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Research Article

Rheological behaviour of cement mortar with recycled organic sand

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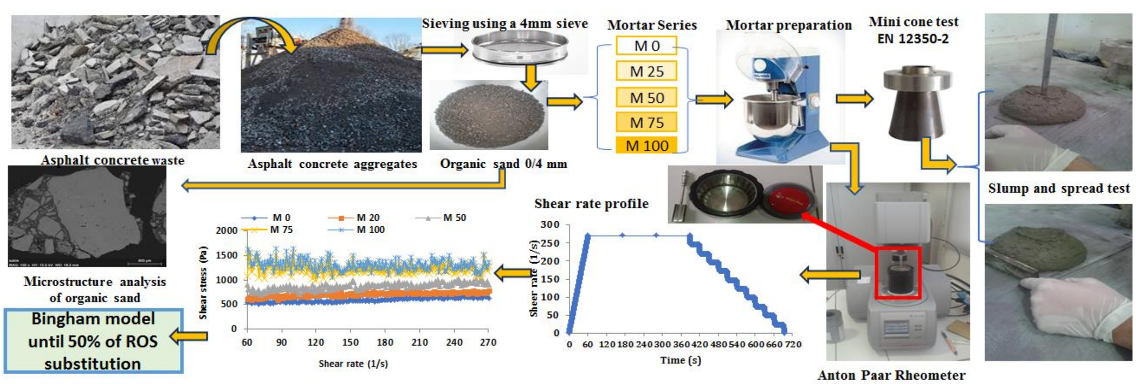
Graphical Abstract:



Highlights:

- Recycled organic sand aggregates define the fresh properties of the recycled mortar.
- Rheological behaviour, slump and spread of recycled mortars are analysed.
- Mortars followed the Bingham model up to 50% of ROS substitution.

Abstract: The aim of this paper is the study of rheological behaviour of the recycled organic sand (ROS) in cement mortar, using derived sand from recycled asphalt pavement (RAP). Four substitutions amount of ROS sands (25%, 50%, 75%, and 100%) against the weight of natural sand (NS) were used to obtain M 25, M 50, M 75, and M 100 respectively which were compared with the reference mortar M 0. In this study, the water/cement (w/c) ratio was kept constant at 0.55 for all mixtures. Fresh properties were given form slump test and spread measurements, when, the rheological parameters such as shear stress, yield stress and plastic viscosity were obtained by using a rotating Anton Paar rheometer; the test result shows that both of slump and spread were negatively affected by increasing the sand substitution. The shear stress, yield stress and plastic viscosity were increased with the increasing the substitution amount. All mortars followed the Bingham model until 50% of ROS substitution, after this amount, the obtained mortars were segregated.

Keywords: ROS Sand, fresh properties, rheology, Bingham model, segregation.

List of abbreviations:

ROS - recycled organic sand

NS - natural sand

RAP - recycled asphalt pavement

RAC - recycled aggregate concrete

M0 - control cement mortar

M25 - cement mortar with 25% of recycled organic sand

M50 - cement mortar with 50% of recycled organic sand

M75 - cement mortar with 75% of recycled organic sand

M100 - cement mortar with 100% of recycled organic sand

CDW - construction and demolition waste

T - shear stress

$\dot{\gamma}$ - shear rate

$\tau 0$ - yield stress

μ - plastic viscosity

C - ordinary Portland cement type CEM I 52.5

W/C - water/Cement ratio

Rpm - round per minute

SEM - scanning electron microscope

SCC - self-compacting concrete

EMV - equivalent mortar volume

R^2 - coefficient of determination

1. Introduction

An excessive amount of construction and demolition waste (CDW) and recycled aggregate pavement (RAP) are generated in urban areas, annually millions of these wastes are produced in Algeria. The aggregates coming from (RAP) are available in high quantities, and their valorisation remains a recurring economic issue (Kumari, Ransinchung, and Singh, 2018; Settari, Debieb, Kadri, and Boukendakdji, 2015; Singh, Ransinchung RN, and Kumar, 2017; Sola and Ozyazgan, 2017). Several researchers developed a recycled aggregate for use in concrete production (Arulmoly, Konthesingha, and Nanayakkara, 2021;

