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International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Ultrasonic Pulse Velocity and Morphology of High Strength Concrete with PVC Waste Aggregate

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Abstract**: *In this paper, morphology and ultrasonic pulse velocity (UPV) of high strength concrete with a relatively high ratio of condensed silica fume and PVC waste aggregate as sand replacement have been examined. The plastic aggregate was obtained from shredding PVC waste sheets used for secondary roofing and covering walls. Variables tested were PVC plastic grading and ratio of sand replacement with such plastic, in addition to curing time of concrete. Results of scanning electron microscopy showed that there is a good bond between PVC aggregate particles and hardened cement paste. There was a relatively small reduction of UPV value of concrete, increased with increasing PVC aggregate content, reached 14.3% at 40% PVC content. The UPV lost is slightly increased with increasing concrete age from 7 days to 56 days. Results also showed that the effect of PVC aggregate grading on the residual UPV is not important. Based on the measured residual properties of high strength with silica fume and PVC granules, there is a high degree of silica fume hydration and the existence of PVC particles has no effect on such hydration.***

Keywords* : *High strength concrete, PVC waste aggregate, Scanning electron microscopy, Ultrasonic pulse velocity.

I. INTRODUCTION

Nowadays, high strength concrete beside the other novel concretes such as self-compacting compensated the classical concrete mainly because of the advances take place in the concrete technology aspects. Nevertheless, concrete with high compressive strength known by its brittle failure and low ductility, and relatively higher unit weight as compared with normal strength concrete. On the other hand, there is a promised future to use different plastic wastes as a supplementary fine aggregate for concrete production. In general, there is a strength loss accompanied with the use of plastic waste aggregate in concrete, mainly attributed to the lower interfacial bond between the cement matrix and PVC particles [1]. Concrete with PVC aggregate is often proposed for applications such as highway crash barriers and other impact loading scenarios. However, practical projects to date which have been carried out for a specific use are still scarce. Recent studies [2,3] on using PVC waste aggregate as sand replacement or PVC powder as cement replacement showed that concrete can undergoes a relatively large deformation before failure. Therefore, it is expected that when PVC aggregate is used in a concrete with low ductility, this addition is helpful to change the brittle mode of failure. Indeed, on using this plastic waste the risk of land and water pollutions can be diminished, because a relatively large daily plastic wastes need to be recycled. The present study is a part on an extensive one on the fundamental properties of high strength concrete containing plastic wastes. The present study aimed at investigation of ultrasonic pulse velocity (UPV) of high strength concrete containing PVC waste aggregate experimentally. The plastic aggregate was obtained via shredding PVC sheets used for secondary roofing and covering walls. Two different plastic aggregate have been used according to the particles size distribution and added to concrete by different ratios up to 40% as sand replacement.

Manuscript published on January 30, 2020.
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II. MATERIALS AND METHODS

A. Materials

The materials used for casting concrete were cement, fine aggregate (normal sand), coarse aggregate (crushed stone), superplasticizer, silica fume, water, PVC aggregate. The cement that used was ordinary Portland cement (Type 1 ASTM), produced by Tasluja factory- Sulaimani, Iraq. Physical properties and chemical composition of the cement obtained from tests indicate that the cement properties are conforming to the ASTM C150 specification limits [4]. The fine aggregate that used in this investigation was clean natural river sand, coarse grading obtained from Drabandikhan quarry- Sulaimani. For the sand used fineness modulus was 3.8, specific gravity was 2.52, water absorption was 1.7% and compacted bulk density was 1989 kg/m^3. Fig. 1 shows total percentage passing of fine aggregate obtained from sieve analysis tests. One can find that the gradation of the sand used is within the limits of ASTM C33 specification [5]. Crushed stone obtained from Tanjaro quarry– Sulaimani with maximum size of 10 mm, SSD specific gravity of 2.65, water absorption of 1.2% and compacted bulk density of 1629 kg/m^3 was used. Fig. 2 shows total percentage passing of the coarse aggregate.

