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Impact of Fine Brick Waste Aggregate Addition on Workability and Compressive Strength of Self-Compacting Mortar

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Abstract— The objective of this research is to investigate whether or not a recycled material such as brick waste (BW) can be used in the concrete mixture as a self-compacting mortar. The possibility of substituting the sand by the brick waste is examined in depth and the brick waste was used as fine aggregate in different proportions varying from 5% to 25% by weight. A series of experimental work was conducted in order to determine the impact of the brick waste on the workability and the compressive strength of the self-compacting mortar. The workability of the concrete was determined by the marsh-cone test as well as by the rheometer test (for fresh mortar). Further the mechanical characteristics of selfcompacting mortar, the compressive strength and tensile strength (for hardened mortar) in bending were investigated and all tests were performed for 7, 28 and 90 days. The results show that brick waste increased the cohesion of the mortars due to its viscosity property. It was observed that the mortar prepared with BW has a low flowability compared to regular mortar. It was noticed that replacement of sand by the waste brick has produced a slight reduction in compressive strength.

Index Terms— brick waste, mortar, workability, compressive strength, tensile strength, flexural strength

I. INTRODUCTION

At the world level, civil works and building construction consume 60% of raw materials extracted from the lithosphere. Of this volume, building represents 24% of these global extractions. The production of concretes and mortars causes serious environmental pollution and huge consumption of nonrenewable resources such as natural calcareous aggregates. [1,]. High architectonic and strength requirements that are currently placed before the constructed engineering conveniences force the constant advancement and development of the technology of the basic construction material, which is cement concrete. Sustainable development in concrete technology can be achieved via conservation of primary materials and enrichment of the durability of concrete structures [2]. In this paper self-compacting concrete (SCC) was developed economically, using sustainable materials such as waste bricks.

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. Since the elaboration of this concrete by Okamura and Ozawa [3–5], numerous works have allowed for a greater familiarity with the properties of this concrete and, above all, of the concrete mix, which ensures its specific characteristics and has enabled elaborating standards for analyzing them [6,7].

The development of a more fluid concrete brought many advantages such as improvements in productivity, energy consumption, working environment, quality. In a short time, self-compacting concrete has developed in different areas of construction industry; so it can be used for in situ application as well as for precast production. Self-compacting concrete is not only an alternative material to normal vibrated concrete it also opens the possibility for radical changes in whole construction process. If the mineral admixtures can replace without any loss in the fresh properties of SCC, the cost will be reduced especially if the mineral admixture is an industrial by-product or waste. Among the mineral additives considered improved the workability properties of mortar [4, 5]. Several predictive models of the rheological behavior of cement-based materials are developed [5-7, 8]. However, these methods require control of the properties of the concrete constituents, in particular the rheology of the grout [9- 10, 11].

Indeed, today's concrete are often composed of mineral additives, their presence affects the behaviour of mortar and therefore the rheological behavior of concrete and all related properties, so it is necessary to study in their presence. The use of cement-based grouts with mineral admixtures can contribute to a technical feasible low cost solution having double benefit for the environment: reducing wastes and consumption of natural resources. Cement grouts were fluid mixtures which contain water, cement, and in some cases chemical admixtures, fine sand, and/or supplementary

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Vol 9, Issue 9, September 2022

cementing materials. The complex rheological behavior of cement based grout is non-Newtonian and thixotropic [12].

The rheology of cement paste is a factor of prime importance regarding the transporting, pumping, pouring and flowability of the material. Many studies on the rheology of cement grouts have shown that these materials are viscoplastic fluids presenting a yield stress which must be reached by the shear stress so that the flow took place [13-15]. The yield stress is regarded as the material property that denotes the transition between solid like and fluid like behaviour. Consequently, it is the minimum stress that makes the fluid flow like a viscous material. Inter-particle forces between the solids in a suspension result in a yield stress that must be overcome to start the flow. In addition, an applied stress that is lower than the yield stress will be resulted in a deformation like a solid instead of flowing of paste [16]. Viscosity is considered to be the most important grouts property. Viscosity is the relationship between shear rate and the stress applied on the material. In the case of non-Newtonian behaviour, it is referred to as 'apparent viscosity' or 'shear rate dependent viscosity'. Cement grouts and cement based materials are subject to hydration process and the viscosity change accordingly the viscosity of the cement based materials. Thus, the rheological behavior of cement based grouts changes with time.

