

## Physical and Mechanical Properties of High Strength Concrete containing PVC Waste as a Sand Replacement

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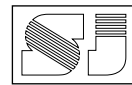
### Abstract

In this research, physical and mechanical properties of high strength concrete containing PVC waste have been investigated. The fine aggregate was replaced with PVC waste with two different gradings (fine grading and coarse grading) at dosages of 0%, 5%, 10%, 20%, and 40% by the volume of aggregate. The properties include physical properties of density and water absorption, mechanical properties of compressive strength, splitting tensile strength and flexural strength. Results show that in general, using 5% PVC replacement in high strength concrete has no appreciable effect to damage the physical and mechanical properties of concrete. With increasing PVC aggregate content, the deterioration of the concrete properties was observed. The coarse graded PVC aggregate has some more effect on the deterioration of concrete properties compared to the fine graded PVC aggregate.

### 1. Introduction

Polyvinyl chloride (PVC) is made from petroleum. It is a kind of thermoplastic polymer which is now in use in various aspects of life, and has grown into a universal polymer. This material is made by the polymerization of the vinyl chloride monomer. This polymer is prepared into either short-life items, such as the ones for medical devices and packaging food, or long-life items

such as windows, doors, roofing sheets, and plumbing pipes (Mohammed, 2019). At global level, request for PVC goes above 35 million tons every year, and it is graded as second afterward polyethylene plastics. In Europe, the most widely utilized plastic is PVC, then polypropylene (PP) and different types of polyethylene (PE) (PE-HD, PE-LLD, PE-LD, PE-MD). It is mostly utilized for the building purposes and construction, electrical and electronics, packaging, and automotive. The

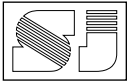


widely global utilization of PVC generally results in a great quantity of waste. Day by day these wastes are rising, and are disposed in landfills (Sadat-Shojai and Bakhshandeh, 2011), but this route currently is not satisfactory in many countries because of the reduction in existing landfilling zones and potential environmental hazards. The risk of PVC plastic waste is greater than the others like polyethylene terephthalate (PET) for the reason that chlorine is present in its compounds, which is around 57% of PVC chemical structure. Burning of PVC waste is not a solution to consume such waste because this process will dismiss dangerous chemical gases into the air such as dioxin compounds and hydrogen chloride (Verma et al., 2016). Recycling seems to be the solution for PVC wastes. Both primary and secondary recycling systems are generally utilized in Asian countries, but there is a humiliation of various properties of plastic solid waste being achieved as byproduct and devours a great amount of energy (Singh et al., 2017). Actually, the recycling of a plastic material can be done 2 to 3 times only, because, after each recycling, the strength of the plastic material is decreased because of thermal degradation. On the other hand, recycling process is harmful to environment because when the plastics melt down, VOCs (volatile organic compounds) are dismissed into the atmosphere, they are harmful to the nearby people, plants and animal's life, (Chang et al., 2014). Reusing PVC waste inside concrete beside the other plastic wastes can be considered as another method of recycling, and this process is a good solution to rescue the environment against pollution. Different properties of normal strength concrete with aggregate partially substituted with plastic aggregate of different sources were studied by the past researchers (Siddique and Khatib, 2008; Gu and Ozbakkaloglu, 2016). With regard of using PVC waste aggregate for concrete production, there is a relatively large number of published works (Kou et al., 2009; Najjar et al., 2013; Senhadji et al., 2015; Surekha and Chandrashekhar, 2015; Bolat and Erksus, 2016; Hajighatnejad et al., 2016; Hussein et al., 2016; Patel and

Dlal, 2017; Seshaiyah and Lalitha, 2017; Latroch et al., 2018; Janardhanan and Priya, 2018; Ceran et al., 2019; Mohammed et al., 2019) deal with the properties of normal strength concrete with different kinds of PVC waste, while Gesoglu et al. (2017) tested properties of self-compacting concrete with compressive strength of 60 MPa modified with PVC waste powder. However; many properties of high strength concrete with, PVC waste have not been well understood, especially for concrete mix with a high ratio of silica fume which is the issue of the current study .

Based on the past records, compressive strength of normal concrete (Najjar et al., 2013; Bolat and Erkus, 2014; Senhadji et al., 2015; Haghghatnejad et al., 2016; Hussein et al., 2016; Latroch et al., 2018; Janardhanan and Priya, 2018; Mohammed et al., 2019), lightweight concrete (Kou et al., 2009) and self-compacting concrete (Gesoglu et al., 2017) is reduced when PVC waste is used as sand replacement, being increased with increasing the plastic content .

