International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 9, September 2018, pp. 323–334, Article ID: IJCIET_09_09_034
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=9
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

IMPROVEMENT OF ORDINARY AND PURE GYPSUM PROPERTIES BY USING POLYVINYL ALCOHOL (PVA)

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ABSTRACT

The present study aims to improve the performance of gypsum material by addition of polyvinyl alcohol (PVA). An experimental investigation was conducted on a series of mixes prepared with two gypsum types; ordinary gypsum (OG) and pure gypsum (PG). For each type, six different PVA solution of 1, 2, 3, 4, 5 and 6 % by mass of gypsum were used. Test parameters of the prepared mixes included; setting time, compressive strength of the specimens subjected to dry and wet environments, modulus of rupture and water absorption at different time intervals. Shear bond strength between PVA modified gypsum and brick specimens of masonry units were also measured. Results showed that setting time increased with increasing PVA in both gypsums used. An improvement in compressive strength (specifically in the specimens that was subjected to the wet environment) and modulus of rupture was noticed when PVA solution was introduced into the gypsum material. PVA modified gypsum specimens also exhibited a noticeable reduction in the rate and total water absorption. The most important advantage of PVA was the improvement in properties of OG mixes compared with that in PG. Besides, coupling bricks and PVA modified gypsum resulted in a remarkable improvement in the shear bond strength of the masonry units, especially when hollow brick specimens were used.

Keywords: Polyvinyl alcohol, gypsum, compressive strength, modulus of rupture, shear bond strength, hollow brick.

Cite this Article: Abo Dhaheer, Mohammed. S,Haider K. Ammash and Kassim Kadhim Hameed, Improvement of Ordinary and Pure Gypsum Properties by Using Polyvinyl Alcohol (PVA), International Journal of Civil Engineering and Technology, 9(9), 2018, pp. 323–334.

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1. INTRODUCTION

With the recent tendency towards the use of massive amounts of building materials to accommodate the great pace in construction, gypsum material (calcium sulphated hydrate, $CaSO_4$ $2H_2O$) is in demand and extensively used in numerous building applications. It is widely used as a binder, indoor finishing material, precast units and boards, partitions and sound isolations [1-2]. Gypsum has several superior properties, including; low density, volumetric stability, thermal and fire resistance, easy fabrication, low price and attractive appearance [2-3]. Beyond the construction field, gypsum can also be used in the dental and medical purposes [4], in the moulding of ceramic products and in Portland cement as a major constituent in order to delay its setting time [5-6]. Despite these superior properties of gypsum, there is concern regarding its strength, setting time, water absorption and durability issues that need to be addressed. To tackle such inferior properties, attempts have been tried by numerous research work, in which the focus has primarily been on modifications of gypsum matrix using different mineral admixtures and reinforcing materials.

With regard to the use of mineral admixtures, it was stated that the incorporation of expanded silica gel granules (a by-product of sodium silicate industry) into the gypsum plays an essential role in improving its physical and hardened properties in terms of thermal conductivity, bulk density and durability [7]. Based on many experimental studies [8-12], the addition of different minerals admixtures (e.g. clay minerals, fly ash, silica fume, Portland cement, cork) can assist in modifying the chemical and physical properties of gypsum matrix, resulting in positive influences on its fresh and hardened properties. Foam additives can also be implemented in gypsum materials in order to improve their damp and sound-proofing properties [7] and to decrease its density [13]. With respect to the use of reinforcing materials, numerous research work was conducted to emphasise the importance of adding different types of fibres to the gypsum mixes [3, 14-17]. It was found that fibres can be effectively used to improve gypsum tensile strength and dimensional stability as well as to hold its structure from corruption and disintegration.

Another important way of enhancing gypsum performance is the utilisation of polymer additives. Unlike minerals admixtures and fibres, polymers can be added to the gypsum in small amounts in order to retard its setting time (i.e. hydration) and/or to enhance its hardened properties [18]. In the fresh properties, the role of polymer is to delay its crystallization/hydration process, causing a prolonged workability associated with setting time [1]. With respect to the hardened properties, the influence of polymer in gypsum matrix seems to have arisen from the change of its microstructure, which often leads to decrease in the pores volume by increasing the crystal interlocking and overlapping [1].

