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Effect of Industrial Pozzolana Materials on Geopolymer Concrete Mixes

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Abstract— The gases emitted into the atmosphere increase significantly with time, due to many reasons, the most important of which is the Portland cement (PC) industry, which in turn represents the most used part of concrete work. To avoid this, the Pozzolanic materials used as substituted to OPC. Then alkaline activated to form the gel which known as aluminosilicate acts as the binder in concrete. Aluminosilicate materials such as silica Fume (SF), GGBS and Rice Husk Ash (RHA) used based geo-polymer concrete (GPC) in this study. Also, normal concrete with grade 45 (M45) is made, then slump test for fresh concretes and compressive strength test for cubes with 15cm3 are done for comparing both geopolymer concrete and M45 under different conditions.

Keywords— RHA, GGBS, SF, M45, SEM, XRD, GPC.

I. Introduction

This document is Ordinary Portland cement (OPC) is the most common material used in concrete as the original material that binds the aggregates through the concrete after the hardening process. Nowadays, the demand for cement is increasing and is still doubly increased by concrete construction around the world. This increasing demand process is leading to the high amount of gas emissions to the atmosphere as a result of the large manufacturing process. Because of the repeated manufacturing process of cement, the environment becomes more polluted by the gases emitted as well as the natural sources of raw materials are on their way to attrition.

In 2009, Dimas et al [1] suggested that materials rich in silica and alumina could interact with highly alkaline solutions to forming an inorganic Al-Si polymer product Si–O–Al–O bonds a substance known as Geopolymer.

Hardjito et al in 2004[2] reported that fly ash (FA) is a substance rich in silica aluminate can be used in the production of geopolymerous concrete. The use of these materials in the production of geopolymer concrete is an important idea, strategy and more environmentally friendly to reduce these industrial waste.

Geopolymer technology is an innovative new technology that can convert various industrial waste materials into the useful and environmentally friendly polymer and geopolymer products. Alumina atoms react with silica atoms to form molecules which are structurally and chemically-equivalent to the natural rock [3]. Geopolymer concrete has shown better abrasion, high impact resistance, and the enhanced bonding property with the low susceptible chemical attack [4]. The emissions of gases sent to the atmosphere and causing environmental pollution caused by the diffuse concrete structures might be reduced with the use of geopolymer concrete which that containing industrial waste.Some Investigation was carried on the geopolymer concrete properties with use industrial wastes like GGBS and FA then it observed that the geopolymer concrete has got strength similar to the normal concrete with better durability [5].

The frequent with increasing use of neglected industrial materials such as FA, SF, GGBS, and RHA have led to a reduction of the global average of the percent clinker of portland cement from 85% in 2003 to about 77% in 2010 and in the future, it is expected to reach about 70% [6].

RHA is one of the most abundant pozzolan materials among industrial and agricultural waste. RHA is one of the most important materials containing a high amount of silica. Hence, it is possible to use RHA to produce concrete, which may lead to the development of the workability, resistance to permeability, low temperature and increased strength in conjunction with age. In economic terms, the use of agricultural or industrial waste materials in concrete production can be considered to reduce the overall cost and to improve the properties of concrete.

The study deals with the comparative investigation of the behaviour a conventional concrete (CC) grade 45(M45) and an environmentally friendly geopolymer concrete (GPC) under using different actions (water curing, room curing and 5% HCL attack). GPC and M45 samples have casted with the optimum percentage replacement of GGBS with RHA and GGBS with SF; the percentage replacement was as a double-sizing system (0%, 20% ... 100%).

II. Experimental

A. *Properties of the materials used*

TABLE I

CHEMICAL COMPOSITION OF MATERIALS USED

Chemical Composition (%)	Cementitious material			
	OPC(53)	**GGBS**	**RHA**	**SF**
SiO_2	20.10	35.20	91.60	92.26
Al_2O_3	4.90	10.70	2.19	0.79
Fe_2O_3	2.50	0.33	0.79	1.57
CaO	65	42.24	0.94	0.43
MgO	3.10	5.98	0.46	0.40
Na_2O	0.20	0.15	0.53	0.38
K_2O	0.40	0.31	0.30	1.31
P_2O_5	0.82	0.11	0.11	-
SO_3	2.30	2.76	-	0.33
Specific gravity	3.20	2.39	1.95	2.62
Colour	Grey	white	Black	Grey