Surekha and Chandrashekhar (2015) investigated compressive strength of various mix proportions of concrete containing 5% and 10% PVC dust as additive. The cement used was replaced with GGBS by various ratios between 30 and 50%, and silica fume by a constant ratio of 8%. They concluded that, there is no harmful effect of PVC dust added to concrete accompanied with the existence of silica fume. Other tests by Seshaiyah and Lalitha (2017) showed that when 20% fly ash and 10% PVC dust are used in concrete, there is no compressive strength loss as compared with concrete mix without any addition. Accordingly, there is a chance to use mineral admixtures in concrete contained plastic aggregate in order to control compressive strength degradation. This study contributes to the rather limited existing literature on the performance of high strength concrete with plastic waste aggregate. This investigation is a continuity of the past one performed by the first author Mohammed et al. (2019) on the properties of normal concrete containing PVC aggregate, but essentially different from this study, because concrete of design compressive strength equal to 90 MPa has



been designed with a very low water/binder ratio and a relatively high silica fume content. In this study, fundamental properties of high strength concrete were investigated taking into consideration the effect of vital parameters of concrete age, PVC aggregate granules size and content as sand replacement. The main objectives behind this study can be summarized as follows: (a) to find out the influence of different ratios of plastic aggregate as fine aggregate replacement derived from PVC sheets on physical properties, workability, and mechanical properties of high strength concrete, (b) to study the effect of PVC aggregate size grading (fineness) on the mentioned properties of concrete, and (c) to investigate the optimum PVC aggregate content, if any, for better practical applications of this novel type of concrete.

## 2. Materials and Methods

### 2.1. Materials

#### 2.1.1. Cement

Cement, sand, gravel, water, silica fume slurry and high range water reducer admixture were used in this investigation. The cement that used in this investigation was ordinary Portland cement (Type I ASTM). The physical properties and chemical composition of the cement used are shown in Tables 1 and 2, respectively. Results of tests on cement indicate that the cement properties are conforming to the ASTM C150 specification limits (ASTM C150, 2012).

#### 2.1.2. Fine aggregate

The fine aggregate that used in this study was clean natural river sand. Properties of sand are given in Table 3. Based on sieve analysis test, fine aggregate particles size distribution are as shown in Fig. 1 according to ASTM C33 specification (ASTM C33, 2016)

#### 2.1.3. Coarse aggregate

Crushed stone with maximum size of 10 mm was used as coarse aggregate. Properties of gravel are given in Table 3, coarse aggregate particles size

distribution are as shown in Fig. 2 according to ASTM C33 specification (ASTM C33, 2016)

#### 2.1.4. Water

Drinking water was utilized for washing coarse aggregate, mixing concrete and curing specimens throughout this study.

#### 2.1.5. Silica fume

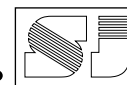
Silica fume is a by-product material from production of elements containing silicon (ACI 116R, 2000). It is a highly pozzolanic material. Micro silica slurry was used in this investigation to produce high strength and durable concrete with a dense matrix. Properties of silica fume slurry are given in Table 4. Fig. 3 shows the silica fume used.

#### 2.1.6. High Range Water Reducer Admixture

Liquid superplasticizer of Polycarboxylate based provided by Idea company-Sulaimani was used in concrete mixes. Properties of superplasticizer are given in Table 4.

#### 2.1.7. Polyvinyl chloride (PVC) Aggregate

In order to prepare PVC waste aggregate, PVC sheets wastes were collected from some local disposal areas. 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. 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) shown in Fig. 4 and the other of 1.2 mm maximum size



(designated as fine PVC aggregate) shown in Fig. 5. Properties of PVC aggregate are given in Table 3. Based on sieve analysis tests, percentage passing of fine and coarse grading PVC aggregate is as shown in Fig. 6, and it conforms to the limits of ASTM C33 specification (ASTM C33, 2016), for fine aggregate.

## 2.2. Concrete mix proportions

To design high strength concrete mix, the recommendation given by Aïtcin (1998) was followed to obtain mix proportions of design compressive strength of 80 MPa. This method of mix design was developed at the Université de Sherbrooke which is a modification of the ACI 211 specification (ACI 211, 1991) 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 5 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, fine and coarse. Table 6 shows mix proportions for the nine concrete mixes .

## 2.3. Mixing approach and specimen's preparation

Designation of concrete mixes given in the table is as follows: M is for mix, C is for coarse grading, F is for fine grading, and the number given is the percentage of sand replacement with PVC aggregate. 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

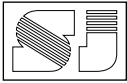
weighed first and mixed for about five minutes using an electrical tilting drum of 0.16 m<sup>3</sup> capacity. 70% of total mixing water then added and after two minutes of mixing, the remained mixing water, silica fume slurry and HRWRDA were added and left to mix for another five minutes till obtaining a homogeneous concrete. Before casting, all the molds: 150x300 mm cylinder, 100x200 mm cylinder and 100x100x500 prism were cleaned and the samples are put to standard curing.

## 2.4. Testing specimens

The measurement of hardened concrete density and water absorption were performed according to ASTM C642 (ASTM C642, 2013) on 100x200 mm cylinders. Average result of three cylinders was determined at the age of 7, 28 and 56 days. The measurement of concrete compressive strength was performed on the standard 150x300 mm cylinders using a digital compression machine of 4000 kN capacity of CONTROLS model-Italy, according to ASTM C39 (ASTM C39, 2012). 3 days before testing, all cylinders were capped using a sulfur- sand mix to give a uniform stress distribution on the specimen's surface during testing. The loading rate was 565 lb/sec (2.5 kN/sec) as per the ASTM C39 specification. The measurement of concrete splitting tensile strength was performed on the 100x200 mm cylinders using the same machine utilized for compression test, according to ASTM C496 (ASTM C496, 2011). The flexural strength test was made on the 100 x 100 x 500 mm prism with third- point loading in accordance to ASTM C78 (ASTM C78, 2010). Average result of three tested samples was determined at the age of 7, 28 and 56 days for the mentioned three tests.

