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Experimental Works on Geopolymer Concrete Composites: Destructive and Non-Destructive Testing

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Abstract*: The main theme of this research work is to study Geopolymer concrete (GPC) composites behavior when different binding materials in certain percentages are replaced completely with cement in order to analyse the mechanical properties and bonding between aggregates and Geopolymer paste. The term Geopolymer was coined by Professor Davidovits in 1978, a kind of inorganic polymer that can be prepared at room temperature by utilizing modern waste. Any material that contains for the most part silicon (Si) and Aluminium (Al) is a source material for the production of Geopolymer. Geopolymer is an inorganic polymer composites which is an eco-friendly sustainable product by replacing the conventional concrete such as Flyash, Ground Granulated Blast furnace slag (GGBS, Silica fume, Metakaolin(MK) and other siliceous materials are used as substitute binders to Portland cement. The properties of GPC have been studied in several researches due to its importance and ability to solve the problems of ordinary Portland cement. GGBS, MK and Rice Husk Ash (RHA) was used as replacement to cement and binder in Geopolymer concrete. The specimens are cured at ambient temperature condition. Mechanical properties of the GPC mix specimens are studied for different time ages (7days, 21days and 28days) and the strengths of the specimens were determined. Alkaline Activator Solutions are prepared in the molarities of 8, 10.

Index Terms*: Geopolymer concrete, cement replacement, Alkaline Activator Solution (AAS), Metakaolin.

I. INTRODUCTION

Cement is the second highest consumed material in the world. The immediate replacement of cement with the environmental friendly material is very much essential in order to reduce the release of carbon emissions into the atmosphere. The development of Geopolymer concrete (GPC) is mainly to reduce the production of Ordinary Portland cements (OPC) that adversely affect the environment. This paper tells about the use of GGBS, MK and RHA as binder material in Geopolymer concrete, investigates the mechanical properties with different molarities of Alkaline Activator Solution. Destructive and non-destructive tests were performed on Geopolymer concrete to evaluate the best mix proportions that yield the highest strength as well as the quality of the concrete. The results obtained in Compressive strength, splitting tensile strength, rebound hammer and ultrasonic pulse velocity (UPV) are nearly supporting.

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II. STUDY AREA

In this paper, studied experimentally and focused on the mechanical properties of the Geopolymer concrete composites. In this concrete mixes, cement is completely replaced with GGBS, MK and RHA in certain percentages to study the Geopolymer concrete mechanical properties. This study was conducted for the time period of 7, 21 and 28 days [6, 8, 9, 10, 11, 12]. Casted specimens are of three types, namely specimens casted with concrete by complete substitute of cement with GGBS, MK and RHA, were mixed with two molarities of NaOH and Na_2SiO_3 solutions with concentrations of 8 and 10.

III. METHODOLOGY

A. Material

Materials used for this study are GGBS, Metakaolin and Rice husk ash as the binder source material, aggregates, water alkaline liquids which consist of sodium hydroxide and sodium silicate. Binding materials GGBS, MK and RHA are the waste byproducts which are available for lesser cost. Locally available 10mm and 20 mm crushed aggregate had been used as coarse aggregate and river sand is used as fine aggregate in the mixes. Tests are conducted for fine and coarse aggregates as per IS: 2386-1963 and IS: 383-1970.

Alkaline Solution/Alkaline Activator Solution (AAS)

The alkaline activator solution (AAS) was a combination of sodium hydroxide (NaOH)/ potassium hydroxide (KOH) and sodium silicate solution. As per the previous studies, NaOH is better than KOH for strength criteria. In this, 8M and 10M solution concentrations are used, where M=molarity. Sodium hydroxide (NaOH) is commonly available in the form of Flakes. NaOH in flakes of 98% purity is purchased from the suppliers (Andhra Scientific Company) had been used. The sodium hydroxide solution is prepared by dissolving the flakes in water. The mass of NaOH solids in a solution varies depending on the concentration of the solution expressed in terms of molarity(M). Distilled water is used to dissolve the NaOH pallets. It is recommended to prepare solution 24 hours before the mix because it liberates large amount of heat. Sodium silicate solution (Na_2SiO_3) are available in the form of liquid are used. First NaOH flakes were titrated with water then sodium silicate solution is added. The alkaline activator solution was prepared one day in advance to the casting of the specimens. While preparing solution, utmost care has to be taken.

