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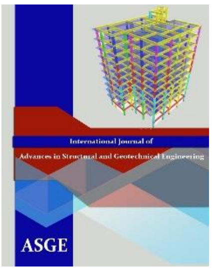

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CHARACTERISTIC OF CEMENT CONCRETE WITH RECYCLED ASPHALT PAVEMENT AGGREGATES

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ABSTRACT

Recycled asphalt pavement (RAP) is the removed and/or reprocessed pavement material containing asphalt and aggregate. The use of RAP in asphalt pavement has become a common practice in the construction of new, and reconstruction of old, hot mix asphalt pavements. Nevertheless, limited researches have been done to examine the potential of incorporating RAP into concrete. Since RAP contains asphalt, it is very likely that the toughness of concrete made with RAP could be improved. An alternative use of RAP is to use it as an aggregate in Portland cement concrete (PCC).

Concrete pavements using concrete with a lower modulus of elasticity would have a lower chance of cracking. On the other hand, the optimal concrete mixture for concrete pavement was a concrete with a proper combination of low modulus of elasticity, and adequate flexural strength.

This study evaluated the feasibility of using concrete containing RAP for concrete pavement applications. Twenty four different concrete mixes containing different percentages of RAP (0%, 15%, 30%, 45%, 60% and 100%) were produced in the laboratory.Different cement content with (250, 300 and 350 kg/m3) and type F fly ash with content (0%, 15%, and 30%) as replacement by cement weight were also used. Moreover, polypropylene fibers with volume fractions of 0%, 0.5% and 1% was used. The present study focused on the mechanical properties of the concrete, mainly, compressive strength, splitting tensile strength, flexural strength that were evaluated.

The test results indicated that RAP could be incorporated into Portland cement concrete without any modification to the conventional equipment or procedures. There was a systematic reduction in the compressive, flexural and split tensile strengths with the incorporation RAP in concrete as compared with that of a reference concrete without RAP.

Keywords: Portland cement concrete; Recycled asphalt pavement (RAP), Mechanical properties, Polypropylene fibers, Fly ash.

1. Introduction

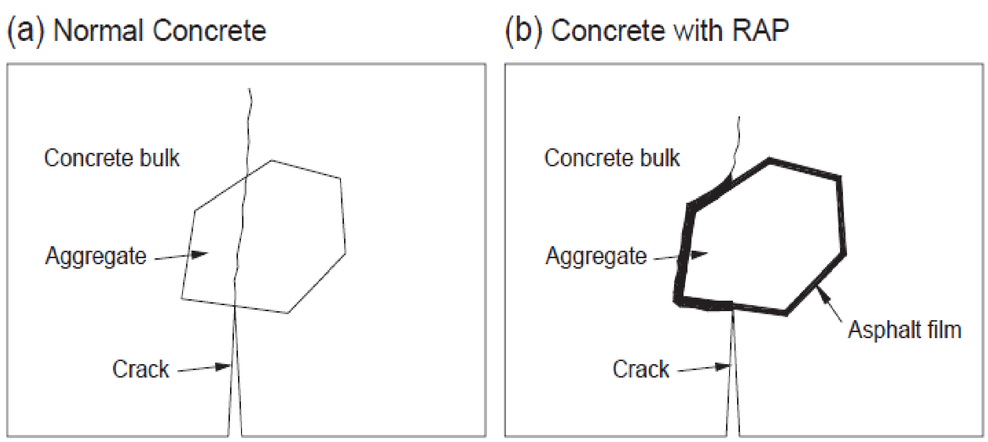
Recycled Asphalt Pavement (RAP) is one of the most commonly used recycled materials. RAP is the term given to removed and /or reprocessed pavement materials containing asphalt and aggregates. RAP is generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. RAP consists of high quality, well-graded aggregates coated by asphalt cement. Every year, millions tons of RAP are generated by asphalt pavement (AC) rehabilitation and reconstruction ((RMRC, 2008), (Khalaf and DeVenny, 2005)) and (Collins and Ciesielski, 1994). Some of RAP have been recycled into new asphalt mixtures and some have been used as pavement base materials. In addition to, a large quantity of RAP still remains unutilized and needs to be put into good use like in Portland cement concrete (PCC) to improve the toughness and ductility of the PCC. Recently, using RAP in PCC has become more and more popular. Most recycled materials applied in PCC are used to replace coarse aggregates such as crushed PCC and RAP ((Baoshan et al., 2006) and (Nagataki et al., 2004)).

Some studies have been conducted on recycled materials, primarily focusing on laboratory evaluation of physical properties. (Kim et al., 2007) found that RAP as base materials had higher resilient modulus, but higher rutting potential than natural aggregates . (Wen et al., 2010) studied the RAP with and without fly ash and compared to crushed aggregate .In addition, at high stress levels, RAP had higher resistance to permanent deformation than natural aggregate material (Jeon et al., 2009). Therefore, the modulus of elasticity of concrete is known to have a major effect on the performance of concrete pavements using concrete with a lower modulus of elasticity would have a lower stress due to the same applied load and thus could have a lower chance of cracking (Tia et al., 1989). (Delwar et al., 1997) examined the stress-strain behavior of PCC containing RAP and found that PCC containing a higher amount of RAP fails at a higher strain level indicating that RAP may contribute to the ductility of PCC. (Michael and Hossiney, 2010) have formed experimental study on Concrete Containing RAP. In this experiment, they had replaced the natural aggregate with the RAP in concrete containing Rap in percentages 0, 10, 20, 40 were casted in laboratory and evaluate performance of replaced concrete. The investigation results shows that, the RAP is adversely affecting on concrete properties of compressive strength, flexural strength and elastic modulus. These properties are decreasing with increasing the percentage of RAP, but it did not affected the thermal expansion, dry shrinkage of the concrete.

Recycled construction and demolition wastes that have been recently assessed to be viable materials for roads, pavements, footpaths and other civil engineering applications include RAP. RAP is mainly used in three ways, first one is using RAP as an aggregate in asphalt hot mix with original aggregate, second, one is extracting the bitumen from the RAP, then using extracted bitumen and coarse aggregates separately in an asphalt mix and third newly adopted is using RAP as aggregate in concrete. On the other hand, using RAP as coarse aggregate consider more economical, minimize natural resources consumption and to reduce negative impacts on an environment ((Reddy, 2016), (Taha et al., 2002) and (Hoyos et al., 2011)).

