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Improvement of Gypsum Characteristics using (T.G.P.) and (P.V.A.) Additives

Ali A. Abbood

Assistant Lecturer , Civil Engineering Department , College of Engineering , Mustansiriyah University .

Abstract : ***In this research , an attempt has been made to study the effect of adding T.G.P. and P.V.A. additives (by weight) separately and together on gypsum characteristics . The research plan consists of investigating two main gypsum properties , namely : the compressive strength and the setting time . According to the plan, the total number of gypsum mixes used is sixteen (eight for each gypsum characteristic) which had been divided in to four groups according to T.G.P. and P.V.A. contents (by weight) : 0.0% , 0.4% (for T.G.P.) , and 0% , 4% (for P.V.A.) . Each group was divided in to two sub-groups according to (water/gypsum) ratios (0.3 and 0.4) . Each sub-group has three cubic (5*5*5)cm samples (to take their average result) . It was found that , the addition of only T.G.P. to the gypsum mixes , increases the setting time , but decreases the compressive strength of gypsum . It was also found that , the addition of only P.V.A. increases the compressive strength but has no obvious effect on setting time . Consequently , it was found that the addition of both T.G.P. and P.V.A. increases (slightly) the compressive strength and (obviously) the setting time . Finally , it was found that , decreasing (water/gypsum) ratio from (0.4) to (0.3) , improves both the compressive strength and the setting time of gypsum mixes .***

Keywords : gypsum (local joss) , tree glue powder (T.G.P.) , polyvinyl acetate (P.V.A.) , compressive strength , setting time .

1. Introduction

In the recent years gypsum products have been exceedingly used as in-door finishing . Houses, especially in the U.S.A. and Europe , are either built from or lined with gypsum-based products favored by architects because of their superior properties , such as obtainable availability of in-expensive raw materials, volumetric stability, acoustic and thermal insulation , fire resistance , quite low toxicity and the comparatively low energy and temperatures needed in its manufacture [1] . Gypsum is also used in several applications beyond the construction field : e.g. in making molds for ceramic products [2] , in medical [3] , and dental accessories or implants [4] , furthermore , it is the major constituent in Portland cement in order to delay its setting time [5] . The numerous applications of gypsum plaster are primarily based on its specified properties [6],[7] .

Many researchers have attempted to develop plaster characteristics and extend its range of applications through the addition of other materials [7],[8],[9] . One of these additives is "Silica gel" (a highly porous form of silica) , it is a by-product of the sodium silicate industry with fabulous heat and fire resistance , chemical-stability , along with a large specific surface area , and high water sensitivity . In addition , its erratic nature reduces density as well as thermal conductivity and promotes the high temperature durability of plaster composites with trivial loss of compressive strength [2],[10] . The yield strength , elastic modulus , and interior bond of plasterboards have been observed to increase whennano-SiO_2 is added[11] . Silica fume, in turn , is a very good pozzolanic material with a high reaction rate , although it is rarely used with gypsum [12] . Many authors have reported that the addition of ultra-fine sand (U.F.S.) or micro-silica improves the mechanical properties of Portland cement pastes [13, 14] .

The water-gypsum ratio has an influence on the basic physical characteristics of the hardened gypsum , such as its volumetric density , total open porosity , and other related characteristics such as its moisture , mechanical, thermal and acoustic insulation properties . The theoretical water/gypsum ratio necessary for the hydration of calcium sulphate hemi-hydrate $CaSO_4 \cdot ½H_2O$ into calcium sulphate dehydrate $CaSO_4.2H_2O$ is (0.187) . Additional water , in a so-called over-stoichiometric quantity , is necessary for the process of hardening of the gypsum paste . The properties of the hardened gypsum made from a gypsum paste by casting , pressing (or vibrating) , depend on the value of the water-gypsum ratio[15] .

2. Experimental Work

2.1 Materials

2.1.1 Gypsum

2.1.1.1 Gypsum products

Materials that are resulted from the calcinations of gypsum ($CaSO_4.2H_2O$) and having the chemical composition of hemihydrate ($CaSO_4.1/2H_2O$) are called "Gypsum Products" . Although they are identical in composition and x-ray diffraction peaks, they are different in their physio-mechanical properties . They consist of three main types : local joss , plaster , and dental stones , each type has several varieties [16] . The first type has our concern in this research .

2.1.1.2 Local joss

The word "joss" is derived from the Assyrian word "jasso". Local joss in Iraq is a material produced from calcined gypsum by the "Koura method" . Gypsum rock pieces are placed on openings in the "koura" dome while the heat source is at the base of the dome . Heating continues for 24 hours . The final product the joss is a mechanical mixture of un-hydrate , bassinet and un-burnt gypsum .

Gypsum (Local joss) used as a main matrix in this project as calcium sulfate hemihydrate gypsum ($CaSO_4.½H_2O$) , which was obtained from the local market in Baghdad .

