EFFECT OF SILANE TREATMENT ON THE MECHANICAL PROPERTIES OF POLYMER CONCRETE MADE WITH RECYCLED PET RESIN AND RECYCLED AGGREGATES

K P Singh[1], Raman Bedi[2], Aditya Bakshi[3]

1, 2, 3, Dr B R Ambedkar National Institute of Technology Jalandhar, India

ABSTRACT. In present work, polymer concrete was made using resin obtained from recycled PET bottles. Five mixtures consisting of various combination of natural and recycled aggregate obtained from construction waste were manufactured with PET resin and silane coupling agent. Two samples of each type of mixture were prepared separately for flexural strength test and compressive strength test. The volume of permeable pores is measured by method as standardized by ASTM C642-006. It was observed that upon substitution from 100% natural aggregate to 100% recycled aggregate in PET, compressive strength decreases by 37%, whereas, a combination of 50% natural aggregate and 50% recycled aggregate decrease compressive strength by 16.5%. And also, the same trend is observed with flexural strength where loss is 32% from moving 100% natural aggregates to 100% recycled aggregates. It has been observed that compressive and flexural strength does increases with the silane treatment of polymer concrete. Volume of permeable pore size decreases with silane treatment. Further increase of about 3.5% was observed in compressive strength with addition of 5% silica fumes as filler.

Keywords: Polymer concrete, PET resin, Recycled aggregates, Silane.

K P Singh is a student of M.Tech, Mechanical Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India.

Dr Raman Bedi is a Associate Professor of Mechanical Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India.

Aditya Bakshi is a student of M.Tech, Mechanical Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India.

INTRODUCTION

Polymer concrete is a composite material obtained after mixing of the polymerized binder, aggregates, initiator and catalyst. Microfillers or coupling agents can also be used to get the desired properties which can be used to meet the desired requirements. Polymer concrete is far better than the conventional concrete because of the following properties: Greater tensile strength than conventional concrete, similar or greater compressive strength to conventional concrete, more flexural strength in comparison to conventional concrete, faster curing, good adhesion to most surfaces, including to reinforcements, low permeability to water and aggressive solutions, good chemical resistance, good resistance against corrosion, lighter weight (depending on the resin content) and allows use of regular filler agents to get desirable properties [4]. The one of the biggest problems which we faces in using the polymer concrete in place of conventional concrete is the high cost of the binder and the natural aggregates. So in this research paper we try to analyze the properties of polymer concrete made with recycled PET resin and recycled aggregates so that we can get polymer concrete at the optimized cost. The PET bottle was patented in 1973. Initially it is considered as a very good discovery as it reduces the size of the waste stream because PET has replaced heavier materials but soon its hazard came into the picture. Because of its non-biodegradable nature soon it became a major portion of municipal solid waste and started posing threat to our ecosystem. After getting patented in 1973 within just four-year first PET bottle got recycled. The best way to copewith this problem is to use PET resin as a binder in polymer concrete especially with recycled aggregate from demolished buildings which is second most major constituent of Municipal solid waste. Use of recycled PET resin also solves one of the biggest problem with polymer concrete which is high cost of binder agent if PET resin obtained from recycled PET bottle will be used then we will get polymer concrete with optimized cost [10].

It is evident from the study of the various research papers that there is a drop in the strength of the polymer concrete when we substitute natural aggregate with recycled aggregate in order to compensate for that we treated our binder with the silane coupling agent and then we compare this with the properties of polymer concrete obtained without silane coupling agent to see its effects [9].

Further we try to add small amount of silica fumes to our polymer concrete and try to compare the effect of silane treatment with addition of silica fumes [1].

RESEARCH SIGNIFICANCE

By doing this research we are trying to contribute to the understanding of the polymer concrete and explore the ways to utilize it in an Eco-friendly way. Also we will be able to get rid of huge amount of PET waste and constructional waste. Results from our study are expected to be used in the following places: Tool bed application [2], Construction of pipes, pumps and valve castings etc, corrosive conditions, making of tunnel lining with smooth profile, corrosion resistance and strength, manufacturing of storage tanks for aggregate frames, larger transfer machine frames, manufacturing of the end winding of conventional and super conducting generators, used in making main spindle housing for CNC machines [8], used in making of small structures of basic manufacturing machines [3].