Debieb, Courard, Kenai, and Degeimbre, 2010; Duan, Hou, Xiao, and Singh, 2020; Irki et al., 2018; Jiang et al., 2019; Vázquez, Barra, Aponte, Jiménez, and Valls, 2014). In almost of research's, the coarse and fine recycled aggregates are from (CDW) (Castaño-Cardoza, Linsel, Alujas-Diaz, Orozco-Morales, and Martirena-Hernández, 2016; Debieb et al., 2010; Guo et al., 2017; Li, 2009; Lima, Leite, and Santiago, 2010; Silva, De Brito, and Dhir, 2018; Tahar et al., 2015 Sahraoui et.al., 2019). The use of (RAP) as coarse aggregate in the production of concrete for structural and non-structural applications has been one of the main alternatives to minimise the environmental impact of irregular deposition of this waste (Kumari et al., 2018; Riccardi, Falchetto, Losa, and Wistuba, 2016; Settari et al., 2015; Singh, Ransinchung, Monu, and Kumar, 2018; Singh et al., 2017).

A large increment of fine (RAP) aggregates specifically recycled organic sand (ROS), in order to be used as a substitute for natural sand in concrete. However, the limited use of fines of (CDW) and fines (RAP) as fractions in structural concrete are tested in the production of cement mortars (Çelik Sola and Ozyazgan, 2017; Lima and Leite, 2012; Miranda and Selmo, 2006; Tahar et al., 2015). Several studies tested the influence of (CDW) on the fresh mortars(Benabed, Azzouz, Kadri, Kenai, and Belaidi, 2014; Braymand, François, Feugeas, and Fond, 2015; de Oliveira, Gomes, and Nepomuceno, 2013; Karim Ez-ziane, Ngo, and Kaci, 2014; Faleschini et al., 2014; Irki et al., 2018; Joudi-Bahri, Lecomte, Ouezdou, and Achour, 2012; Lima, Toledo Filho, and Gomes, 2014; Ngo, Bouvet, Debieb, and Aggoun, 2017), but few types of research have been studied the effect of (ROS) on the even state on the cement mortar (Çelik Sola and Ozyazgan, 2017; Riccardi et al., 2016; Singh et al., 2018; Singh et al., 2017); (Flora Faleschini et al., 2014) studied the Rheology of fresh concretes with recycled aggregates, when, González-Taboada, I., et al., analysed the rheological behaviour of self-compacting concrete made with recycled aggregates González-Taboada, González-Fonteboa, Martínez-Abella, and Seara-Paz, 2017; Güneyisi, Gesoglu, Algın, and Yazıcı, 2016; Lima et al., 2014; Silva et al., 2018), Sahraoui, M et.al., investigated the effect of sand types on the flowability and rheology of SCC (Sahraoui, M et.al., 2019), Kesseir, M et al. studied the effect of the valorisation of the natural pozzolan on rheological and mechanical properties of high performance mortar (Kesseir, M et al. 2020), Tekin, K et al. have evaluated the effects of particle size optimisation of quartz sand on the rheology and ductility of engineered cementitious composites (Tekin, K et al. 2022).Other recent research has investigated the adhesion and rheological properties of fresh mortar with manufactured sand as a replacement for river sand (Ren, Q et al. 2024).Rheology provides valuable insights into the characteristics of fresh concrete, aiding in the optimization of its composition and attainment methods. Rheological models have demonstrated efficiency in predicting the fresh properties of cementitious composites (Nazar, S et al.2020), offering a scientific approach compared to reliance solely on intuition. A flow curve depicts the relationship between shear stress (τ) and shear rate ($\dot{\gamma}$), distinguishing between two primaries rheological behaviors: viscous fluid and viscoplastic fluid. Newtonian fluids represent the simplest case within the viscous fluid category. Literature widely examines the rheological characteristics of fresh cement-based materials, revealing their possession of a yield stress (τ_0) (Jiang, D et al.2020, Li, B. 2021), essentially categorizing them as viscoplastic fluids. The archetype of such materials is the Bingham fluid, which exhibits a linear correlation between shear stress and shear rate once flow initiates (when $\tau > \tau_0$), characterized by a constant plastic viscosity (μ). The flow behavior of the Bingham fluid is encapsulated by Equation (1)