(Baoshan et al., 2005) had done Laboratory investigation of concrete containing RAP .They are used the RAP as aggregate in both fine and coarse. in this study they are prepared four concrete mixes with and without RAP the RAP using percentages for mixes are 0%&0%,100%&100%,100%&0%,0%&100% both coarse RAP and fine RAP respectively in each case. The authors conclude that from investigation result the concrete made with one coarse RAP is giving good strength than other. RAP concrete had more toughness than nominal concrete. Therefore, as a composite, the performance of concrete can be improved for high toughness and crack resistance using RAP in PCC. Concrete made with RAP, asphalt forms a thin film at the interface of cement mortar and aggregate, which can be used to arrest crack propagation shown in **Fig.(1).** Thus, crack develops around rather than go through aggregate particle, during which more energy can be dissipated. This is likely to be the toughness improvement of concrete made with RAP aggregates ((Maalej, 1996) and (Baoshan and Zhao et al., 1998)).

(Athar, 2008) had conducted study on the Performance-Related Tests of recycled aggregates .This study is performing test on RAP using as aggregates in the unbounded base and sub base pavement layers. Athar conducted different laboratory test for selection material and to find properties of material on the RAP, test are like sieve analysis for screening, toughness test, moisture and absorption test, stiffness test and frost susceptibility. The properties of RAP adversely affecting the performance of the unbound base and sub base pavements like shear strength, durability, stiffness of layer..etc. Whatever the usage of RAP, in unbounded base and sub base pavement layer make project more lower cost.



(Fig. 1) Crack propagation in concrete and concrete with RAP (Baoshan et al., 2005).

This paper is a discussion of the results of tests carried out to assess the performance of RAP as a replacement of coarse aggregate in PCC. The performance in concrete of RAP was compared with natural aggregate.

2. Experimental program

Laboratory experiment was carried out to investigate the material characteristics of PCC incorporated with RAP. Recycled asphalt pavement was considered to replace the natural aggregates from the control PCC mixture. Laboratory fabricated RAP materials were prepared for this study. Compressive, flexural and split tensile strength tests were employed to evaluate the mechanical properties of hardened concrete at the curing time of 7, 28 and 56 days.

2.1 Materials

Cement

The cement used was Portland cement (CEM 1 42.5N) obtained by the SWEDY Company and complies with Egyptian standard specification [ESS 4756-1/2013]. The properties of the cement used are illustrated in (**Table 1**).

Water

Tap water free from impurities was used for mixing and curing the test specimens according to the requirement of the [ECP 203/2007].

(Table 1) Physical and mechanical properties of the cement used

Property		Value	[ESS 4756-1/2013]
Specific gravity		3.15	———
Initial setting time (min)		90	≥ 60 min
Final setting time (min)		300	≤ 600 min
Standard consistency (W/C %)		28	———
Fineness %		7	< 10
Soundness (mm)		3	≤ 10
Compressive strength, MPa	2 days	13	≥ 10
	28 days	48	≥ 42.5, ≤ 62.5

Fly ash

Class (F) Fly ash, produced in a coal-fired power plant was used in this study. It complies with the chemical and physical requirements of [ASTM C618] and relevant international quality standards for fly ash. The chemical composition and physical properties of fly ash according to the manufacturer are given in the (**Table 2**). Obtained from Sika Company for construction- Egypt.

(Table 2) The chemical composition of fly ash according to the manufacturer

Component	Percentage of Fly ash (%) by mass	ASTM C618 Specifications
Silicon(SiO_2)	47.0-55.0	70.0 min
Aluminum (Al_2O_3)	25.0-35.0	70.0 min
Iron (Fe_2O_3)	3.0-4.0	70.0 min
Manganese (Mn_2O_3)	0.1-0.2	70.0 min
Calcium (CaO)	4.0-10.0	Not specified
Magnesium (MgO)	1.0-2.5	Not specified
Phosphorus (P_2O_3)	0.5-1.0	Not specified
Potassium (K_2O)	0.5-1.0	Not specified
Sodium (Na_2O)	0.2-0.8	Not specified
Titanium (TiO_2)	1.0-2.0	Not specified
Sulphur (SO_3)	1.0-0.5	5.0 max
Loss On Ignition (LOI)	0.5-2.0	6.0 max
Specific Surface Area (Cm^2/g)	5000	Not specified

Specific gravity	2.6	----

Chemical admixture

A high range water reducer (HRWR) (Trade name: sika-viscocrete 3425 produced by Sika company for construction- Egypt) was used as superplasticizer meeting the requirements of [ASTM C494] type F&G. it is a brown liquid having a density of approximately 1.08 kg / liter at room temperature. The admixture was added by 0.5-1.5% by weight of binder as recommended by the manufacturer.

Fine aggregate

The fine aggregate used in the experimental program was natural siliceous sand with average gradient area. Its characteristics satisfy the requirements of [ECP 203/2007]. It was clean and free from impurities. The grading of the used sand as well as the limits of ECP (2007) are given in (**Table 4**). The grain size distribution curve of the used sand is presented in **Fig. (2)**. The physical and mechanical properties of the sand are shown in (**Table 3**).