## 3. Results and discussion

The results obtained in this study are interested and may clear the way for further experiments on the behavior of high strength concrete with plastic waste granules. A relatively large amount



of test data was obtained. Test results of concrete physical and mechanical properties and their percentage change compared to control mix are given in Table 7 and Table 8, respectively. Test results on each property examined and discussed, some details are given in the following sections .

### **3.1. Physical properties**

#### **3.1.1. Density**

Test results of hardened concrete density and its percentage change compared to control mix are shown in Table 7 and Table 8, respectively. Figs. 7, 8 and 9 show variation of concrete density with PVC aggregate ratio at the age of 7 days, 28 days, and 56 days respectively. Test data show a clear reduction in concrete density when PVC aggregate is increased. The reduction in density is attributed to the lower density of PVC aggregate as compared with natural fine aggregate density. The maximum reduction in density is occurred at 40% PVC aggregate replacement for both coarse grading and fine grading PVC aggregates of maximum values between 5.12% and 6.26%. The density loss is slightly higher for those mixes contained coarse grading PVC aggregate and slightly reduced with increasing concrete age from 7 days to 56 days. It can be observed that the density loss is relatively low as compared with that obtained by the past investigations (Kou et al., 2009; Najjar et al., 2013; Hussein et al., 2016; Bolat and Erkus, 2016), in which scrapped PVC pipe and PVC Waste from door and window industry were used. This difference may be attributed to the size distribution and increasing the packing of aggregate using PVC sheet, not been well done in the case of using scrapped PVC pipes. These results are in harmony with the findings of Mohammad et al. (2019) where PVC sheet aggregate was used as a partial replacement of natural fine aggregate or coarse aggregate.

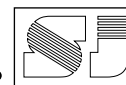
#### **3.1.2. Water absorption**

Test results of concrete water absorptions and its percentage change compared to control mix are shown in Table 7 and Table 8, respectively. Figs. 10 ,11 and 12 show variation of water absorption percentage with PVC aggregate ratio at the ages of 7, 28 and 56 days respectively. Results show that the maximum increasing in concrete water absorption percent value is occurred at 40% PVC aggregate replacement for both fine and coarse PVC aggregate gradings of maximum values between 32.33% and 46.82%. Results also show that the absorption percentage is moderately increased when more than 10% of coarse graded PVC aggregate is used instead of fine aggregate one, and slightly increased with increasing concrete age. In general, increasing of absorption can attributed to the reduction of packing of concrete mass structure and honeycombing accompanied with the use of high ratio of PVC aggregate. Water absorption values of high strength concrete mixes with PVC aggregate measured in this study is considerably lower than that measured by the past investigators worked on normal strength concrete with PVC aggregate (Ceran et al., 2019 and Mohammed et al., 2019), but moderately higher than that measured by Haghghatnejad et al. (2016). It should be noted that the obtained test data are in contrast to some past test data (Bolat and Erkus, 2014 and Ceran et al., 2019) in which they found a reduction of concrete absorption with the increase of PVC aggregate in concrete. This may be attributed to using synthetic PVC granules of regular shapes by these authors essentially different from those used in this study obtained from simple crushing .

### **3.2. Mechanical Properties**

#### **3.2.1. Compressive strength**

Test results of concrete compressive strength and its percentage change compared to control mix are shown in Table 7 and Table 8, respectively. Figs. 13, 14 and15 show variation of concrete compressive strength value with PVC aggregate



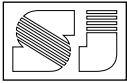
percentage at 7 days, 28 days, and 56 days age, respectively. Based on the results obtained, it can be observed a continuous and steady reduction in compressive strength with increasing PVC aggregate content, except for mixes MC5 and MF5, there is a slight compressive strength enhancement, ranging between 4.3% and 4.6%. However, this improvement in the compressive strength is not important because at the given PVC content there is no splitting tensile strength and flexural strength enhancements. Results show that the maximum reduction in the compressive strength reached 30.2% and 25.1% for concrete specimens MC40 and MF40, respectively at 56 days curing age. Results also indicate that replacement of fine aggregate with coarse grading PVC aggregate will lead to higher compressive strength loss as compared with the replacement with fine grading PVC aggregate for same replacement level. The strength loss can be attributed to using plastic with flaky particles and low mechanical strength of the plastic in addition to high deformation under load, because of the low elastic modulus of the plastic. Compressive strength loss obtained in this study is considerably lower than that obtained by Surekha and Chandrashekhar (2015) at 5% and 10% PVC contents. The strength loss obtained in this study is also lower than that obtained by Bolat and Erkus (2016), Janardhanan and Priya (2018) and Hussein et al. (2016) for 10% PVC content, and also lower than that by Gesoglu et al. (2017) and Bolat and Erkus (2016) for 20% PVC content. Furthermore, compressive strength reduction for MC40 and MF40 is lower than that obtained by Haghghatnejad et al. (2016). The reason behind the low compressive strength loss obtained in this study is due to the lower w/b ratio used beside the pozzolanic action of silica fume, leading to a stronger transition zone and better bond between aggregate particles and cement paste, and as consequence, lower cavities and pores formation .