Over the last decades, advances in polymer technology have been achieved, and variety of polymer-based admixtures such as; liquid resins, redispersible polymer powders and water soluble polymers have been successfully applied in different engineering fields [19]. With regard to the water soluble polymers, various types are used, as for example, polyethylene oxide (PEO), polyethylene imine (PEI), polyacrylic acid (PAA), polyacrylamide (PAAm) and polyvinyl alcohol (PVA) [20]. Among them, a detailed literature has been conducted and revealed that PVA can effectively contribute to improvement in the properties of construction materials, e.g. aggregate, cement mortar and concrete [21-26]. According to the previously published literature, it is unfortunate to note that the use of PVA in gypsum material does not appear to have been investigated (to the best of our knowledge). Thus, the main objective of this study was to experimentally investigate the influence of PVA addition on the properties of fresh and hardened gypsum mixes. Two types of gypsum materials (ordinary and pure gypsums) at different PVA solution was employed. The study was then extended to investigate the influence of PVA on the shear bond strength of brick masonry units. Based on the obtained results, the optimal content of PVA was also determined.

2. EXPERIMENTAL PROGRAM

2.1. Materials

Two types of locally produced gypsum (OG and PG) were used in this study. Polyvinyl alcohol (PVA), which is 98% hydrolysed, was used. The solution of polymer was prepared by dissolving 60 g of PVA powder in 1 litre of water. After the powder was dissolved, the solution was allowed to cool down at ambient temperature in the laboratory. For each gypsum type, seven different mixes differing in PVA amounts (0, 1, 2, 3, 4, 5 and 6% by the mass of gypsum) were prepared. The solution of PVA was substituted by an equivalent amount of mixing water in all prepared mixes. The water to gypsum ratios (W/G) were 0.45 and 0.57 for OG and PG, respectively.

2.2. Specimens preparation and test procedure

Gypsum, water and PVA were mixed together and then cast into steel moulds after the setting time test was performed. For each gypsum mix, 50 mm cubes were used for compressive strength and water absorption tests, whereas 40×40×160 mm prisms moulds were used for modulus of rupture test. After the setting took place, gypsum samples were taken out of the moulds and they were exposed to a laboratory environment until the testing age. The test procedure given by ASTM C472 [26] was adopted for testing the gypsum specimens used. For the two types of gypsum used, compressive strength was tested in dry and wet conditions. The dry condition was performed on the specimens that had been left in the laboratory environment, while the wet condition was done on the specimens that had been prepared for water absorption test (after immersing the specimens for 24 hr). Here, the absorption test was conducted on gypsum specimens for different time intervals (from 5 min to 1440 min, i.e. 24 hr). Extending the PVA application, shear bond strength between PVA modified gypsum and brick masonry units was also investigated following EN 1052-3 [28]. Uniform vertical compression load was applied to the masonry specimens, which were constructed from solid and hollow bricks and PVA modified gypsum. Figure 1 shows the bricks arrangement of the masonry unit and their setup configuration in the testing machine.

(A) **(B)**

Figure 1 (A) Bricks arrangement in the masonry unit, (B) Shear bond strength test

3. RESULTS AND DISCUSSION

3.1. Setting time

Gypsum setting is a transition period during which the properties of material changes from fresh to hardened state. This change occurs due to the development of hydration products [1]. Setting time test results of the produced gypsum mixes are given in Table 1 and Figure 2. It can be seen that it increases with increasing PVA amounts. The maximum increase was about 42% and 33% in OG and PG, respectivelly. Generally, the influence of PVA on setting time is more obvious in OG than in PG (Figure 2). As stated by Mucha et al. [1], polymer is effective in delaying the hydration/crystallization process of gypsum mixes. However, such process occurs faster in case of mixes without polymer. Serhat and Kahraman [7] investigated the pore morphology of polymer modified gypsum with the aid of scanning electron microscopy (SEM) technique, which showed that the presence of polymer causes that gypsum crystals develop slowly in comparison with that of unmodified gypsum.

Generally, gypsum setting time depends notably on its raw materials, manufacturing technology, place and duration of storage, and the presence of additives [18]. From the one hand, the rapid setting of gypsum is positive as it enables fast moulds removal in different construction applications. From the other hand, rapid setting negatively affects the gypsum construction process, which becomes practically a very difficult task and gives no way of preparing substantial quantities of gypsum pastes [18]. That is, for this reason, different additives were used for controlling gypsum setting time [1, 5-6]. According to the results of the present study, the incorporation of PVA in gypsum mixes could be a possible option to overcome the difficulties in the construction process by increasing the mix setting time and improving its workability as well. In this experimental work, the improved workability of gypsum paste was judged by visually observing a better flowability when PVA solution was added.