EXPERIMENTAL WORK

Materials Used

Resin

Our resin was prepared by the depolymerization of PET through glycosis. The binder be used has an industrial name as AROPOL IN 7120. AROPOL IN 7120 is a low viscosity, medium reactivity, orthoterephthalic unsaturated polyester resin. AROPOL IN 7120 is a non-thixotropic and non-accelerated resin.

Table 1 Properties of uncured resin

Typical liquid resin properties	*Properties at 25°C*	*Value (Winter)*	*Value (Summer)*	*Unit*
	Viscosity Brookfield RV2,20rpm	320-350	320-350	cps
	Acid value	17-24	17-24	Mg KOH/g
	Styrene content + 3.0 % Co-oct (1%) + 1.5 % MEKP-50	36-40	36-40	%
	Peak exotherm	170-190	170-190	^{0}C

Typical cured resin properties (Curing at room Temperature for 24 hrs and then post cure at 80°C/4hrs) are shown in the following Table.

Table 2 Typical cured resin properties

Properties	*Value*	*Unit*	*Test Method*
Tensile strength	60	MPa	ISO 527-2
Tensile modulus	2800	MPa	ISO 527-2
Elongation at break	2.4	%	ISO 527-2
Flexural strength	100	MPa	ISO 178
Flexural modulus	3000	MPa	ISO 178
Heat deflection temperature	65	^{0}C	ISO 75 -2
Hardness	38-40	Barcol	ASTM D 2583
Water Absorption at 25 °C	22	mg	ISO 62

It was found that the Polymer Concrete does not gain any appreciable strength even after 45 days of curing. So that's why we use Cobalt naphthanate (CoNp) and methyl ethyl ketoneperoxide (MEKP) as an initiator and promoter respectively [5].

Aggregates

We used various combinations of natural and recycled aggregates. Aggregates which we are used are having following aggregate sizes:-

Table 3 Three different sizes with fixed composition

Size	*Percentage (Composition)*
4.75 mm to 10 mm	39.6%
2.36mm to 4.75mm	33.5%
150 micron to 300 micron	25.9%

Various combinations of mixture of natural and recycled aggregates to be tested with/without silane treatment are as follows:

1) 100 NA = 100% natural aggregate
2) 70 NA-30 RA = 70% natural aggregate and 30% recycled aggregate
3) 50 NA-50 RA =50% natural aggregate and 50% recycled aggregate
4) 30 NA-70 RA=30% natural aggregate and 70% recycled aggregate
5) 100 RA = 100% recycled aggregates [6].

Silane coupling agent

We use ɤ-amino propyl triethoxysilane as an coupling agent in order to have good bonding between the fibrous or particulate inorganic component and the organic matrix polymer. Its properties are as follows [9].

Table 4 Properties of silane coupling agent

Molecular formula	$C_9H_{23}NO_3Si$
Molecular weight	221.37 g
Melting point	-700 ^{0}C
Boiling point	2170 ^{0}C
Density	0.946 g/ml at 250^{0}C
Refractive index	1.422
Flash point	2050 ^{0}F
Sensitivity	Moisture Sensitive

Microfillers

Fly ash will be used as microfiller for obtaining good bonding strength between the polymer matrix and the aggregates [1]. The chemical composition of the fly ash is given in following Table.

Table 5 Fly Ash

Constituent	*Percentage*
Silicon oxide	58.83
Aluminum oxide	32.62
Ferrous oxide	3.44
Calcium oxide	7.52
Magnesium oxide	1.075
Sulphur trioxide	1.538
Unburned carbon	2.58

Further silica fumes will also be used to enhance the mechanical properties of the polymer concrete. Then we compare the physical properties of polymer concrete with silica fumes with properties of polymer concrete with silane treatment [1].