It is observed that the gradation of the gravel used is within the limits of ASTM C33 specification [5].

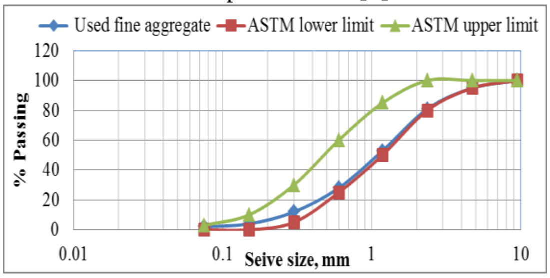

Fig. 1.Grain size distribution of fine aggregate and ASTM C33 limits

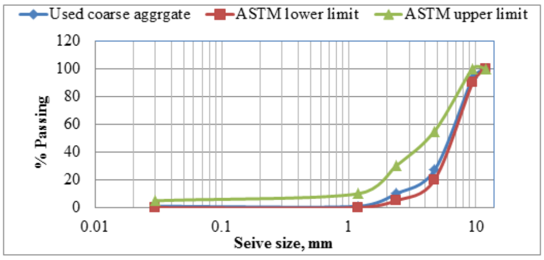

Fig. 2.Grain size distribution of coarse aggregate and ASTM C33 limits

In order to prepare PVC waste aggregate, PVC sheets wastes were collected from some disposal areas in Sulaimai city. Such plastic sheet is frequently used in Kurdistan- Iraq for false roofing and covering walls and there is a waste of about ten kilograms after finishing for one story residential house. The collected plastic was washed to remove the dirt and imported particles, and then subjected to primary and secondary crushings. Primary crushing of PVC sheet was made in a plastic recycled factory and relatively irregular and coarse graded particles were obtained. Because of a poorly graded of crushed PVC aggregate, this aggregate is not useful for concrete making and there was a need for the secondary crushing. This was made utilizing a grain milling machine (see Fig. 3). Secondary crushing was made to obtain two types of PVC aggregate according to the fineness, one of 5 mm maximum size (designated as coarse PVC aggregate) and the other of 1.2 mm maximum size (designated as fine PVC aggregate). Specific gravity of the PVC aggregate used was 1.4 and compacted bulk density was 846.9 kg/m^3. Based on sieve analysis tests, percentage passing of coarse grading PVC aggregate is as shown in Fig. 6, and for this aggregate fineness modulus is 4.46. One can observe that the plastic aggregate is coarser than the sand required according to the ASTM C33 specification [5]. Fig. 7 shows percentage passing of the fine grading PVC aggregate in addition to the specification's limits. It is observed that the grading falls within the limits of the ASTM C33. For this plastic aggregate, fineness modulus was found to be 2.64.

Polycarboxylate based super-plasticizer (Gantre 99) provided by Idea company-Sulaimani was used for the high strength concrete mixes. Properties of the super-plasticizer used are as follows: specific gravity is 1.1, PH is 6.9, solid content is 30% and was found to contain no any chloride. Silica fume slurry was also used to produce high strength concrete. Condensed micro silica slurry of Admix MS560 type was used for high strength concrete mix. This mineral admixture was consisted of 40% solid content, 1% WRD and 59% water by weight. Specific gravity was 1.4, PH was 9.5 and was of bold greyish color.

Fig. 3.Secondary crushing using grain milling machine

Fig. 4. View of coarse PVC aggregate

Fig. 5. View of fine PVC aggregate

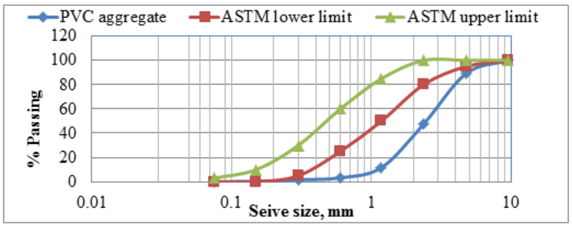

Fig. 6. Grain size distribution of coarse graded PVC aggregate and ASTM C33 limits