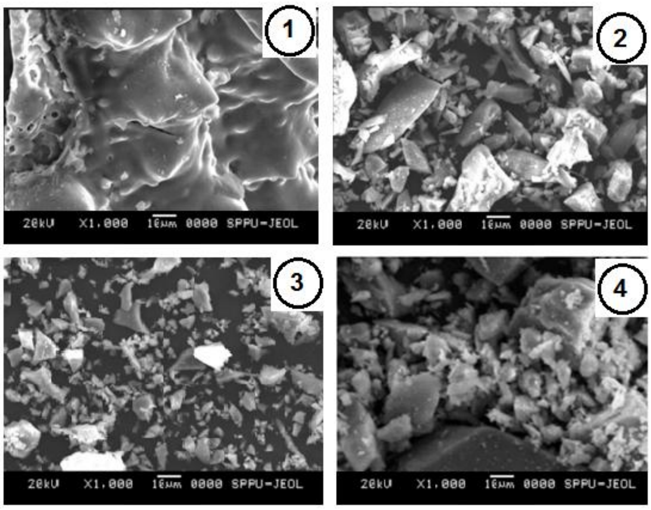


Fig. 1 SEMA of (1) RHA, (2) GGBS, (3) SF and (4) OPC

Sodium silicate solution and Sodium Hydroxide (NaOH) are used as alkaline activator. Sodium Hydroxide (NaOH) known is very good GP activator commonly utilized as the alkaline solution. Sodium cations boost best geopolymerisation, if compared to potassium cations, because of that it can be migrated easier thru the network within gelatin-stage being smaller. The GPCs strength values have got high values at early ages using 8M. [7].

The aggregates used were having two types; one of them was coarse aggregate with three different sizes which are they 7mm, 12mm and 20mm. Coarse aggregates have angular shape, Specific Gravity between 2.79 -2.87, Bulk Density Kg/m^3 is between 1515-1534 and black colure. The second type was the fine aggregate (river sand).

III. MIX PROPORTION

The control concrete used with strength 45MPa was as the reference and a comparison with GPCS for all specimens under tests and noticing the differences between them. Various substitutions of SF/GGBS and RHA/GGBS to manufacturing of the GPC to obtain a high-strength of GPC after that compare it with a regular concrete strength of 45MPa. The GPC was made using the w/total mix is 0.19 with $SiO_2/Na_2O = 2$.

TABLE II
MIX PROPORTIONS OF GPC

Materials		**(Mass/SF)**
Aggregates	20 mm	0.68
	12 mm	0.91
	07 mm	1.59
River sand		1.36
Silica Fume (SF)		1
Super Plasticizer (SP)		0.015
Sodium Hydroxide Solution		41(8M)
Sodium Silicate Solution		0.25

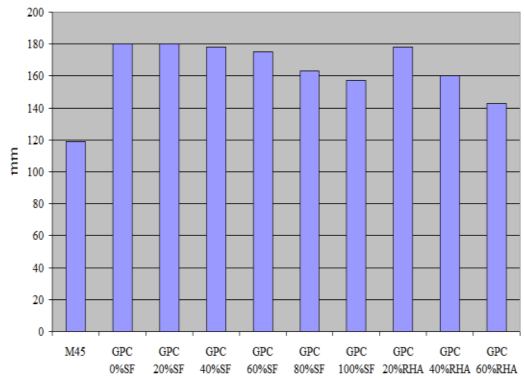
IV. PREPARATION OF CUBES

The system followed was that after covering the inner face of the iron molds with oil and casting the fresh concretes in them, then left those molds for 24 hours and then disassembled the molds and distributed them to the treatment places assigned to each. After 24 hours of casting, during the dismantling of the concrete cubes of the GPC which composed of (80%SF+20%GGBS), (100%SF+0%GGBS) and (40%RHA+60%GGBS) it was observed that it should be left for more time after 72 hours of casting to facilitate the removing cubes from the molds.