PROCEDURE FOR PREPARATION OF SAMPLES

First of all, sieving of crushed stones at given sizes should be done. It was properly washed to remove dirt or any impurity. Then the aggregates will be put in the oven to remove moisture even the slightest of moisture as that will be highly detrimental to the final strength. Then aggregates of various sizes are mixed into a container according to the above table. Then required amount of fly ash will be added to the container. Then the mixture should be mixed vigorously. A separate container whose mass already we know should be taken. Then measured amount of PET resin should be poured in that container .We add silane coupling agent as an integral blend. Then we add silane coupling agent to the resin by 1.0% weight. Then mixture of resin and silane coupling agent should be thoroughly mixed with the stirrer. Then the mixture of resin and silane coupling agent should be added to the mixture of aggregates and fly ash. Then 3% of MEKP should be added to the mixture. Then again mixture should be mixed thoroughly. Then 1.5% of CoNp should be added and then again mixture should be mixed then this mixture should be poured in the mould to get specimen of desired shape and size. After one day specimens are taken out of the mould. Then specimen is cured for the duration of 12 days. Then various testing’s have been done on the samples.

Table 6 Table of constituent for various mixtures

Com	*A1 (g)*	*A2 (g)*	*B1 (g)*	*B2 (g)*	*C(g)*	*T. L. (g)*	*Fly Ash (g)*	*Resin (g)*
1	2930.4	0	2479	0	1916.6	7400	1000	1600
2	2051.2	879.12	1735.3	743.7	1916.6	7400	1000	1600
3	1465	1465	1239.5	1239.5	1916.6	7400	1000	1600
4	879.12	2051.28	743.7	1735.3	1916.6	7400	1000	1600
5	0	2930.4	0	2479	1916.6	7400	1000	1600

For further improvements in compressive strength 5% more silica fumes is added to mixture of 50% natural and 50% recycled aggregate and sample for compressive stress is being manufactured. The Table for that is as follows.

Table 7 Table of constituent for mixture with silica fumes

A1(g)	*A2 (g)*	*B1(g)*	*B2(g)*	*C(g)*	*T.L.(g)*	*Silica fumes(g)*	*Fly ash (g)*	*Resin (g)*
409.9	409.9	346.7	346.7	536.8	2070	150	300	480

Here, Com = Composition of polymer concrete obtained by different combination of natural and recycled aggregates

A1 = Natural aggregate of size 4.75 mm to 10 mm
A2 = Recycled aggregate of size 4.75 mm to 10 mm
B1 = Natural aggregate of size 2.36 mm to 4.75 mm
B2 = Recycled aggregate of size 2.36 mm to 4.75 mm
C = Natural aggregate of size 150 micron to 300 micron
T.L.= Composition left after subtracting resin and fly ash
Resin = Mixture of MEKP, CoNp and Silane coupling agent

TESTING PROCEDURES

Compression testing of polymer concrete

The static compressive strength tests were conducted using 2000 kN capacity Compression Testing Machine at National Institute of Technology, Civil lab. For this two cubes of 100 mm dimension of each mixture of natural and recycled concrete were made and tested and then there average value has been taken and plotted on vertical bar graph to see the variation.

Flexural testing of polymer concrete

Two polymer concrete bar of dimensions 50 x 50x 305 mm size were also prepared of each mixture of natural and recycled aggregate with and without silane coupling treatment and then center point test is performed on a cyclic loading machine. After that there average value has been taken and plotted on vertical bar graph to see the variations of flexural strength [5].

Volume of permeable pore size

It is well known that the mechanical behavior of any material is predominately dependent on its composite structure. The presence of pores can adversely affect the material's mechanical properties such as failure strength, elasticity and creep strains. Polymer concrete, which differs from other materials, has a large volume of permeable pore voids. It is also important to determine how its mechanical performance is affected by the presence of pores. For determining the volume of permeable pore size we perform standard test methods according to the method mentioned in ASTM C 642-06 (2006) [7].