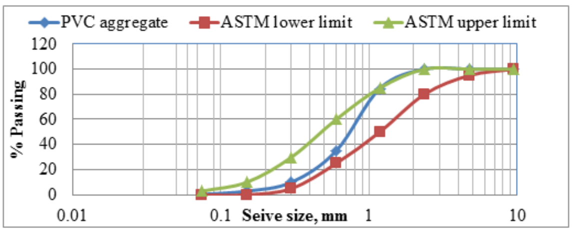

Fig. 7. Grain size distribution of fine graded PVC aggregate and ASTM C33 limits

B. Concrete Mixes and Preparation of Specimens

For concrete mix design, the recommendation given by Aïtcin [6] was followed to design a concrete mix of 80 MPa compressive strength. This method of mix design was developed at the Université de Sherbrooke which is a modification of the ACI 211 (Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete) specification for mix design. In this investigation eight trial mixes were prepared with different w/b ratios, cement content, coarse and fine aggregates content, silica fume and HRWR in order to determine the optimum mix proportion for the control mix without plastic aggregate. Trial mixes were tested at the age of 28 days and the best mix was that gave maximum compressive strength with the minimum standard deviation, which were found to be 83.02 MPa and 2.22 MPa respectively. Table 1 shows materials content per one cubic meter of this concrete. For other mixes, natural fine aggregate was replaced by 5, 10, 20 and 40% PVC aggregate by volume. Since there were two types of PVC aggregate with regard the grading, there were a total of nine mixes. Natural aggregates were prepared under the SSD state but the PVC aggregate was used in a dry state. The cement, fine aggregate, coarse aggregate and PVC aggregates were weighed first and mixed for about five minutes using an electrical tilting drum of 0.16 m^3 capacity. 70% of total mixing water then added and after two minutes of mixing, the remained mixing water, silica fume slurry and HRWRDA were added ant left to mix for another five minutes. Two types of steel molds were used for casting 100*200 mm cylinders and 100*100*500 mm prisms. The inner surfaces were thoroughly oiled before casting concrete. The molds were filled with concrete in three layers and vibrated. Later, the upper face of the concrete inside the mold was leveled and finished using a steel trowel. The samples were left for 24 hours in the molds, and afterwards they were taken out and transferred to water tank for curing at a temperature of 20±1 C° for periods of 7, 28 and 56 days. After that curing had been completed, all specimens were left in the laboratory to dry for 7 days before testing.

C. Testing Procedure

The 100x200 mm cylinder specimens were used in order to prepare a small specimen required for the morphological analysis using scanning electron microscopy. It is necessary to obtain a small undamaged pellet due to cracking (about 10 gm) to carry out the morphological test. For this purpose, a 10 mm thick disc was cut from the whole cylinder using an electrical diamond saw (see Fig. 8) from which a small pellet had been taken. Scanning electron microscopy device used for analysis was FEI QUANTA 400 model and on using many pictures had been taken for analysis. This test was carried out on those concrete mixes containing 40% PVC aggregate content. Nondestructive test of ultrasonic pulse velocity was performed using portable non-destructive digital indicator, commercially is known as (PUNDIT E48), produced by CONTROLS Company (see Fig. 9). UPV test was made on the 100 x 100 x 500 mm prisms according to BS1881: Part 203 [7]. The time taken by the pulse to travel from one face of the concrete to another one was recorded by the device, dividing the path length of 500 mm by the measured time will lead to the pulse velocity. Average of three measurements was taken for UPV at the ages of 7, 28 and 56 days.

Fig. 8. View of sawed cylinder (a) Concrete with coarse grading plastic (b) Concrete with fine grading plastic

Fig. 9. Ultrasonic pulse velocity tester 58-E0048

III. RESULTS AND DISCUSSION

A. Morphology

The results obtained in this study are interested and may clear the way for further experiments on the behavior of concrete with plastic waste granules. SEM test was performed on concrete with sand replaced by 40% coarse or fine graded PVC waste aggregate.