The most use model is the Bingham model which is widely used owing to its simplicity and the linear relationship between shear stress and shear rate. However, the rheological behaviour of cement based materials could be better explained by the Herschel-Bulkley model since it can explain the shear-thinning [16- 17, 18] or shear-thickening behavior [20, 21], depending on many parameters such as solid concentration (water/cement ratio), interaction between particles (attractive due to the effect of viscosity agents or repulsive due to the effect of superplasticisers), size and shape of grains [22]. In all the cases, it can be described satisfactorily by the Herschel–Bulkley model characterized by three parameters: yield stress $\square_0$, consistency K and exponent b which relate, in the case of simple shear, the shear stress □ to the shear rate γ [23].

The main objective of this study was to evaluate the effect of the percentage of replacement of sand by brick waste, the water-to-cement ratio (W/C), the dosages of superplasticiser (SP) and viscosity agent (VA) on the rheological and mechanical properties.

II. MATERIALS USED

The cement used was a CEM I 42.5 having a specific gravity of 3.11 g/cm^{3}and a Blaine specific surface area of 3118 cm^2/g.

The mineralogical composition of cement is presented in Table 1

Table 1 : Composition of cement

Compounds	C3S	C2S,	C3A	C4AF
% weight	52.02	28.9	6.71	12.28

Natural sand was used as fine aggregate with a maximum size of 3.75 mm. The water absorption of the sand found to be 2.07% and porosity 39.4%. The compactness is 60.6%. Natural sand used mainly composed of S_iO_2 with a higher content of 90%.

The brick waste was collected from the brickyards of Guerouaou in the Blida district. The brick waste was grounded and used as fine aggregate with a maximum size of 2.50 mm. The absorption of water, the porosity and the compactness of waste bricks were estimated and were found to be equal to 2.22%, 53.1% and 46.9% respectively. The chemical composition of brick waste is presented in Table2

Table 2: Chemical composition of brick waste

Compounds	S_iO_2,	AL_2O_3	Fe_2O	MgO	K_2O
% weight	65.24	28.9	2.96	1.92	1.09

The superplasticiser (SP) used was Medaplast SP40 based on polynaphthalene sulfonate (PNS) with a specific density of 1.2 and a solid content of 40%. The viscosity agent (VA) was Cimcil L25 in liquid solution and having density of 1.20.

III. EXPERIMENTAL PROCEDURES

3.1 Marsh cone test

The Marsh cone test measures the flow time of a given volume of a grout through a cone of a standard size. The funnel Marsh cone used in this study has a capacity of 1000 ml. The time needed for a grout sample to flow through the cone is proportional to the viscosity of the grout. The flow time increases with an increase in viscosity. The flow time measurement is established by taking a representative sample of 1000 ml of grout, plugging the lower orifice of the cone. Once the grout passed through the orifice of the funnel, the time for flowing of grout was recorded.

3.2 Rheometer test

The test used to measure the rheological parameters of the mortar was Haake RheoStress .1. The principle of the test is to shear a sample of mortar between two plates in horizontal surfaces, one was at rest and another one was mobile (rheometer plate-plate geometry). This rheometer was equipped with a valve rotor speed imposed. After several adjustments, the gap between the two plates was validated to 4.5 mm. Tests were performed at 20°C (± 1°C). The flow curves were analysed and modelled by the software, Kaleida Graph (Version -4.03). The protocol followed in this investigation was as follows: presheared at 10 s^{-1} followed by a rest period of 2 min, then a linear ramp increasing rate from

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0 to 70 s^{-1} was applied through the rheometer for 5 min [23].

3.3 Mechanical properties

Mechanical properties were performed on mortar samples of dimensions 4×4×16 cm^3 in accordance with EN 196-1[22] at different curing times 7, 28 and 90 days. The flexural strength was measured using a three point bending test. The distance between supporting pins is 100 mm [22]. All the test specimens were demoded after 24 h and then stored under water in curing tanks with room temperature (23 ± 2 C).

IV. EXPERIMENTAL PROGRAM

The various compositions tested are formulated constant mass. Mixing was done in a standard drum-type mixer. The waste brick and sand were first mixed in dry state until the mixture become homogenous. The cement were added to the dry mixture, and mixing continued until the mixture become homogenous. Finally, the mixing water containing the superplasticizer admixture was added to the rotating mixer and mixing continued to assure complete homogeneity. Superplasticiser and viscosity agent are expressed in percentage of the mass of cement. The compositions of mortar tested are summarized in the form of groups with in each case one or two components, which varied. The experimental program of four groups of mortar is summarised in Table3.