Fig. 2 Casting Cubes of concretes

V. RESULT AND DISCUSSION

A. SLUMP TEST

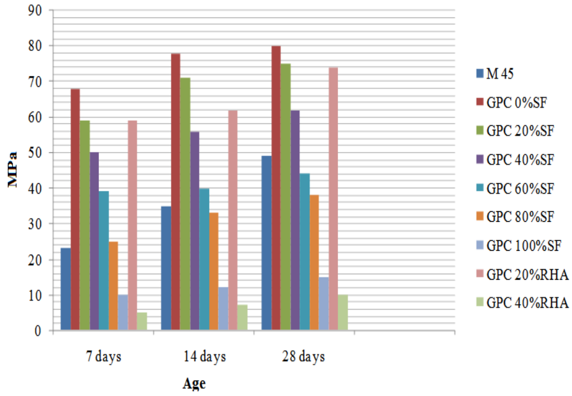


Graph 1 Slump values

B. ***The Compressive Strength Test***

❖ ***Room curing***

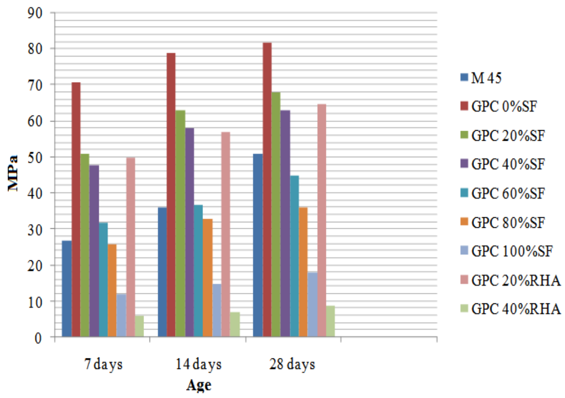
The average of the compressive strength test results under the effect of room curing for both M45 and GPCs specimens with partial replacement are shown in the Graph 2 at different curing periods.



Graph 2 M45 and GPCS cubes under effect of ambient temperature

Generally, it is seen that the early and highest compressive strength results had given by GPC mixes contain 100% GGBS (GPC 0%SF and GPC 0%RHA) at all ages as compared to all GPC mixes even M45. Increasing GGBS amounts in the GPC mixes achieved the high strength in ambient curing without water curing [8, 9]. The GPC mixes 0%SF, GPS 20%SF, GPC 40%SF, GPC 20%RHA and GPC 40%RHA had a clear superiority in all ages with an increase in strength exposure time to room treatment conditions compared with M45. GPC 60%SF gained strength at 7 and 14 curing ages more than M45 values, although at 28days M45 samples gained strength less than M45. GPC 100%SF and GPC 60%RHA at all the ages have had less strength values.

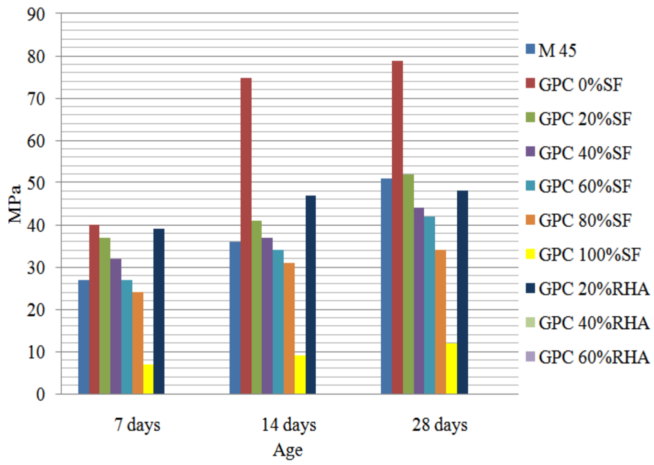
❖ ***Water curing***



Graph 3 M45 and GPCS cubes under effect of submerging in water

In Graph 3 the strength results shown GPC 0%SF and GPC 0%RHA have gained the highest values under the effect of water curing at the all ages. GPC 20%FS, GPC 40%SF, GPC 20%RHA and GPC 40%RHA have got strength more than M45. Also, it has observed that M45 strength was more than GPC 60%SF, GPC 80%SF, GPC 100%SF and GPC 60%RHA strength at all ages of room curing. It can be presumed that an increase in GGBS substitution level in GP mixes enhances strength improvement.