Table- I Concrete Mix Proportion

w/b ratio	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (after correction) (kg/m^3)	Silica fume (% of cement)	HRWR (% of cement)
0.23	486	1075	714	40.6	25	1.3

Figs. 10 and 11 show the enlarged view of concrete with coarse grading PVC aggregate, while Figs. 12 and 13 show the view of concrete with fine grading PVC aggregate. Important observations can be made essentially different from those reported by the past investigators worked on morphology of concrete containing different plastic wastes. According to Fig. 10 surface texture of PVC is not smooth and is considerably rough.

This roughness characteristic has an important effect to enhance the interfacial bond between PVC particle and hydration products of cement (see Fig. 11). A homogeneous structure of hardened cement paste is observed mainly consists of C-S-H gel, because the existence of portlandite has been ceased by the silica fume used in concrete mix. The good bond between PVC particles and hardened cement paste in addition to the high homogeneity were responsible to improve important properties of high strength concrete with PVC aggregate. According to Figs. 12 and 13, the fine PVC particle was well distributed and bonded to the hardened cement paste with a minimum flaws or cavities. The interfacial bond between fine PVC particle and hardened cement paste is shown in Fig. 13 from which a strong bond can be observed without flaws or cavities. A relatively good bond observed from the mentioned images illustrates that there is chemical compatibility between the two materials, PVC and hardened cement paste. This behavior could not be seen for normal concrete containing PVC aggregate or other plastics. Microstructure of a relatively low concrete strength with PVC granules was analyzed by Ceran et al. [8] using scanning electron microscopy (SEM). Based on their images the surface of the PVC granule is rough, and a strong composite structure between PVC granule and concrete has been observed. As a result, the PVC granule was bonded to concrete and forms a compact and homogeneous structure. Some voids were also noticeable in SEM analyses of PVC concrete. The occurrence of these voids was attributed to the tension between cement paste and granules or separation of granules during breaking the sample for SEM analysis. Results also show that fly ash is successfully completed the hydration reaction.