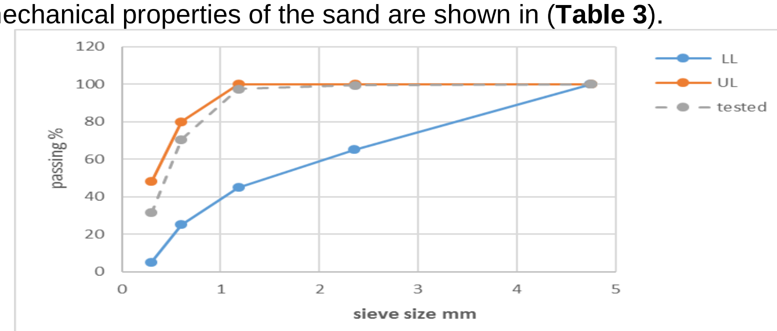


Fig. (2) Grain size distribution of the used sand

(Table 3) Physical and mechanical properties of sand, limestone and RAP used

Property	sand	Limestone	RAP
Specific gravity	2.65	2.5	2
Unit weight (t/m3)	1.72	1.4	1.4
Void ratio (%)	35	44	10
Fineness modulus	2.54	6.05	6.08
% clay and fine matter (by weight)	2%	0.5	0.2

(Table 4) Grading of the used sand

Sieve size mm	4.75	2.36	1.18	0.6	0.3
% Passing	100	99.5	97.5	70.5	31.5
% Passing ECP (203/2007)	-	65-100	45-100	25-80	5-48

Coarse aggregate

The coarse aggregate used was crushed limestone and RAP, which satisfies the requirements [ECP 203/2007]. The specific gravity for limestone and RAP were 2.5 and 2, respectively. The physical and mechanical properties of the crushed limestone and (RAP) are shown in the (**Table 3**). On the other hand, the grading as well as the limits of ECP for used aggregate are presented in (**Table 5**). The grain size distribution curve of the used coarse aggregate is presented in **Figs. (3)** ,and **(4),** respectively for limestone and RAP.

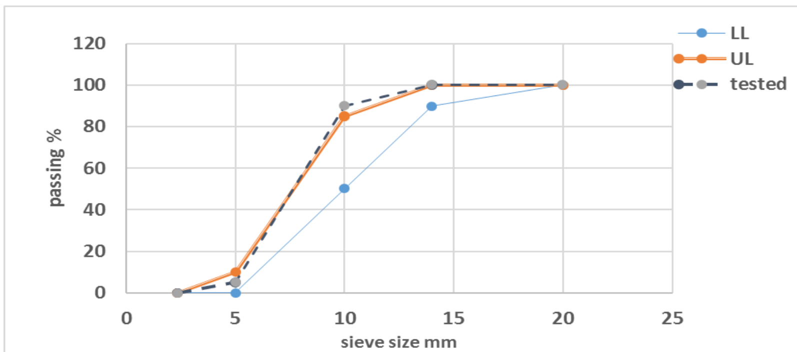


Fig. (3): Grading of the used limestone

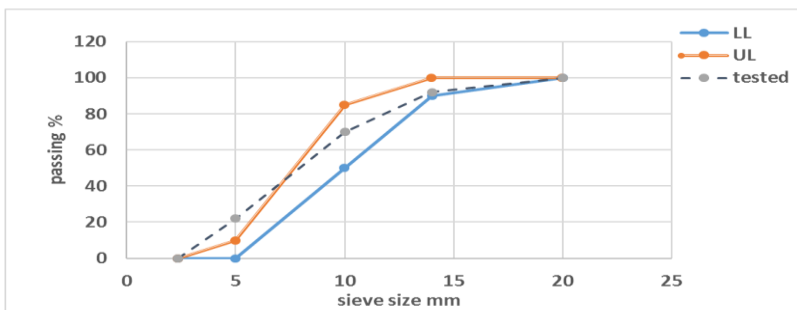


Fig. (4): Grading of the used RAP

(Table 5) Grading of the used limestone and RAP

Sieve size (mm)	20	14	10	4.75
% Passing (limestone)	100	100	90	5
% Passing (RAP)	100	92	70	22
% Passing ECP [203/2007]	100	90-100	50-85	0-10

Fibers

Polypropylene fibers was added to RAP mixes with different fiber volume fractions to produce the mixture. **Figure (5)** shows the shape of polypropylene fibers. The properties of polypropylene fibers according to the manufacturer are presented in (**Table 6**).

Fig. (5) Polypropylene fibers used

(Table 6) Properties of the investigated polypropylene fibers

Property	**Value**
Specific gravity (g/cm³)	0.91
Water absorption	0
Melting point (ċ)	250
Young's modulus (MPa)	3.45×10^{3}
Tensile strength (MPa)	550-700
Elongation at failure (%)	21
Width crossing	circular
Length (mm)	6-12
Diameter (micron)	18
Aspect ratio	333-1000

2.2 Production of concrete mixtures

The concrete mix proportions with 0%,15%, 30%, 45%, 60% and 100% RAP by weight of coarse aggregate were designed for this research study. The cement content was 250 kg/m^3, 300 kg/m^3 and 350 kg/m^3 with percentage water/binder (W/b) ratio 0.43 to 0.57 In addition needed depending on the workability of concrete. Concretes were produced by using fly ash as partial replacement of Portland cement with percentage of 10%, 20% and 30% by weight of cement. (**Table 7**) shows all the concrete mixtures that were evaluated in this research study and the mix proportions for these different concrete mixtures. The concrete mix proportions were designed by using absolute volume method (Eq. 0).

$$\frac{C}{\gamma C}+\frac{W}{\gamma W}+\frac{S}{\gamma S}+\frac{AG}{\gamma AG}+\frac{RP}{\gamma RP}+\frac{FA}{\gamma FA}+\frac{SP}{\gamma SP}+AIR=1000\ \text{Lit}$$

(Eq. 0)

Where:

C: Cement content, (kg/m^3),
W: Water content, (kg/m^3),
S: Fine aggregate content, (kg/m^3),
AG: Coarse aggregate content (Kg/m^3),
RP: Recycled asphalt pavement (RAP) (Kg/m^3),
FA: Fly ash content, (Kg/m^3),
SP: Super plasticizer (Kg/m^3),
γc: Specific gravity of cement (3.15),
γs: Specific gravity of fine aggregate (2.65),
γAG: Specific gravity of coarse aggregate (2.5),
γRP: Specific gravity of RAP (2),
γW: Specific gravity of water (1.0),
γSp: Specific gravity of superplasticizer (1.08),
γFA: Specific gravity of fly ash (2.6).