RESULTS AND DISCUSSION

Results of compression test of samples obtained after the silane treatment of the binding agent are as follows:

Table 8 Compressive strength of specimen with silane treatment

Composition	*Specimen 1 (MPa)*	*Specimen 2 (MPa)*	*Average Strength (MPa)*	*Standard deviation*
100 NA	91.2	89.4	90.6	1.341
70NA-30 RA	90.3	85.4	87.85	3.46
50 NA-50RA	80.9	70.3	78.6	7.49
30NA-70 RA	78.2	62.7	70.45	10.9
100 RA	57.6	56.3	56.95	0.919

Values of average compressive strength are then plotted on the vertical bar graph with respect to its constitution. A gradual reduction in strength was observed as the recycled aggregate content increased. This effect may be due to the weaker bond of the old mortar adhering to the recycled concrete aggregate, which may have caused a reduction in the strength of the Recycled polymer concrete .It should be noted that loss of strength from going to 100% natural aggregate to 100% recycled aggregate is almost 37%. While for 70:30 ratio would be 3.05% while for 50:50 would be 16.5% and for 30:70 ratio would be 22.22%.

Figure 1 Compressive strength vs composition

Results of flexural test of samples obtained after the silane treatment of the binding agent are as follows.

Table 9 Flexural strength of the samples with silane

Com	*First specimen (KN)*	*Second specimen (KN)*	*Average flexural load*	*Average flexural stress (MPa)*
100NA	6.69	8.43	7.56	27.6696
70NA-30RA	7.63	6.8	7.215	26.4069
50NA-50RA	6.3	5.47	5.885	21.5391
30RA-70NA	6.08	4.6	5.34	19.5444
100RA	5.17	4.48	4.825	17.6595

Values of average flexural strength are then plotted on the vertical bar graph with respect to its constitution and comparisons are to be made. It has been evident from the following figure that maximum flexural strength will be achieved when there is 100% natural aggregate is present into the mixture but will fall after when some portion of natural aggregate is replaced by recycled aggregate. This effect was due to the weaker bond of the old mortar adhering to the recycled aggregate, which may have caused a reduction in the strength of the polymer concrete.

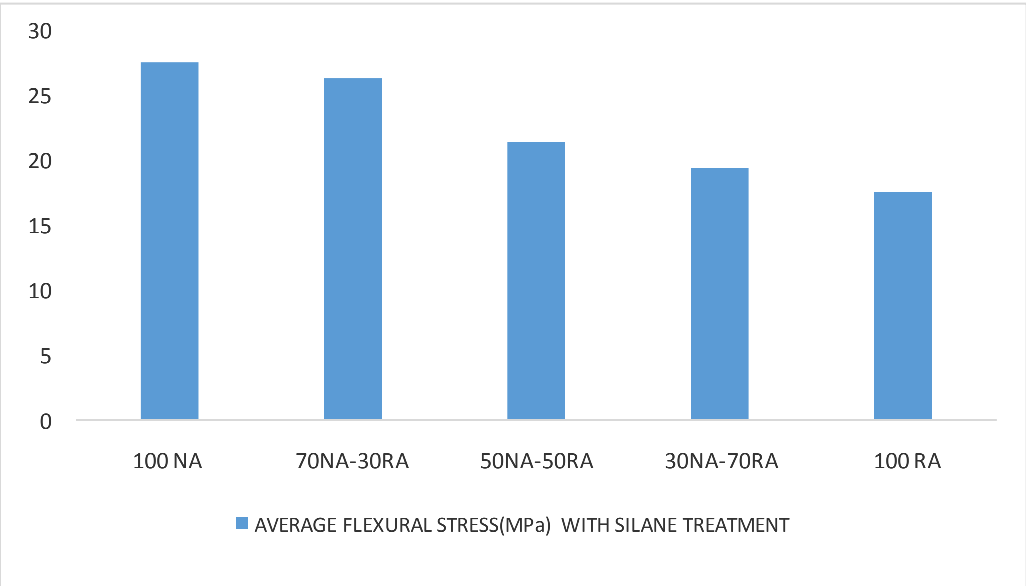

Figure 2 Flexural strength vs composition

The results of tests for finding the volume of permeable pore size of samples obtained after the silane treatment of the binding agent are as follows:

Table 10 Volume of permeable pore space

Composition	*Volume of permeable pore space*
100 NA	0.684585
70NA-30RA	0.746651
50NA-50RA	0.905146
30NA-70RA	0.977006
100 RA	1.402276

After performing all tests for all possible combinations, a curve will be obtained for each sample and with their values as shown in the following figure. From the following Figure we can see that from going 100% natural aggregate to 100% recycled aggregate permeable pore space among the samples increases this increase could also be one of the reasons for reduction in compression and flexural strength when we move from 100% natural aggregate to 100% recycled aggregate. The reason for this increase of volume of permeable pore size is due to the weaker bond of the old mortar adhering to the recycled aggregate.