Table 3. Experimental program

Group	W/C	Replacement level BW (%)	SP (%)	VA (%)
1	0.38	0, 5, 10, 15, 20, 25	0.2;0.4;0.6;0.8;1;1.2	0
2	0.42	0, 5, 10, 15, 20, 25	0.2;0.4;0.6;0.8;1;1.2	0
3	0.38	10	0.2;0.4;0.6;0.8;1;1.2	0.5, 1, 1.5, 2
4	0.42	10	0.2;0.4;0.6;0.8;1;1.2	0.5, 1, 1.5, 2

Notations: SP: Superplasticiser; VA: Viscosity agent; W: Water; C: Cement; BW: Brick waste.

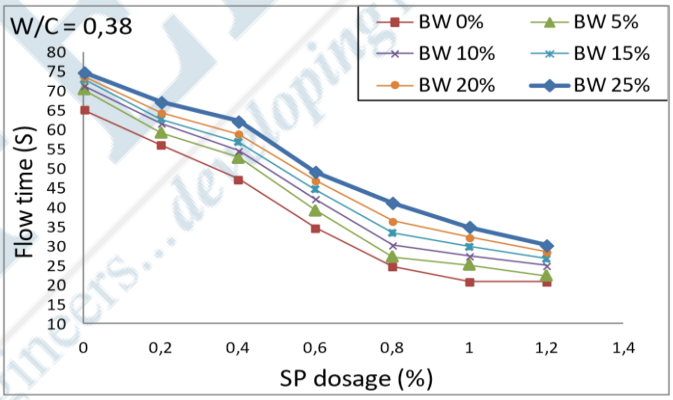
V. RESULTS AND DISCUSSION

5.1 Marsh cone

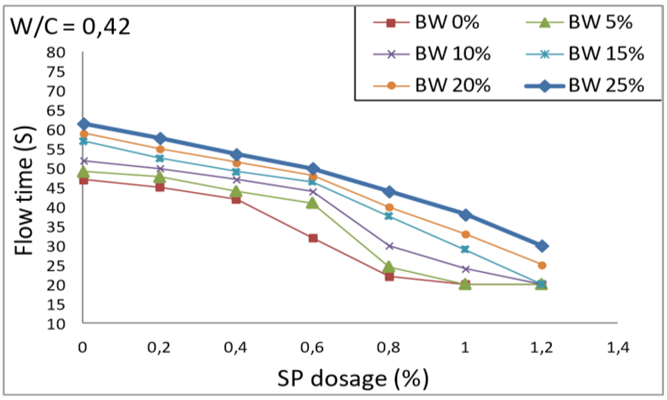
In this part, the analysis of the results led to investigate the effect of combined variables of the dosages of brick waste, SP and VA on the flowability of Self Compacting Mortar.

Figures (1.1) and (1.1) present the results of the flow time values of Marsh cone of groups 1 and 2 mixes made without viscosity agent in function of the variation of SP and quantity of brick waste. As expected, the increase of dosage of SP resulted in a reduction of flow time. This was due to thicker adsorbed polymer layer of SP on the particles and consequently weaker van der Waals attraction between the particles. Therefore, lower forces are needed to disperse the particles and lower cohesivity [23]. This can be attributed to better steric and electrostatic repulsions among cement particles that react with SP, leading to a better deflocculation of the particles in the paste and thus reducing the plastic viscosity.

As expected, the reduction of W/C ratio led to ancrease in the flow time values. This can be attributed to less free water for lubrication of particles leading to a more friction between particles and therefore increasing the viscosity and reducing the flowability [20].



1.1



1.2

Fig. 1 – Variation of the flow time versus SP and BW% for mortar of groups 1 and 2

The flow time increased with the increase in the quantity of brick waste in the Self Compacting Mortar. Figure 2 shows the results of the variation of the flow time obtained for pastes made at the water-to-cement ratios were kept constant 0.38

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Vol 9, Issue 9, September 2022

and a dosage of SP = 1%. The increase of brick waste (BW) from 5 to 25 % led to an increase in flow time. This can be attributed to decrease setting time of brick waste compared to the sand. An increase in the flow time can be explained by the significant need for water of the brick waste [5]. The water-to-cement ratios were kept constant 0.38. [24] It was also noted that the progressive substitution of dune sand by the crushed clay brick waste with percentages of less than 15%, has a significant negative influence on the workability.

For fixed dosage of SP at 1%, the flow time with a BW 5% was decreased from 52.5 S to 43.7 S for replacement level BW 25%. Thus, the substitution of the mortar by the brick waste has an inverse effect on the fluidity of the mortar.