Fig. (a)

Fig.(b) Casted Cubes of GPC Specimens

B. Geopolymer Concrete Mix design

As there is no proper code provisions are available for the mix design of Geopolymer concrete, the density of Geopolymer concrete was assumed to be 2400 kg/m^3, and the other calculations were made based on the density of concrete as per the design proposed by Lloyd and Rangan (2010)[1]. The combined total volume occupied by the coarse and fine aggregates was assumed to be 77 %. The alkaline activator solution (AAS) to binder ratio was taken to be 0.40.

Mix of GGBS based Geopolymer Concrete

1. Density of the GGBS based Geopolymer concrete = **2400**Kg/m^3
2. Coarse and Fine aggregates are considered as 77% of density of GPC = **1848 kg/m^3**
3. In the total weight of aggregates, coarse aggregates occupy 65% = **1201kg/m^3**

Fine aggregate occupy 35% = 35/100*1848 = **647kg/m^3**

1. Taking the Alkaline solutions to GGBS ratio as 0.40
   Alkaline solution / GGBS = 0.40
   Alkaline solution + GGBS = 2400-1848 = 552kg/**m^3**
   GGBS content = **394kg/m^3**
2. Calculation of Alkaline solution quantity = (2400-1848-394) = **158kg/m^3**

Na_2Sio_3 to NaOH ratio taken as = 2.5
Sodium silicate + Sodium hydroxide = **158kg/m^3**
Na_2Sio_3 / NaOH = 2.5
Sodium silicate = 113kg/m^3
Sodium hydroxide = 158-113 = **45kg/m^3**
Water Content = 15% of GGBS
= 15/100*3= **59litres/m^3**

Table 1.The mix proportions are given in

Materials	Quantities
GGBS (Binder)	394kg/m^3
Coarse Aggregate (20mm)	1201kg/m^3
Fine aggregate	647kg/m^3
Na_2Sio_3	113kg/m^3
NaOH	45kg/m^3
Molarity	8M
Water	59kg/m^3
Na_2Sio_3 / NaOH	2.5
Alkaline solution / GGBS	0.40
GPC MIX RATIO (Binder: FA: CA)	1 : 1.64 : 3.05

C. Mix Proportions

W/GP Solids =0.21, Binder/GGBS = 1, Fine aggregate =1.64, Coarse aggregate = 3.05.

After getting the final quantities of mix proportions, cubes, cylinders and beams had been casted.

IV. CURING OF SPRCIMENS

The specimens are gone in moulds at intact room temperature about to 24 hours. The specimens are then divide from the moulds and cured for 7, 21 and 28 days.

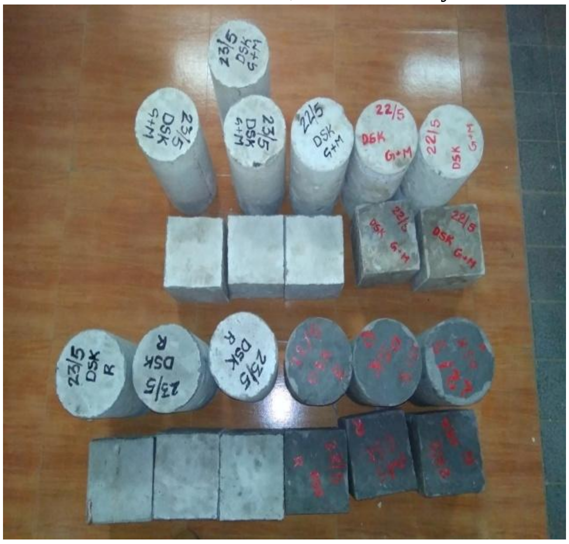

Fig (c) GPC Specimens after removing moulds

Testing of Specimens: The specimens are secured to endure proper testing on schedule in time. The casted specimens are tested as per the Indian standard guidelines, and cleaning off the surface water, as per IS 516-1959. The performance of GGBS, MK+GGBS, GGBS+MK+RHA based geopolymer concrete are make it ready for destructive and non-destructive tests (NDT). The NDT comprises of Ultrasonic pulse velocity (UPV) and rebound hammer while the DT includes both compressive strength and splitting tensile strength.

A.Compressive Strength (CS) values of GP Concrete:

The CS of GPC specimens containing binder percentage replaced cement completely with GGBS, Metakaolin and Rice Husk Ash with different percentages tabulated below. Specimens of size (150 x 150 x 150 mm) are casted and tested as per IS 516: 1959 [2]. The hardened properties strength of the GPC specimens are calculated for 7, 21 and 28 days for 8 and 10 Molarity.