2.1.2 Tree Glue Powder (T.G.P.)

Tree glue is taken from trees called (Arak) usually grow in Iran , it is crushed and used primarily for wooden works , but here it is used (may be for the first time) as an additive to gypsum mixes .

2.1.3 Polyvinyl Acetate (P.V.A.)

Polyvinyl acetate (P.V.A.) , commonly referred to as wood glue , white glue , carpenters glue , school glue , Elmer's glue in the U.S. , or PVA glue, is an aliphatic rubbery synthetic polymer with the formula ($C_4H_6O_2$) , it is also used (unprecedentedly) here in our present work as an additive to gypsum works .

2.1.4 Mixing water

Ordinary potable water was used for mixing to all gypsum mixes in this study.

2.2 Gypsum Mixes

Eight mixes of gypsum have been studied in this research, these mixes were divided in to four groups according to T.G.P. and P.V.A. contents (by weight) 0.0% and 0.4% (for T.G.P.) and 0% and 4% (for P.V.A.) . Each group was divided into two sub-groups according to (water/gypsum) ratio (0.3 and 0.4) , these mixes are shown in Table (*) .

All mixes were made by weighted quantities (gypsum , T.G.P. , P.V.A. , and water) . In the beginning , T.G.P. was added to the gypsum and be dry- mixed , then the specified quantity of the water was added to the mix , re-mix manually for (approximately 30 seconds), then poured in to the mold. The mold has been vibrated benefiting from the vibration of a(small generator) for about 10 seconds . After about 30 minutes , the cubic (5×5×5cm) specimens were taken off from the mold . Then , the specimens were exposed to the direct sun light for about one week at approximately 38 C° heat . For P.V.A. , the required quantity of it is added to the required quantity of water and mixed very well , then they are added to gypsum .

Table (*): Description of mixes

Mix No.	T.G.P content % by weight	P.V.A content % by weight	(W/G) ratio	Ingredients Per (100g) Gypsum
Mix 1	0.0	0.0	0.30	(100g) Gypsum +(0.0g) T.G.P +(0.0g)P.V.A +(30g) water
Mix 2	0.4	0.0	0.30	100g) Gypsum +(0.12g) T.G.P +(0.0)P.V.A +(30g) water
Mix 3	0.0	4.0	0.30	100g) Gypsum +(0.0g) T.G.P +(1.2)P.V.A +(30g) water
Mix 4	0.4	4.0	0.30	100g) Gypsum +(0.12g) T.G.P +(1.2)P.V.A +(30g) water
Mix 5	0.0	0.0	0.40	100g) Gypsum +(0.0g) T.G.P +(0.0)P.V.A +(40g) water
Mix 6	0.4	0.0	0.40	100g) Gypsum +(0.16g) T.G.P +(0.0)P.V.A +(40g) water
Mix 7	0.0	4.0	0.40	100g) Gypsum +(0.0g) T.G.P +(1.6)P.V.A +(40g) water
Mix 8	0.4	4.0	0.40	100g) Gypsum +(0.16g) T.G.P +(1.6)P.V.A +(40g) water

2.3. Mixing procedure

All mixes were made by weighted quantities (gypsum, T.G.P. , P.V.A. , and water) . In the beginning T.G.P. was added to the gypsum and be dry- mixed , then the specified quantity of the water was added to the mix , re-mixed manually for (approximately 30 seconds) , then poured in to the mold . The mold has been vibrated benefiting from the vibration of a (small generator) for about 10 seconds . After about 30 minutes , the cubic (5×5×5cm) specimens were taken off from the mold . Then , the specimens were exposed to the direct sun light at approximately 38 C° heat for about one week . For P.V.A. , the required quantity of it is added to the required quantity of water and mixed very well , then they are added to gypsum .

2.4. Testing program

In this research, the 50 mm cubic specimens were tested at age of about one week or over to evaluate the compressive strength [tests are carried out according to ASTM C473][17] .

3. Results & Discussion

3.1. Compressive strength

3.1.1 T.G.P. only

3.1.1.1 Effect of T.G.P. content on compressive strength of gypsum with various (W/G) ratios

Fig (1) and Table (1) show the results of the compressive strength of the gypsum specimens with respect to T.G.P. content . These results shows that the compressive strength (slightly) decreases with the increasing of T.G.P. content , for both (water / gypsum) ratios (0.3 and 0.4) , the reason for this decrease might be related to the chemical effect of T.G.P. on the (water - gypsum) reaction which weakens the interior bound between gypsum crystals . The descending effect of adding T.G.P to the mixes, is clearly obvious for (water/gypsum) ratio (0.3) rather than (0.4) .