Table 1 Setting time (min.) test results of OG and PG mixes

Gypsum type	W/G	PVA (% by gypsum weight)						
		0	1	2	3	4	5	6
OG	0.45	6.0	6.0	6.5	7.5	8.0	8.5	8.5
PG	0.57	7.5	7.5	8.5	9.0	9.5	9.5	10.0

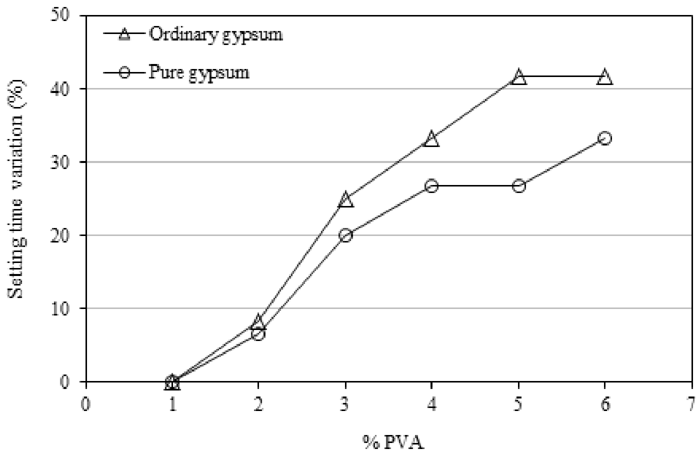

Figure 2 Setting time variation (%) of OG and PG versus PVA addition

3.2. Compressive strength

Table 2 presents the compressive strength test results of OG and PG mixes, and Figures 3-5 give their variations expressed as proportional percentages to the control mixes (i.e. 0% PVA). Table 2 shows that compressive strength improves continuously with increasing PVA in the mix. Indeed, the incorporating of PVA in gypsum appears to be more effective in OG than in PG, and more specifically, in the specimens that were subjected to a wet environment. For the mixes made with 6% PVA, it is clear from Figure 3 that compressive strength of OG increases by about 27% and 44% in the dry and wet specimens, respectively, compared with 17% and 23% in PG mixes (Figure 4). The improvement in compressive strength may be attributed to the ability of PVA to change gypsum microstructure and fill the pores of its matrix, especially in OG. Generally, PG has lower porosity than OG, and thereby, increasing PVA has less effect in improving compressive strength in both dry and wet environments.

It is known that strength of gypsum develops through a process of three stages [2]. These are (1) interlocking matrix development of dehydrating needles, (2) interior stress relief due to the pressure build-up as needles, and (3) strength development throughout the excess water removal. Here, it can be assumed from this process that the presence of excess moisture in gypsum specimens (i.e. specimens subjected to the wet condition) affects its strength as it affects the formation of crystals. This, in turn, weakens the bond in gypsum and leads to physical and chemical deterioration. This conclusion is confirmed by the test results shown in Figure 5, which showed that the wet to dry compressive strength ratio of the control mix was about 61% (39% strength loss) and 70% (30% strength loss) in OG and PG, respectively. That means the wet environment was detrimental to the gypsum mechanical properties. However, this deterioration can be, relatively, mitigated by the use of PVA as it protects the gypsum matrix from the external moisture, causing lower dropping in compressive strength. From Figure 5, it can be clearly seen that the wet to dry compressive strength ratio in OG increases from 61% (in the control mix) to 69% when up to 6% PVA was used. This is expected as PVA solution, which is distributed in gypsum pores, will prevent water from penetrating through the gypsum particles. Concerning PG mixes, a marginal increase (from 70% to 73%) in the wet to dry compressive strength ratio was observed. In general, since PG matrix has comparatively dense and more homogeneous than OG, the negative effect of the wet environment on its compressive strength was relatively less (Figure 5). Nevertheless, a positive influence of PVA on compressive strength of PG was observed in both dry and wet environment, as seen in Figure 4.