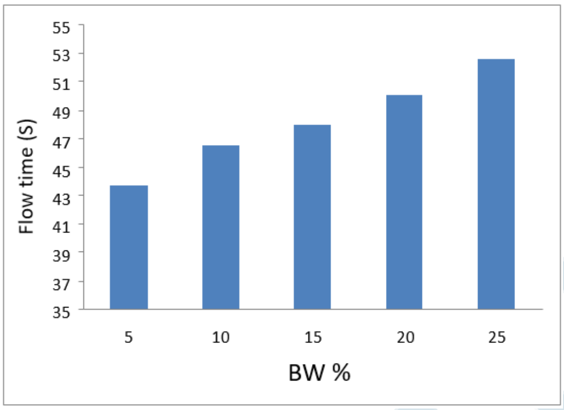
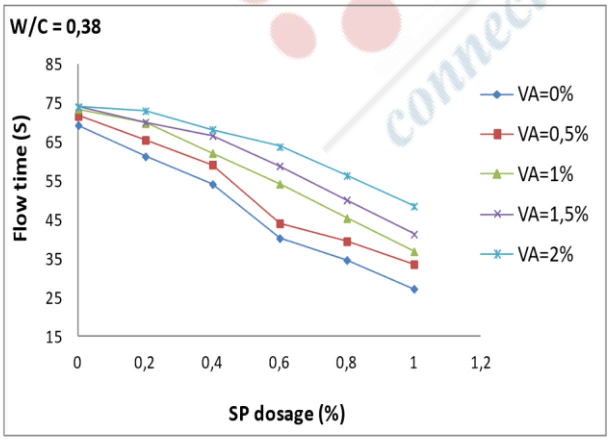
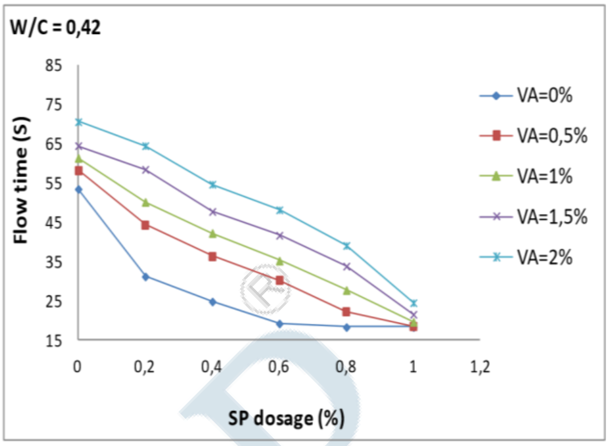


Fig. 2 – Variation of the flow time as a function of BW% for a fixed SP 1%

Figures (3a) and (3b) show the results of flow times of groups 3 and 4 (made with VA) with the variation of SP and VA, where the BW % was fixed at 10%. Similarly in this case of group of mixes, the increase of SP led to a reduction in flow times for mixes containing VA. It can be observed that an increase in the flow time values as VA increased from 0 to 2%, regardless of the dosage of superplasticiser and W/C ratio (038 and 042).



a



b

Fig. 3 – Variation of flow time versus SP and VA for groups 3 and 4.

The influence of the dosage of viscosity agent on the flow time is presented in Figure (4) for the same ratio (W/C = 0.38) and a fixed dosage of SP at 1% and BW = 10%. There is significant variation in the flow time as a function of the dosage of the viscosity agent. It increases in the flow time of control mix (0% VA) by 8.5% and 39%, respectively when the dosage of VA increased to 0.5% and 2%. At constant water-to-binder ratio (w/b) the addition of viscosity modifying agents (VMA) causes a decrease of mortar flow and an increase of flow time (V-funnel test) and at a constant dosage of superplasticizer (SP) mixtures with VMA require a higher w/b to keep the same flow properties as the reference mixtures without VMA [24].

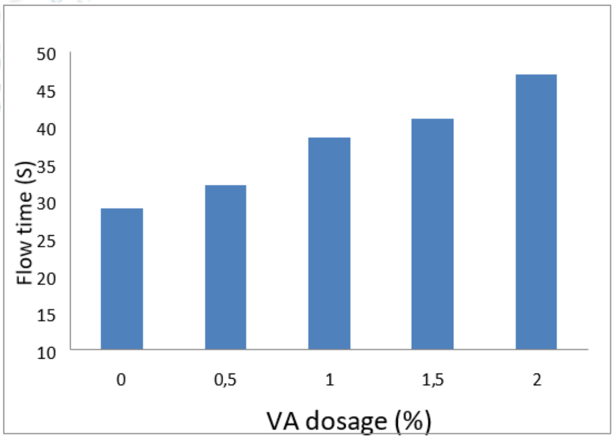


Fig. 4 – Variation of flow time versus VA and SP = 1%

5.2 Rheological parameters

In this section we have studied the behaviour of the various self-compacting pastes by rheometer tested without and with the viscosity agent. For these cases, we studied the combined influence of the content of brick waste and SP on the yield stress and plastic viscosity.