### 3.2.2. Splitting tensile strength

Test results of concrete splitting tensile strength and its percentage change compared to control mix are shown in Table 7 and Table 8, respectively. Figs. 16, 17 and 18 show variation of concrete splitting tensile strength value with PVC aggregate percentage at the age of 7 days, 28 days, and 56 days, respectively. Again, similar to the case of compressive strength, there is no tensile strength loss of concrete with PVC content of 5%. For larger plastic content it can be observed a continuous reduction in the splitting tensile strength, for concrete mixes with both fine and coarse grading PVC aggregate. According to the test data, maximum reduction in the splitting tensile strength is occurred at 40% PVC aggregate replacement for both fine and coarse grading PVC aggregates, which are between 30.33 % and 34.55 % for 7, 28, and 56 days ages. Results also show that the reduction of splitting tensile strength on using coarse grading PVC aggregate is close to that on using fine grading PVC aggregate. The reason behind splitting tensile strength loss can be attributed to the same factors mentioned for the case of compressive strength, especially the damage of the interfacial bond between the plastic and hardened cement paste on loading. The tensile strength loss obtained in this study is considerably lower than that obtained by Hussein et al. (2016) and Surekha and Chandrashekhar (2015) at 5% and 10% PVC contents. Loss of splitting tensile strength take place is close to that obtained by Kou et al. (2009) for lightweight concrete, obtained by Gesoglu et al. (2017) for SCC and obtained by Mohammed et al. (2019) and Ceran et al. (2019). However, the loss take place is higher than that obtained by Haghghatnejad et al. (2016) for concrete continuously cured in water .

### 3.2.3. Flexural strength

Test results of concrete Flexural strength and its percentage change compared to control mix are shown in Table 7 and Table 8, respectively. Figs.



19, 20 and 21 show variation of flexural strength value with PVC aggregate percentage at 7 days, 28 days, and 56 days age, respectively. One can observe that there is a very small strength loss for concrete with 5% PVC content. However; similar to the case of compressive strength, there is a continuous reduction in the flexural strength with increasing PVC aggregate content larger than 5% PVC content, for concrete mixes with both PVC aggregate grading. Based on test results, higher PVC aggregate content accompanied with higher flexural strength loss, in which there is a maximum value of flexural strength loss of 24.2% and 21.3% for MC40 and MF40 concrete mixes, respectively at 56 days age. Results also showed that the effect of PVC aggregate grading on the residual flexural strength is not important. It is worthy to compare the current test data on flexural strength with those given by the past researchers. Surekha and Chandrashekhar (2015) found a very small reduction in flexural strength of concrete mix with 8% silica fume when PVC dust is added by 5% and 10%. Accordingly, these test data are close to test data obtained in current investigation, and highlighting the useful effect of the silica fume used. The flexural strength obtained is close to those obtained by Gesoglu et al. (2017) for SSC with 10% PVC powder content, but higher strength is observed at 5% PVC content. The measured flexural tensile strength loss is considerably smaller than that measured by Hussein et al. (2016) and Latroch et al. (2018), but larger than that obtained by Mohammed et al. (2019) for normal strength concrete with PVC aggregate.

#### Conclusions

Fundamental properties of high strength concrete contained PVC waste as sand replacement were investigated in this study and the results were discussed. Furthermore, the following concluding remarks can be drawn:

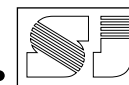
- 1- Clear reductions in the concrete density are observed with the incorporation of PVC aggregates for all mixes. The maximum

reduction in density was 6.26% occurred at 40% coarse PVC waste replacement.

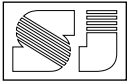
- 2- The water absorption of concrete is not changed well for both fine and coarse grading PVC waste at 5% incorporation compared to the control mix. The maximum reduction in water absorption was 46.82% occurred at 40% coarse PVC waste replacement.
- 3- There is a slight enhancement of the compressive strength at 5% PVC content. A continuous and steady reduction in compressive strength with increasing PVC aggregate content is observed.
- 4- There is no tensile strength loss of concrete with 5% PVC content. The maximum reduction in splitting tensile strength was 34.55% occurred at 40% coarse PVC waste replacement..
- 5- There is a very small flexural strength loss for concrete with 5% PVC content. The maximum reduction in flexural strength was 24.2% occurred at 40% coarse PVC waste replacement
- 6- The coarse graded PVC aggregate has some more effect on the deterioration of concrete properties compared to the fine graded PVC aggregate.

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## الخصائص الفيزيائية والميكانيكية للخرسانة عالية المقاومة الحاوية على النفايات PVC كبدل للرمل

نافذة صابر محمد

أ.م.د. ازاد عبدالقادر محمد

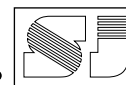
جامعة السليمانية، كلية الهندسة، قسم الهندسة المدنية

### المستخلص

تم في هذا البحث دراسة الخصائص الفيزيائية والميكانيكية للخرسانة عالية القوة التي تحتوي على نفايات PVC، تم استبدال الركام الناعم بمجموع نفايات الـ PVC بنوعين مختلفين (الركام الناعم والخشن) بجرعات 0 %، 5 %، 10 %، 20 %، و 40 % من الحجم الكلي. وتشمل الخصائص التي تمت دراستها الخصائص الفيزيائية للكثافة وامتصاص الماء، والخصائص الميكانيكية لمقاومة الانضغاط، مقاومة الشد الانشطاري ومقاومة الانحناء. تشير النتائج إلى أنه، بشكل عام، فإن استخدام 5 % PVC في الخرسانة عالية المقاومة ليس له تأثير ملموس على تدني الخصائص الأساسية للخرسانة. مع زيادة المحتوى الكلي PVC، لوحظ تدهور في خصائص الخرسانة. إن ركام PVC المتدرج الخشن له تأثير أكثر على تدهور خصائص الخرسانة مقارنة بالركام PVC المتدرج الناعم.