(Table 7): Concrete mixes proportional, kg/m^3

Mix No	MIX ID	Fiber %	W/C %	SP %	C	Sand	Lime.	RAP	Fly ash	Water	Slump (mm)	Flow (%)
1	**R0-250**	0	0.43	0.5	250	585	1170	0	0	122.5	50	20
2	**R15-250**	0	0.43	0.5	250	704	1197	211	0	107.5	5	20
3	**R30-250**	0	0.43	0.5	250	585	819	351	0	107.5	20	28
4	**R0-300**	0	0.57	0	300	598	1196	0	0	171	50	28
5	**R15-300**	0	0.57	0	300	582	989	175	0	171	30	20
6	**R30-300**	0	0.57	0	300	568	795	340	0	171	150	68
7	**R45-300**	0	0.57	0	300	571	630	513	0	171	13	60
8	**R60-300**	0	0.57	0.5	300	557	445	669	0	171	0	68
9	**R100-300**	0	0.57	0.5	300	510	0	1020	0	171	160	68
10	**R0-350**	0	0.57	0.5	350	560	1120	0	0	199.5	110	60
11	**R15-350**	0	0.57	0.5	350	546	928	163	0	199.5	180	68
12	**R30-350**	0	0.57	0.5	350	532	745	319	0	199.5	180	36
13	**R100-350**	0	0.57	0.5	350	478	0	956	0	199.5	180	39
14	**R15-300-F10**	0	0.57	0.5	270	580	986	174	30	171	190	50
15	**R15-300-F20**	0	0.57	0.5	240	577	981	173	60	171	180	52
16	**R30-300-F10**	0	0.57	0.5	270	566	792	340	30	171	10	50
17	**R30-300-F20**	0	0.57	0.5	240	563	788	338	60	171	210	45
18	**R30-300-F30**	0	0.57	0.5	210	561	785	336	90	171	180	60
19	**R30-350-F10**	0	0.45	0.5	315	564	790	338	35	157.5	50	60
20	**R30-350-F20**	0	0.45	0.5	280	561	785	337	70	157.5	110	63
21	**R30-350-F30**	0	0.45	0.5	245	558	781	334	105	157.5	190	66
22	**R30-300-F20-P0.5**	0.5	0.45	1	240	563	788	338	60	135	180	10

23	**R30-350-F20-P0.5**	0.5	0.45	1	280	561	785	337	70	157.5	180	10
24	**R30-350-F20-P1**	1	0.45	1.5	280	561	785	337	70	157.5	180	15

2.3 Specimens preparation

The molds were placed on a smooth levelled surface and oil coating was done on the sides of the molds for removal of the specimen from the molds. The concrete was placed in cylinders, beams, and cube mixing molds with compacting, vibrator and then their surface were finished using towel. The specimens used in this study were categorized as follows:

Cubes with 150 mm side length were used for determining compressive strength (Fc) for the investigated mixes at different ages. (7, 28 and 56 days). Cylinders with 100 mm diameter and 200 mm length were used for determining splitting strength by splitting method (Ft) at different ages at (7and 28 days). Beams with a square section of the 100 mm side length 500 mm total length and the clear span 400 mm were used to determine the flexural strength (Ff) at different ages (7 and 28 days).

2.4 curing of concrete

All the investigated specimens were kept in their molds and covered with plastic sheets for 24 hours in laboratory at temperature (25 ± 2) °C and 50% RH, then they removed from the molds and remarked with ID's then immerged in clean water at 20 °C until taken out for testing.

2.5 Test proceedings

Workability of concrete mixes were found out by slump cone test and Flow table test as shown in **Figs. (6)** ,and **(7)**, respectively. After casting specimen are allow to set for 24 hour after than removed from mold, specimens are immersed in a curing tank up to 28 days for curing. After the required curing time, the test specimens are removed from the curing tank and allow to dry surface moisture and then tests performed on the specimen.

Fig. (6) Slump cone test

Fig. (7) Flow table test

Compression strength test was performed on the cube specimens at the ages of 7, 28 and 56 days by using a digital hydraulic compressive strength-testing machine 2000 kN capacities, as shown in **Fig. (8)**.

Fig. (8) Compressive strength testing machine

3. Test results and discussion

(Table 8) shows the mix results of the concrete mixes containing different percentages of RAP. The results of the fresh concrete tests are shown in (**Table 7**).

3.1 Workability of Concrete

Slump test and flow test are methods to measure the workability and determine consistency of fresh concrete. It can be seen that the values of slump and flow percentage were decreased slightly with increasing RAP content.

3.2 Properties of hardened concrete

The test results regarding the average of compressive strength, splitting tensile strength, and flexural strength for different concrete mixtures are shown in (Table 8).

(Table 8): The test results of the concrete mixes containing RAP at different ages

Mix No	MIX ID	Compressive Strength (MPa)			Splitting strength (MPa)		Flexural strength (MPa)	
		7 D	28 D	56 D	7 D	28 D	7 D	28 D
1	R0-250	15	18	25	1.8	1.75	2	2.6
2	R15-250	13	16	18	1.3	1.75	3.5	3.8
3	R30-250	11	14	17	1.8	2	3.3	3.3
4	R0-300	20.15	23.5	25	1.9	2	3.78	4.5
5	R15-300	17.1	18.5	21.5	1.65	1.7	5.9	6
6	R30-300	13.4	15	20	1.15	1.6	2.6	3.9
7	R45-300	10.3	15	16	1.2	1.5	5.2	6
8	R60-300	10.6	14.4	18	1	1.3	2.2	3.11
9	R100-300	7.9	9.6	12	0.9	1	2.75	3.15
10	R0-350	24.5	36.7	40	1.9	2	5	5.05
11	R15-350	14.7	25	30	1.6	1.7	3	3.8
12	R30-350	14.8	21	25	1.2	1.9	3.8	4.1
13	R100-350	10.3	12.1	15	1.3	2.4	3.2	4
14	R15-300-F10	10.5	19.5	21.9	1.5	1.6	2.25	4
15	R15-300-F20	11.5	16	17.8	1.2	1.4	2.5	3
16	R30-300-F10	8.5	12.8	15	1.1	1.55	2.8	3
17	R30-300-F20	7.2	11	15	1	1.35	2.6	2.8
18	R30-300-F30	10.1	14.5	17	1	2	2.1	3.1
19	R30-350-F10	19.4	23.5	26	1.3	1.8	5.5	5.8
20	R30-350-F20	20	23.5	25.3	1.5	1.7	4	6
21	R30-350-F30	14.4	16	19.5	1.6	1.7	3	3.9
22	R30-300-F20-P0.5	12.6	16.2	22.3	1.85	2	3.5	3.7
23	R30-350-F20-P0.5	19.5	22	25.6	1.2	1.5	2.2	3.6
24	R30-350-F20-P1	16	20	27	1.5	2.4	2.8	3.7