Table 1: Effect of T.G.P. content on gypsum compressive strength with variable (W/G) ratios

Mix No.	(T.G.P/ W)% by weight	Compressive strength MPa	Percentage of decrease	(W/G) ratio
Mix 1	0.0	8.63	----	0.3
Mix 2	0.4	7.64	12.3	
Mix 5	0.0	4.64	----	0.4
Mix 6	0.4	4.47	3.7	

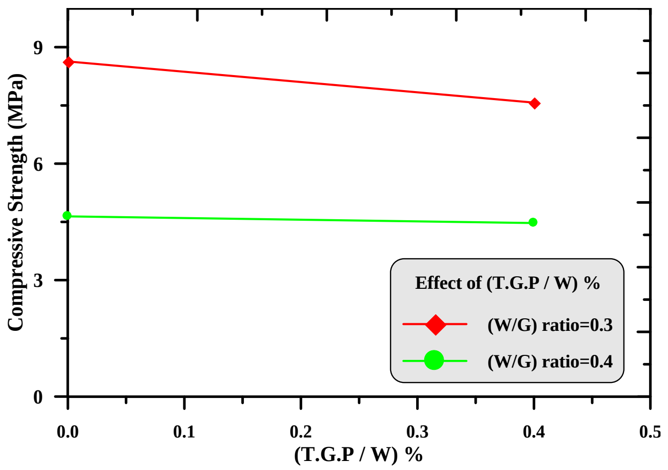


Figure 1: Effect of T.G.P. content on gypsum compressive strength with variable (W/G) ratios

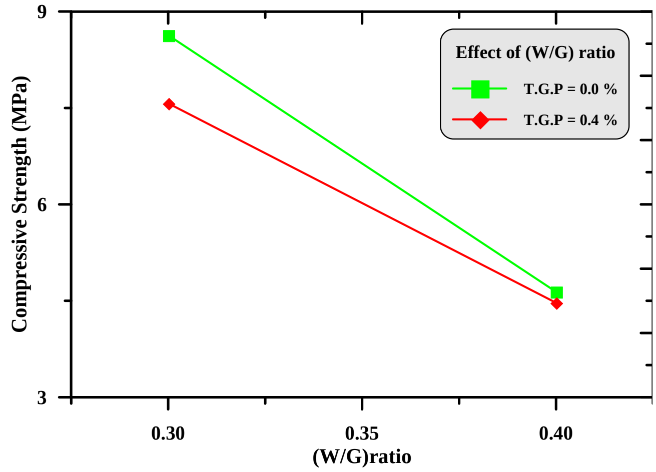


Figure 2: Effect of (W/G) ratio on compressive strength of gypsum with variable T.G.P. content

3.1.1.2 Effect of (W/G) ratio on compressive strength of gypsum with various T.G.P. contents

Fig.(2) and Table(2) show the effect of (W/G) ratio on the compressive strength of gypsum with various T.G.P. contents. These results illustrate that the compressive strength of the specimens decreases with increasing (W/G) ratios for all T.G.P. contents (by weight) 0.0% and 0.4% .The reason of this result may be attributed to the fact that when (W/G) increases, the excessive water will stimulate the gliding of particles and then decrease the cohesion between them which lead to the decrease in compressive strength , another interpretation behind this result is that when the water increase, the amount of water excessive to the reaction water will produce voids after its evaporation and hence weakens the gypsum internal structure and as a result leads to a decrease in the material strength .

Table(2) illustrated that the percentage of decreases of compressive strength when increasing (W/G) ratio , is quite obvious but it decreases with adding T.G.P. . The reason of this phenomena , may be attributed to the chemical effect of T.G.P. , that decreases the interior bond between gypsum crystals and hence lowering the effect of (W/G) ratio .

Table 2: Effect of (W/G) ratio on compressive strength with variable T.G.P. content

Mix No.	(W/G) ratio	Compressive strength MPa	Percentage of decrease	(T.G.P / W)% by weight
Mix 1	0.3	8.63	----	**0.0**
Mix 5	0.4	4.64	46.2	
Mix 2	0.3	7.64	----	**0.4**
Mix 6	0.4	4.47	41.0	

3.1.2 P.V.A. only

3.1.2.1Effect of P.V.A. content on compressive strength of gypsum with various (W/G) ratios

Fig.(3) and Table(3) displays the result of the compressive strength of the gypsum specimens with respect to P.V.A. content. These results reveal that the compressive strength increases slightly with the increasing of P.V.A. content for both (water/gypsum) ratios (0.3 and 0.4) . The interpretation of this increase may be because the adhesive nature of P.V.A. that tends to strengthen the bond between gypsum particles , in addition to the emulsifying nature of P.V.A. eases gliding of particles and gives an effect on eliminating the interior voids in the mix .