**الكلمات المفتاحية:** الخرسانة عالية القوة، الخصائص

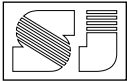
الميكانيكية، PVC نفايات، الخصائص الفيزيائية.

**Table 1: Physical properties of cement.**

Physical properties	Test results	ASTM C150 specification limits
Specific surface area (Blaine method), (m <sup>2</sup> /kg)	365	≥260
Setting time (min)		
1) Initial setting time	161.9	≥ 45 min.
2) Final setting time	230	≤ 375 min
Compressive strength (MPa)		
1) 3 days compressive strength	23.5	≥ 12
2) 7 days compressive strength	28.3	≥ 19
Soundness (%) (autoclave method)	0.27	≤ 0.8%

**Table 2: Chemical composition of cement.**

Oxide Composition	Content, %	ASTM C150 specification limits
SiO <sub>2</sub>	21.2	-
Al <sub>2</sub> O <sub>3</sub>	4.7	-
Fe <sub>2</sub> O <sub>3</sub>	3.25	-
CaO	61.45	-
MgO	2.95	≤ 6%
SO <sub>3</sub>	2.4	≤ 3.0%
Loss On Ignition (L.O.I)	2.2	≤ 3%
Lime Saturation Factor (L.S.F)	0.88	0.66–1.02
Insoluble residue (I.R)	0.71	≤ 0.75
<b>Main Compounds (Bogue's equations)</b>		
C <sub>3</sub> S	46.9	-
C <sub>2</sub> S	25.85	-
C <sub>3</sub> A	6.7	-
C <sub>4</sub> AF	11.95	-



**Table 3: Properties of fine, coarse and PVC aggregate.**

Properties	Fine aggregate	Coarse aggregate	PVC aggregate
Fineness modulus	3.8	-	2.64* - 4.46 **
Specific gravity	2.52	2.651	1.4
Water absorption, %	1.7	1.2	-
Bulk density, kg/m <sup>3</sup>	1988.5	1628.88	847

\* 2.64 for (fine PVC aggregate)

\*\* 4.46 for (coarse PVC aggregate)

**Table 4: Properties of silica fume slurry and superplasticizer.**

Properties	Silica fume slurry	Superplasticizer
Specific gravity	1.4	1.1
PH	9.5	6.9
Solid content (%)	40	30
Appearance	Dense slurry of greyish color	Liquid light yellow color

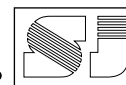
**Table 5 Concrete mix proportion**

w/b*	Cement (kg/m <sup>3</sup> )	Silica fume** (% of cement)	Coarse aggregate (kg/m <sup>3</sup> )	Fine aggregate (kg/m <sup>3</sup> )	Water (before corrections) (kg/m <sup>3</sup> )	Water (after corrections)*** (kg/m <sup>3</sup> )	HRWR (% of cement)
0.23	486	25	1075	714	125	40	1.3

\* b is the binder mass (cement + silica fume)

\*\* Silica fume slurry contains 60% water

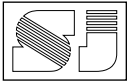
\*\*\*Water after correction= Water before correction - (Water from silica fume slurry + Water from superplasticizer)

**Table 6 Concrete mix proportions.**

Concrete ID	Cement (Kg/m <sup>3</sup> )	w/b	Sand (Kg/m <sup>3</sup> )	Gravel (Kg/m <sup>3</sup> )	PVC aggregate (Kg/m <sup>3</sup> )	Silica fume slurry % of cement content	HRWRA %
M0	486	0.23	714	1075	-	%25	1.3
MC5	486	0.23	698.8	1075	15.2	%25	1.3
MF5	486	0.23	698.8	1075	15.2	%25	1.3
MC10	486	0.23	683.6	1075	30.4	%25	1.3
MF10	486	0.23	683.6	1075	30.4	%25	1.3
MC20	486	0.23	653.18	1075	60.82	%25	1.3
MF20	486	0.23	653.18	1075	60.82	%25	1.3
MC40	486	0.23	592.35	1075	121.65	%25	1.3
MF40	486	0.23	592.35	1075	121.65	%25	1.3