B. Split tensile strength test values of GP Concrete:

In order to measure the splitting tensile strength, three (150 mm diameter, 300 mm height) cylinders for each of the combination are tested at 7, 21 and 28 days of the immersion. Ambient-cured cylinders (control specimens) are tested for comparisons. The test was carried out as per the guidelines stated by Indian Standards IS 5816 (1999) for the splitting tensile strength [3].

C. Rebound Hammer Test and UPV Test

The rebound hammer test was carried out on the GPC specimens with flatten, neat and wither surface. For the unleveled surfaces present on the concrete, the surface was rubbed with grinding wheel or stone. The point of locating the hammer must be 20mm away from the boundary surface and discontinuity shapes. The rebound hammer shall be kept right angle to the specimens surface of the concrete.

At each of the specimen surface, numbers of observations are recorded and the average of these recorded observations gives the values of the strength of concrete. The rebound hammer test was conducted on the specimens attaining the ages of 7, 21 and 28 days in order to find out the effect of partially replacing with GGBS, metakaolin, rice husk ash on geopolymer surface hardness and penetration resistant. The test was performed as per the guidelines stated by Indian Standards IS 13311 (Part 1):1992 for the ultrasonic pulse velocity[4] and IS 13311 (Part 2): 1992 for the rebound hammer test[5].

Table 2: Concrete quality guidelines for Rebound hammer

Rebound number	Concrete Quality
>40	Very good
30-40	Good
20-30	Fair
<20	Poor

UPV test was carried out on the samples attaining the age of 7, 21 and 28 days in order to examine the impact of different types of specimens geopolymer concrete uniformity. A set of geopolymer concrete consists of three cubes were tested by calculating the velocity of ultrasonic pulses for three times by direct, semi-direct and indirect transmission which means nine reading for each cube [7] . The outcome value for each of the transmission was compared with the guidelines as in Table 3.

Table 3: Concrete quality guidelines for UPV

Pulse Velocity (m/s)	Concrete Quality
> 4500	Very good to excellent
3600-4500	Good to very good but slightly porosity may exist
3000-3500	Satisfactory but loss of integrity is suspected
2100-3000	Poor and loss of integrity exist
< 2100	Very Poor

V. EXPERIMENTAL RESULTS

In this section, Results of preliminary analysis are explained in detail. To develop Geopolymer concrete composites, various mix proportions are prepared in order to examine the change in compressive strength, split tensile strength of concrete with change in concentration of sodium hydroxide(NaOH) solution i.e. Molarity (M) was observed by keeping all other variables like curing temperature, sodium silicate to sodium hydroxide solution ratio constant. The ambient curing condition for all trial mixes.

DESTRUCTIVE TESTS

COMPRESSIVE STRENGTH TEST

The compressive strength of concrete has been evaluated using 2000kN capacity hydraulic testing machine. For compressive strength test cube of size 150mm X 150mm X 150mm size are tested in compression as per the Indian Standard guidelines stated in IS: 516-1959[2].

Table (a): GPC Specimens CS results of 8Molarity

Specimen category	Binder material	Specimen strength (N/mm^2)		
		7 Days	21 Days	28 Days
GPC1	GGBS	11.6	38.7	39.4
GPC2	GGBS+MK(10%)	4.2	12.6	24.7
GPC3	GGBS+RHA (10%) + MK (15%)	2.9	6.2	18.6

Table (b): GPC Specimens CS results of 10 Molarity

Specimen category	Binder material	Specimen strength (N/mm^2)		
		7 Days	21 Days	28 Days
GPC1	GGBS	13.1	39.8	39.9
GPC2	GGBS+MK (10%)	9.4	24.9	32.8
GPC3	GGBS + MK (15%)+ RHA (10%)	8.7	15.7	33.8

The above tables (a) and (b) are the compressive strength results for the different GPC specimens having 8 and 10 Molarity conditions. It infers that a Compressive Strength of 10 Molarity GPC specimens exhibits better results when compared to 8 Molarity Specimens. There is a decrease in strength when rice husk ash is supplemtal as a binder material in the mix. In GPC3, 10M Specimens shows an increase in CS strength when compared with GPC2.

The graphical illustration of the table (a) and (b) is presented in the subsequent fig. (1) and fig. (2).