The rheograms recorded by us tests Haake RheoStress 1 of the different paste followed a law of Herschel-Bulkley type

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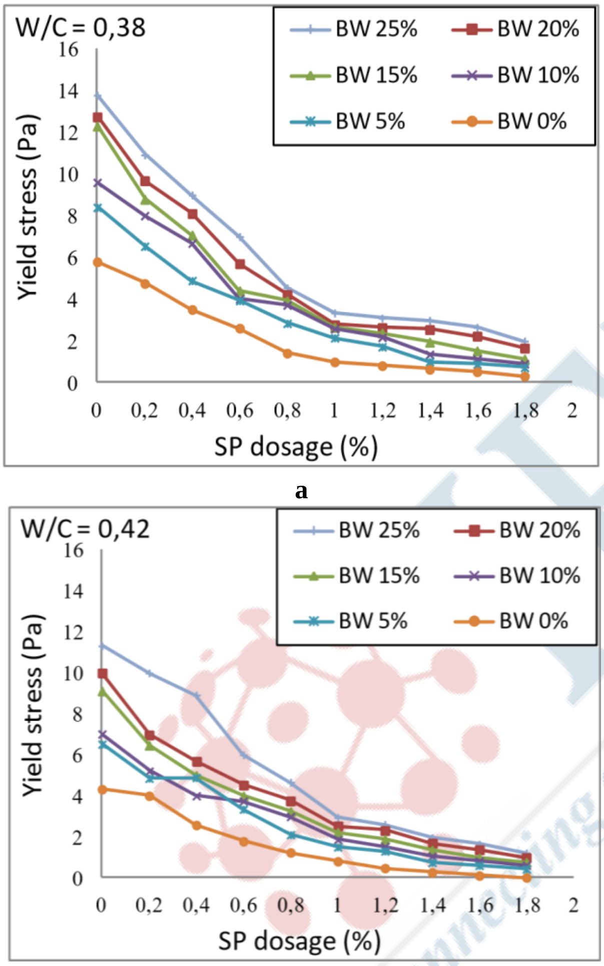
Vol 9, Issue 9, September 2022

that is expressed by equation (1). These results were consistent with what was reported in the literature [28- 29, 30,].

$$\tau = \tau_0 + b(\gamma)c \qquad (1)$$

Where: τ is the shear stress, τ_0 the yield stress, γ represents the shear rate, b the consistency and c the fluidity index.

Figure (5) shows the variation of the yield stress in function of SP for the case of pastes of groups 1 and 2 made with W/C = 0.38 and 0.42, and the replacement percentages of BW was varied from 0 to 25%.



b

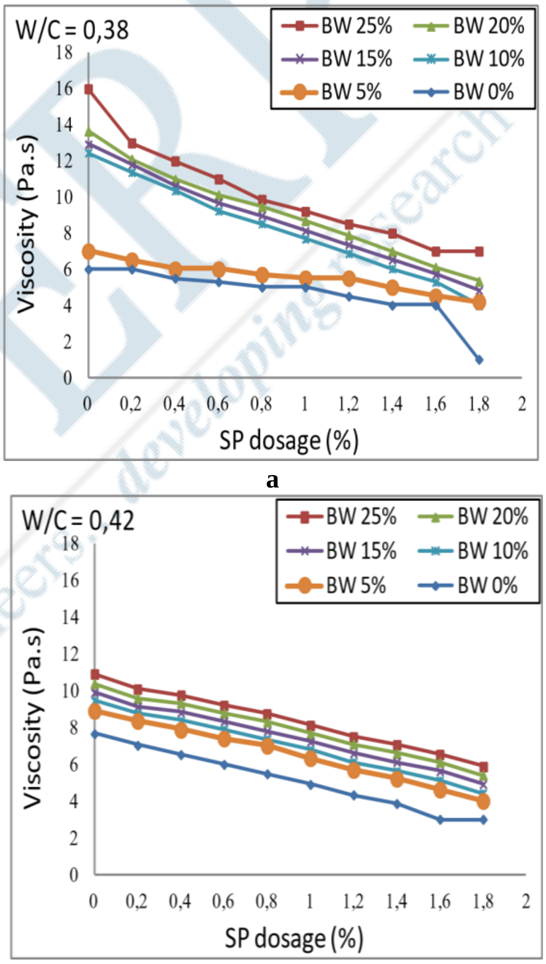
Fig. 5 – Variation of the yield stress versurs SP for mortar of groups 1 and 2.