**Table 7: Test results of concrete properties.**

Properties	Density (kg/m <sup>3</sup> )			Water absorption (%)			Compressive strength (MPa)			Splitting tensile strength (MPa)			Flexural Strength (MPa)		
	7-day	28-day	56-day	7-day	28-day	56-day	7-day	28-day	56-day	7-day	28-day	56-day	7-day	28-day	56-day
Curing period															
M0	2503.8	2512.4	2516.9	1.041	0.83	0.74	67.6	89.5	97.4	6.43	6.76	7.19	9.87	10.62	11.88
MC5	2475.3	2486.2	2494.2	0.99	0.83	0.73	70.5	91.85	98.77	6.42	6.7	7.14	9.86	10.6	11.8
MF5	2483.8	2493.8	2504.4	1.03	0.83	0.73	70.71	94.81	99.89	6.45	6.73	7.15	9.85	10.61	11.83
MC10	2444.2	2473.6	2483.6	1.16	0.92	0.82	63.	78.45	82.3	5.94	6.18	6.38	9.19	9.43	10.63
MF10	2434.7	2448.1	2490.4	1.13	0.90	0.78	65.26	80.27	86.35	6.04	6.21	6.49	9.35	9.75	10.85
MC20	2407.3	2457.5	2463.2	1.25	1.05	0.9	61.66	75.08	78.96	4.54	4.89	5.70	8.47	8.95	9.7
MF20	2415.6	2450.6	2466.1	1.2	0.98	0.87	63.38	76.62	80.23	4.56	5.04	5.86	8.76	9.01	9.95
MC40	2347	2370.8	2383	1.48	1.21	1.09	51.89	63.71	68	4.21	4.47	4.9	7.6	8.16	9.01
MF40	2352.5	2373.1	2388	1.38	1.14	1.0	58.37	69.3	73	4.29	4.55	5.01	7.91	8.45	9.35



**Table 8: Percentage change in concrete properties.**

Properties	Change in Density (%)			Change in Water absorption (%)			Change in Compressive strength (%)			Change in Splitting tensile strength (%)			Change in Flexural Strength (%)		
	Curing period	7-day	28-day	7-day	28-day	56-day	7-day	28-day	56-day	7-day	28-day	56-day	7-day	28-day	56-day
MO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MC5	-1.134	-1.04	-0.90	-1.79	-0.52	-1.22	4.29	2.63	1.41	-0.15	-0.89	-0.72	-0.10	-0.22	-0.67
MF5	-0.8	-0.74	-0.5	-1.02	-0.71	-1	4.6	5.93	2.56	0.31	-0.51	-0.54	-0.15	-0.06	-0.41
MC10	-2.38	-1.54	-1.32	11.18	10.64	10.42	-6.51	-12.35	-15.5	-7.67	-8.59	-11.35	-6.93	-11.22	-10.48
MF10	2.76	-2.56	-1.06	8.21	8.47	5.81	-3.46	-10.32	-11.35	-5.99	-8.11	-9.73	-5.27	-8.19	-8.67
MC20	-3.85	-2.18	-2.13	20.12	26.11	21.62	-8.79	-16.11	-18.93	-29.39	-27.63	-20.75	-14.14	-15.7	-18.35
MF20	-3.52	-2.46	-2.02	15.32	17.01	18.11	-6.24	-14.4	-17.62	-29.08	-25.39	-18.53	-11.25	-15.18	-16.25
MC40	-6.26	-5.64	-5.32	41.94	45.19	46.82	-23.24	-28.82	-30.2	-34.55	-33.83	-31.9	-22.99	-23.19	-24.2
MF40	-6.04	-5.54	-5.12	32.33	36.8	35.27	-13.65	-22.57	-25.1	-33.21	-32.62	-30.34	-19.86	-20.39	-21.3

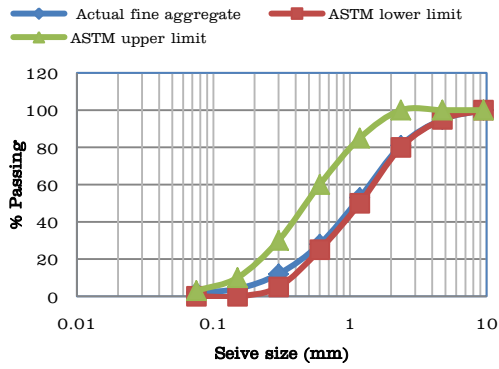
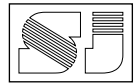


Fig. 1: Grain size distribution of fine aggregate.

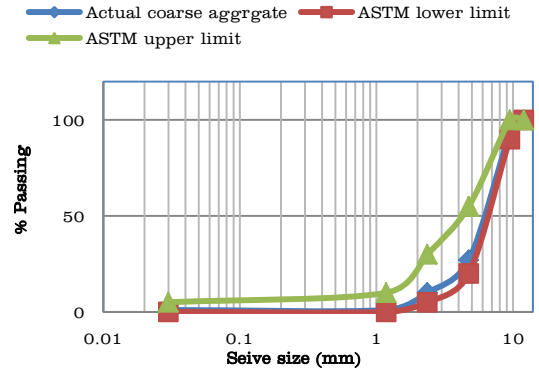


Fig. 2: Grain size distribution of coarse aggregate.



Fig. 3: Silica fume slurry.



Fig. 4: View of coarse grading PVC aggregate.



Fig. 5: View of fine grading PVC aggregate.

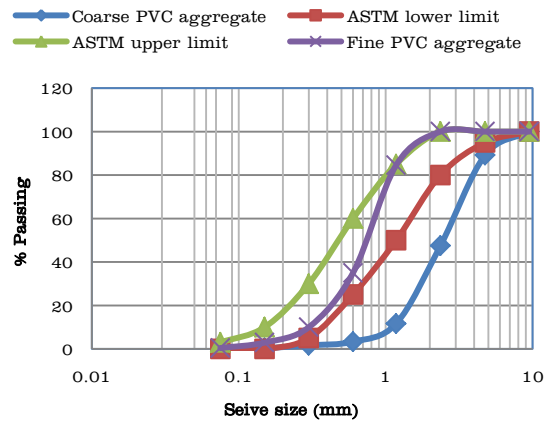


Fig. 6: Grain size distribution of PVC aggregate.