Table 3: Effect of P.V.A. content on compressive strength of gypsum with various (W/G) ratios

Mix No.	(P.V.A./W) % by weight	Compressive strength MPa	Percentage of increase	(W/G) ratio
Mix 1	0.0	8.63	----	0.3
Mix 3	4	8.75	1.4	
Mix 5	0.0	5.16	----	0.4
Mix 7	4	5.60	8.5	

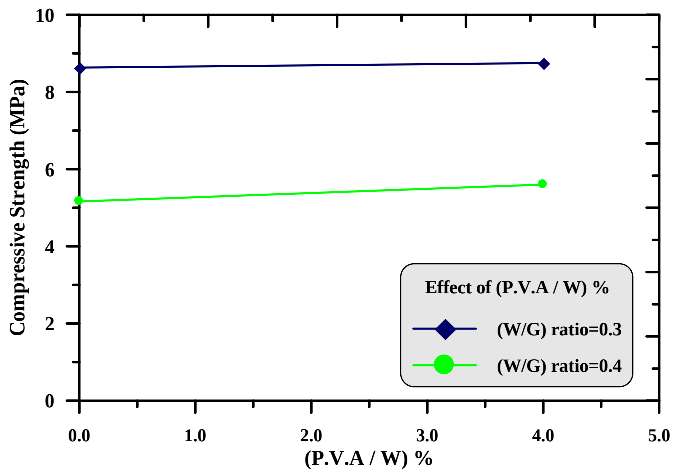


Figure 3: Effect of P.V.A. content on compressive strength of gypsum with various (W/G) ratios

3.1.2.2 Effect of (W/G) ratio on compressive strength of gypsum with various P.V.A. content

Fig.(4) and Table(4) illustrates that the compressive strength of the specimens decreases with increasing (W/G) ratio for all P.V.A. contents (0% and 4%) . The reason of this decreasing maybe because of the trapped air bubbles generated during the mixing process and the evaporation of the excessive water not being entered in the reaction process.

Note

From the above results for T.G.P. only and P.V.A. only , it is obvious that the worst results of compressive strength of gypsum occurred for a (water / gypsum) ratio of (0.4) , therefore , this ratio will be disregarded for the following investigation study of the effect of adding both T.G.P. and P.V.A. on the compressive strength computations .

Table 4: Effect of (W/G) ratio on compressive strength of gypsum with various (P.V.A.) contents

Mix No.	(W/G) ratio	Compressive strength MPa	Percentage of decrease	(P.V.A./W)% by weight
Mix 1	0.3	8.63	----	0
Mix 5	0.4	5.16	40.2	
Mix 3	0.3	8.75	----	4
Mix 7	0.4	5.6	36	

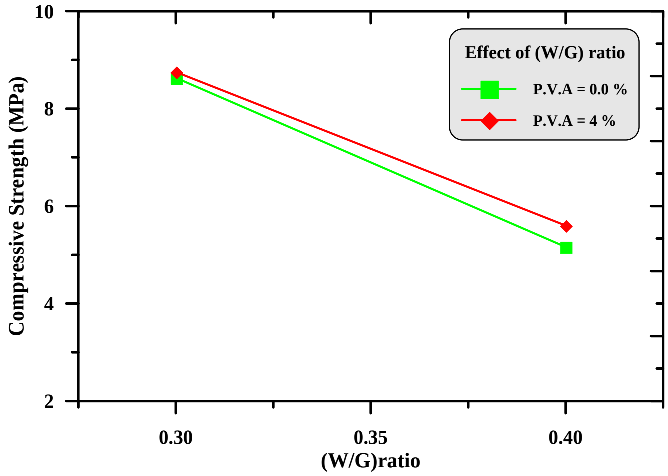


Figure 4: Effect of (W/G) ratio on compressive strength of gypsum with various (P.V.A.) contents

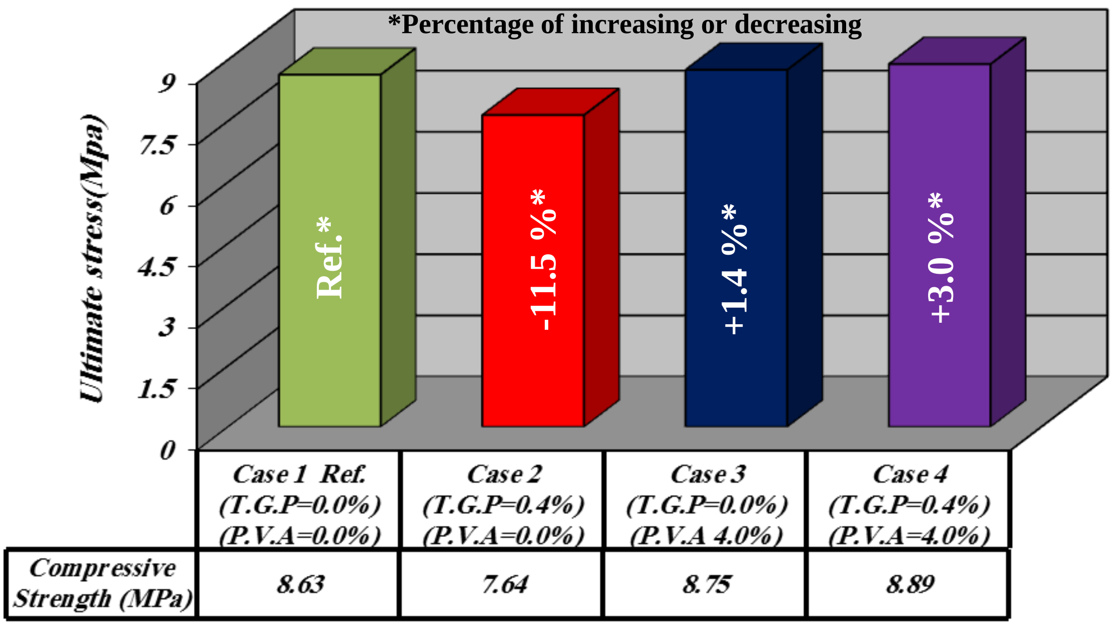
3.1.3 Both T.G.P. and P.V.A.