In these figures, it can be observed that the increase in SP dosage and W/C led to a reduction in the yield stress values, while BW kept constant.

Depending on the mode of action of SP and SP-particle interaction, i.e., compatibility and affinity between the cement and SP, it coats the grains, especially fine particles (cement and fine addition) by adsorbing SP on the surface and make grains flocculate [30]. Meanwhile, the substitution of mortar by brick waste (BW varied from 0 to 25%) resulted in an increase of yield stress (Fig. 5).

In Figure (6), the combined influence of the content of brick waste and SP on the viscosity of the various selfcompacting mortar are plotted for groups 1 and 2. Similarly to the results of yield stress, the increase of W/C and SP led to a reduction in the plastic viscosity. In contrary, the substitution of sand by brickwaste increased significantly the plastic viscosity.

The results showed that superplasticizers improve the workability of self-compacting concrete (SCC) by significantly decreasing the static and dynamic shear thresholds. However, their effect on the plastic viscosity depends strongly on the dosage used [31].



b

Fig. 6 – Variation of plastic viscosity versus SP for mortar in groups 1and 2.

Figure (7) shows the results of the yield stress depending on the variation of VA and SP, replacement percentage BW is set at 10%, the paste is formulated in a ratio W/C equal to (0.38 for the group 3 and 0.42 for group 4). In Figure (7), it can observed that for these self-compacting mortar, the variation of yield stress values increased a slightly with the increase with increasing VA, while keeping all other parameters constant W/C, BW% and SP.

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 9, Issue 9, September 2022

These results were consistent with the use of the viscosity agent which is often used to make the viscous materials without affecting too much their yield stress. The addition of SP at 0.4% lowered the yield stress for any dosage of VA, while W/C kept fixed. Moreover, it also notes that the yield stress values decreased with increasing of W/C.

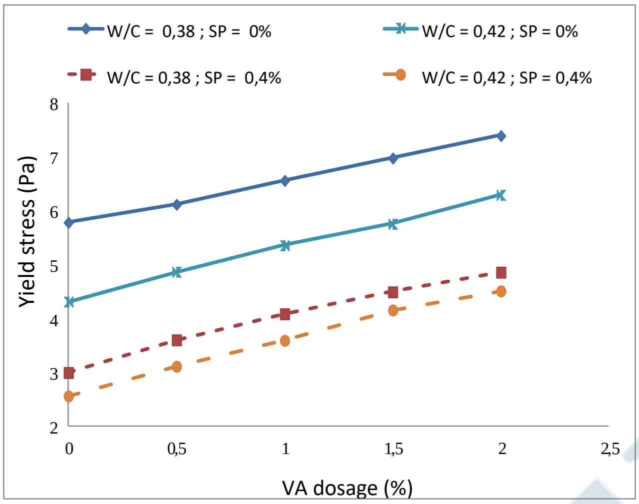

Fig. 7 – Variation of the yield stress versus VA and SP for mortar of groups 3 and 4.

Figure (8) shows the results of the viscosity as a function of the variation of VA and SP, the replacement level the sand by brick waste is set at 10%, the mortar is formulated in a ratio W/C equal to (0.38 for the group 3 and 0.42 for group 4).

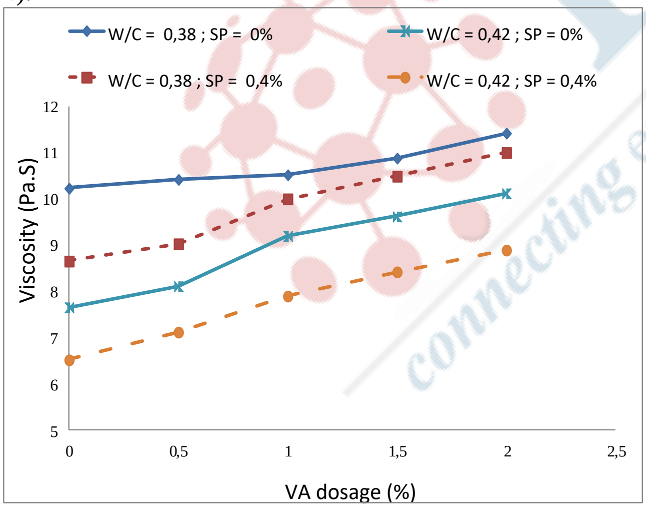

Fig. 8 – Variation in viscosity versus VA and SP for mortar of groups 3 and 4

From these figures it can be seen that the values of plastic viscosity increased slightly with increasing of VA, when all other parameters (W/C, BW% and SP) were kept constant. Adding 0.4% of SP resulted in a reduction of plastic viscosity for any W/C and dosage of VA.