SPLIT TENSILE STRENGTH (STS) TEST

Table (c): GPC Specimens STS results for 8 Molarity

Name of the Specimen	Binder material	strength of specimen (N/mm2)		
		7 Days	21 Days	28 Days
GPC1	GGBS	0.09	0.28	1.27
GPC2	GGBS+MK(10%)	0.0016	0.27	1.19
GPC3	GGBS + MK (15%)+ RHA (10%)	0.0017	1.08	1.16

Table (d): GPC Specimens STS results for 10 Molarity

Name of the Specimen	Binder material	strength of specimen (N/mm2)		
		7 Days	21 Days	28 Days
GPC1	GGBS	0.27	1.77	2.27
GPC2	GGBS+MK(10%)	0.21	1.11	1.79
GPC3	GGBS + MK (15%)+ RHA (10%)	0.15	1.20	1.51

The above tables (c) and (d) are the splitting tensile strength results for the GPC Composite specimens having 8 and 10 Molarity conditions.

It infers that a split tensile Strength of 10 Molarity GPC specimens exhibits better results when compared to 8 Molarity Specimens. There is a decrease in strength when rice husk ash is added as a binder material in the mix. The graphical illustration of the table (c) and (d) is presented in the subsequent fig. (3) and fig. (4).

NON-DESTRUCTIVE TEST RESULTS

Rebound hammer

Table (e): Result for rebound hammer of 8M

Specimen/ Mix No.	Rebound number					
	7-days	Quality of Concrete	21-days	Quality of Concrete	28-days	Quality of Concrete
GPC1	19	Poor	23	Fair	29	Good
GPC2	5	Poor	15	Poor	22	Fair
GPC3	4	Poor	12	Poor	20	Fair

Table (f): Result for rebound hammer of 10M

Specimen/ Mix No.	Rebound number					
	7-days	Quality of Concrete	21-days	Quality of Concrete	28-days	Quality of Concrete
GPC1	25	Fair	29	Fair	33	Good
GPC2	9	Poor	15	Poor	26	Fair
GPC3	8	Poor	12	Poor	27	Fair

The above tables (e) and (f) are the rebound number results for the GPC Composite specimens having 8 and 10 Molarity conditions. It infers that a rebound bound number of 10 Molarity GPC specimens exhibits better results when compared to 8 Molarity Specimens.

The graphical illustration of the table (e) and (f) is presented in the subsequent fig. (4) and fig. (5).

Ultrasonic Pulse Velocity Test

The average of the results of UPV for Geopolymer concrete with different combinations on direct, semi direct and indirect transmission mode shown in the below tables.

Table (g): Result for UPV of 8M Specimens for 28 days

GPC Mix	Average Recorded Pulse Velocity (m/s)	Quality of Concrete
GPC1	4350	Good to very good but slightly porosity may exist
GPC2	3846	Good but slightly porosity may exist
GPC3	3571	Satisfactory but loss of integrity is suspected

Table (h): Result for UPV of 10M Specimens for 28 days

GPC Mix	Average Recorded Pulse Velocity (m/s)	Quality of Concrete
GPC1	3575	Satisfactory but loss of integrity is suspected
GPC2	1327	Very Poor
GPC3	1578	Very Poor

Table (h): Result for UPV of 10M Specimens for 28 days

From the tables (g) and (h), it clearly infers that quality of concrete is good when alone GGBS as a binder material in Geopolymer concrete mix. In addition, it shows better quality of concrete mix at 10 molarity concentration.

The graphical illustration of the tables (g) and (h) is presented in the subsequent fig. (6) and fig. (7).

NDT results are comparatively nearly matching with the DT results for some of the geopolymer concrete composites.

VI. CONCLUSIONS

1. Studied the mechanical properties of Geopolymer concrete composites and compared the results of destructive and Non-destructive test results of the GPC mixes at 8 and 10 Molarity concentration.
2. From the experimental analysis, it is clear that water/binder ratio and alkaline solution/binder ratio are the major regulatory factors in designing the Geopolymer mix design for various grades.
3. The strength of cubes, cylinders with 10 Molarity is higher than the ones with 8 Molarity specimens and the same supported by NDT results.
4. Alone replacement of GGBS gives best results when compared with other two binder materials.
5. The Effect of replacement of RHA shows the abnormal decrease in the CS and STS values compared other binder materials like GGBS, MK.
6. RHA at 28 days of 10 Molarity specimens shows better results when compared with 8 molarity GPC corresponding mixes.
7. The ultrasonic pulse velocities of all the specimens are increased with respect to ascending time period. However, at the age of 7 days, the pulse velocity unusually dropped for all the specimens. The geopolymer concrete generally have good quality concrete with slight porosity.
8. For rebound hammer, results obtained from ultrasonic pulse velocity are not satisfactorily matching for 10M specimens. Entire geopolymer concrete specimens were summarized as poor quality for GPC2 and GPC3 for 7 and 21 days curing.
9. The reduction in water content favours the formation of geopolymerization process, which demands for increase of NaOH and Na_2Sio_3. Hence it is recommended high molarity concentrations for medium and high grade.