3.1.3.1 Effect of T.G.P. and P.V.A. contents on compressive strength of gypsum

Bar Chart(1) shows the effect of using both T.G.P. and P.V.A. on the compressive strength of gypsum in comparison with three reference cases , namely :

- Case 1 Ref.1 : No additives (pure gypsum) .
- Case 2 : T.G.P. only .
- Case 3 : P.V.A. only .

The results illustrate that when using both additives(T.G.P. / W = 0.4%) , (P.V.A. / W = 4%) (case 4) , the compressive strength increases by 3% with respect to (case 1 Ref.) , and by 16.36% in comparison with (case 2) , and by 1.6% compared with (case 3) . This result could be interpreted perhaps by the combined effect of T.G.P. and P.V.A. which leads to this improvement of gypsum compressive strength .



Bar Chart (1): Effect of T.G.P. and P.V.A addition on gypsum compressive strength for (W/G = 0.3)

3.2. Setting time

One of the most disadvantages of gypsum mixes ,precisely in the preparation of the gypsum paste is that its setting time is rather small (e.g. compared with cement or concrete paste) and this disadvantage doesn't provide enough comfort for the workers to do their job freely , this promotes us to investigate the effect of our additives (T.G.P. and P.V.A.) individually and together on gypsum setting time .

Setting time is usually measured by a device called (Vicat apparatus), which consist of a 300 gm. weighted rod ended with a needle (5cm long) and (1mm in diameter) fixed by a holder with a graduated plate and a semi-cone pan (60*70*40)mm in dimensions .

3.2.1 (T.G.P.) alone

3.2.1.1 Effect of T.G.P. content on gypsum setting time with various W/G ratios

Table(5) and Fig.(5) display the result of using T.G.P. additives individually on gypsum setting time . The results show that T.G.P. additive obviously increases the setting time for both W/G ratios 0.3 and 0.4.

Table 5: Effect of T.G.P. content on gypsum setting time with various (W/G) ratios

Mix No.	(T.G.P / W) % by weight	Setting Time (min.)	Percentage of increase	(W/G) ratio
Mix 1	0.0	7.33	----	0.3
Mix 2	0.4	22.12	201.6	
Mix 5	0.0	13.55	----	0.4
Mix 6	0.4	27.47	102.7	

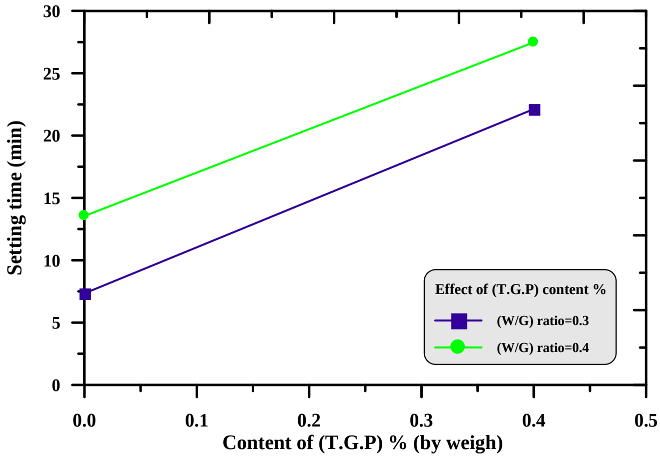


Figure 5: Effect of T.G.P. content on gypsum setting time with various (W/G) ratios

3.2.1.2 Effect of W/G ratio on gypsum setting time with various T.G.P. contents

Table (6) and Fig. (6) show that the increasing of W/G ratios causes an increase in gypsum setting time for both T.G.P. contents (0.0 and 0.4) .

