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RECYCLING WASTE FOR THE PRODUCTION OF SUSTAINABLE MORTARS FOR BRICK MASONRY

Extended abstract

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Background

For many years bedding mortars have been considered a secondary component in structural brick masonry walls and they were classified only on the base of their binder (see, e.g., the Italian law DM 20/11/1987 concerning the Regulation for designing, building, testing and strengthening masonry) rather than characterized for their actual mechanical performance. This approach has recently changed and joint mortars have gained higher and higher attention, as they substantially influence the final mechanical performance of masonry. At the same time, a growing awareness of the sustainability issue has been registered in the field of building materials (Bignozzi, 2011), given the extremely high environmental impact of the construction sector (Franzoni, 2011) and its expected increase due to the global population growth (estimated to pass from 6.5 billion in 2005 to about 9.0 billion in 2035 (Dixit and Fernandez-Solis, 2010)). In this scenario, mitigating the consumption of raw materials and energy the manufacturing of building materials is of paramount importance and recycling waste and by-products appears as a feasible route toward this goal.

Nevertheless, while recycling waste in concrete was widely investigated and has now entered the building practice, even if with some limitations and die-hard prejudices, the use of not hazardous waste and by-products for masonry (and in particular for mortar joints) is much less considered, despite the widespread presence of structural masonry and wall plug all over the word.

In this paper, different mortars with improved sustainability were prepared, partially or totally substituting the fine aggregate with recycled fractions (sand from grounding demolished concrete or end-use tyre rubber) or replacing the cement with a low-carbon binder (alkali-activated binder).

After a first characterization of the mortars in terms of strength and microstructure, some brick masonry triplets were built and characterized to assess their properties, with particular reference to their shear behaviour, in view of their possible use in masonry buildings in seismic zones of the world.

Methods

A reference mortar (*REF*) was prepared with cement CEM II/A-LL 42.5R (EN 197) and standard quartz sand (EN 196-1), according of the same proportions of the EN 196-1 standard mortar (450 g cement, 1350 g sand) and adjusting the amount of water in order to obtain a mortar diameter at the flow table test (EN 1015-3) equal to 18±1 cm (water 250 g). This flow was considered representative of the workability of a typical mortar for brick masonry construction.

Mortars with improved sustainability were prepared according to the following formulations, respect to REF:

- mortars with a partial (25%) or total substitution of the natural quartz sand with recycled sand, obtained by grinding the concrete coming from the demolition of the well known unauthorised structures in Punta Perotti, Italy

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(Manzi et al., 2013). The grain size distribution of the recycled sand was selected in order to reproduce the distribution of the natural one. These mortars were labelled as *DEM25%* and *DEM100%* respectively;

- mortars with a partial substitution (25 v/v% and 50 v/v%) of the natural sand with ground end-use tyre rubber (*RUB25%* and *RUB50%*). Exploring new routes for tyre rubber recycling is of great environmental relevance after to the European Directive 99/31/EC banned the disposal of this kind of waste (Ferretti and Bignozzi, 2012). Also in this case the grain size distribution of the recycled aggregate was selected in order to reproduce the distribution of natural sand;
- mortar where cement was totally substituted with an alkali-activated binder (*AAB*). Such binder was obtained from 300 g ladle slag from steel production, 200 g metakaolin and 300 g aqueous solution of NaOH 8M and sodium silicate (weight ratio 1:1).

In all the mortars the amount of water was adjusted in order to achieve the same workability obtained for REF. The resulting water amounts were 283 g for DEM25%, 455 g for DEM100%, 300 g for RUB25%, 330 g for RUB50% and 100 g for GEO.

For each mortar, 3 prisms 4×4×16 cm^3 were prepared in a Hobart mixer, according to the procedure in EN 196-1, demoulded after 1 day and then cured at 20±2 °C and relative humidity >90% up to 28 days.

Then masonry triplets were built using three full bricks (RDB, Italy), having size 5.5×12×25 cm^3 and mean compressive strength 36 MPa. Mortars of 1 cm thickness were placed between the bricks, previously water saturated. Curing at room conditions (T = 20±2 °C and RH = 45±5%) for 28 days followed. Before the tests, the triplets were left to further dry at room conditions for 1 more week.

Compressive strength test was carried out on the mortar prisms at 28 days according to the procedure in EN 196-1. Microstructural characterization was performed by mercury intrusion porosimetry (Porosimeter 2000 Series Carlo Erba and Fisons Macropore Unit 120). Given the presence of a low elastic modulus and compressible fraction (tyre rubber) in the mortars RUB25% and RUB50%, the porosimetry was not carried out on the relevant samples and the main physical-mechanical parameters (bulk density and open porosity) were obtained by water absorption test and hydrostatic weighing of the water saturated mortar samples.

The masonry triplets were tested for shear strength in an Amsler Wolpert Machine (100 KN), under constant strain rate 1 mm/min (Amsler Wolpert Machine, 100 KN), with no lateral constraint (Gentilini et al., 2012), according to the scheme in Fig. 1 (left). The shear strength values obtained are the average of three samples.