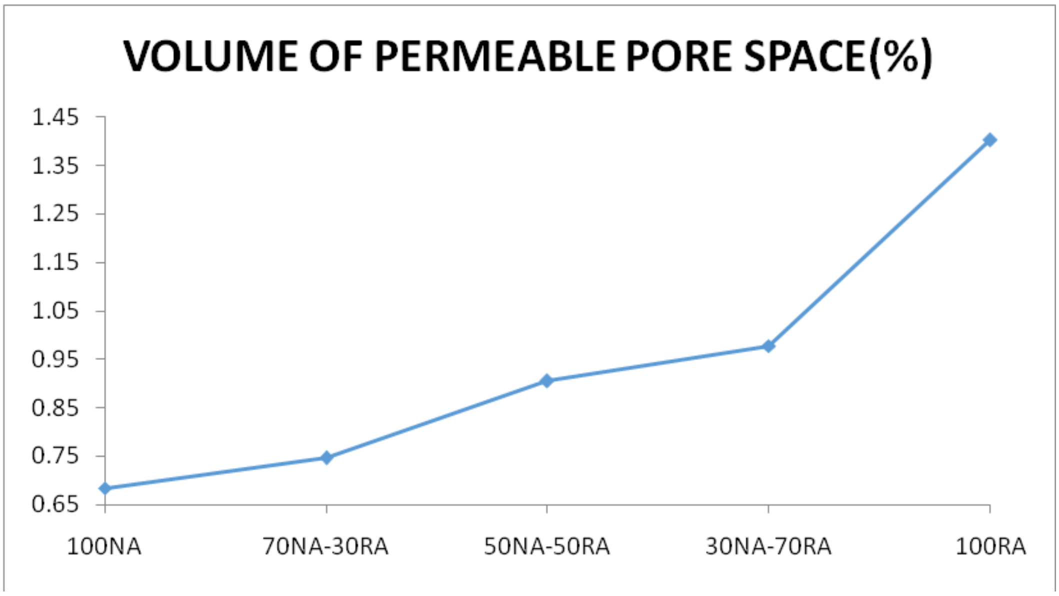

Figure 3 Volume of permeable pores vs Composition

Effect of silane treatment on compressive strength of polymer concrete

For comparison purpose readings of average value of polymer concrete without silane treatment has been taken from Mr. Aditya Bakshi student of M.Tech, Mechanical NIT Jalandhar (2016) with my average values of polymer concrete with silane treatment from table no 8 has been taken in the following Table.

Table 11 Comparison of compressive strength with silane and without silane treatment

Composition	*Average value of compressive strength with silane (MPa)*	*Average value of compressive strength without silane (MPa)*
100 NA	90.6	89.8
70NA-30RA	87.85	84.35
50NA-50RA	78.6	76.95
30NA-70RA	70.45	68.15
100RA	56.95	56.65

The value of compressive strength for both polymer concrete with silane treatment and without treatment is taken from table no 11 and bar charts are drawn for comparison basis as following. It has been observed that there is a small rise in the compressive strength after the silane treatment of the binding agent. The rise may be here because of the reduction of volume of permeable pore size in the samples. The rise in compressive strength is small may be because in compression testing pore sizes further reduces due to the applied force, also may be due to the reason polymer concrete is far more stronger in compression than tension.

