir et al., 2010], durability [Tan ad Du, 2013a and Tan and Du, 2013b], mechanical strength [Mollo, 2016, Corinaldesi et al., 2005 and Degirmenci et al., 2011] thermal properties [Sikora et al., 2017], aesthetic properties [Lu et al., 2017,Penacho et al., 2014 and Ling and Poon, 2011]. This paper presents the results of experimental tests carried out to evaluate the possibility of using crushed waste glass cullet as a replacement for fine aggregate in cement mortars. Performed tests concern fresh (workability) and hardened (density and water absorption) properties of mortars with different replacement rates of natural sand aggregate with WG.

Materials and Methods

Locally made type IV grey pozzolanic cement (GPC), meeting the European Standards UNI EN 197-1:2011 and EC 1-2015 UNI EN 197-2:2014

Mix Notation	Sand	Cement	Fine aggregate		Total water
	Subst. [%]	[kg]	RS [m^3]	WG [m^3]	[kg]
CM	0	300	1	0	150
WG 20	20	300	0.8	0.2	150
WG 40	40	300	0.6	0.4	150
WG 60	60	300	0.4	0.6	150
WG 80	80	300	0.2	0.8	150
WG 100	100	300	0	1	150

2. Mix proportions of mortar mixtures.

(CEM IV/A 32.5 R) is used. Fine aggregate is river sand (RS) with most of the particles passing through the 1.00 mm sieve (84.4%). Glass aggregate is the residual fraction of waste glass from a local recycling company. Chemical characteristics of RS and WG are shown in Tab. 1. Glass aggregate is flamed (until the residual char is also eliminated) to remove all possible contaminations. Because of its breakable nature, glass particles exhibit angular shape, sharp edges and the texture of its surfaces is smoother than sand. Then, to avoid elongated particles, that can negatively affect mortars behaviour, only glass particles with Φ < 1 mm are used. Particle size distribution of sand and glass aggregates are determined by sieve analysis (UNI EN 1015-1:2007). Particle density of both aggregates and sand water content after 7 days exposure to air are determined by the pycnometer method (UNI EN ISO 17892-3:2016). Glass water content is assumed to be zero, given the non-porous nature of the material. Mortar mixtures are prepared using tap water with a pH of 7.9. The amount of cement is kept constant (300

Sieve Size [mm]	**Passing [%]**		
	Sand	**Glass (total)**	**Glass (used)**
25.40	100.00	100.00	100.00
19.00	100.00	100.00	100.00
9.51	100.00	100.00	100.00
4.75	100.00	99.14	100.00
2.00	94.57	95.50	100.00
1.00	84.44	59.88	100.00
0.50	62.56	17.96	29.99
0.30	39.58	6.44	10.75
0.15	15.68	2.05	3.43
0.075	5.19	1.02	1.70
< 0.075	0.00	0.00	0.00

3. Fine aggregates particle size distribution.

kg/m^3) and the water/binder/aggregate (W/B/A) ratio is fixed at 0.5/1/3. Glass is used to replace sand from 20% to 100% by weight, with a substitution step of 20%. A total of six mortar mixes are prepared, including a control mix (CM), obtained using 100% sand aggregate. To keep W/B/A ratio constant, the amount of water to be added changes proportionally to the amount of glass, since sand aggregate requires less water than glass to obtain mortars with same rheological properties. This is because of sand absorbed water content (intrinsic humidity), that covers up for a part of the total water needed. To calculate the effective humidity of sand, the measured value of the water content is decreased by the amount of chemically bound water (adsorbed), estimated at 1.5%. Mix proportions of all mixtues are given in Tab. 2. Mortar mixes are prepared according to the standard procedure (UNI EN 1015-2:2007), using a rotating drum type mixer. The consistence of the fresh mixtures, so called "workability", is evaluated by a slump test performed with an "Abrams cone" device (UNI EN 12350-2:2009). With each mixture, samples are made (UNI EN 1015-2:2007) using steel moulds sized 40 x 40 x 160 mm. After casting, mortar specimens are covered with a plastic sheet and kept curing at 20±2°C for the next 24±2 h. At that point, dry bulk density of hardened mortar is determined as the average value of three specimens (UNI EN 1015-10:2007). Mortar specimens are then demoulded and stored in a water tank for curing at 20±2°C until the day of testing. Water absorption of hardened

Degree of workability	Slump [mm]	Class	Slump [mm]	Consistency
Very low	0 - 25	S1	0 - 20	Dry
Low	25 - 50	S2	20 - 40	Stiff
Medium	50 - 100	S3	40 - 120	Plastic
High	> 100	S4	120 - 200	Wet
			> 200	Sloppy

4. Consistency classification according to the Standard.

mortars is determined according to UNI EN 1015-18:2004 standard.

