"Investigation of the Hardening and Strength Characteristics of Gypsum in Mould Casting for POLY-CRETE™"

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Abstract: Poly-crete™ is an engineered asbestos-free alternative building material product recently innovated from polyethylene waste materials. Mould design and fabrication is an important step in the final production of prototype 600 mm x 600 mm ceiling boards of Poly-crete. Hardness, strength, durability and weight of moulds have been found to be directly related to the mix ratio of Portland cement, sand aggregate and gypsum (plaster of paris-pop) used in the production of moulds. It is established in this study, through the measurement of hardness (on the Mohs' Scale) and final weight of production trials, that a mix ratio of 1½ sand + ¾ cement + ¾ pop (by volume) produces the best durable mould with a setting time of less than 30 minutes and a hardness of about 3.25. Even though the mix ratio of 2 sand + 1 cement + 0 pop demonstrated the highest hardness/strength characteristics, with a hardness of about 3.75, it was considered to be too heavy and bulky for routine use. Its setting time of about 24 hours was also considered to be too long (cf. 30 minutes for product with 3/4 pop) for its mass production to be economical and profitable. A third mix ratio of 1½ sand + ½ cement + 1 gypsum (pop) also gave a product with a fairly good setting time of about 30 minutes and a hardness of about 3.25. On the other hand, a mix ratio of 1½ sand + 1 cement + ½ pop took more than 4 hours to set/harden and with a hardness of about 3.5. The studies, therefore, indicate that the addition of pop to a normal sand-cement mix serves to reduce the setting time – that is, the mix hardens more quickly, though with a corresponding decrease in strength/hardness. Unacceptably long setting time results are obtained with products containing cement in higher proportion than that of pop. In other words, the ration of pop in the mixture must be either equal to or greater than that of cement to obtain a short setting time. On the whole, however, it was found that the mould mix with equal proportion of cement and pop gave the best and optimum mould production in terms of both short setting time and hardness/strength considerations. This was the case with the mould cast at a mix ratio of 1½ sand + ¾ cement + ¾ pop and is therefore recommended for future poly-crete mould production. It is estimated that a typical SME – (Small Medium Enterprise) polycrete production factory based on Franchise Business Model would require about 300 moulds for optimal operation.

Keywords: *(polyethylene fibers, poly-crete, asbestos-free, building materials, gypsum-pop; composite materials, mould casting, mix ratio).*

1.0 Introduction

Poly-crete™ was recently innovated as a new asbestos-free composite building material product derived from waste products, viz: i). poly-fiber- (shredded/granulated polyethylene packaged water sachets waste), ii). off-cut paper and iii). Portland cement. The results of the development process, which were presented at The Role of Engineering and Technology in Achieving Vision 20:2020 (RETAV) Conference at the Obafemi Awolowo University, Ile-Ife, November, 2009 [1], showed that, this engineered composite material is not only a viable alternative to the long-existing asbestos-cement building material products such as roofing and ceiling sheets, but will also help in no small measure in the sustainable management of polyethylene sachets waste which are already constituting a menace and pollution hazard in most urban areas of Nigeria [3].

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Moreover, it will be an environmental and health-friendly alternative since asbestos is known to be carcinogenic and its use in countries like the USA has been totally discontinued [2]. Subsequent studies on *poly-crete* have been geared towards, improving its strength-to-weight characteristics [4], and also in improving the prototype production techniques to make its commercialization more viable and investor-friendly. It is in the light of this that weight reduction studies on *poly-crete* were embarked upon and after testing several possible weight combinations of aggregates of the constituent materials, a drop in weight from 4.4 kg to 3.35 kg was achieved for the final product. These results were subsequently presented at 5th International Conference of Africa-Materials Research Society (A-MRS) in Abuja, December 2009 [4]. The present study is part of that continuing quest to improve on the product quality and production characteristics of poly-crete and sets out to investigate the best mould mix ratios that will result in final durable moulds with the least production setting time and the best hardness or, at least, a compromise between the two. A mould with a fast setting time is economically viable in the sense that it will facilitate the casting and de-moulding of many moulds in a day. On the other hand, a fast-setting but brittle product would not serve the purposes of mould durability. Several trials were carried out with various mould mix ratios of aggregates (sand, cement and gypsum) to be able to come out with the best formulation. The role played by gypsum in achieving optimal results was a focal part of the study. Towards this goal, particular attention was paid to the gypsum ration in the composite mix since gypsum is known to reduce the setting time of a sand-cement mix [5]. This paper, therefore, presents and discusses the results obtained from the various mould mix ratios and highlights the role that gypsum, in particular, plays in the hardening and strength development of the moulds.