Table 6: Effect of (W/G) ratio on setting time with various T.G.P content

Mix No.	(W/G) ratio	Setting Time (min.)	Percentage of increase	(T.G.P / W) % by weight
Mix 1	0.3	7.33	----	0.0
Mix 5	0.4	13.55	84.8	
Mix 2	0.3	22.12	----	0.4
Mix 6	0.4	27.47	24.2	

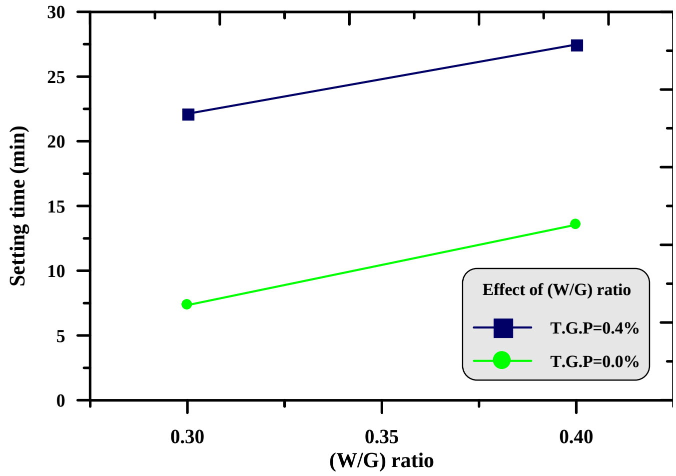


Figure 6: Effect of W/G ratio on gypsum setting time with various T.G.P. contents

3.2.2 (P.V.A.) alone

3.2.2.1 Effect of P.V.A. content on gypsum setting time with various W/G ratios

Table(7) and Fig.(7) show that P.V.A. additive has no significant effect in increasing the setting time of gypsum for both W/G ratios .

Table 7: Effect of P.V.A. content on gypsum setting time with various (W/G) ratios

Mix No.	(P.V.A. / W) % by weight	Setting Time (min.)	Percentage of increase	(W/G) ratio
Mix 1	0.0	7.33	----	0.3
Mix 3	0.4	7.63	4.1	
Mix 5	0.0	13.55	----	0.4
Mix 7	0.4	14.67	8.2	

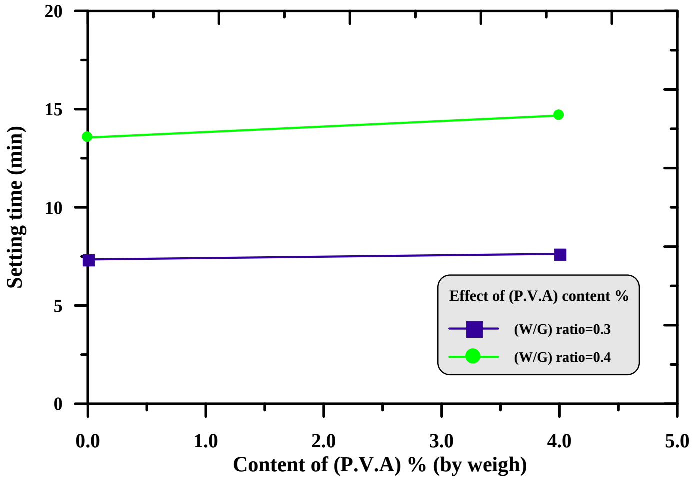


Figure 7: Effect of P.V.A content on gypsum setting time with various (W/G) ratios

3.2.2.2 Effect of W/G ratio on gypsum setting time with various P.V.A. contents

Table (8) and Fig.(8) illustrate that increasing W/G ratio causes an increase in gypsum setting time and the percentage of increase is higher for P.V.A. content of (4.0) than for (0.0) one.

Table 8: Effect of W/G ratio on gypsum setting time with various P.V.A. contents

Mix No.	(W/G) ratio	Setting Time (min.)	Percentage of increase	P.V.A. / W) % by weight
Mix 1	0.3	7.33	----	0.0
Mix 5	0.4	13.55	84.8	
Mix 3	0.3	7.63	----	4.0
Mix 7	0.4	14.67	92.1	

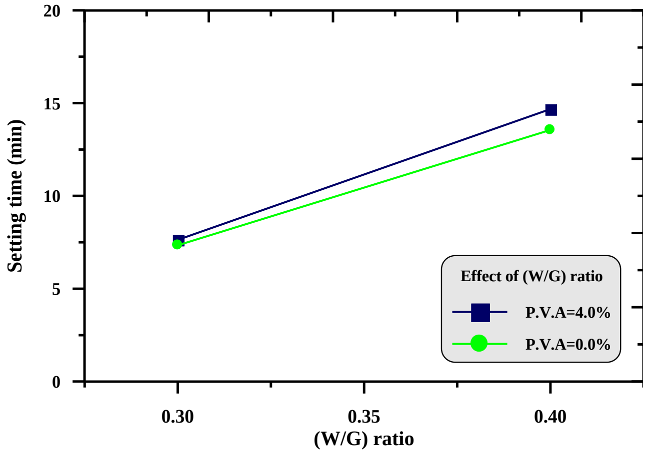
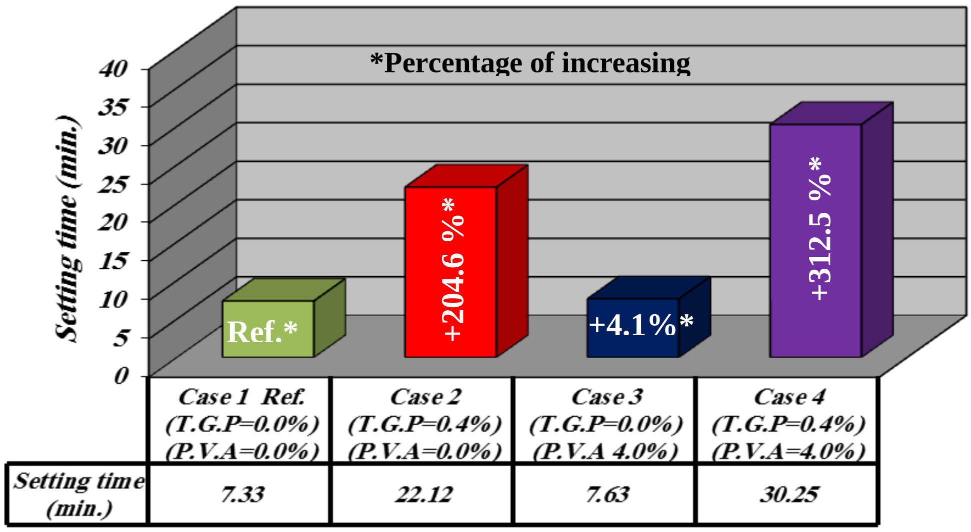