Results and Discussion

Specific gravity of RS and WG is found 2.71 and 2.49, respectively. The particle size distributions of sand and glass aggregates are reported in Tab. 3. The "glass (total)" column shows the particle size distribution of glass as collected from the recycling plant, while the "glass (used)" column depicts the distribution of only particles with a diameter smaller than 1 mm. Fineness modulus of RS and used WG is found to be 3.4 and 5.1, respectively. Actual humidity of sand is 6.9%, that is 8.4% (water content) – 1.5% (adsorbed water). For the workability test, the decrease in height of the centre of the slumped mortars, after the Abrams cone is removed, is measured and compared to the classes provided by the Standard (Tab. 4). The test shows that mortar workability decreases with increasing glass content, as shown in Tab. 5. CM belongs to S2 class and has a stiff consistency. These features are kept by WG20 and WG40. WG60, instead, still showing stiff consistency, is in class S1. Remaining mixes belong to S1 class and have dry consistency.
The reduction in workability can be due to the angular shape of the glass particles, very different from those of sand that, thanks to their rounded shape, reduce friction. Another cause might be the specific surface of glass, which hinders the sliding between the cement matrix and aggregate particles. Glass smoother surface, compared to that of

Mix	Slump [mm]	Slump [%]	Class	Consistency
CM	35.5	11.7	S2	Stiff
WG20	27.5	9.2	S2	Stiff
WG40	25.5	7.5	S2	Stiff
WG60	21.0	7.0	S1	Stiff
WG80	12.0	4.0	S1	Dry
WG100	10.0	3.3	S1	Dry

5. Slump test classification of tested mortars.

sand, also requires a higher amount of water for hydration and a greater quantity of cement paste to be completely covered and lubricated. Tab. 6 reports the results of the hardened density (ρ) assessment test. They show that the density of mortars decreases with increasing glass content. The CM sample has the highest hardened density value among all the mixes (2.12 g/m^3), while the WG100 sample has the lowest value (2.02 g/cm^3), with a reduction rate of 4.7%. The lower density of glass mortars is related to the relatively low specific gravity of glass (2.49 g/cm^3) compared to natural sand (2.64 g/cm^3). Results of the water absorption test are shown in Tab. 7. Water absorption has a vaguely increasing trend with increasing of glass replacement, although the trend is not regular. The higher water absorption rate shown by glass mortars may be due to i) the greater specific surface of the glass and ii) to the increase in the volume of voids due to the angular nature of the glass particles, which create larger spaces both among the aggregate particles and between the cement matrix and the aggregates. WG100 is an exception as its water absorption is almost the same than CM.

Conclusions

Performed tests show the feasibility of using waste glass, as it comes from the recycling plant, i.e. with no need for additional grinding, as a substitute for natural aggregates in cement mortars. Obtained results

Mix	1 day weight [g]	ρ [g/cm^3]	Standard deviation	Decreasing rate
CM	542.8	2.12	0.0065	-
WG20	538.1	2.10	0.0144	0.9
WG40	532.2	2.08	0.0106	1.9
WG60	528.8	2.07	0.0142	2.4
WG80	518.5	2.03	0.0099	4.3
WG100	516.7	2.02	0.0169	4.7

6. Hardened density values of tested mortars.

are encouraging and comparable with those achieved by other authors using glass pre-treated before experiment. Based on the results obtained from the performed tests, it is possible to conclude the following:

- Workability of fresh mortar reduces as the percentage of sand replacement with glass increases. However, up to substitutions in the order of 40%, the class and the consistency of the obtained mortar remain unchanged.
- Increasing the glass content results in a lighter material. Indeed, the hardened density of WG mortars decreases with increasing glass content by about 1% each 20% sand replacement. Glass mortar with 100% aggregate substitution shows the minimum value of density, about 5% lower than CM.
- Water absorption has an oscillatory trend, slightly increasing with glass content. Further tests are need for a better understanding of this behavior, especially for mortar with 100% sand replacement.

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Mix	1 day weight [g]	7 day weight [g]	Water absorption [%]
CM	542.8	553.5	2.0
WG20	538.1	547.8	1.8
WG40	532.2	542.8	2.0
WG60	528.8	542.0	2.5
WG80	518.5	534.8	3.1
WG100	516.7	527.5	2.1

7. Water absorption of tested mortars.

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La III° edizione del Convegno Internazionale dedicato a "Il riciclaggio di scarti e rifiuti in edilizia: dal *downcycling* all'*upcycling* verso gli obiettivi di economia circolare" si è tenuta a Roma il 24 maggio 2019.
I contributi raccolti, articolati in tre sezioni ("Saggi", "Ricerche" e "Architetture e Paesaggi") e provenienti da quattordici differenti sedi universitarie, propongono delle riflessioni comuni sulle implicazioni ambientali, economiche, sanitarie e sociali nella gestione dei rifiuti. Anche se non possono essere letti in continuità perché restituiscono differenti punti di osservazione del tema trattato, i contributi restituiscono un quadro complessivo che offre lo spunto per diverse riflessioni.

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