Table 2 Compressive strength and modulus of rupture (MPa) test results

% PVA	Compressive strength				Modulus of rupture	
	Dry OG	Wet OG	Dry PG	Wet PG	Dry OG	Dry PG
0	4.55	2.76	6.54	4.57	1.59	2.68
1	4.80	2.98	6.70	4.85	1.71	2.81
2	5.00	3.17	7.10	5.00	1.83	2.89
3	5.13	3.34	7.25	5.21	1.90	3.11
4	5.48	3.66	7.46	5.38	1.96	3.18
5	5.72	3.89	7.62	5.55	2.08	3.30
6	5.77	3.97	7.64	5.60	2.12	3.33

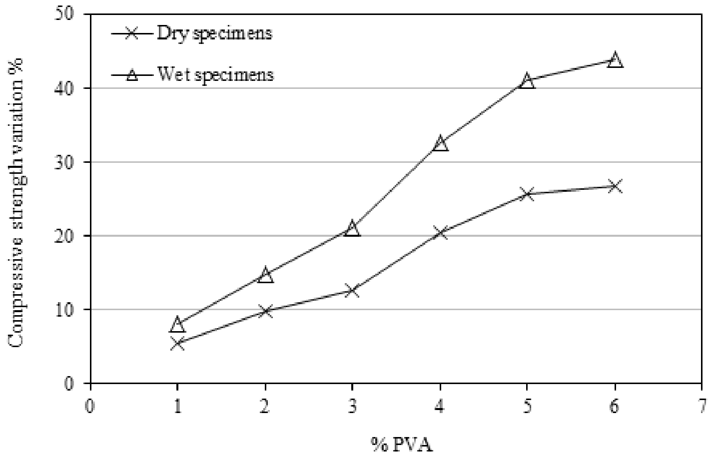

Figure 3 Compressive strength variation (%) of OG versus PVA addition

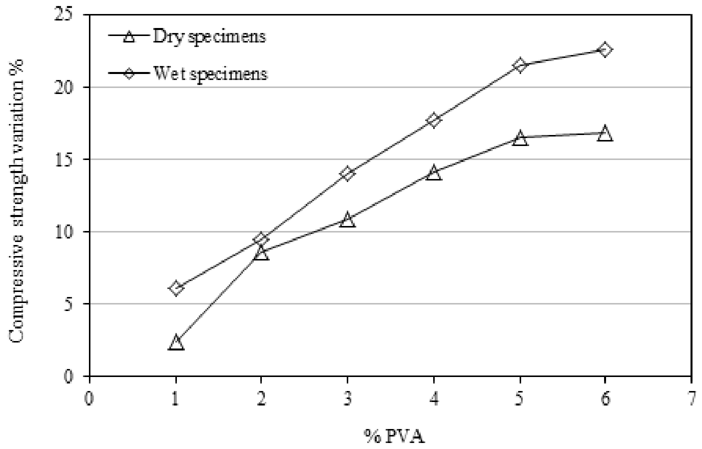

Figure 4 Compressive strength variation of PG (%) versus PVA addition

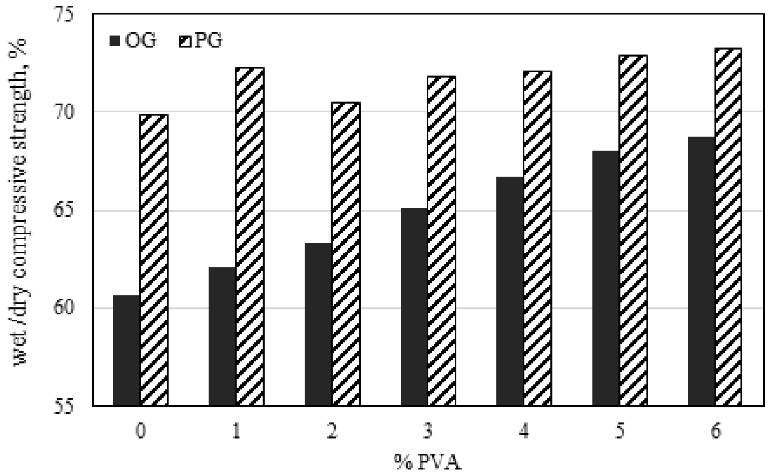

Figure 5 Compressive strength ratio of wet to dry specimens PVA addition

3.3. Modulus of rupture

Modulus of rupture test results (determined as the average of three specimens per mix) of OG and PG mixes are given in Table 2 and Figure 6. As expected, an increase in PVA amounts increases modulus of rupture of the gypsum mixes. The increase is more pronounced in OG than in PG, especially when more than 4% PVA is added. Generally, modulus of rupture is found to have almost similar tendency to that of compressive strength. With the higher addition of PVA, the maximum increase is about 33% in OG and 24% in PG. As observed in compressive strength, addition of PVA has less influence on improving modulus of rupture of PG as its porous nature has a relatively lower proportion of voids than OG. Generally, the increased modulus of rupture could come from the fact that polymers can have a high tensile capacity and provide a good adhesion when they are used with other materials. The increase in overlapping and interlocking of crystals growth with the addition of polymer could be another reason behind that improvement in modulus of rupture. This was in good agreement with the results reported in [1].