3.2.1 Compressive strength

The influence of various factors such as using different cement content, replacing RAP by crushed limestone aggregates (natural aggregates), using of FA as a replacing by cement weight as well as the addition of polypropylene fibers (PP) with different volume fractions on the compressive strength of concrete mixes after 7, 28 and 56 days is tabulated in **(Table 8)** and plotted in **Fig. (9)**

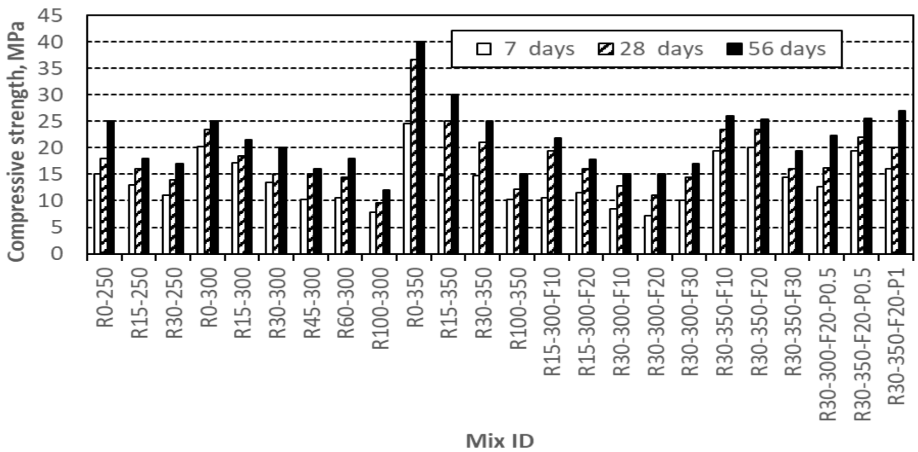


Fig. (9): Compressive strength test results of all concrete mixes at different ages

Effect of using different cement content

The effect of using different cement content at 250, 300, and 350 kg/m^3 was studied through mixes R0-250, R0-300 and R0-350. It is observed from **Fig. (10)** That the compressive strength of concrete mixes increased from 15 to 24.5 MPa after 7 days with increasing the cement content, and after 28 days, it increased from 18 to 36.7 MPa. While, after 56 days it increased from 25 to 40 MPa. The compressive strength improved after 28 days by 30.6 and 105.6% for mixes R0-300 and R0-350, respectively, over mix R0-250 (mix with cement content 250 kg/m^3).

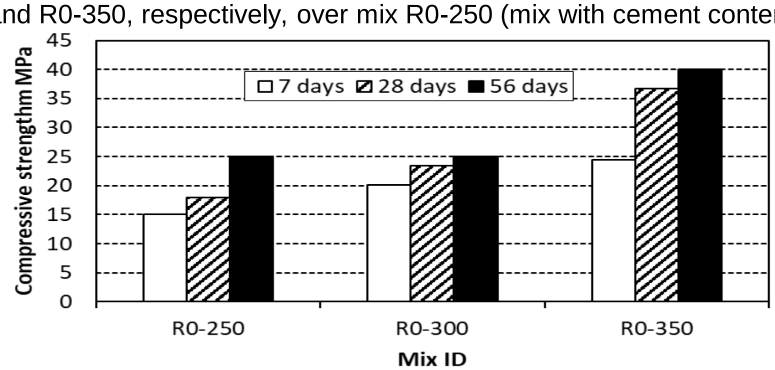


Fig. (10): Effect of using different cement content on compressive strength

Effect of using RAP

At cement content 250 kg/m^3, the effect of using RAP at 0, 15 and 30% replacement by crushed limestone was studied through mixes R0-250, R15-250 and R30-250, respectively, and depicted in **Fig. (11).** It is recorded that the compressive strength of concrete mixes decreased from 15 to

11 MPa after 7 days, and after 28 days, it decreased from 18 to 14 MPa. While, after 56 days it decreased from 25 to 17 MPa. The compressive strength decreased after 28 days by 11.11 and 28.6% for mixes R15-250 and R30-250, respectively compared with mix R0-250 (mix without RAP).

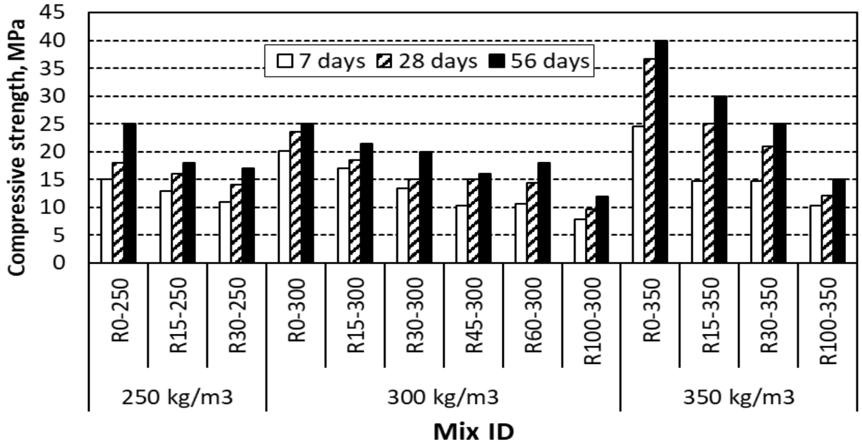


Fig. (11): Effect of using RAP with different cement content on compressive strength

At cement content 300 kg/m^3, the effect of using RAP at 0, 15, 30, 45, 60 and 100% replacement by crushed limestone was studied through mixes R0-300, R15-300, R30-300, R45-300, R60-300, and R100-300 respectively, and plotted in **Fig. (11).** It is noticed that the compressive strength of concrete mixes decreased from 20.15 to 7.9 MPa after 7 days, and after 28 days it decreased from 23.5 to 9.6 MPa. While, after 56 days it decreased from 25 to 12 MPa. The compressive strength decreased after 28 days by 21.3, 36.17, 36.17, 37.7 and 59.2% for mixes R15-300, R30-300, R45-300, R60-300 and R100-300, respectively compared with mix R0-300 (mix without RAP).