Figure 8: Effect of W/G ratio on gypsum setting time with various P.V.A. contents

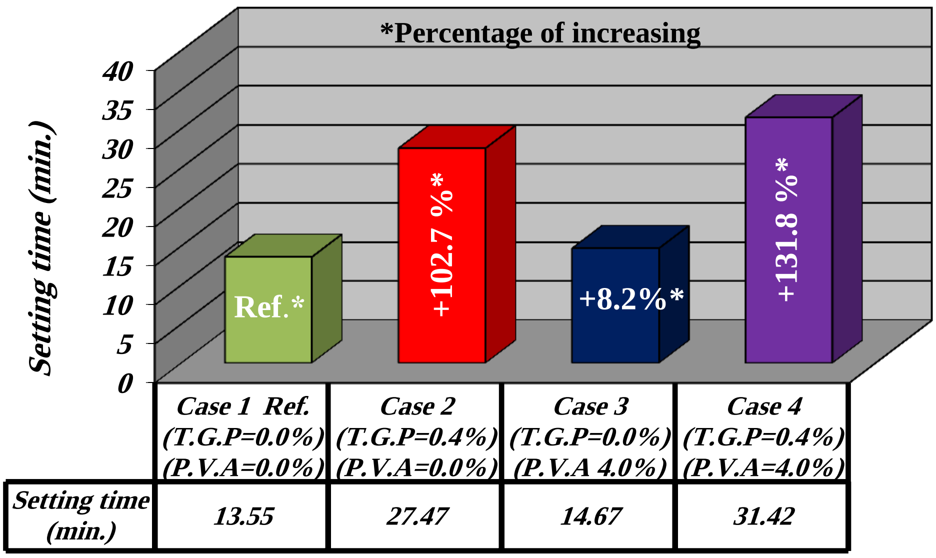
3.2.3 (T.G.P.) and (P.V.A.) together

3.2.3.1 Effect of T.G.P. and P.V.A. contents on setting time of gypsum .

Bar Charts (2) & (3) show that when both T.G.P. and P.V.A. additives where used , their combined effect has been magnified , especially for (W/G = 0.3) , rather than (0.4) one . This might be attributed to perhaps some chemical reaction that occurred between the two additives which produce this gain .



Bar Chart (2): Effect of T.G.P. and P.V.A addition on gypsum setting time for (W/G = 0.3)



Bar Chart (3): Effect of T.G.P. and P.V.A addition on gypsum setting time for (W/G = 0.4)

4. Conclusions

1) Addition of T.G.P. alone to the gypsum mix decreases the compressive strength of gypsum. This decrease includes both (water/gypsum) ratios 0.3 and 0.4 . The percentage of decrease in compressive strength is higher for (W/G = 0.3) than for (W/G = 0.4) .
2) Addition of P.V.A. alone to gypsum mix, improves the compressive strength of gypsum . This improvement is higher for (W/G = 0.4) than for (W/G = 0.3) .
3) Addition of both T.G.P. and P.V.A. (as a target case) to the gypsum mix , improves (slightly) the compressive strength of gypsum .
4) Addition of T.G.P. alone to the gypsum mix , (clearly) increases the setting time of gypsum .
5) Addition of P.V.A. alone , (slightly) increases the setting time of gypsum .
6) Addition of both T.G.P. and P.V.A. (as a target case) to the gypsum mix , (obviously and by large amount) increases the setting time of gypsum .