2.0 Materials and Methods

Materials used in this study include:

i. Portland cement, gypsum (Plaster of Paris-pop) and sand;
ii. Water, trowel, mixing bowl, weighing balance etc.;
iii. 600mm x 600mm Patterned Wooden Master Moulds;
iv. Minerals on the Mohs' Scale: talc, gypsum, calcite, fluorite, apatite, feldspar, microcline, quartz, corundum.

2.1 Portland Cement, Gypsum (pop) and Sand

Portland cement and sand (silica) are well-established constituents of composite materials such as concrete [6]. Gypsum, otherwise known as "Plaster of Paris or pop", is a very soft sulfate mineral of chemical formula, $CaSO_4.2H_2O$, which presents itself often as monoclinic, massive, flat or elongated, and generally prismatic crystals and whose color ranges from colorless to white even though, with impurities, it could be yellow, tan, blue, pink, brown, reddish brown or gray. Plate 1 shows the pinkish crystal while plate 2 shows the colorless to whitish crystal. Gypsum dissolves over time in water and has a wide variety of uses: as a plaster finish for walls and ceilings; fertilizer and soil conditioner; a binder in fast-dry tennis clay court; a major source of dietary calcium; shampoos and many other hair products; as an additive in some traditional Chinese and Indian medicines; as a component of Portland cement used to prevent flash setting of concrete [5]. In this work, it is used principally in preventing flash setting and in quickening the hardening of the molding process.

2.2 Mix Processing Stages & Trial Mixes

The materials used and the processing stages in the casting of the moulds are presented in Plates 3, 4 & 5 while Plates 6(a) – (c) give the trial cast moulds with their corresponding mix ratios. They are presented in increasing gypsum (pop) mix ratios.

Plate 1: Pinkish crystal of Gypsum

Plate 2: Colorless to white elongated crystals of Gypsum.

Plate 3: Weighing the materials (gypsum)

Plate 4: The cement and sand are mixed with water first before adding gypsum.

Plate 5: Mixing the 3 constituents of the composite mould with water.

Plate 6a: (2 sand + 1 cement + 0 pop) trial mix cast

Plate 6b: (1½ sand + 1 cement + ½ pop) mix mould being cast (600 mm x 600 mm).

Plate 6c: (1½sand + ¾cement + ¾ pop) mould (600 mm x 600 mm).

2.3 Hardness/Strength Determination

Plate 7 gives the Mohs' scale minerals used for the hardness determination, which included: Talc (1), gypsum (2), calcite (3), fluorite (4), feldspar (4-7, mean=5.5), quartz (7), topaz (8) & corundum (9). The testing procedure involved scratching each trial mix mould with all the Mohs' Scale minerals available (see list above). The hardness value is thus represented by the mean of the values between which it falls. For instance, if calcite (hardness = 3) scratches the sample but gypsum (hardness = 2) does not scratch the sample (or is scratched by the sample), then the hardness of the sample lies in the range 2-3 (or 2.5).

Plate 7: Mohs' scale Minerals used for the hardness determination:
from L to R: Talc (1), gypsum (2), calcite (3),
fluorite (4), feldspar, (4-7, mean = 5.5),
quartz (7), topaz (8) & corundum (9).