At cement content 350 kg/m^3, the effect of using RAP at 0, 15, 30 and 100% replacement by crushed lime stone was studied through mixes R0-350, R15-350, R30-350 and R100-350, respectively, and shown in **Fig.(11)** . It is recorded that the compressive strength of concrete mixes decreased from 24.5 to 10.3 MPa after 7 days, and after 28 days, it decreased from 36.7 to 12.1 MPa. While, after 56 days it decreased from 40 to 15 MPa. The compressive strength decreased after 28 days by 31.9, 42.8 and 67.1% for mixes R15-350, R30-350 and R100-350, respectively, respect to mix R0-350 (mix without RAP).

Effect of using FA

At using RAP 15%, the effect of using FA at 0, 10 and 20% replacement by cement weight was studied through mixes R15-300, R15-300-F10 and R15-300-F20, respectively, and shown in **Fig. (12).** the compressive strengths were (17.1, 10.5 and 11.5), (18.5, 19.5 and 16) and, (21.5, 21.9 and 17.8) at 7, 28, and 56 days, respectively. It is noticed that the compressive strength decreased with the increasing of FA replacement. The differences were (-38.6 and -32.7%), (+5.4 and -13.5%) and (+1.9 and -17.2%) for mixes (R15-300-F10 and R15-300-F20) at 7, 28 and 56 days, respectively compared with mix R15-300 (without FA).

At using RAP 30%, the effect of using FA at 0, 10, 20 and 30% replacement by cement weight was studied through mixes R30-300, R30-300-F10, R30-300-F20 and R15-300-F30 at cement

content 300 kg/m^3, and mixes R30-300, R30-300-F10, R30-300-F20 and R15-300-F30 at cement content 350 kg/m^3, respectively, as shown in **Fig.(12).**
At using RAP 30% and 300 kg/m^3 cement content, the compressive strengths were (13.4, 8.5, 7.2 and 10.1), (15, 12.8, 11 and 14.5) and, (20, 15, 15 and 17) at 7, 28, and 56 days, respectively for using FA at 0, 10, 20 and 30%. It is noticed that the compressive strengths decreased with the incorporating of FA by cement replacement compared with mix without FA at all ages. While, using RAP 30% at cement content 350 kg/m^3, the compressive strengths were increased up to 20% FA at all ages and then the compressive strengths were decreased at 30% FA.

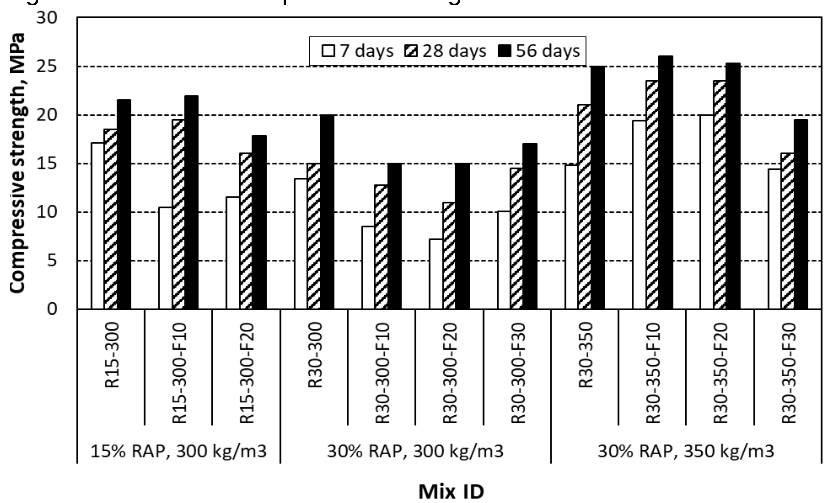


Fig. (12): Effect of using FA with different cement content and RAP on compressive strength

Effect of using polypropylene fibers

The effect of different volume fractions of PP fibers on compressive strength is depicted in **Fig. (13).** It can be observed from the figure that the compressive strength increased by using the volume fraction of PP fibers 0.5% at cement content 300 kg/m^3. The increases were 72, 47.2 and 48.6% for mix R30-300-F20-P0.5 over reference mix R30-300-F20 (without PP fibers) at 7, 28 and 56 days, respectively.
Whereas adding PP fibers with volume fractions of 0.5% and 1% at cement content 350 kg/m^3 caused slightly decrease in the compressive strengths at ages 7 and 28 days when compared to control mix without fibers. While, at 56 days an increase of 6.7% was observed for mix R30-350-F20-P1 over mix R30-350-F20 (without PP fibers).

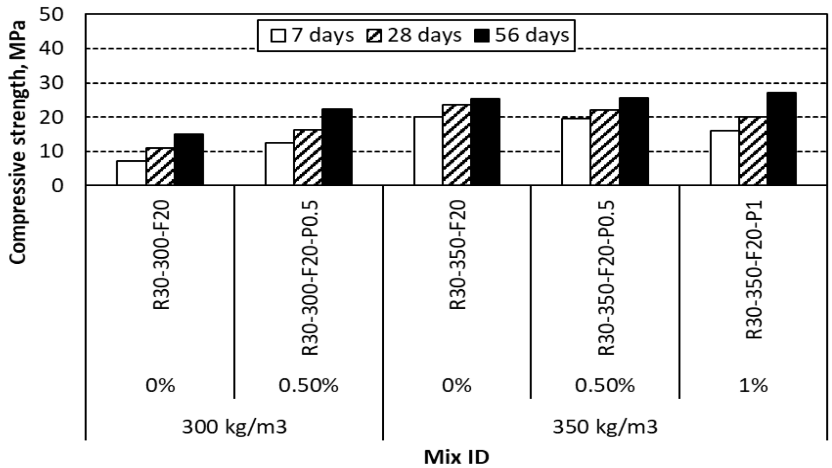


Fig. (13): Compressive strength test results of RAP mixes containing PP fibers and FA