❖ ***5% HCL attack***

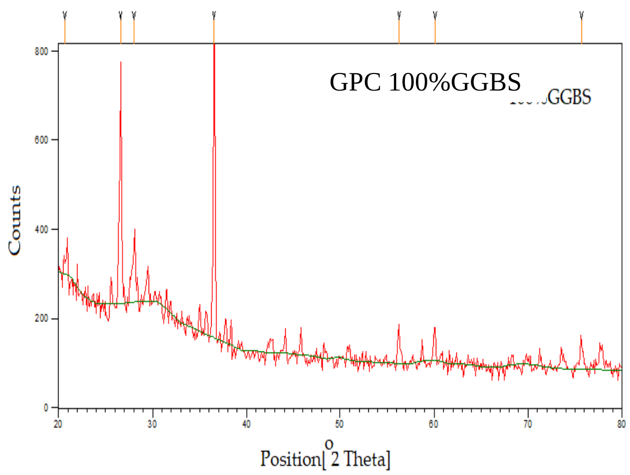


Graph 4 M45 and GPCS cubes under effect of 5%HCL attack

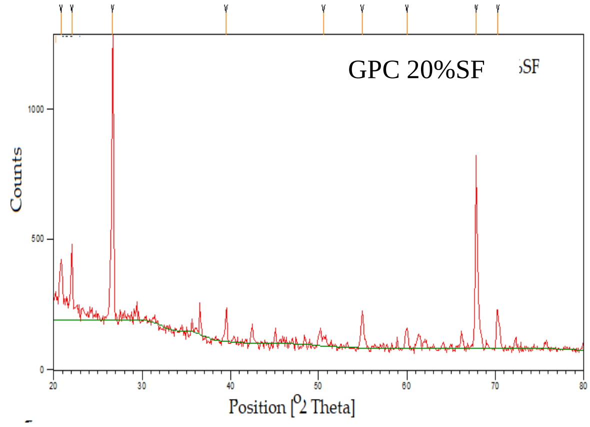
The effect of 5%HCL attack was clear on the compressive strength values of the concretes as shown in Graph 4. GPC 0%SF and GPC 0%RHA have gained more values of strength under HCL attack than other mixes at all test ages specified. GPC 06%SF, GPC 80%SF and GPC 100%SF the strength gained were less than M45 samples strength under the same conditions and ages. GPC 20%RHA strength values at 7days and 14days attack were more than M45 values, although at 28days the GPC 20%RHA samples gained less strength than M45.

❖ ***X-Ray Diffraction (XRD)***

Graph 5 shows the XRD patterns result of the GP samples, which that produced by GPC 100%GGBS. GGBS is an inorganic polymer binder which essentially composition from an aluminasilicate chemical, although impurities such as calcium and iron oxides are in general occurs chemical constituents of the GP system. Using of 5%HCL solution as attack condition, displays high peaks between 25^o–40^o[2Th]; whose the highest peaks existed at 26.5^o[2Th] and 36.5^o[2Th]. By refer to SEMA results of samples that contained 100%GGBS showed that, they acquire a coherent matrix and strength results, it has obtained an early strength with slightly different after attacked by 5%HCL. That is because of the Albite, which might accompanied with the strength enhancement zone in the GPC matrix. And due to Thenordite compound that have been formed, can resist of the de-hydrates of the materials and water sucking [10].

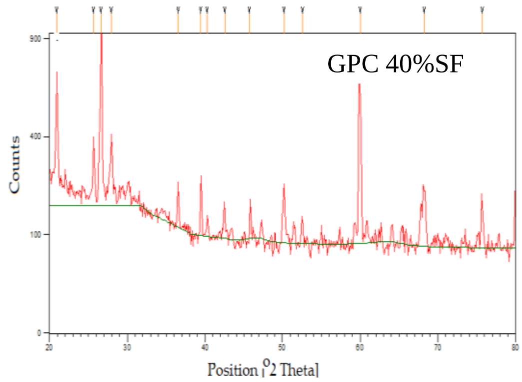


Graph 5 XRD pattern of the GPC 100%GGBS based geopolymer exposed to 5% HCL solution



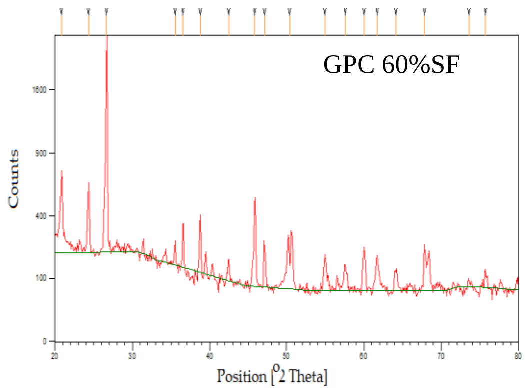
Graph 6 XRD pattern of the GPC 20%SF based geopolymer exposed to 5% HCL solution