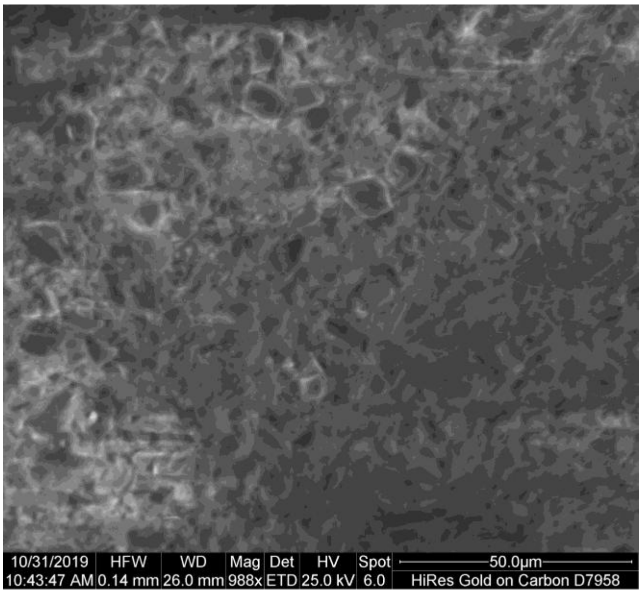

Fig. 10. Surface of embedded PVC particle in concrete

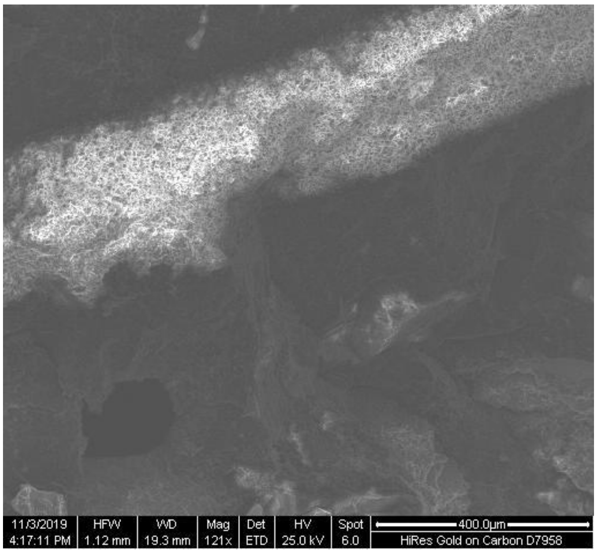

Fig. 11. Interfacial bond between PVC particle and cement paste

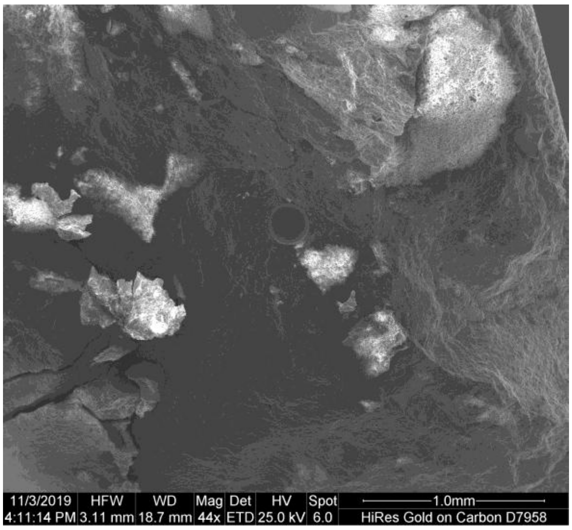

Fig. 12. View of PVC particle embedded in concrete

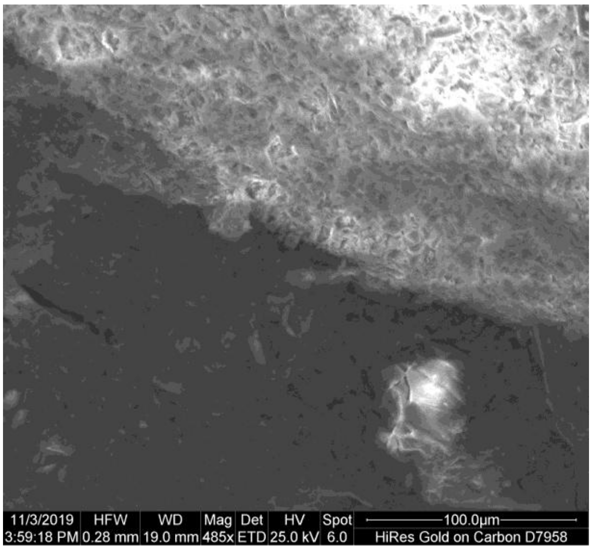

Fig. 13. Interfacial bond between PVC particle and cement paste

B. Ultrasonic Pulse Velocity

Simple test was carried out on compacted layers of PVC sheet of thickness between 5 mm to 10 mm to determine ultrasonic pulse velocity (UPV) of PVC material. Results showed that the average UPV value is 1432 m/s with coefficient of variation equal to 30.2%. The PUV value of PVC plastic is only 29% of the measured UPV of control concrete at the age of 28 days. As stated before, SEM analysis indicated a strong bond between PVC material and cement matrix. Since a part of natural aggregate was replaced with PVC aggregate particles having a low UPV value, one can expect a reduction in the UPV of concrete with the plastic aggregate. UPV of high strength concrete with or without PVC aggregate was measured at the ages of 7, 28 and 56 days, and the results are given in Table 2. The test data include mean value, coefficient of variation, the percentage change in the UPV, and concrete quality according (IS 13311 (Part 1): 1992) [9]. The later specification had been set to assess the quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc. Figs. 14, 15 and 16 show variation of concrete UPV values with PVC aggregate percentage at the age of 7 days, 28 days, and 56 days respectively. Test results indicate that UPV values of samples decreased as the percentage of PVC waste aggregate in the mixture increased. However, the UPV loss is relatively small as compared with that of normal strength concrete with PVC aggregate. The reason of the UPV reduction is attributed to the reduction of ultrasonic wave transmission as a result of substituting normal fine aggregate particles with PVC ones. The authors think that the higher PVC resistance to pulse velocity is the unique cause and there is no role of cavities and flaws between PVC particles and hardened cement paste. This has been confirmed based on SEM test mentioned before. The percentage change in UPV values is shown in Table 2. Results show that the maximum reduction in UPV value is occurred at 40% PVC aggregate replacement for both fine and coarse grading PVC aggregate. Results show that the percentage of UPV reduction is 12.62%, 13.1% and 14.3% for concrete at the ages of 7, 28, and 56 days respectively. The effect of PVC grading