$$\tau = \tau_0 + \mu\dot{\gamma} \qquad (1)$$

where τ is the shear stress applied to the material, τ_0 is the yield stress; μ is the plastic viscosity and $\dot{\gamma}$ present the shear rate. The fresh mortars are tested in cylindrical samples at different rotate speed, and measuring the torques exerted to maintain rotation.

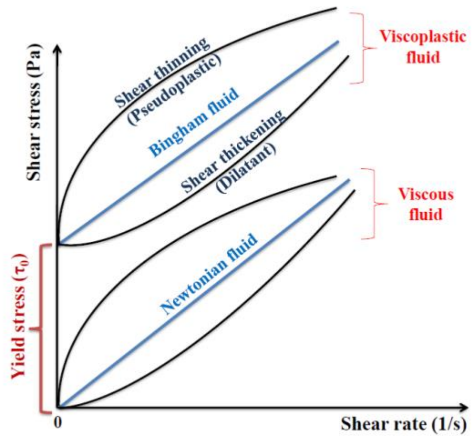


Figure 1. Flow curve for viscous and viscoplastic fluids (Safiddine, S, et .al 2021).

The objective of this study is the examination of the (ROS) influence on the rheological behaviour of fresh mortars as a partial replacement of natural sand, and predict the segregation resistance of mortars based on recycled sands using a very efficient rheometer, rather than just optimising mixes using conventional methods based on mortar slump and flow, in order to obtain the optimum substitution amount.

2. Materials and methods

2.1. *Materials*

For all mortar mixtures, an Ordinary Portland Cement (C) type CEM I 52.5 with a Blaine finesse of 359 m²/kg was used, its chemical and mineralogical composition is summarized in Table 1.

Table 1. Chemical and mineralogical composition of cement.

Properties	Chemical composition (%)								Mineralogical composition (%)			
Cement	SiO_2	AL_2O_3	Fe_2O_3	CaO	SO_3	MgO	K_2O	Na_2O	C_3S	C_2S	C_3A	C_4AF
	20.3	5.20	3.1	64.0	3.10	0.9	0.8	0.21	41.8	33.3	5.1	10.7
Blaine finesse (m^2/kg)	359											

The ROS sand was used as substitution with natural sand, which is composed of natural sand with more than 70.69% of calcite assembled by a carbon.

2.2. *Mix design*

Five mix designs with ROS sand, (M 25, M 50, M 75, and M 100) and a reference mortar (M 0) without any substitution is made. To well understand the effect of ROS amount on rheological properties, the mortar composition was varied. In this study, the W/C ratio and the cement content were kept constant for all mixes (W/C = 0.55, C = 400 g, W= 247.5 g).

Table 2. Mortar compositions.

		M 0%	M 25%	M 50%	M 75%	M 100%
Cement (g)		450	450	450	450	450
Sand (g)	NS	1350	1012.5	675	337.5	0
	ROS	0	337.5	675	1012.5	1350
Water (g)		247.5	247.5	247.5	247.5	247.5
W/C		0.55	0.55	0.55	0.55	0.55

2.3. *Mortar preparation*

In order to confirm a comparable result, the same mixing sequence and the same mixer were used for all mixtures, this parameter can avoid the effect of mixing procedure and equipment on mortar rheology. According to EN 196-1, the fresh mortar is prepared under 62.5 rpm as the following steps:

- Mixing the dry constitutions of mortars for one minute.
- Adding progressively the water during the next 30 seconds.
- Continuing the mixing for one minute it was stopped for 30 seconds in order to scrape off the material that had adhered to the sides of the mixing bowl with a plastic spatula.
- Second mixing for one minute.