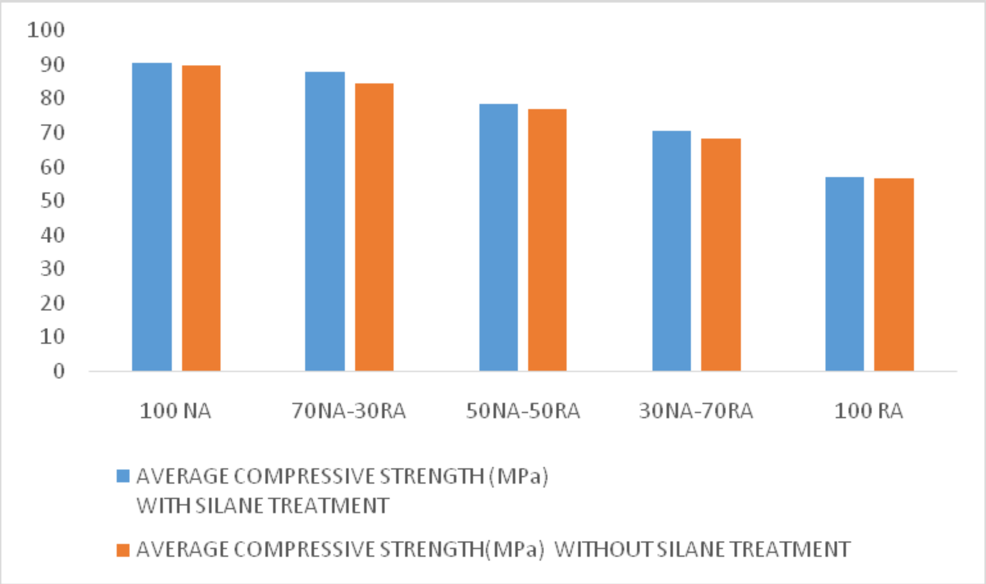

Figure 4 Comparison of compressive strength with silane and without silane treatment

Effect of silane treatment on flexural stress of polymer concrete

For comparison purpose readings of average value of flexural strength of polymer concrete without silane treatment has been taken from Mr. Aditya Bakshi student of M.Tech Mechanical NIT Jalandhar with my average values of polymer concrete with silane treatment from Table no 9 has been taken in the following Table.

Table 12 Comparison of flexural stress with silane and without silane treatment

Composition	*Average value of flexural strength with silane (MPa)*	*Average value of flexural strength without silane (MPa)*
100 NA	27.66	21.55
70NA-30RA	26.407	19.581
50NA-50RA	21.53	18.208
30NA-70RA	19.54	17.7693
100RA	17.66	17.27

The values of average flexural strength with silane treatment and without silane treatment has been plotted against composition from Table 12 in a bar chart below and the comparison between them is been observed.

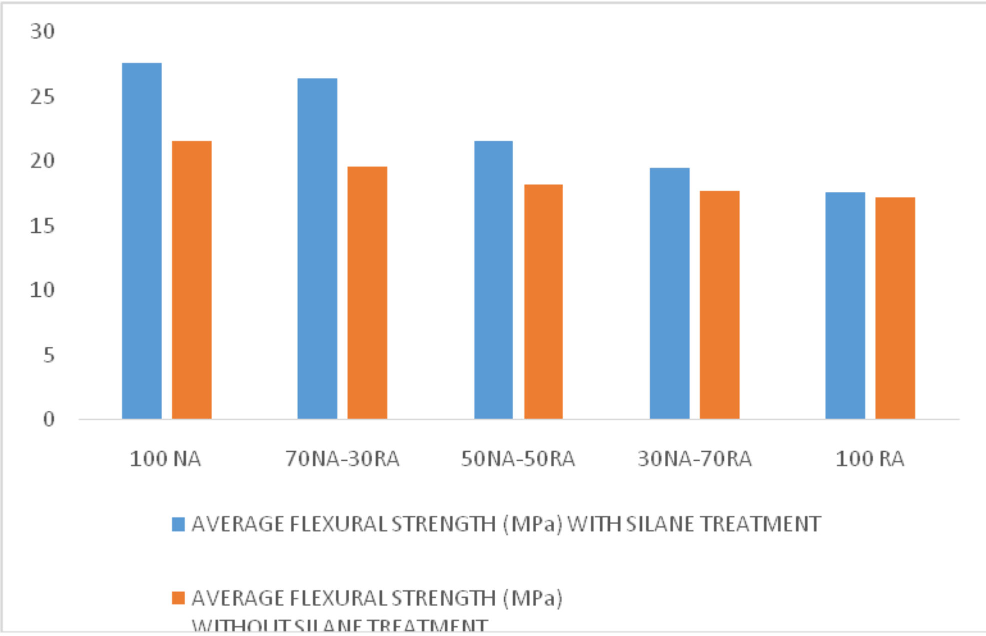

Figure 5 Comparison of flexural strength with silane and without silane treatment