on the residual UPV was found to be not important. IS 13311 (Part 1): 1992 [9] reported that the UPV value of an excellent quality concrete should be above 4.5 km/s, and for good quality concrete should between 3.5 and 4.5 km/s. Concrete specimens M0, MC5, MF5, MC10, MF10, MC20, and MF20 at 7,28, and 56 days curing age according to (IS 13311 (Part 1): 1992 [9]) can be considered as excellent in quality, but the quality of MC40 and MF40 specimens are considered as good quality at 7,28, and 56 days curing age. Results shown in Table 2 indicate that COV is reduced with increasing concrete age. This can be attributed to increasing the homogeneity of concrete containing PVC aggregate with age. It is worthy to compare the UPV variation of high strength concrete and that of normal strength concrete obtained by the other researchers. UPV loss for HSC is considerably low as compared with that of normal strength concrete containing PVC aggregate (Mohammad et al. [2], Senhadji et al. [10] and Latroch et al. [11]).

SEM analysis by Senhadji et al. [10] showed that the quality of the interfacial transition zone between PVC aggregate and cement paste appears is quite poor compared to that between the cement-paste matrix and conventional aggregate. Larger air bubbles were generated in the cement paste of concrete made with PVC aggregate. So, the morphology of normal strength concrete with PVC is different as compared with that of HSC examined in this study. Based on their tests the UPV loss at 50% sand replaced with PVC aggregate is 17%. Other tests by Latroch et al. [11] showed that the interfacial transition zone (ITZ) between the EPVC aggregates and the cement paste is not as good as the one found between the matrix and the natural aggregates. The SEM analysis reveals a weaker adhesion between the cement matrix and the EPVC aggregates as compared to that detected between the cement matrix and natural aggregates. Moreover, it was found that larger pores appeared in the cementitious matrix of the composite after the addition of EPVC aggregates. The presence of these pores is an additional factor which contributes to the reduction in the compressive strength and weight of the composite mortars. In contrast, the reduction of UPV was not so large for the same concrete mix tested. Keeping in mind that there is a strong bond between the PVC and hardened cement paste in high strength concrete examined in this investigation. Since the maximum UPV reduction is 14.2% at 40% PVC content, therefore, one can conclude that the existence of pores or flaws in the transition zone has small effect on the UPV transmission.