References

[1] Khalil, A.A.; Gad, G.M. “Mineral and chemical constitutions of the UAR gypsum raw materials”. Indian Ceramics, 16 (1972) 173 - 177.Cited by reference [9].
[2] Combe, E. C.; Smith, D. C. “Some Properties of Gypsum Plaster” . J. Brit. Dent., 17 (1964) 237-245. Cited by reference [9].
[3] Peters, C. P.; Hines, J. L.; Bachus, K. N.; Craig M. A.; Bloebaum, R. D. “Biological Effect of Calcium Sulfate as Bone Graft Substitute in Ovine Metaphyseal Defects” J. Biomed. Mater. Res. A., 76, No3 (2005) 456-462. Cited by reference [9].
[4] Craig, R. G. “Restorative Dental Materials” 7th Edition, St. Louis, Toronto, and Princeton. The C.V. Mospy comp., (1989) 303-330. Cited by reference [9].
[5] Papageorgiou, A.; Tzouvalas, G.; Tsimas, S. “Use of Inorganic Setting Retarders in Cement Industry” Cem. Concr. Res., 27 (2005) 183-189. Cited by reference [9].
[6] El-Maghraby, H.F.; Gedeon, O.; Khalil, A.A. “Formation and Characterization of Poly(vinyl alcohol – co – vinyl Acetate – co-itaconic Acid/Plaster Composites: part II: Composite Formation and Characteristics” Ceramic Silikaty 51, nº 3 (2007) 168-172. Cited by reference [9].
[7] Bas_pinar, S. M.; Kahraman, E. “Modifications in the properties of gypsum construction element via addition of expanded macroporous silica granules”. Construction and Building Materials 25 (2011) 3327–3333. http://dx.doi.org/10.1016/j.conbuildmat.2011.03.022 Cited by reference [9].
[8] Khalil, A.A.; Abdel kader, A. H. “Preparation and physicomechanical Properties of Gypsum Plaster-Agro Fiber Wastes Composites” Interceram Int. J. Refractories Manual (Special Technologies) 21(2010), 62-67.Cited by reference [9].
[9] A. A. Khalil, A. Tawfik, A. A. Hegazy, M. F. El-Shahat"Effect of different forms of silica on the physical and mechanical properties of gypsum plaster composites"Materiales de Construcción Vol. 63, 312, 529-537,octubre-diciembre 2013
[10] Murat, M.; Attari, A. “Modification of some physical properties of gypsum plaster by addition of clay minerals”, Cem. Concr.Res., 2(1991) 378–87. Cited by reference (9).
[11] Wen, L.; Yu-he, D.; Mei, Z.; Ling, X.; Qian, F. “Mechanical properties of nano SiO2 filled gypsum particle board” Trans Nonferrous MetalsSoc China 16 (2006), 361-364. Cited by reference [9].
[12] Fu, X.; Chung, D.D.L. “Effects of silica fume, latex, methylcellulose, and carbon fibers on the thermal conductivity and specific heat ofcement paste.” Cem.Concr. Res., 27, nº 12 (1997), 1799-1804. Cited by reference [9].
[13] Shebl, S.S.; Seddeq, H. S.; Aglan, H. A. “Effect of micro-silica loading on the mechanical and acoustic properties of cement pastes”Construction and Building Materials 25 (2011), 3903-3908. http://dx.doi.org/10.1016/j.conbuildmat.2011.04.021 Cited by reference [9].
[14] Ogawa, K.; Uchikawa, H.; Takemoto, K.; Yasui, I. “The mechanism of the hydration in the system C3S-pozzolana”, Cem. Concr. Res.,10 (1980) 683-696. Cited by reference [9].
[15] F. Wirsching, “Drying and Agglomeration of Flue Gas Gypsum, (ed. Kuntze, R., A.)”, The Chemistry and Technology of Gypsum Philadelphia: American Society for Testing and Materials, 1984, pp 161-174.Cited by reference. Padevět, P. Tesárek, T. Plachý "Evolution of mechanical properties of gypsum in time",INTERNATIONAL JOURNAL OF MECHANICS , Issue 1, Volume 5, 2011
[16] Zeki A. AljubouriAuday M. Al-Rawas "Physical Properties and Compressive Strength of the Technical Plaster and Local Juss"Iraqi Journal of Earth Sciences, Vol. 9, No. 2, pp 49-58, 2009
[17] ASTM C472 – 99 (Reapproved 2009). Physical Testing of Gypsum Plaster and Gypsum Concrete, Annual Book of ASTM Standard, September, 1, 2009.
[18] Sayonara M. M. Pinheiro and GladisCamarini "Characteristics of Gypsum Recycling in Different Cycles" IACSIT International Journal of Engineering and Technology, Vol. 7, No. 3, June 2015.
[19] J. Lewry and J. Williamson, “The setting of gypsum plaster: part II The development of microstructure and strength,” Journal of Materials Science, vol. 29, pp.5 524-5528, 1994. Cited by reference [18] .
[20] Q. L. Yu and H. J. H. Brouwers, “Microstructure and mechanical properties of b-hemihydrate produced gypsum: An insight from its hydration process,” Construction and Building Materials, vol. 25, pp.3149-3157, 2011 Cited by reference [18] .