From the figure 5 and table no 12 it has been shown that flexural stress do increases even with 1% silane treatment of polymer concrete .This shift may be due to the high bonding properties of silane coupling agent because of which bond formation between aggregates and resin improves significantly that's why the presence of voids in concrete decreases which increases the flexural strength.

Effect of silane treatment on volume of permeable pore size of polymer concrete

For comparison purpose readings of volume of permeable pore size of polymer concrete without silane treatment has been taken from Mr. Aditya Bakshi student of M.Tech

Mechanical NIT Jalandhar with my average values of polymer concrete with silane treatment from Table no 10 has been taken in the following Table.

Table 13 Comparison of volume of permeable pore size with silane and without silane treatment

Composition	*Volume of permeable pore size with silane (MPa)*	*Volume of permeable pore size without silane (MPa)*
100 NA	0.6845854	0.764347
70NA-30RA	0.7466516	1.031223
50NA-50RA	0.9051466	1.319222
30NA-70RA	0.9770060	1.380351
100RA	1.4022763	1.523485

The values of volume of permeable pore sizes with silane treatment and without silane treatment has been plotted against composition from Table 13 in a bar chart below and the comparison between them is been observed.

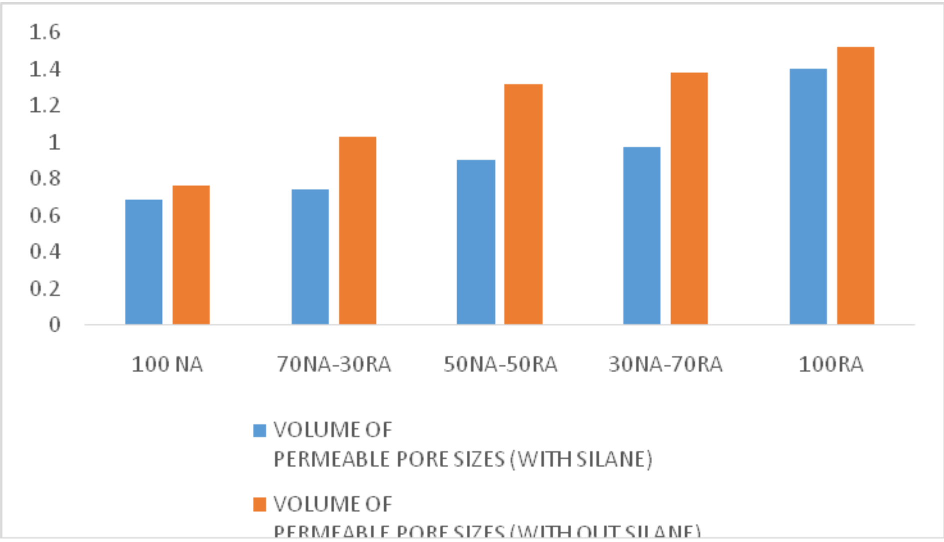

Figure 6 Comparison of volume of permeable pore size with silane and without silane treatment

It is evident from the Table 13 and Figure 6 that volume of permeable pore size decreases with addition of silane coupling agent. This shift may be due to high bonding properties of silane coupling agent because of which bond formation between aggregates and resin improves significantly that’s why the presence of voids in concrete decreases.

Effect of addition of silica fumes on compressive strength

In addition to fly ash, 5% more silica fumes were used in one set of samples with 50% Natural aggregates and 50% recycled aggregates to find the effect of increase in percentageof micro-fillers and effect of use of silica fumes on the compressive strength of polymer concrete. The result is presented below

Table 14 Comparison of polymer concrete with or without silica fumes

Composition	*Compressive strength (with silica fumes) (MPa)*	*Compressive strength (without silica fumes)(MPa)*
50NA-50RA	81.4	78.6

As observed from the table above an appreciable increase of about 3.5% was observed with addition of silica fumes as filler.

