MECHANICAL PROPERTIES OF POLYMER CONCRETE MADE WITH NATURAL AND RECYCLED AGGREGATES USING PET RESIN

A Bakshi[1] , R Bedi

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

ABSTRACT In this work, PET(Polyethylene terephthalate) was recycled and used as the resin to bind the aggregates. Both natural and recycled aggregates were used in the study. There is problem of non-biodegradability with both PET and construction wastes which were recycled and used in this study. This leads to Sustainable growth. In present study five mixtures consisting of various combination of natural and recycled aggregate obtained from construction waste were manufactured with PET resin . 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 48%.Whereas a combination of 50% natural aggregate and 50% recycled aggregates decreases compressive strength by 15%. And also, the same trend is observed with flexural strength where loss is 25% from moving 100% natural aggregates to 100% recycled aggregates. Increase of about 3.5% was observed in compressive strength with addition of 5% silica fumes as a filler.

Keywords: Polymer Concrete, PET resin, Recycled Aggregates, Natural aggregates

Aditya Bakshi is a student of M.Tech , Mechanical Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India. His research interests are study of variation in properties of polymer concrete made with recycled PET resin and different combinations of natural and recycled aggregate and different type of fillers.

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

INTRODUCTION

Polymer concrete is a composite material which results from polymerization of a monomer/aggregate mixture. The polymerized monomer acts as binder for the aggregates and the resulting composite is called "Concrete." The properties of polymer concrete differ greatly depending on the conditions of preparation. For a given type of polymer concrete, the properties are dependent upon binder content, aggregate size distribution, nature and content of the micro filler, curing conditions, and so forth.[1]

The main problem we face in using 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 optimized cost without much loss of properties.

Polymer concrete had initially been developed as an alternative material in the domain of civil engineering but over a period of time, owing to its superior properties, it has been used as a replacement material in many mechanical applications as well. These properties are rapid curing, high compressive strength, high specific stiffness and strength, resistance to chemicals and corrosion, ability to mould into complex shapes, excellent vibration damping and low water absorption.

RESEARCH SIGNIFICANCE

In this research we are trying to contribute to the understanding of the polymer concrete and find the ways to use it in practical ways so that it is both economical to use and retains its superior properties when recycled aggregates are used. Also we will be able to get rid of huge amount of PET waste and constructional waste. Results from our study can be used in the following places:

- Hangars for airplanes
- Tool bed application[2]
- Construction of Pipes, pumps and valve castings etc. subject to corrosive conditions.
- Manufacturing of the end winding of conventional and super conducting generators.
- Used in making main spindle housing for CNC machines[3]
- Used in making of small structures of basic manufacturing machines[4]
- Used in sea port construction and in marine areas
- Foundation of hydraulic machines
- Manufacturing of storage tanks
- Making of tunnel lining with smooth profile

EXPERIMENTAL WORK

Resin

The 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, ortho terephthalic unsaturated polyester resin. AROPOL IN 7120 is a non-thixotropic and non-accelerated resin

Table 1 Properties of uncured resin

PROPERTIES AT 25°C	VALUE (WINTER)	VALUE (SUMMER)	UNIT
Viscosity Brookfield RV2,20rpm	320-350	320-350	Cps
Acid value	17-24	17-24	mgKOH/g
Styrene content	36-40	36-40	%
+ 3.0 % Co-oct (1%)			
+ 1.5 % MEKP-50			
Peak exotherm	170-190	170-190	^{0}C

Typical cured resin properties (Curing at Room Temperature for 24 hrs and then Post cure it at 80 °C for 4hrs) is 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

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 ketone peroxide(MEKP) as an initiator and promoter respectively.[5]

Aggregates

Various combination of natural and recycled aggregates were used. Aggregates which were 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 natural and recycled aggregates were tested which are designated 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]

Micro Fillers

Fly ash was used as microfiller for obtaining good bonding strength between the polymer matrix and the aggregates[7].The chemical composition of the fly ash is given in following table:

Table 4 Fly Ash

CONSTITUENT	PERCENTAGE
SILICON OXIDE	58.83
ALMUNIUM 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 was also used to enhance the mechanical properties of the polymer concrete.