The overall, the pattern is not very sinuosity but at the same time has clear peaks at 26.6°[2Th] and 67.8°[2Th]. In comparison of 80%GGBS+20%SF samples with the high altitude peaks for the samples with 100%GGBS, there are 10°[2Th] are different to the left side. SF is known has a precise size that helps to fill the gaps between GP composition which improve of the mechanical properties as well as inhibit water absorption and abrasion resistance. Which related to the interaction of Ca species with freely dissolved silica in the matrix to forming CSH and that accumulate in the free pores, and then transformed to crystalline form at the final treatment ages [11]. This can be observing through the compressive test, there is a high early compressive strength at 7 days for GPC 20%SF samples even at 28 days.



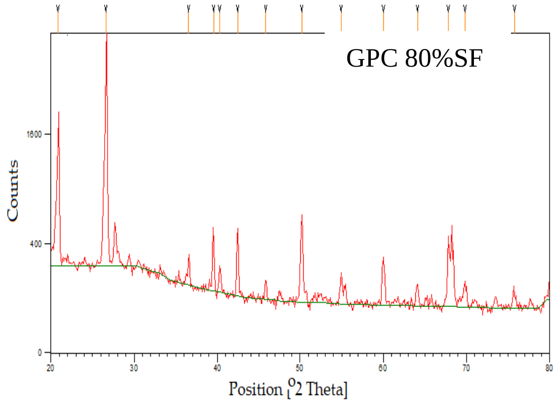
Graph 7 XRD pattern of the GPC 40%SF based geopolymer exposed to 5% HCL solution

Graph 7 shows that with an increase of SF to 40% and decrease of the GGBS to 60%, it is clear can see that the X-ray analysis gave a very irregular pattern of diffraction, also presence of the peaks from angle 20 to 70°[2Th]. The highest peaks were centred at 26.6°[2Th] and Followed by 59.9°[2Th]. The highest summit notes that is shifted to the left by 4°[2Th] than the GPC 100%GGBS contained. This pattern using XRD analysis has different irregular pattern when the samples contain lower rates of SF and greater amount of GGBS which relies to contribution presence of the glass content in GGBS.



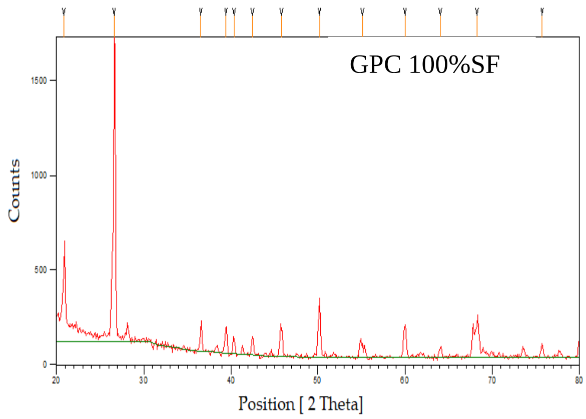
Graph 8 XRD pattern of the GPC 60%SF based geopolymer exposed to 5% HCL solution

Graph 8 shows the XRD patterns of the GPC 60%SF, a diffuse band at 20–46^o[2Th]. Has been observed for this pattern, were clearly shown the peaks of the irregular pattern by increased SF with low GGBS contained. And of these peaks were concentrated at 20.8^o, 24.3^o, 26.6^o and 45.8^o [2Th] which the highest peak took the left direction by 10^o [2Th] if compared with samples have contented 100%GGBS. By observing the microscopic examination of the sample found a group of small cracks and some of the gaps that were filled with solutions also the results of the strength obtained values less than Its predecessors in all ages of 5%HCL curing, thus reducing the resistance of the pressure as the amount of SF increases.