2.4. Test methods

To characterize the rheological behaviour of the different mortars, two tests, specifically a mini-cone and rheological test were performed. In the first test, we have measured the slump and the spread; where the rheological properties were obtained from the second test. The testing details are given below.

2.4.1. Mini-cone test

This test consists to use a cone with a half dimension given in the norm NF EN 12350-2 to perform the slump and the spread of the approximately 687 ml of mortar involved (Safiddine, Debieb, Kadri, Menadi, and Soualhi, 2017), the upper diameter was 50 mm, the lower diameter was 100 mm and a height of 150 mm. After one minute, the cone was softly lifted and the diameter of the pad formed was measured under tow perpendicular directions; which the spread value obtained is the average value of the two measurements; the slump measured in parallel to the spread test (Schwartzentruber and Catherine, 2000).

Figure 2. Mini-cone test.

2.4.2. Rheological-test

In this study, rheological parameters were measured using Anton Paar rheometer. The rheological behaviour of mortars was monitored during the first 50 min since the constituents were mixed (Lima et al., 2014). The type of this rheometer is a rheometer with concentric cylinder, the lower cylinder turns in rotation to the geometry of a ray agitator of 15 mm and of height 40 mm. The extern cylinder is a 74 mm of diameter and a height of 85 mm; this last equipped with 24 vertical rays on the interior generating surface. Every ray is a right section of shape squared of 1 mm of quote.

Figure 3. Anton Paar rheometer.

Mortars and concrete can be described in several cases with adequate accuracy by the Bingham model (Boisly, Kastner, Brummund, and Ulbricht, 2014; Lima et al., 2014; Hamza Soualhi et al., 2017; H Soualhi et al., 2014). In this study, the studied mortar is considered as a fluid, when fluid rheology methods are solicited to describe the mortar flow; two fundamental rheological parameters: the yield stress and the plastic viscosity according to the Equation. 1; the shear rate profile is presented in figure 4.

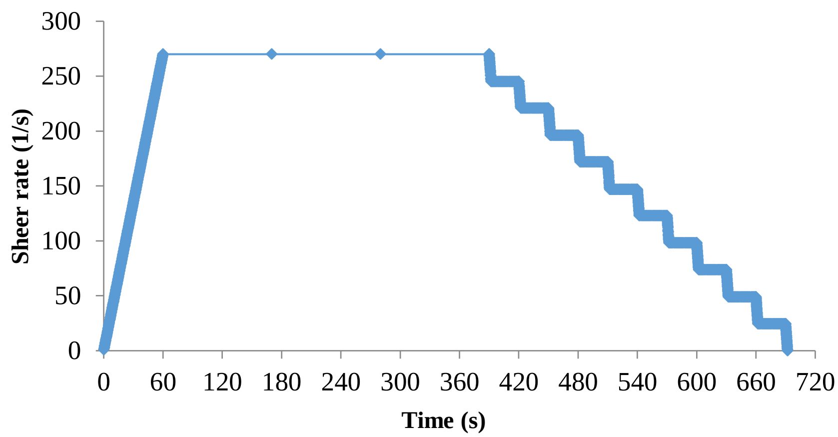


Figure 4. Shear rate profile.

3. Experimental results and analysis

3.1. Aggregates characterization

The qualitative evaluation of the surface of the particles was performed by SEM analysis showed in Figures 4.a and 4.b of natural and recycled organic sand, it can be observed that the texture surface of ROS is rougher than natural sand. The natural sand sample presented a particle shape more rounded, as previously described in the literature (Westerholm, Lagerblad, Silfwerbrand, and Forssberg, 2008) as compared with ROS are slightly more elongated than the natural sand caused by the assemblage of more than two natural particles; the results found are in concordance with the obtained result by (Lima et al., 2014).