Analysis of CS values by graph

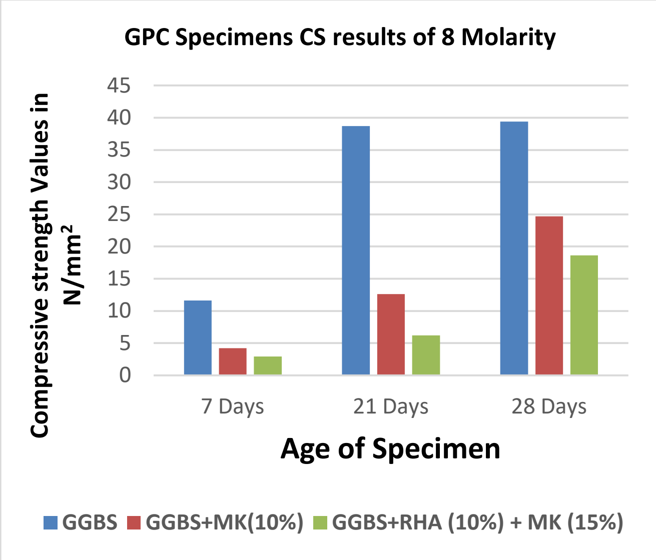

Fig.1. Represents CS results of 8M

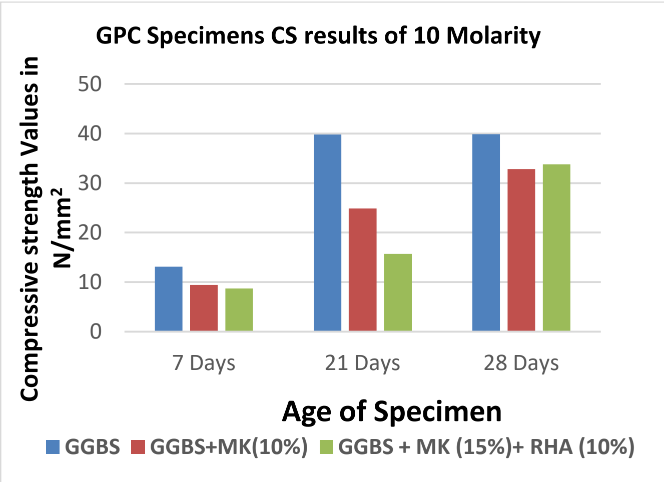

Fig.2. Represents CS results of 10M

Analysis of STS values by graph

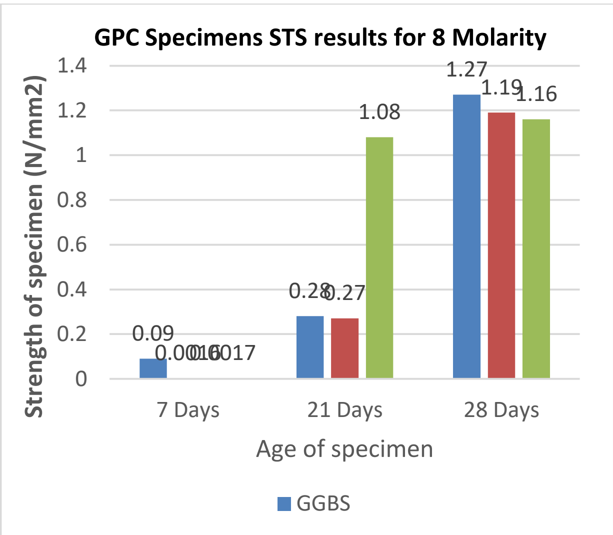

Fig.3. Represents STS results of 8M

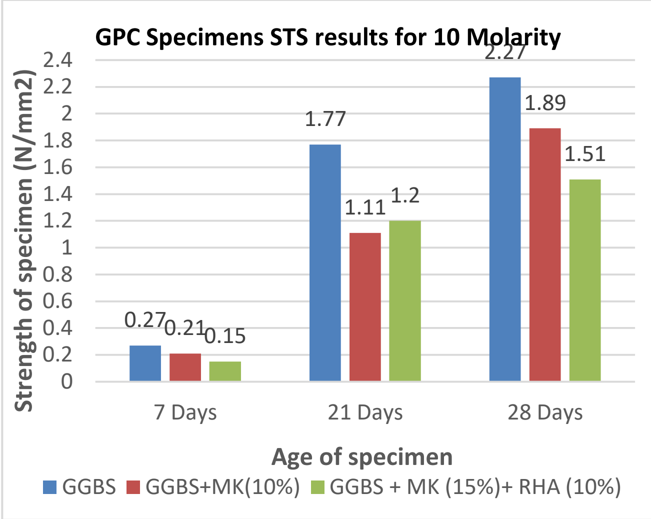

Fig.4 Represents STS results of 10M

Analysis of Rebound Number values by graph

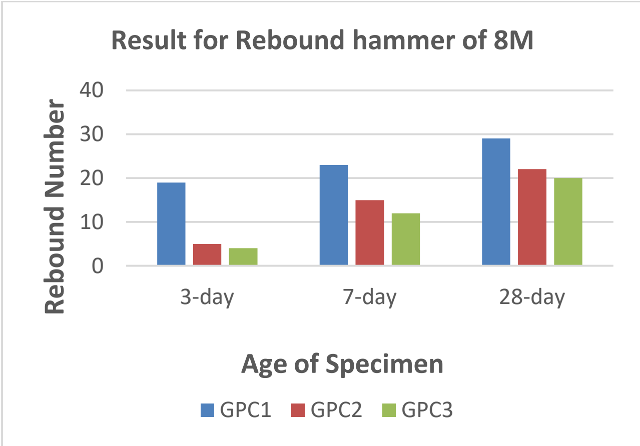