PROCEDURE FOR PREPARATIONS OF SAMPLES

First of all, sieving of crushed stones at given sizes is done. It is properly washed to remove any dirt or impurity. Then the aggregates are put in the oven to remove moisture as even the slightest of moisture will be highly detrimental to the final sample strength. Then aggregates of various sizes are mixed into a container according to the specified sizes. Then required amount of fly ash is added to the container. Then measured amount of PET resin is poured in that container. Then 3% of MEKP (Methyl ethyl ketone per oxide)which is a catalyst is added to the mixture. Then mixture should be mixed thoroughly. Then 1.5% of CoNp (Cobalt napthanate) is added and the mixture should be mixed again quickly as the hardener will cause it to solidify quickly 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 a duration of 12 days in normal working conditions. Then various tests are done on the samples.

Table 5 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 was added to mixture of 50% natural and 50% recycled aggregate. The table for that is as follows:

Table 6: 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 PET resin

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, Jalandhar Civil lab .For this two cube of 100 mm dimension for each mixture of natural and recycled concrete were made and tested and then there average value has been taken and plotted to see the variations.

Flexural Testing of Polymer Concrete

Two polymer concrete bar of dimensions 50 x 50x 305 mm size were prepared for each mixture of natural and recycled aggregate and then center point test is performed on them on a cyclic loading machine. After that there average value has been taken and plotted to see the variations of flexural strength.

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. For determining the volume of permeable pore size we perform standard test methods as per method mentioned in ASTM C 642-06 (2006).[8]

RESULTS AND DISCUSSION

Compression Test Result

The results of compression testing are presented below-:

Table 7 Results of compression testing

COMPOSITION	COMPRESSION TESTING SPECIMEN 1 MAX STRESS(MPA)	COMPRESSION TESTING SPECIMEN 2 MAX STRESS (MPA)	AVERAGE STRESS(MPA)	STANDARD DEVIATION
100NA	90.7	88.9	89.8	1.37
70NA-30RA	87.2	81.5	84.35	4.03
50NA-50RA	78.7	75.2	76.95	2.47
30NA-70RA	73.7	62.6	68.15	7.848
100RA	54.7	58.6	56.65	2.75