As with the yield stress, the values of plastic viscosity decreased with the increase in the ratio W/C. It can be noted that for paste made with W/C = 0.42, the plastic viscosity values were very low.

For the effect of viscosity agent on the plastic viscosity, in case of self-compacting paste, it is slightly small compared to what is presupposed that, because the main role of viscosity agents is to bring the robustness to paste. As reported in the literature [33] the yield stress is found to monotonically increase with Viscosity-Modifying Admixtures (VMA) content, while the consistency presents a minimum indicating the existence of an optimum value of the VMA for which the workability of the cement paste is maximum.

5.3 Correlation between flow time and viscosity

The results shown in Figure (9) correspond to those of the correlations between the flow times and the plastic viscosities for pastes made with the same ratio W/C and BW is set at 10% in the presence of the viscosity agent. It can be noted that the flow time increased with the increase in the plastic viscosity. In general, the flow time correlated very well with the plastic viscosity [34].

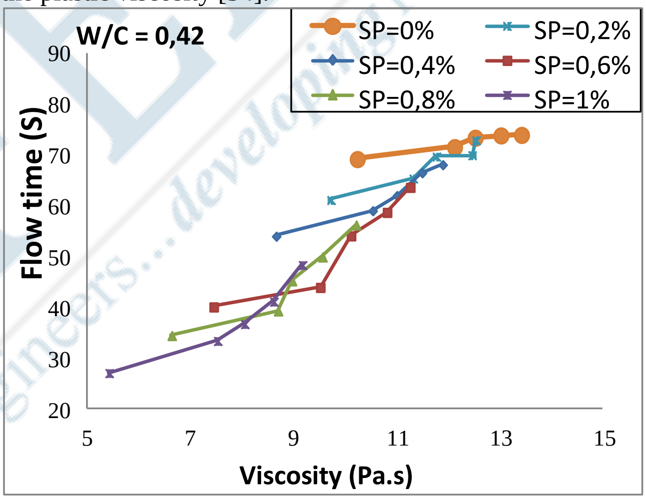

Fig. 9 – Correlation between the flow time and plastic viscosity to the pastes of the group 4

The results in Figure 9 shows that the flow times increased with the increase in plastic viscosities. In this case of mixes, the dosage of VA was increased. The flow time and the plastic viscosity were reduced when the dosage of SP increased from 0.2 to 1%. Similarly, to these groups of mixes, the flow time correlated very well with the plastic viscosity.

The increase of VA led to an increase in flow time, yield stress and plastic viscosity. This can be attributed to the entanglement and intertwining of VA polymer chains and the association of water between adjacent chains. At low shear, and especially at high concentrations, the intertwining of polymer chains can exhibit an increase in the apparent viscosity [34]. The factors that influence flow are described by Darcy's Law where the flow rate is inversely proportional

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Vol 9, Issue 9, September 2022

to fluid viscosity. Therefore, VA increased the viscosity of the matrix and will improve the water retention.

An increase in SP content resulted in a reduction of the flow time, yield stress and plastic viscosity while the fluidity of grout is improved. This was due to thicker adsorbed polymer layer of SP on the particles and consequently weaker van der Waals attraction between the particles. Therefore, lower forces are needed to disperse the particles and lower cohesivity [23]. This can be attributed to better steric and electrostatic repulsions among cement particles that react with SP, leading to a better deflocculation of the particles in the paste and thus reducing the plastic viscosity. The effects of VA and SP on paste correspond with the findings of other researchers [11-12, 23].

Good relationships between Self- compacting concrete rheology parameters measured with the use of a rheometer (yield stress and plastic viscosity issued from modified Bingham model) and fresh properties of SCC were obtained (Yield stress with L-Box ratio and plastic viscosity with V-funnel and Pd) with respect to the effects of type and content of used sands [34].

5.4 Mechanical properties

The compressive strength was studied at 7, 28, and 90 days. The effect of the brick waste content on the compressive strength of similar mixes can be seen. According to these results, figure 10 show the results of compressive strength of group 2 (made with ratio W/C = 0.42) with the variation of replacement level of sand by brick waste (0 to 25%), where the SP % was fixed at 1%.