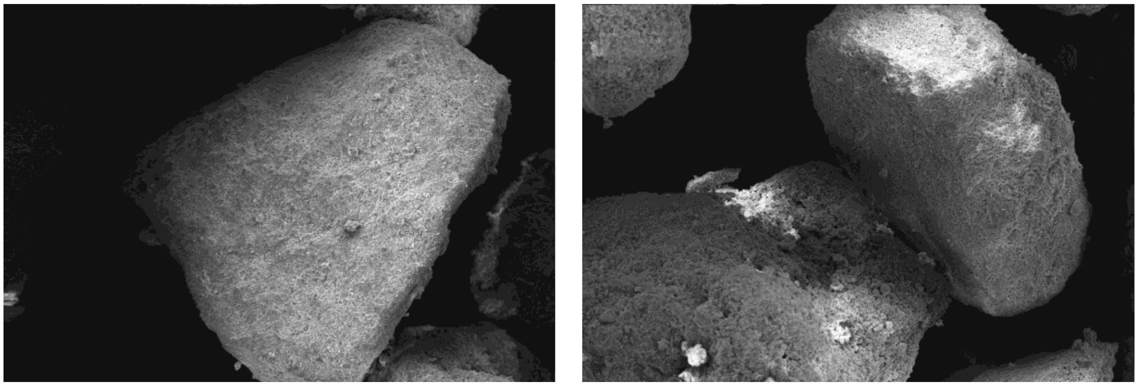


Figure 5. Surface texture of a).natural sand (left), b). organic sand (right).

The ROS has an irregular shape and size nevertheless fibrous structures can clearly be observed (Çelik Sola and Ozyazgan, 2017); mainly, the rough texture when both natural and recycled coarse aggregates are crushed-shaped and the fines content in the recycled aggregate lead to different rheological variations in SCC (González-Taboada et al., 2017).

3.2. Slump test and spread properties

The properties of mortars with ROS sand at the fresh state are presented in figure 6, the flowability decreased as the ROS replacement ratio increased. The statement that the spread decreases means that the material becomes more and more rheo-fluid when increasing the percentage of ROS. The EMV method strongly reduces slump and thus causes an increase in yield stress also affects plastic viscosity (Faleschini et al., 2014) and negatively influences the workability and rheology of fresh concrete (Bizinotto, Faleschini, Fernández, and Hernández, 2017). According to previous research of (González-Fonteboa, González-Taboada, Carro-López, and Martínez-Abella, 2021; Safiddine et al., 2017; Tahar et al., 2015), the workability of mortar is affected by increasing the content of recycled sand. The decrease in workability may attribute to the angular and irregular shape of the recycled sand particle that can improve the friction between the particles of sand mixture (Safiddine et al., 2017).

Since, according to Nehdi et al. and Artelt et al., the replacement of material with another of different specific surface area, could change the wet surface area and the amount of adsorbed water (Nehdi, Mindess, and Aïtcin, 1998, Artelt and Garcia, 2008).

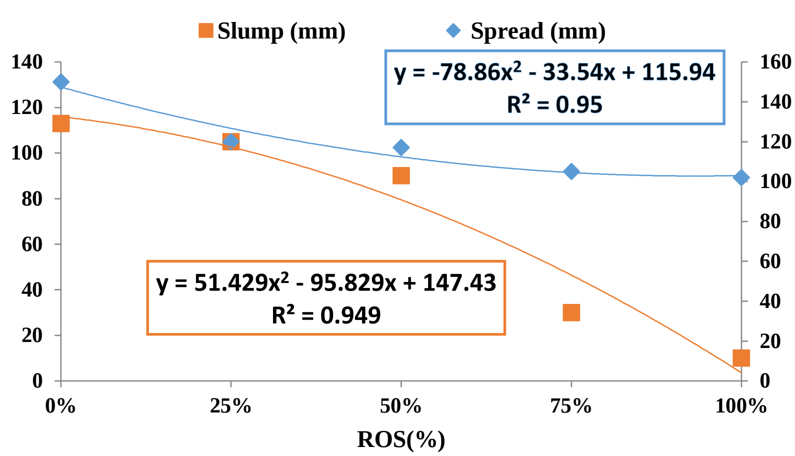


Figure 6. Spread / slump curve.