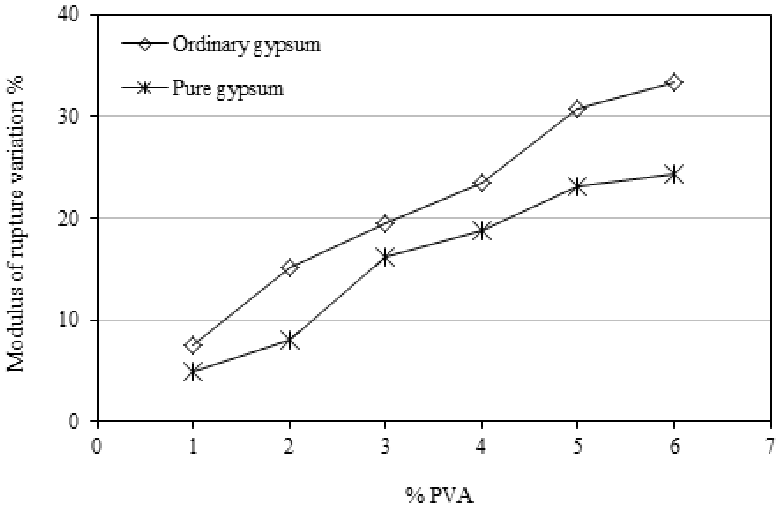

Figure 6 Modulus of rupture variation (%) of PG versus PVA addition

3.4. Water absorption

The water absorption of gypsum is a key concern in controlling its durability, and without paying attention to it, deterioration to its mechanical properties can occur. In other words, any reduction in gypsum water absorption can result in an enhancement in its durability performance. The water absorption test of PVA modified gypsum was performed via immersing both OG and PG specimens in water for different time intervals (from 5 to 1440 min.). The test results presented in Figures 7-8 reveal a noticeable reduction in gypsum water absorption for different PVA contents and for various immersion time intervals. Increasing PVA up to 6% can efficiently decrease the total water absorption from 49% to 35% and 39% to 30% in OG and PG, respectively. This could be due to the pore-blocking effect of PVA polymer (i.e. the porosity of the gypsum matrix decreases as a large proportion of pores volume is filled with PVA). Accordingly, a promising opportunity with regard to the gypsum durability can be expected with the use of PVA. It is interesting to note that the incorporation of PVA not only decreases the total absorption, but it reduces the rate of absorption as well. This can possibly be represented by overall water absorption (absorption at a certain time, after which the amount of absorbed water is very low). Apparently from Figure 7-8, the overall water absorption of the control OG and PG specimens (0% PVA) occurs at about 20 and 120 min., respectively. However, when 6% PVA is added, the time needed for gypsum specimens to reach their overall absorption increases to 350 min. The considerable change in the rate of water absorption could come from the ability of PVA in coalescencing and bridging the defects that are existing in gypsum matrix.