The compressive strength test was performed in a Metro Com machine (400 t, 4 MPa/s), after capping the samples with a cement-based grout, according to the scheme in Fig. 1 (right). The compressive strength is the average of three samples.

Fig. 1. Scheme of the shear and compressive test and a triplet during the testing

Results and discussion

The results obtained on the mortar samples are reported in Table 1.

Substituting quartz sand with recycled sand from demolished concrete can lead to a decrease in the compressive strength of the mortar respect to REF, due to an increase in the total open porosity of the material. This is due to the intrinsic porosity of the recycled aggregate, which contains not only crushed aggregates but also cement paste. The higher porosity of the recycled sand also involves a significant increase in water demand for achieving the same workability than the reference mortar (283 g and 455 g for DEM25% and DEM100% respectively, against 250 g for REF).

Conversely, the use of ground tyre rubber (RUB25% and RUB50%) involves a slight porosity decrease respect to the reference sample, as the water absorption of the rubber is essentially zero, and a drastic decrease in compressive strength. However, given the low density of tyre rubber, the bulk density of the relevant mortar is very low. In terms of water demand at the fresh state, the mortar with recycled tyre rubber requires more water than REF, probably due to the angular shape of the rubber particles which hinders the fresh mortar flowability. The mortar with alkali-activated binder exhibits a slightly higher porosity and a lower compressive strength than REF.

In Table 1 the results obtained on the masonry triplets are summarized, comparing the shear and compressive strength and the shear modulus of the recycled mortars with those of the reference one.

In terms of compressive strength (Fig. 2), the decrease experienced by the triplets with the recycled mortars is less pronounced respect to the decrease experienced by the mortars alone, due to the confinement exerted by the bricks on the mortar layers. For example, substituting a 25% of the sand with recycled sand from concrete demolition (DEM25% in Table 1) leads to a masonry compressive strength substantially identical to REF. Also in the case of AAB, the reduction of compressive strength in the masonry triplet is much more limited than in the mortar prisms.

Conversely, a 25% substitution of sand with sand from concrete demolition almost redoubles the shear strength of the triplets respect to REF and does not substantially alters the shear modulus, probably due to the angular shape of the recycled sand, which opposes the shear sliding. However, when the sand is fully substituted with recycled one, the effect of the porosity increase prevails and the shear strength slightly decreases, but in any case marginally respect than in the case of mortars alone. In any case, the partial substitution of sand with tyre rubber causes a significant loss of shear strength and modulus (Table 1), although a possible contribute to the energy dissipation during earthquake is still to be investigated. In the case of the alkali-activated binder, the decrease of shear performance is considerable.

Table 1. Samples properties (σ_c= mean compressive strength, OP=open porosity, ρ = bulk density, σ_s= mean shear strength, $\Delta\sigma_c$= variation of compressive strength compared to REF, $\Delta\sigma_s$= variation of shear strength compared to REF, ΔG= variation of shear modulus compared to REF)

Sample	*Mortars*			*Masonry triplets*				
	σ_c *(MPa)*	*OP (%)*	ρ *(g/cm^3)*	σ_c *(MPa)*	$\Delta\sigma_c$ *(%)*	σ_s *(MPa)*	$\Delta\sigma_s$ *(%)*	ΔG *(%)*
REF	47.5	18.0	2.04	40.7	-	0.8	-	-
DEM25%	39.8	22.0	1.92	39.2	-4	1.5	+80	+5
DEM100%	22.2	35.4	1.64	28.6	-30	0.7	-16	+3
RUB25%	14.2	17.4	1.70	25.6	-37	0.6	-30	-20
RUB50%	3.5	14.7	1.35	18.4	-55	0.3	-66	-53
AAB	32.2	21.2	2.06	35.4	-13	0.3	-66	-44

Fig. 2. A triplet after the compressive strength test

Concluding remarks

Sustainable mortars containing different recycled fractions in place of sand or binder were formulated, prepared and characterized, and their properties compared with those of a reference cement-based mortar.

Then, the compressive and shear performance of brick masonry models manufactured with these mortars was investigated.

The results obtained for the brick triplets showed that the substitution of a 25% of natural quartz sand with a recycled sand from concrete demolishing involves almost an identical compressive strength and a strong benefit in terms of shear strength (+80%), leaving substantially unaltered the shear modulus. This increase is of great relevance when masonry is subjected to seismic actions.

For a 100% substitution, however, the beneficial effect of the angular aggregate shape is counterbalanced by its higher porosity respect to the natural sand, hence a slight decrease in the shear strength (-16%) and a marked decrease in compressive strength (-30%) are found.

The use of recycled sand also involves a higher water demand for achieving a suitable fresh state workability. The use of tyre rubber as a replacement for sand has a beneficial effect in terms of mortar bulk density, but it leads to a performance downfall, although its possible contribution to energy dissipation in dynamic conditions is currently under investigation. The alkali-activated binder involves a moderate decrease in compressive strength of the triplets (-13%), but a relevant worsening of their shear behaviour.

Hence a reduction of AAG mortar porosity, by an improvement of the formulation of the precursors, seems necessary for improving the mortar properties and it is presently under investigation.

Keywords: alkali-activated materials, C&D waste, end use tyres, shear behaviour, sustainability

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