Fig.5 Represents rebound hammer results of 8M

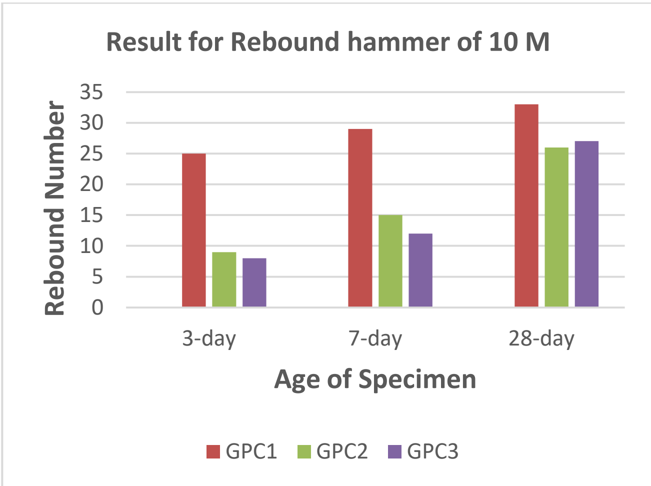

Fig.6 Represents rebound hammer results of 8M

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Analysis of UPV values by graph

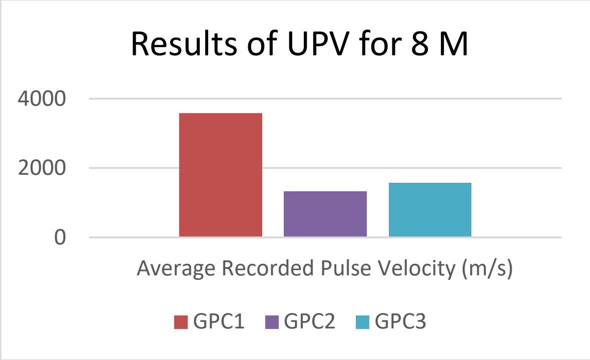

Fig.6 Represents UPV results of 8M

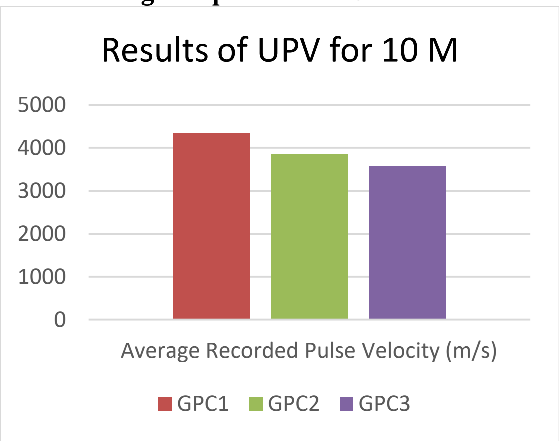

Fig.6 Represents UPV results of 10M

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