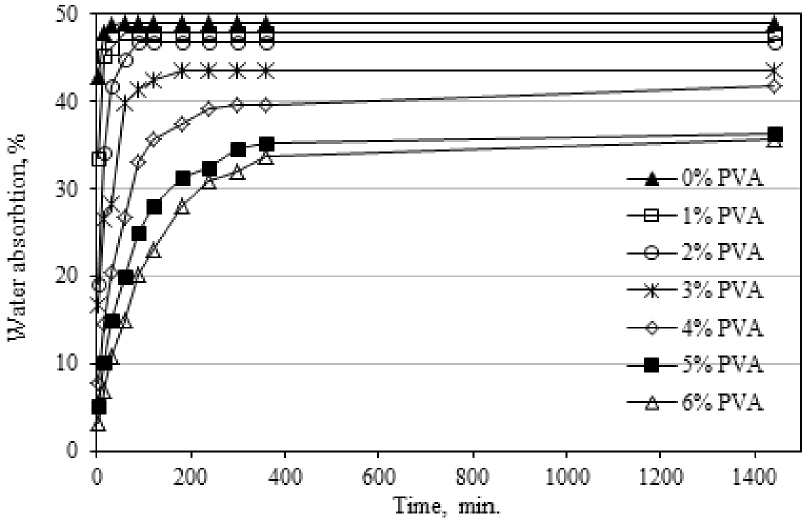

Figure 7 Absorption of OG versus PVA dosages at different curing periods

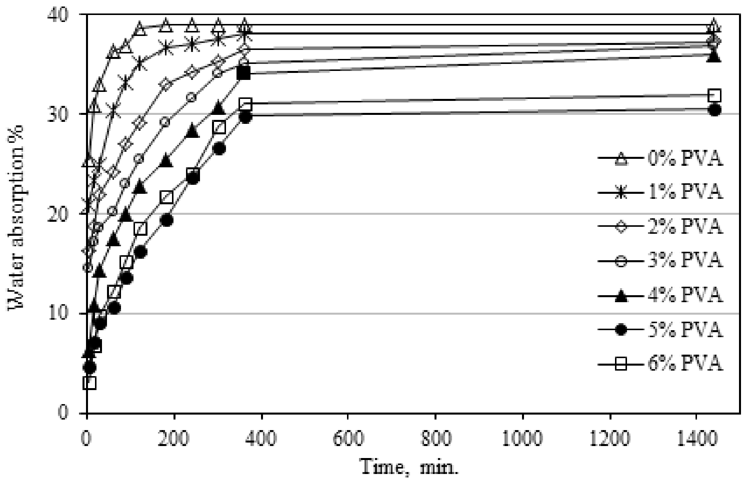

Figure 8 Absorption of PG versus PVA dosages at different curing periods

3.5. Shear bond strength of brick masonry units

Masonry is a layered composite comprising of mortar and masonry units. To evaluate the structural response of a masonry building, mechanical properties of masonry units are worth examining [29]. Several parameters have been adopted to investigate the load bearing capacity of existing masonry constructions. These include; compression, flexural, shears and poll-out tests [30]. One of the important parameter to be evaluated in the masonry buildings is the shear bond strength [30, 28]. The importance of sufficient masonry shear bond strength is necessary to resist the stresses that arise from different types of loading conditions [29]. Considering the above results, the use of PVA in gypsum has been proved to be superior in enhancing its engineering properties. Here, as the gypsum material is widely used as binder in masonry units, shear bond strength between PVA modified gypsum and bricks in masonry unit are worthwhile to be investigated. To avoid unnecessary duplication of laboratory work, only 3% and 6% PVA were added to the gypsum in order to investigate its influences on shear bond strength. Also, only OG paste was prepared as it is usually used as a binder material.

A number of approaches and techniques have been proposed to evaluate the shear strength test. Among them, a simple and easy to perform technique, as described in EN 1052-3 [28], was applied in the present study. For this purpose, three masonry units for each of PVA addition were composed. Each unit was made of three brick specimens and two gypsum paste joints in-between (see Figure 1 above). A uniform vertical compression load was applied until the failure occurred as a result of de-bonding between gypsum paste and brick units. Shear bond strength was calculated by dividing the registered maximum load by the area of two contact joints shear plane of the unit. To avoid an eccentric load during the test, each unit has a symmetric structure with a contact-joint area of approximately 120 x 160 mm along a gypsum paste layer of 10 mm thick, (as schematically shown in Figure 9).

From Figures 10-11, it can be easily understood that a significant enhancement in shear bond strength was achieved by coupling bricks and PVA modified gypsum. For the solid brick units, shear bond strength increased by 21% and 36% when 3% and 5% PVA was added, whereas for the hollow bricks, the increase was 29% and 51%, respectively. In the present test, it can be mentioned that cracks initiate and propagate (within the load application) at brick-gypsum interface before full separation takes place. Then, the brick unit fails due to the bond loss. In this regard, the presence of PVA has a crucial impact in changing the microstructure of brick-gypsum interface, which is considered the weakest zone in the masonry unit. This seems to be the main reason behind that remarkable improvement in shear bond strength. Another reason could be associated with the existence of a superior adhesion between the brick contact surface and PVA modified gypsum paste.