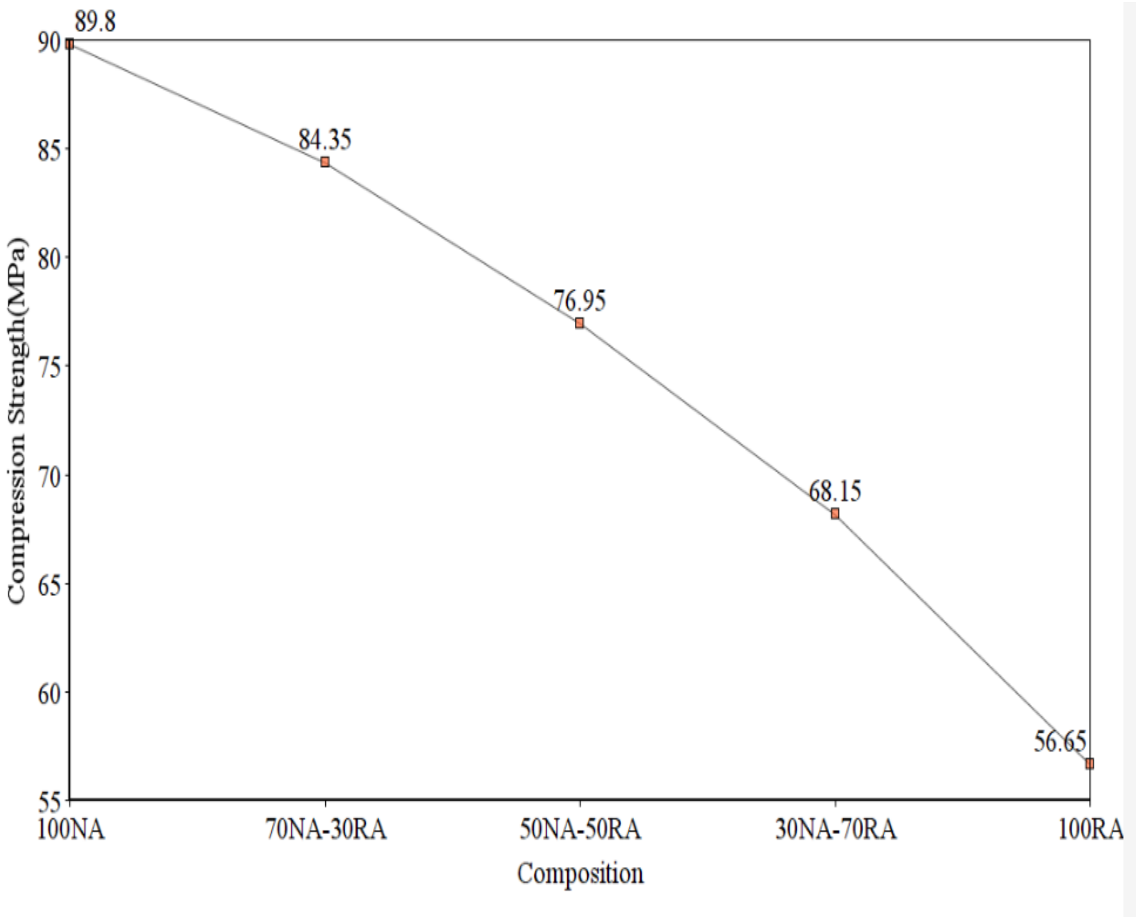

Figure 1 Composition v/s compression strength

As shown from the above data in the recycled-PET polymer concrete with recycled concrete aggregates (RPC), a gradual reduction in strength was observed as the recycled aggregate content increased. This effect was 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 RPC. It should be noted that loss of strength from going to 100% natural aggregate to 100% recycled aggregate is almost 48%.While for 70:30 ratio would be 3.85% while for 50:50 would be 14% and for 30:70 ratio it was 30%.

Flexural Test Result

Table 8 displays the flexural strength of polymer concrete samples (MPa) for each run having two replicates. The average strength for each run has been reported in the following table:-

Table 8 Flexural Strength of the samples

COMPOSITION	LOAD (SPECIMEN 1)	LOAD (SPECIMEN 2)	AVERAGE LOAD	FLEXURAL STRESS (MPA)
100NA	5.74	6.04	5.89	21.5574
70NA-30RA	5.38	5.32	5.85	19.581
50NA-50RA	5.28	4.67	4.975	18.2085
30NA-70RA	5.2	4.51	4.855	17.7693
100RA	5.08	4.36	4.72	17.2752