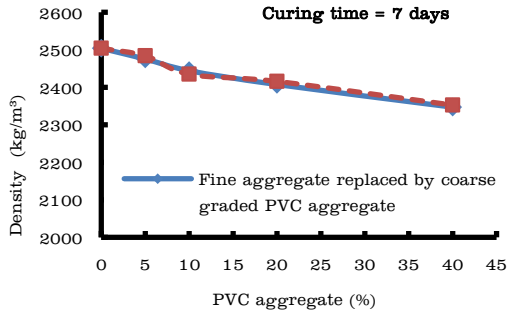
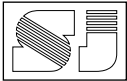


Fig. 7: Variation of density with PVC at 7-day.

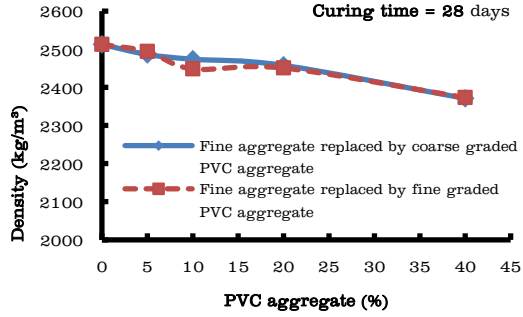


Fig. 8: Variation of density with PVC at 28-day.

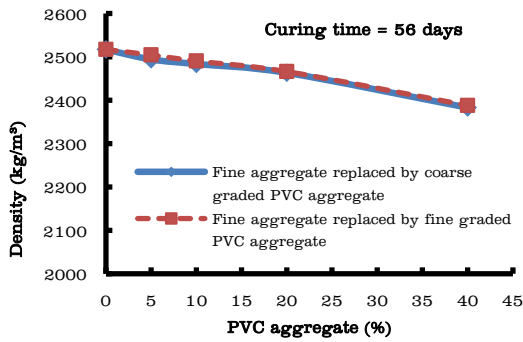


Fig. 9: Variation of density with PVC at 56-day.

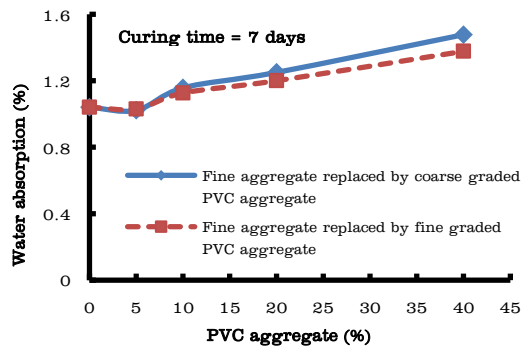


Fig. 10: Variation of water absorption with PVC at 7-day.

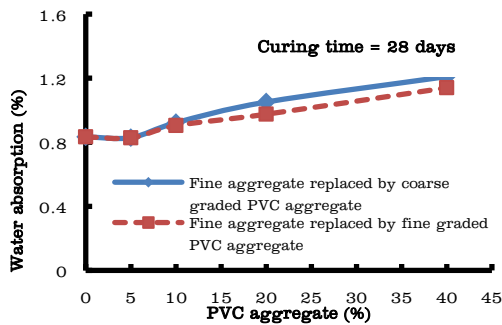


Fig. 11: Variation of water absorption with PVC at 28-day.

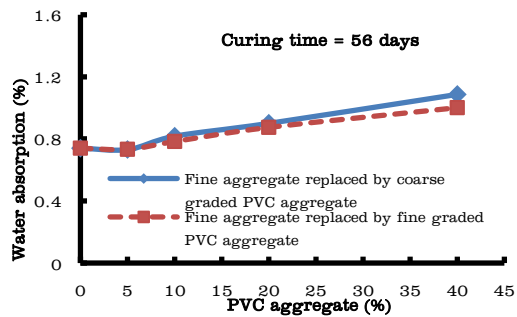


Fig. 12: Variation of water absorption with PVC at 56-day.

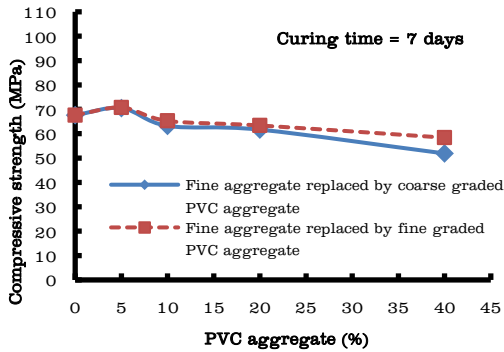
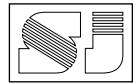


Fig. 13: Variation of compressive strength with PVC at 7-day.

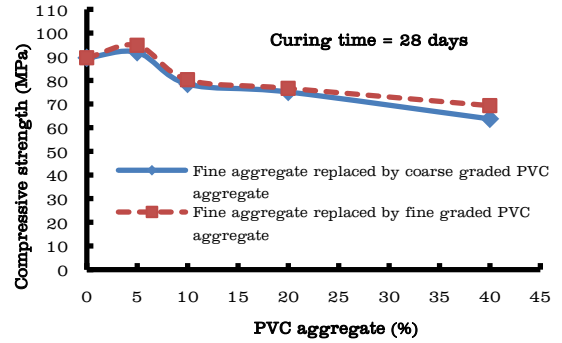


Fig. 14: Variation of compressive strength with PVC at 28-day.