In other research, the self-compactibility characteristics of the concretes are remarkably improved by the replacement levels of CRCA and FRCA used in SCC mixtures (Güneyisi et al., 2016). (Diego Carro-López et al., 2018) demonstrated that all rheological behaviour of self-compacting concrete was increased with increasing the fine recycled aggregates amount.

3.3. Rheological properties

Sheared materials were considered as Bingham fluid to determine the rheological parameters from measurements, the progress of the torque with the rotational speed is shown in Figure 7. Recycled mortars show higher torque resistance, as observed than natural mortar, which can be explained by the significant presence of fine particles (Esteves, Cachim, and Ferreira, 2010); in our study, we can see that the segregation is obtainable for mortars with 75 % and 100 % of ROS.

The test results show that mixtures have Bingham materials behaviour, the yield stress and plastic viscosity were obtained from the Brookfield Anton Paar rheometer.

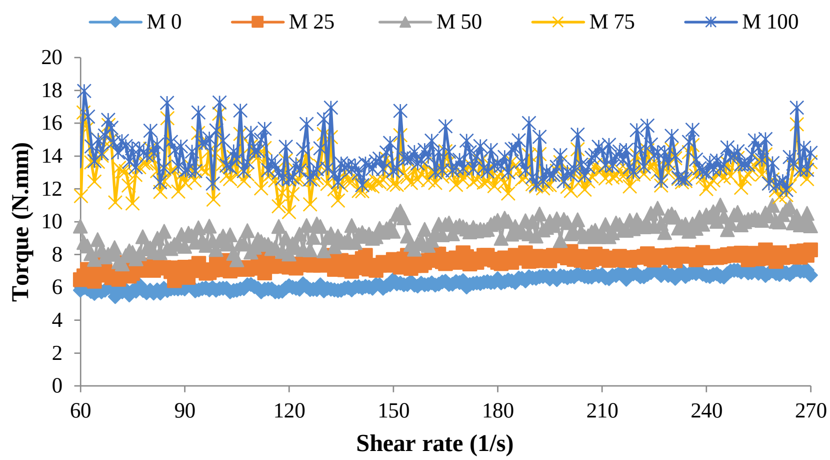


Figure 7. Torque variation of ROS mixtures.

Experimental data from the Brookfield rheometer results for all mortars are indicated in figure 8. The Bingham model resulted in an adequate fitting, with all values of the coefficient of determination (R^2) higher than 0.88; it is clearly observed that the shear stress is higher for the mixtures based on 50% of ROS sand, with the increase of the shear rate.

After this replacement amount (up to 50%), shear stress is more hysteresis than other mortars which is considerate as segregation sign (Faleschini et al., 2014); it can be seen that the ROS aggregate has a significant effect on the rheology of the cement mortar, recycled mortars show higher shear stress, which can be explained by the greater presence of organic particles and the particle shape (Esteves et al., 2010).

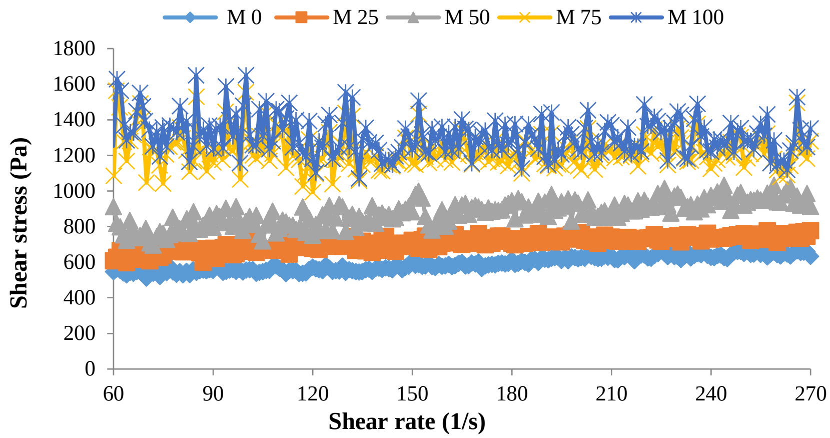


Figure 8. Shear stress variation of ROS mixtures.