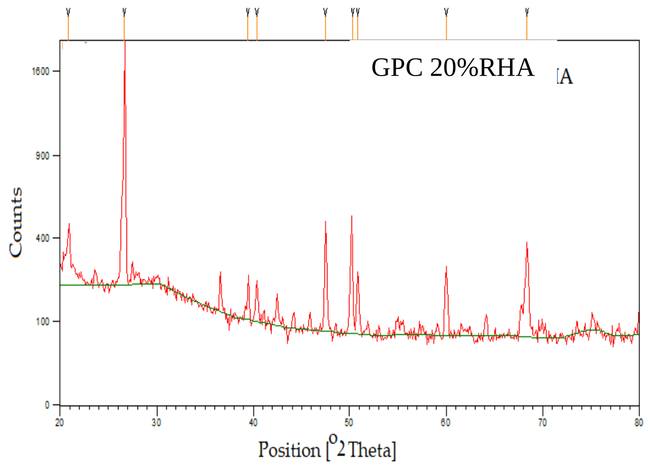
Graph 9 XRD pattern of the GPC 80%SF based geopolymer exposed to 5% HCL solution

The XRD pattern of GPC 80%SF was obtained as shown in Graph 12. As indicated by of high humps registered between 20°and 27° which can be seen clearly at 20.8^o[2Th] and 26.6^o[2Th]. The patterns shown the decreased and increased the humps between 20^o to 69^o which is due to the higher specific surface area of SF material (7-10% by mass)can interacting with dissolved calcium of the waste concrete materials then forming CSH that has positively affect geopolymerization process by formulation centres of nucleation for the formation and GP accumulation. Also, the increasing the SF content (7% to 10% by mass) leads to the negative action by forming agglomerates that concentrated in the small area which hinder of both the GP phases and the formation CSH [11].



Graph 10 XRD pattern of the GPC 100%SF based geopolymer exposed to 5% HCL solution

Graph 10 presents the XRD patterns analysis of the alkali activated GP blend containing 100% ratio of SF with 0%GGBS and 5%HCL solution attacked up to 28 days. From the XRD data, can be noticed that growth of the band in the region of 20° to 27°[2Th] for aluminosilicate gel. The peaks had a concentration of 20.8°[2Th] and 26.6°[2Th]. The peaks had a concentration of 20 to 26. With the change of the silica ratio to 100%, the pattern deviated at the highest point of about 10°[2Th] to the left, compared to the patternthat has 100%GGBS. The XRD data coincides with the direction of compressive strength, where the amorphous content in GP materials increased and same time increasing of the SF content causes precipitation sites to the GP accumulation. By increase of the SF content also leads to imperfect wetting for the climate that hinders the spread of GP chains then weakens its mechanical properties.



Graph 11 XRD pattern of the GPC 20%RHA based geopolymer exposed to 5% HCL solution

Graph 11 shows the XRD patterns of the GPC 20%RHA GPC powder. The pattern has sharp peaks superimposed at hump between 20–70^o [2Th.]. The sharp peaks were divided into 20.8^o, 26.6^o, 47.5^o and 68.3^o. The highest peak was in the direction of the left by approx 10 degrees, with a sampling of GPC 100%GGBS. The highest peak formed from amorphous silica which is the major constituent in RHA [12, 13]. While that very weak peaks are from crystalline silica phase and quartz also present. According to RHA chemical composition (TABLE II) the silica as amorphous phase mainly presents with cristobalite [14] and trace crystalline quartz. On the other hand, the highly peaks likely because of presence C-S-H gels through of the GPC samples rather than $CaCO_3$ [15].

VI. CONCLUSION

1. In general the fresh geopolymer concrete that contained different pozolana materials with 0% to 100% ratios have gained slump values higher than M45.
2. The slump values of the fresh geopolymer concrete based on GGBS/SF and GGBS/RHA decreased with increase of GGBS dosage in the mixtures.
3. The compressive strength of geopolymer concrete contained 100%GGBS gained the highest strength for all the geopolymer concrete mixes even M45.
4. Using SF ratios 0% to 40% give strength for geopolymer mixes higher than M45 at all ages of curing, while using 60%SF including the mixes leads to gain strength higher than M45 strength at 7 and 14 days.
5. Using RHA ratios 0% to 20% give strength for geopolymer mixes higher than M45 at all ages of curing, while using more than 20%RHA including the mixes leads to gain strength lower than M45 strength at all ages.
6. An increase of GGBS dosages in geopolymer mixes leads to an early strength using the effect of different conditions although a small increase in the strength at 14 and 28 days under same conditions.
7. Under the conditions of the effect of 5%HCL solution, it was observed that the GPC 100%GGBS obtained the highest value of the strength at the specified ages and the reduction in the amount of GGBS in the mixtures leads to a decrease in values.
8. Through the results obtained from the 5%HCL solution attack, GPC can be considered as usable in applications exposed to acidic environments.

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