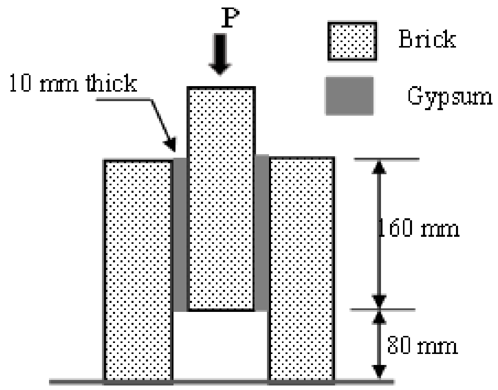

Figure 9 Schematic diagram of the shear bond strength test

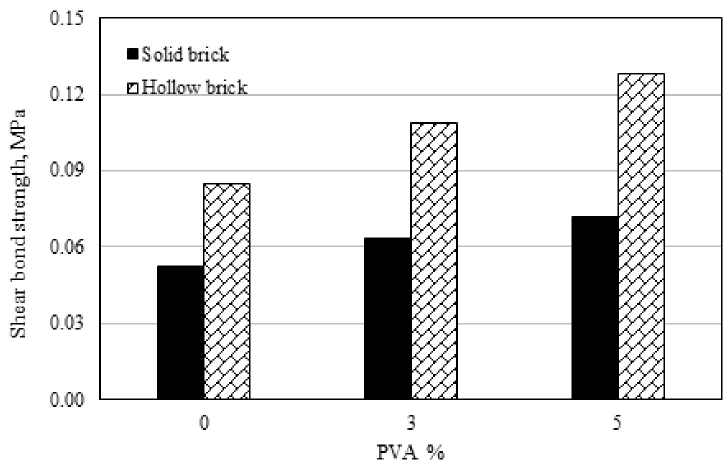

Figure 10 Shear bond strength Versus PVA% for solid and hollow bricks

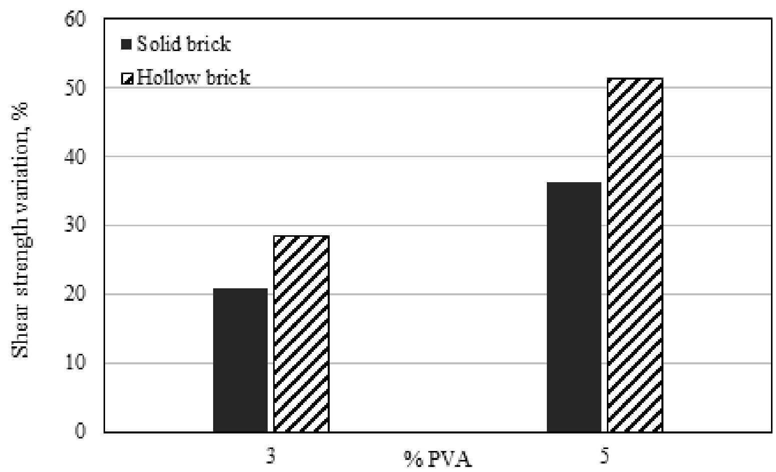

Figure 11 Shear strength variation of gypsum (%) versus PVA addition

4. CONCLUSIONS

Based on the above findings and discussion, the following conclusions can be drawn:

1. PVA can be advantageous in increasing setting time and providing a better flowability of both OG and PG pastes.
2. The results confirmed the superiority of PVA in improving gypsum compressive strength and modulus of rupture, as well as decreasing the rate and total water absorption. The most important advantage of PVA was the improvement in the performance of OG mixes.
3. The wet environment of gypsum specimens (i.e. specimens subjected to wet conditions by immersing them in water for 24 hr) was found to be detrimental to their performance as far as the compressive strength is concerned. To some extent, this detrimental effect can be successfully alleviated by the use of PVA.
4. The attempt to combining bricks and PVA modified gypsum in masonry units allowed to achieve a substantial enhancement in their shear bond strength. In certain situations, this enhancement is of prime importance when shear bond strength needs to be imposed as a design criterion in brick masonry units.
5. The results of the present study were, indeed, encouraging and evidently confirmed that the use of PVA is a simple and reliable way to improve the gypsum fresh and hardened performance. Herein, the performance of gypsum mixes at the maximum PVA addition (6%) was marginally better than that of 5%, and thus, the latter could be considered as the optimum amount.

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