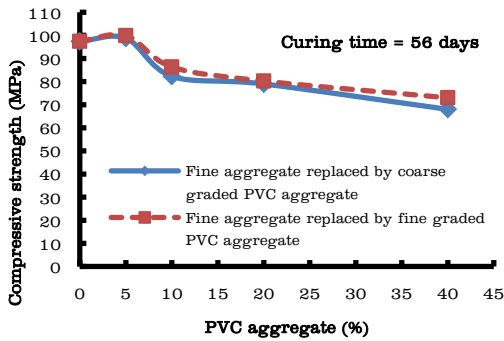


Fig. 15: Variation of compressive strength with PVC at 56-day.

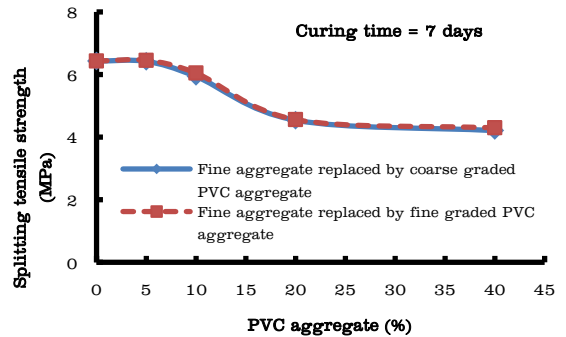


Fig. 16: Variation of splitting tensile strength with PVC at 7-day.

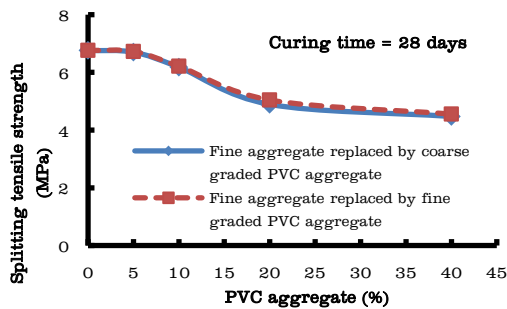


Fig. 17: Variation of splitting tensile strength with PVC at 28-day.

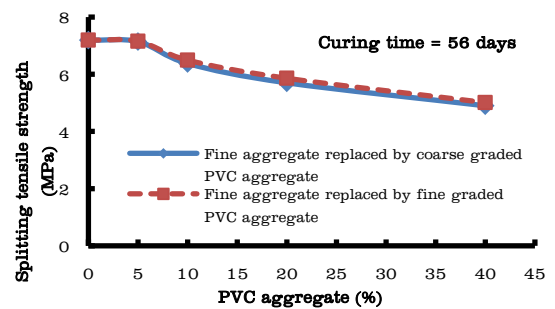


Fig. 18: Variation of splitting tensile strength with PVC at 56-day.

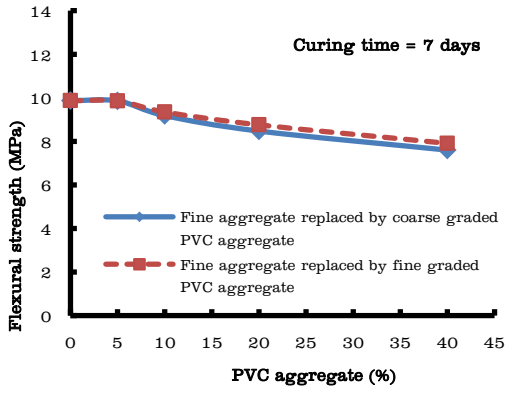
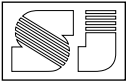


Fig. 19: Variation of flexural strength with PVC at 7-day.

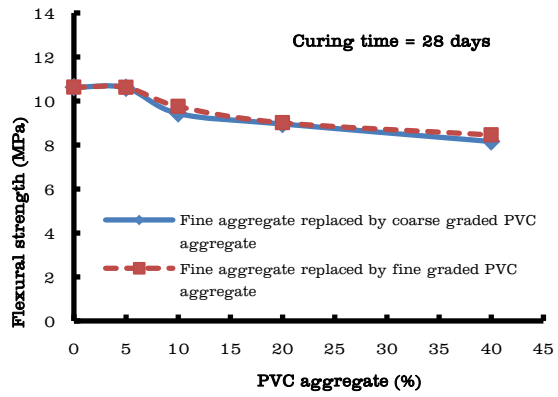


Fig. 20: Variation of flexural strength with PVC at 28-day.

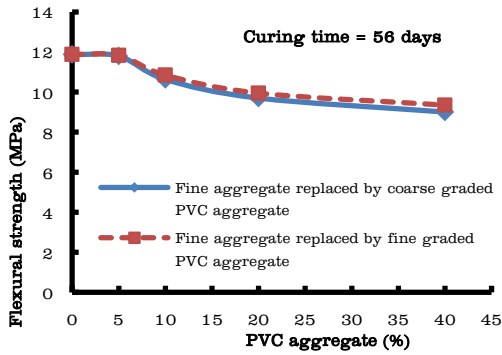


Fig. 21: Variation of flexural strength with PVC at 56-day.