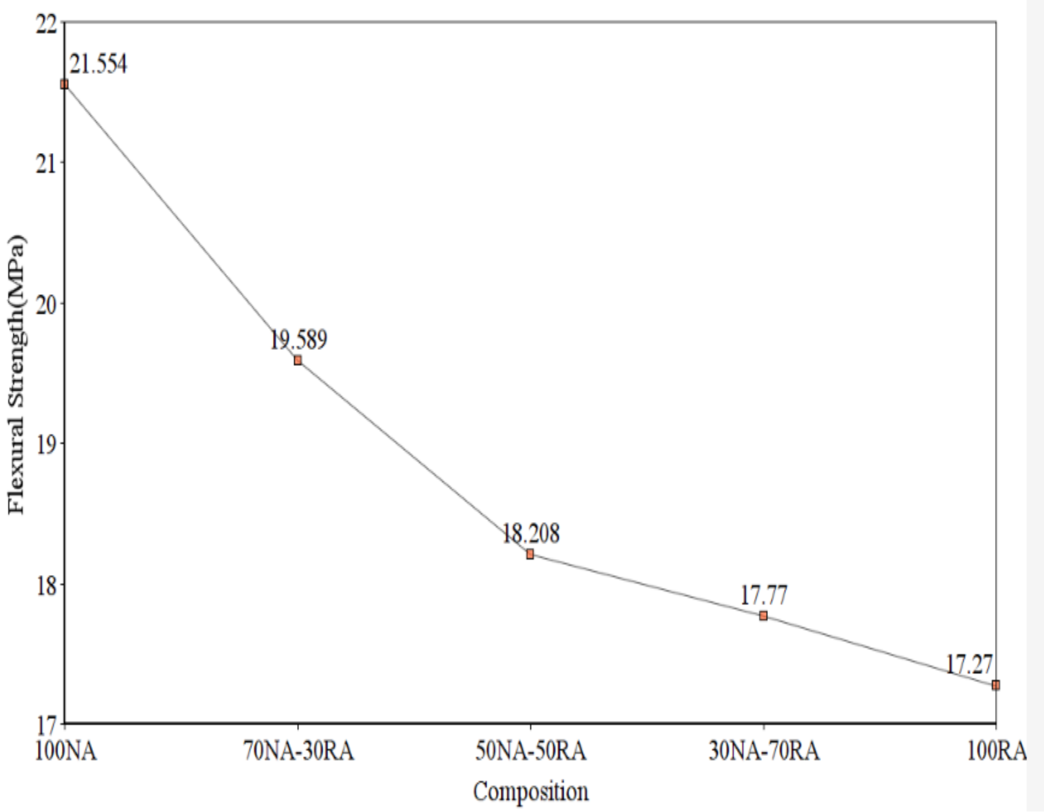

Figure 2 Flexural strength v/s composition

It has been seen from the above data 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 concrete aggregate, which may have caused a reduction in the strength of the RPC.

Volume of Permeable Pores

The results of tests for finding the volume of permeable pore size of samples obtained are as follows:

Table 9 Volume of permeable pore space

COMPOSITION	VOLUME OF PERMEABLE PORE SPACE
100 NA	0.764347
70NA-30RA	1.031233
50NA-50RA	1.0319222
30NA-70RA	1.380351
100 RA	1.523485

After performing all tests for all possible combinations we see that on going from 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.

Absorption Capacity

The results of tests for finding the absorption capacity of samples obtained are as follows:

Table 10 Absorption Capacity

COMPOSITION	ABSOPTION CAPACITY (% by weight of sample)
100 NA	0.371931
70NA-30RA	0.505971
50NA-50RA	0.652575
30NA-70RA	0.633579
100 RA	0.770692

From the figure it is clear that water Absorption capacity of the samples also increases from going 100% natural aggregate to 100% recycled aggregate. This increase may be due to increase in the void or permeable pore space in the sample.

EFFECT OF ADDITION OF SILICA FUMES

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 percentage of micro-fillers and effect of use of silica fumes on the compressive strength of polymer concrete. The result is presented below

Table 10 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 natural aggregates have better compressive strength and flexural strength and less permeable pore sizes compared to recycled aggregates 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 there. It will help us to use off the waste recycled aggregate.

Compressive strength has drop of almost 48% on moving from a mix of 100NA to 100RA. It has complete use of recycled aggregate but loss in strength is high. There is an increase of 35% in Compressive strength in moving from 100 RA to 70RA-30NA which is very significant and shows that a small addition of natural aggregate improves the qualities very considerably. Compressive and Flexural strength has drop of almost 15% from moving mix of 100NA to combination of 50NA-50RA and an increase of about 44% from 100 RA. So 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 a filler in composition having combination of 50% recycled aggregate and 50% natural aggregates.

FUTURE SCOPE

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

More percentage of micro-fillers can be used in the mix than present use of 10%. The effect of increase in percentage of micro filler on the strength can be observed.

Effect of use of mixture of fillers of different kind like silica fumes, fly ash etc. can be viewed.

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 to find the most optimum mix.

Effect of coupling agents like Silane coupling agent or Titanate coupling agents on various properties can be observed

REFRENCES

1. R. BEDI AND R. CHANDRA, Reviewing some properties of polymer concrete, no. August, pp. 47–68, 2014.
2. I.V. SCHMIDT , A.S. DEGTYAREVA, Development and Testing of Concrete Mix for Machine Tool Base Element, Procedia Engineering 206 (2017) 1215–1220
3. VRTANOSKI G.,DUKOVSKI V. Modelling and Design of Main Spindle Box Made of Polymer Concrete. In: Hinduja S. (eds) Proceedings of the 34th International MATADOR Conference. Springer, London(2004)
4. VIVEK A,VIJAYA HOLLA, M.S.KRUPASHANKARA, Polymer Concretes for Machine Tool Structures – A Review, International Journal of Innovative Research in Science, Engineering and Technology,vol.5,2016
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. 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.
8. ASTM C 642-06, Standard test method for Density, Absorption and voids in Hardened Concrete", ASTM, USA. (2006)
9. https://en.wikipedia.org/wiki/Polymer concrete
10. https://en.wikipedia.org/wiki/Polyethylene_terephthalate