Splitting tensile strength

The influence of various factors such as using different cement content, replacing RAP by crushed limestone aggregates (natural aggregates), using of FA as a replacing by cement weight as well as the addition of polypropylene fibers (PP) with different volume fractions on the splitting tensile strength of concrete mixes after 7 and 28 days is tabulated in **(Table 8)** and plotted in **Fig. (14)** .The splitting tensile test specimen is shown in **Fig. (15).**

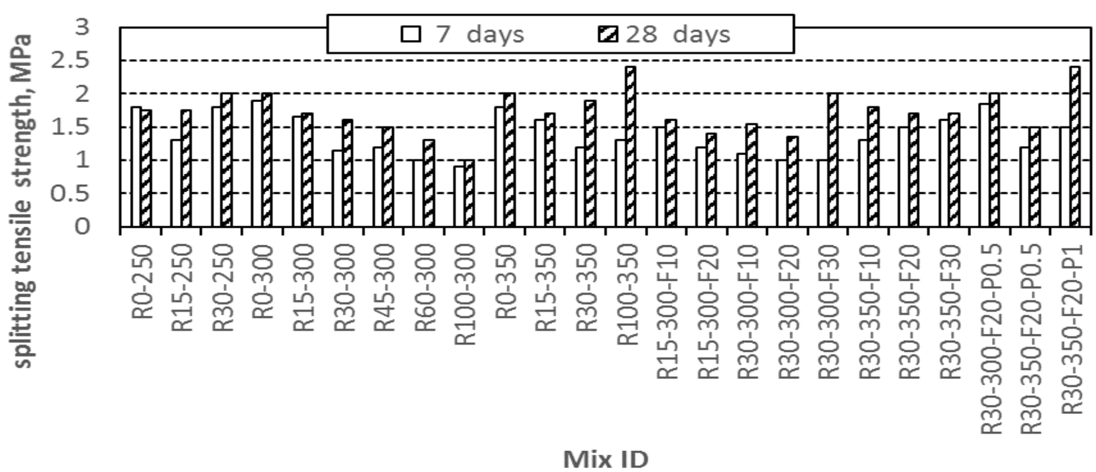


Fig. (14): splitting tensile strength test results of all concrete mixes at different ages

Fig. (15) Splitting tensile strength testing machine

Effect of using different cement content

The effect of using different cement content at 250, 300, and 350 kg/m^3 was studied through mixes R0-250, R0-300 and R0-350. It is observed from **Fig. (16).** that the Splitting tensile strength of concrete mixes increased from 1.8 to 1.9 MPa after 7 days with increasing the cement content, and after 28 days it increased from 1.75 to 2 MPa.

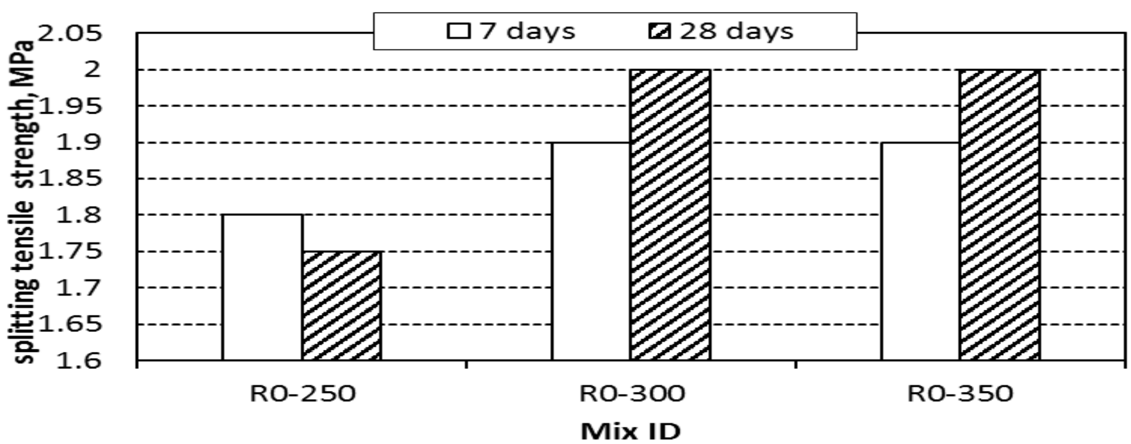


Fig. (16): Effect of using different cement content on splitting tensile strength

Effect of using FA

At using RAP 15%, the effect of using FA at 0, 10 and 20% replacement by cement weight was studied through mixes R15-300, R15-300-F10 and R15-300-F20, respectively, and shown in **Fig. (17).** the splitting tensile strength were (1.65, 1.5 and 1.2) and, (1.7, 1.6 and 1.4) at 7, and 28 days, respectively. It is noticed that the splitting tensile strength decreased with the increasing of FA replacement.

At using RAP 30%, the effect of using FA at 0, 10, 20 and 30% replacement by cement weight was studied through mixes R30-300, R30-300-F10, R30-300-F20 and R15-300-F30 at cement content 300 kg/m^3, and mixes R30-300, R30-300-F10, R30-300-F20 and R15-300-F30 at cement content 350 kg/m^3, respectively, as shown in **Fig.(17).**

At using RAP 30% and 300 kg/m^3 cement content, the splitting tensile strength were (1.15, 1.1, 1 and 1)and,(1.6, 1.55, 1.35 and 2) at 7and 28 days, respectively for using FA at 0, 10, 20 and 30%. It is noticed that splitting tensile strength decreased with the incorporating of FA by cement replacement compared with mix without FA. While, using RAP 30% at cement content 350 kg/m^3, splitting tensile strength were increased up to 10% FA and then the splitting tensile strength were decreased at 30% FA.