3.0 Results and Discussion

Table I gives the results of the relative hardness tests performed on the six (6) trial mix moulds investigated in this work using mineral specimens on the Mohs' Scale of Hardness with the attendant aim of highlighting the role gypsum (pop) plays in the setting/hardening time of the samples. The table indicates that as the ratio of gypsum in the moulds increases from 0 to ¾ (by volume), the setting/hardening time reduces drastically from 24 hours (the mix mould with 0 gypsum), to less than 30 minutes (mix mould with ¾ gypsum); while the corresponding hardness decreases progressively from 3.5-4 (mean = 3.75) to 3-3.5 (mean = 3.25). This observed trend in the setting times proves to be normal since gypsum itself hardens quickly with water, being the reason why it is used as Plaster of Paris (POP) [5]. The hardening trend is also normal because gypsum's major role as an additive to cement is usually to prevent flash-setting and thus ensure improved hardness development with time as the hydration processes responsible for hardness proceeds. These desirable effects are usually achieved with small amounts of gypsum, being the reason why the hardness observed with the mix moulds tends to decrease with increasing amounts of gypsum; the optimal gypsum mix ration in this work, therefore, came to be ¾ gypsum (by volume). Both the setting times and the hardness development have been demonstrated in this work to be critical in poly-crete mould production. That is why, with regards to hardness, even though the mix of ratio 2 sand + 1 cement + 0 pop demonstrated the highest hardness/strength characteristics, with a hardness of about 3.75, it was considered to be too heavy and bulky and therefore uneconomic for routine mould production. Its setting time of about 24 hours was also considered to be too high (cf. <30 minutes for product with ¾ pop) for its production to be profitable, considering the fact that many moulds need to be produced daily. The same argument applies to the mould with a mix ratio of (1½ sand + ½ cement + 1 gypsum) which gave a product with a favorable setting time of about 30 minutes but with a hardness of only about 2.5. The mould with a mix ratio of (1½ sand + 1 cement + ½ pop) with a favorable hardness of 3.5 was also eliminated because it took more than 4 hours to set/harden since its production needed double the amount of water as in the mould mix with ½ cement. This implies that the mix ratio of (1½ sand + ¾ cement + ¾ gypsum), providing a setting time of less than 30 minutes and a hardness of about 3.0-3.5 (mean = 3.25), is the compromise optimal mix producing the best/most durable mould product. In other words, the mould mix with a gypsum ration of ¾ (relative to 3 by volume) is the best for *poly-crete*^{TM} mould production even though mix moulds with gypsum ratios slightly less (e.g. ½) or slightly more (e.g. 1) could also be used provided the cement ratio is less than or equal to (but not more than) that of the gypsum.

4.0 Conclusion

In this work, it has been established that the mould having a mix ratio of (1½ sand + ¾ cement + ¾ gypsum), with a setting time of less than 30 minutes and a hardness of about 3.25, is the best/most durable optimal mix ratio for poly-crete mould production. Thus, successfully establishing the most appropriate gypsum ration needed for economic routine poly-crete mould fabrication is a major achievement of this study. Since moulds that are durable and long-lasting can now be produced this has further enhanced product quality and overall viability of *poly-crete*™ production and has increased the prospect for its successful commercialization.

Table I : Result Summary of Relative Hardness/Strength Measurements of Mould Mix Ratios of Polycrete™ on the Mohs' Scale.

SAMPLE MIX RATIOS	HARDNESS (MOHS' SCALE)											
	TALC (1)	GYPSUM (2)	CALCITE (3)	FLUORITE (4)	+FELDSPAR (4-7)	*APATITE (5)	*MICROCLINE (6)	QUARTZ (7)	TOPAZ (8)	CORUNDUM (9)	SETTING TIME	SAMPLE HARDNESS
2S + 1C + 0P (1.65 Kg)	X	X	X	X/√√	√	-	-	√	√	√	> 24 hrs	3.75
1½S + 1C + ½P (? Kg)	X	X	X	√	√	-	-	√	√	√	30 mins	3.5
1½S + ¾C + ¾P (? Kg)	X	X	X	XX/√	√	-	-	√	√	√	< 30 mins	3.25
1½S + ½C + 1P (1.65 Kg)	X	X	√	√	√	-	-	√	√	√	> 4 hrs	2.5
1S + 1C + 1P (1.40 Kg)	X	XX/√	√	√	√	-	-	√	√	√	1 hr	1.3-1.5
2S + 0C + 1P (1.40 Kg)	XX/√	√	√	√	√	-	-	√	√	√	1 hr	1.0

√ = Scratches Sample
X = Scratched by Sample
X/√√ = Scratches the sample but is also slightly scratched by the sample
XX/√ = Scratched by Sample but also slightly scratches the sample
S = Sand
C = cement
P = POP (gypsum)

* Specimens of these minerals were unavailable

\+ Feldspar scratches fluorite (hardness = 4) but is scratched by quartz (hardness = 7). Hence, hardness is in range 4-7 (mean = 5.5). Testing with apatite and microcline (both unavailable) could narrow down this range.

5.0 References

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