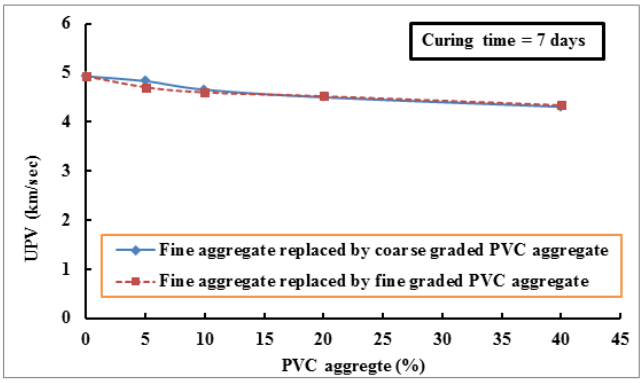

Fig. 14. Variation of UPV value with PVC aggregate

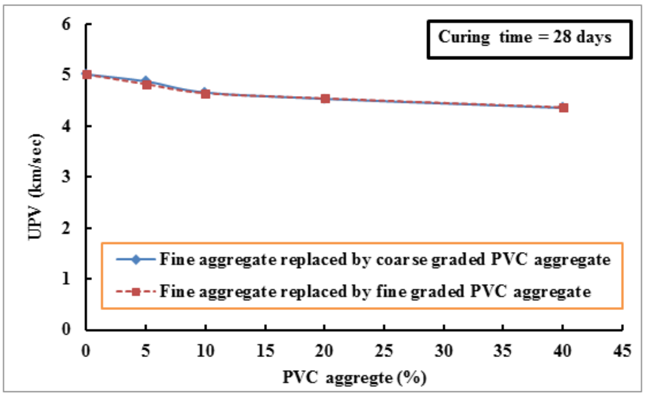

Fig. 15. Variation of UPV value with PVC aggregate

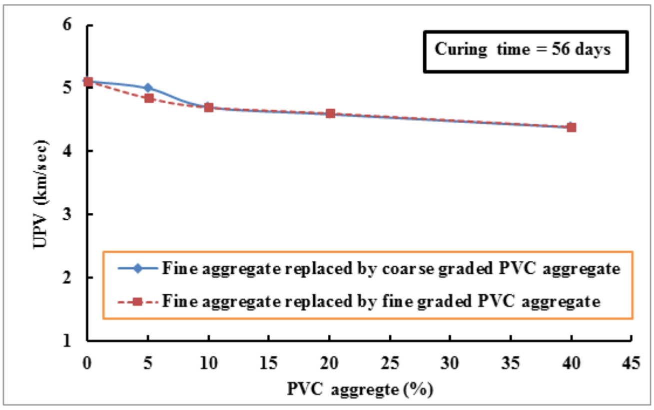

Fig. 16. Variation of UPV value with PVC aggregate

IV. CONCLUSION

From this research study the following conclusions can be drawn:

1- SEM analysis showed that there is a strong bond between PVC particles and the hardened cement paste in the interfacial zone of high strength concrete. This can be attributed to the rough texture of PVC at the microscopic level and chemical homogeneity between the two materials.

2- There is a UPV loss when the natural aggregate is replaced with the PVC waste one, being increased with the increase of the plastic addition. However, the reduction is relatively small and not more than 14.2% at 40% sand replacement with PVC aggregate. Also, there is a slight increase of UPV value with increasing concrete age for the same plastic content.

3- PVC aggregate grading has a small effect on the microstructure and UPV behaviors of high strength concrete.

4- Since a relatively high ratio of silica fume was used for concrete mixes and there is a relatively good residual properties, one can conclude that the silica fume was hydrated well and the existence of PVC plastic particles has no effect on the hydration of silica fume.

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Table-II Results of UPV value and quality grading according to IS 13311 (Part 1): 1992 [8]

Code	UPV (m/sec) (7 Days)	COV (%)	Percentage change of UPV	UPV (m/sec) (28 Days)	COV (%)	Percentage change of UPV	UPV (m/sec) (56 Days)	COV (%)	Percentage change of UPV	Concrete quality grading
M0	4930	1.27	0	5021	1.20	0	5111	1.13	0	Excellent
MC5	4831	0.61	-2.0	4883	0.52	-2.74	5000	0.2	-2.17	Excellent
MF5	4708	3	-4.5	4830	1.02	-3.8	4842	0.68	-5.26	Excellent
MC10	4657	1.16	-5.54	4665	1.68	-7.08	4700	0.86	-8.04	Excellent
MF10	4602	1.94	-6.66	4652	1.51	-7.34	4694	1.02	-8.16	Excellent
MC20	4501	1.1	-8.7	4541	0.09	-9.55	4587	0.92	-10.24	Excellent
MF20	4523	1.74	-8.26	4550	0.67	-9.37	4600	1.65	-10.0	Excellent
MC40	4308	1.43	-12.62	4363	1.44	-13.1	4380	0.32	-14.30	Good
MF40	4341	0.89	-11.95	4373	1.03	-12.9	4385	0.16	-14.2	Good