CONCLUSIONS

- On comparing our data with other studies, it has been observed that silane coupling agent do improves the compressive strength and flexural strength.
- It has been observed that rise in compressive strength is small than in flexural strength. This might be because of the reason that polymer concrete has high strength in the compression than the tension .As failure in flexural testing is due to the low tensile strength of the sample. As tensile strength increases marginally due to reduction in volume of permeable pore size after silane treatment flexural strength also increases.
- Compressive strength decreases from moving mixture of 100% natural to 100% recycled aggregate.
- Flexural strength decreases from moving mixture of 100% natural to 100% recycled aggregate.
- Permeable pore space increases from moving mixture of 100% natural to 100% recycled aggregate.
- Water absorption capacity of samples increases from moving mixture of 100% natural to 100% recycled aggregate.
- Compressive and Flexural strength has drop of almost 3% from moving mix of 100% natural aggregate to combination of 70% Natural aggregate and 30% recycled aggregate which is low but saving in natural aggregate is also very low.
- Compressive and Flexural strength has drop of almost 35% from moving mix of 100% natural aggregate to 100% recycled aggregate it has high saving in natural aggregate but loss in strength is high
- Compressive and Flexural strength has drop of almost 12% from moving mix of 100% natural aggregate to combination of 50% Natural aggregate and 50% recycled aggregate in this case material saving is also significant and loss in strength is also not very bad. So, this mix is closest to the optimum mix.
- Increase of about 3.5% was observed with addition of silica fumes as filler in composition having combination of 50% recycled aggregate and 50% natural aggregates.
- In influencing the compressive strength. The order of influence is Resin>filler> silane.

FUTURE SCOPE

Following are the improvements and tests that can further be done in this project in my opinion:

- As we know combination of 50% natural aggregate and 50 % recycled aggregate more quantity of micro fillers like silica fumes can also be added to further enhance the strength of results
- In above experiments we fixed the quantity of silane coupling agent to 1% but in future experiments we can increase it.
- More number of samples should be made between the combination of 70% natural aggregate and 30% recycled aggregate and 50% natural aggregate and 50 % recycled aggregate.

REFRENCES

[1] M.S. M. Norhasri, M. S. Hamidah, and A. M. Fadzil, “Applications of using nano material in concrete : A review,” *Constr. Build. Mater.*, vol. 133, pp. 91–97, 2017.

[2] I.V. Shmidt, A.S. Degtyareva" Development and Testing of Concrete Mix for Machine Tool Base Element "Procedia Engineering 206 (2017) 1215–1220

[3] Vivek A, VijayaHolla, M.S. Krupashankara "Polymer Concretes for Machine Tool Structures – A Review" International Journal of Innovative Research in Science, Engineering and Technology,vol.5,2016

[4] R. Bedi and R. Chandra, “Reviewing some properties of polymer concrete,” no. August, pp. 47–68, 2014.

[5] F. Mahdi, H. Abbas, and A. Ali, “Flexural , shear and bond strength of polymer concrete utilizing recycled resin obtained from post consumer PET bottles,” *Constr. Build. Mater.*, vol. 44, pp.798–811, 2013.

[6] B. Jo, S. Park, and J. Park, “Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates,” vol. 22, pp. 2281–2291, 2008.

[7] ASTM C 642-06(2006)"Standard test method for Density, Absorption and voids in Hardened Concrete", ASTM, USA.

[8] Vrtanoski G., Dukovski V. (2004) Modelling and Design of Main Spindle Box Made of Polymer Concrete. In: Hinduja S. (eds) Proceedings of the 34th International MATADOR Conference. Springer, London.

[9] P.Mani, A. K. Gupta, and S. Krishnamoorthy, “Efficiency of some silane coupling agents and of the method of their application in polyester resin concrete,” *J. Mater. Sci.*, vol. 18, no. 12, pp. 3599–3605, 1983.

[10] https://en.wikipedia.org/wiki/Polyethylene_terephthalate