Figures 9 a and b, showed the evolution of yield stress and viscosity of mixtures with the w/c ratio of 0.55; it can see that the RBS leads to increase values of yield stress and a viscosity (Tahar et al., 2015).

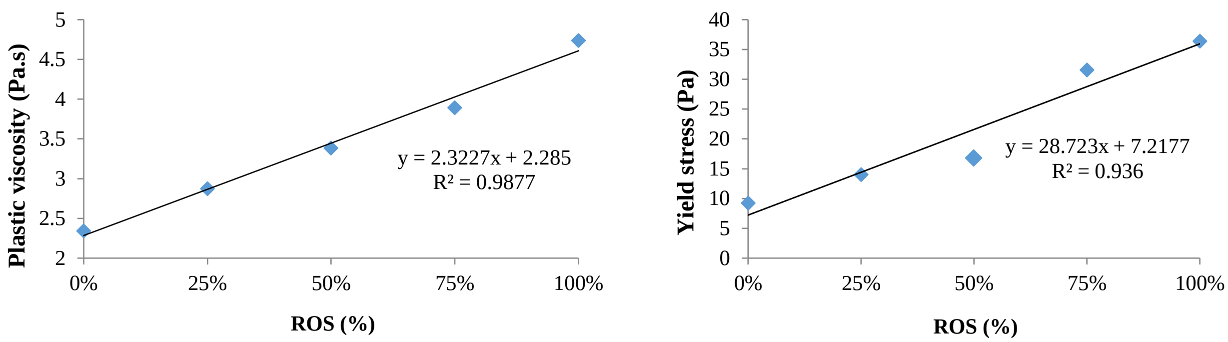


Figure 9.ROS sand substitution effect on a). plastic viscosity (left); b). yield stress (right).

The addition of recycled materials like the ROS sand can affect the workability of mortars, the irregular shape of ROS sand grains presented in figure 10 can increase the grains friction of sand mixture and decrease workability. Subsequently, increase the yield stress (Safiddine et al., 2017). According to (Flora Faleschini et al,.2014) recycled aggregate concrete (RAC) can be modelled as a Bingham fluid, viscosity and yield stress can properly describe its rheological behaviour; while the use of dry recycled aggregates leads to the absorption of the mixing water in uncompensated mixes, causing an increase in both yield stress and plastic viscosity(Silva et al., 2018).

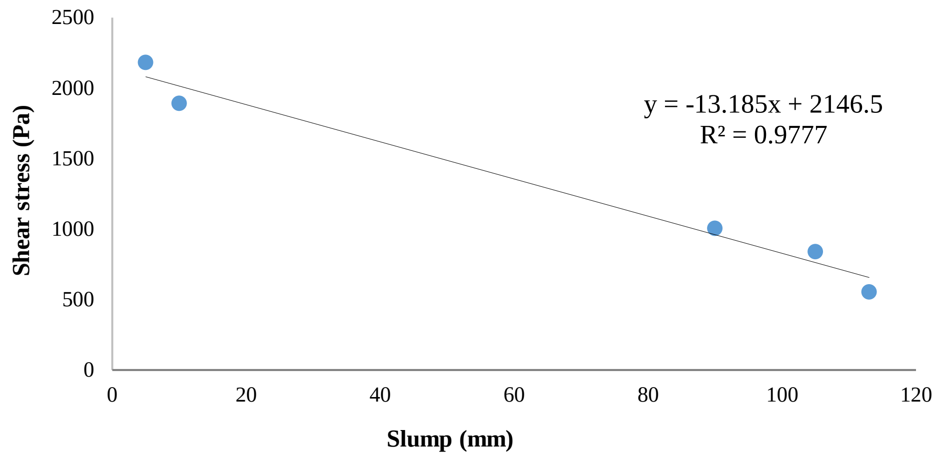


Figure 10.Shear stress / slump test relationship.