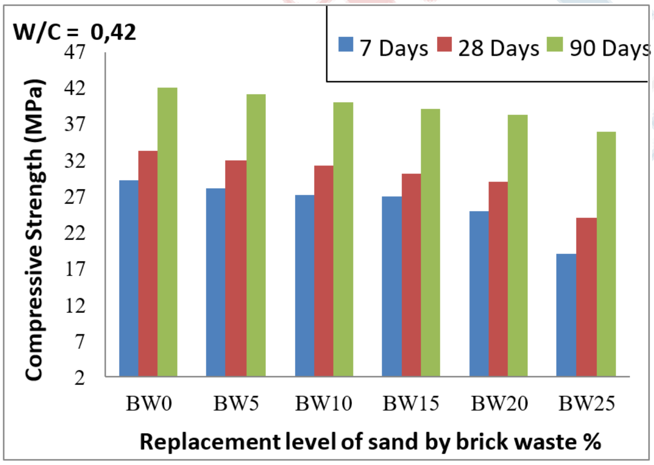

Fig. 10 Influence of the incorporation of BW% on compressive strength

The results of the compressive strength test are shown in Figure 10. At first sight, recycled brick aggregates do not present good enough properties to be used in structural applications because of its low strength and its high level of water absorption. In general, substituting sand with brick waste reduced the compressive strength relative to the reference mix (BW0%).

At 28 days, the results of stutied mixtures showed that the highest reduction in compressive strength 34% was when substituting 25% brick waste, while substituting 10% BW resulted in a lower reduction in compressive strength, about 11%, than the control sample (BW0%). This decrease is mainly due to the porosity of the brick waste [35,36].

Fig. 11 illustrates the effect of brick waste samples as an additive to mixture on the flexural strength of samples over a curing period of 90 days.

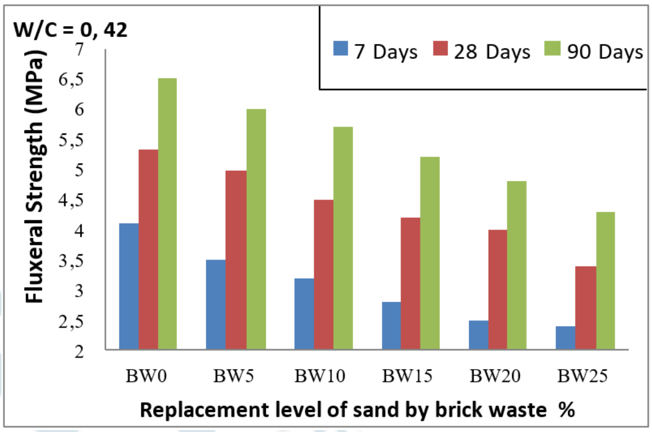

Fig. 11. Influence of the incorporation of BW% on flexural strength

From the results obtained, it is evident that the flexural strength increases with age for all mortars prepared. at 28 days, the decreasing rates increased with the increase of replacement level. Respectively, the flexural strength values reduced by 6%, 8%, 17%, 20 and 37% at substitution rates of 5%, 10%, 15%, 20 and 25%. An increase in the replacement level the sand by brick waste resulted in a reduction of the mechanical properties of mixtures. However, some studies carried out [37- 38, 39] have shown that the use of this kind of aggregates in middle strength concretes (<45 MPa) produces low decrease of strength for percentages of substitution up to 30%, or even show a better performance for low percentages when only the fine fraction is substituted by recycled brick aggregates.

VI. CONCLUSIONS

The effects of the addition of waste of brick waste (BW), superplasticizer (SP), viscosity agent (VA), and water-tobinder ratio (W/C) on the rheological and mechanical properties were investigated.

Based on the results of this investigation, the following conclusions can be drawn:

The dosage of SP has a significant effect on the values of flow time, yield stress, and plastic viscosity. An increased dosage of SP led to a reduction in flowability, and the rheological parameters. This can be attributed of better steric and electrostatic repulsions between cement particles that react with SP in their surfaces.

The variation in the VA dosage showed moderate effect on the flow time, yield stress and plastic viscosity. This can be attributed to the entanglement and intertwining of VA polymer chains and the association of water between adjacent chains. VA also binds to the water phase of the paste matrix, which resulted in increased water retention. In fact, an increase in VA led to reduced flow time, yield stress, and plastic viscosity.

For given dosages of SP and VA, an increased percentage of brick waste (reduction of sand to brick waste percentage BW) led to an increase in flow time, yield stress, and plastic viscosity. With this feature, brick waste decreases workability; on the other hand, it contributes to increase cohesion with increasing in the viscosity.

As expected, the reduction of water-to-cement ratio (W/C) significantly increased the flow time, yield stress, and plastic viscosity.

The sand substitution by brick waste (BW) has decreased the fluidity and strength of self-compacting mortars.

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