The reasons of the experimentally observed increase of yield stress and plastic viscosity in mixtures relate to the few amounts of fine particles in the mixture, the increased quantity of recycled aggregates, which have a more irregular shape and rougher texture than natural aggregates (Bizinotto et al., 2017); in other literature, it is possible to observe a contradiction that the presence of recycled aggregate cause a lowering of both yield stress and plastic viscosity; this last may be associated with the presence of fines particles coming from the recycled aggregate fractions and the higher amounts of water of recycled mortars (Corinaldesi and Moriconi, 2009; Lima et al., 2014).

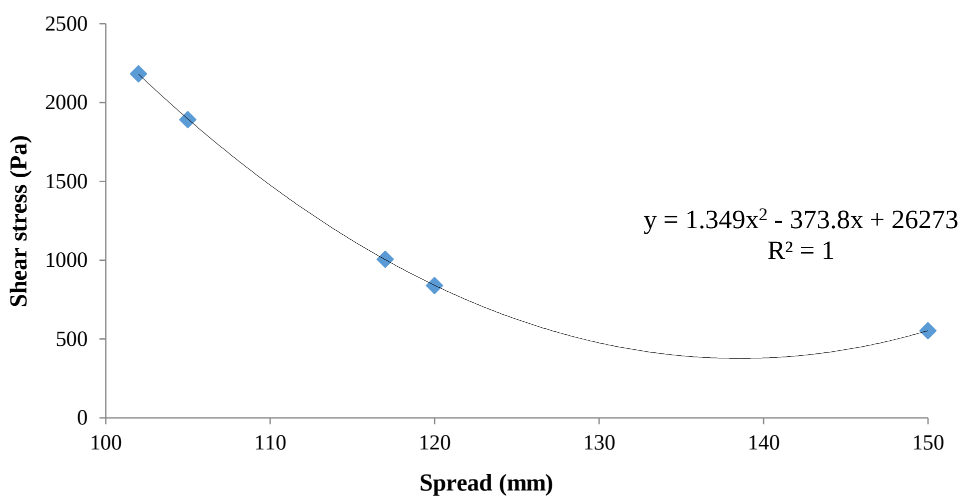


Figure 11.Shear stress / spread test relationship.

The relationships between static and rheological test are shown in figures10 and 11, this correlations between fresh mortars parameters can be advantageous to use a simple test usually available in the construction industry. The plot of yield stress versus slump (Figure 11) shows an acceptable correlation (Safiddine et al., 2017).

According to the test results, the diagrams in the relation of spread, yield stress for mortars present a direct relation that encourages predicting these parameters by a simple static test (K Ezziane and Kadri).

4. Conclusions and comments

Based on the results obtained and experimental conditions from this study, the following conclusions can be drawn:

1. From the scanning electron microscopy; the recycled organic sand is rougher than natural sand.
2. Replacing the sand with 50% ROS sand reduces the slump by 20%, about 75% for 75% substitution ratio and 91% for mixture based 100% ROS.
3. Similarly, replacing the sand with 50% ROS sand reduced the spread by 22%, whereas after replacing the sand with 75% ROS, the spread reduction was kept almost constant at around 30%.
4. The Bingham model can be considered for ROS mortars up to 50% substitution ratio; mixtures based on 75% and 100% of ROS sand show troubled behaviour.
5. The rheological behaviour of recycled mortars was strongly influenced by increasing the percentage of ROS up to 50% of the substitution ratio.
6. It can be concluded that after 50% substitution, the mortars show a risk of segregation, in correlation with the visual monitoring of the mixtures based on 75% and 100% ROS with the rheological turbulences.
7. Good correlation between the rheological tests and the empirical tests, with a high coefficient of determination.
8. Preserving natural aggregates and reusing recycled aggregates as much as possible is the aim of this project; to this end, we want to study the rheology behaviour of mortars using binary and ternary recycled sands.

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Conflicts of interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

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