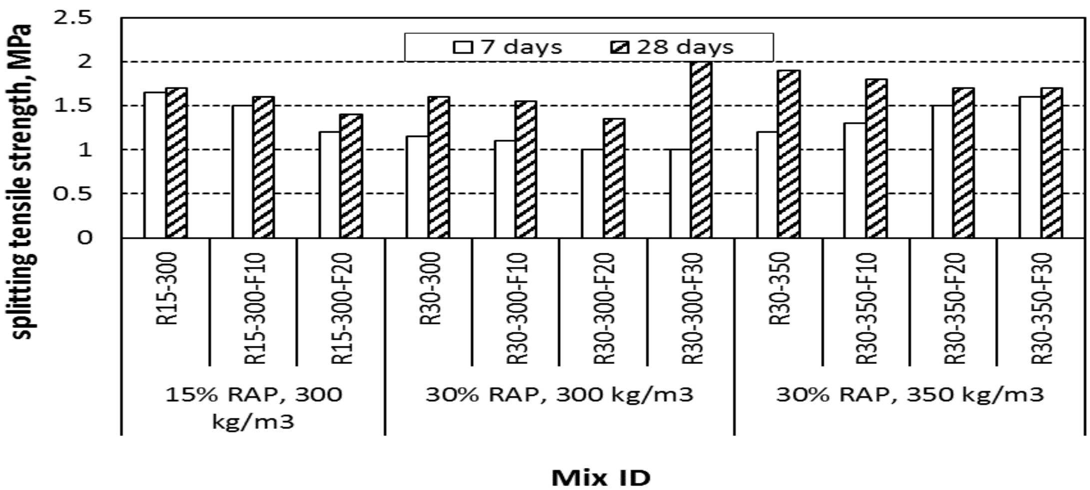


Fig. (17): Effect of using FA with different cement content and RAP on splitting tensile strength

Flexural strength

The influence of various factors such as using different cement content, replacing RAP by crushed limestone aggregates (natural aggregates), using of FA as a replacing by cement weight as well as the addition of polypropylene fibers (PP) with different volume fractions on the flexural strength of concrete mixes after 7 and 28 days is tabulated in **(Table 8)** and plotted in **Fig. (18)**. the tests were performed using the Universal testing machine with 300 kN total capacity as shown in **Fig. (19).**

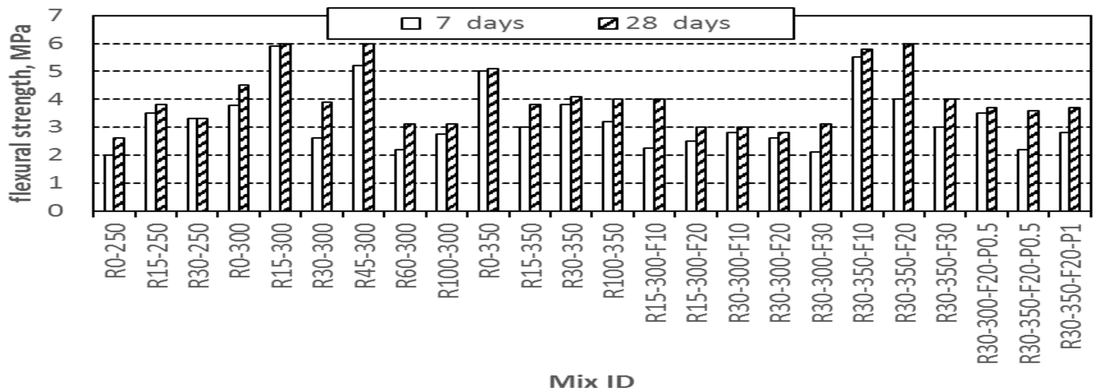


Fig. (18): flexural strength test results of all concrete mixes at different ages

Fig. (19): Universal testing machine (300 KN) for testing specimen under flexural

Effect of using different cement content

The effect of using different cement content at 250, 300, and 350 kg/m^3 was studied through mixes R0-250, R0-300 and R0-350. It is observed from **Fig. (20)** That the flexural strength of concrete mixes increased from 2 to 5 MPa after 7 days with increasing the cement content, and after 28 days it increased from 2.6 to 5.05 MPa.

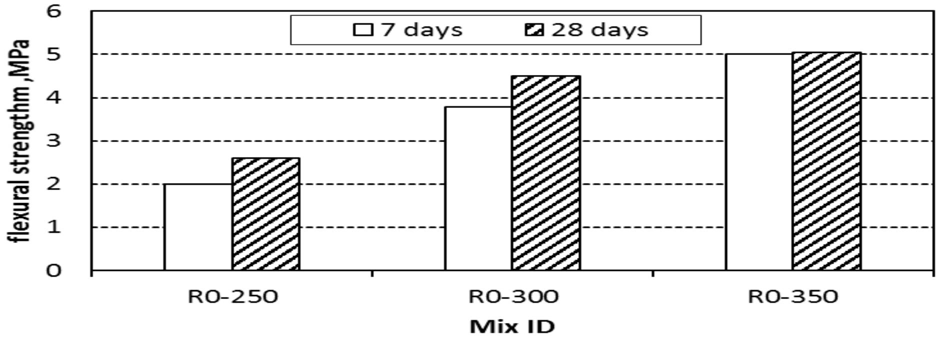


Fig. (20): Effect of using different cement content on flexural strength

Effect of using RAP

At cement content 250 kg/m^3, the effect of using RAP at 0, 15 and 30% replacement by crushed lime stone was studied through mixes R0-250, R15-250 and R30-250, respectively, and depicted in **Fig. (21)**. It is recorded that the flexural strength of concrete mixes increased from 2 to 3.3 MPa after 7 days, and after 28 days it increased from 2.6 to 3.3 MPa.

At cement content 300 kg/m3, the effect of using RAP at 0, 15, 30, 45, 60 and 100% replacement by crushed lime stone was studied through mixes R0-300, R15-300, R30-300, R45-300, R60-300, and R100-300 respectively, and plotted in **Fig.(21)** . It is noticed that the flexural strength of concrete mixes decreased from 3.78 to 2.75 MPa after 7 days, and after 28 days, it decreased from 4.5 to 3.15 MPa.

At cement content 350 kg/m^3, the effect of using RAP at 0, 15, 30 and 100% replacement by crushed lime stone was studied through mixes R0-350, R15-350, R30-350 and R100-350, respectively, and shown in **Fig.(21)** . It is recorded that the flexural strength of concrete mixes decreased from 5 to 3.2 MPa after 7 days, and after 28 days it decreased from 5.05 to 4 MPa.

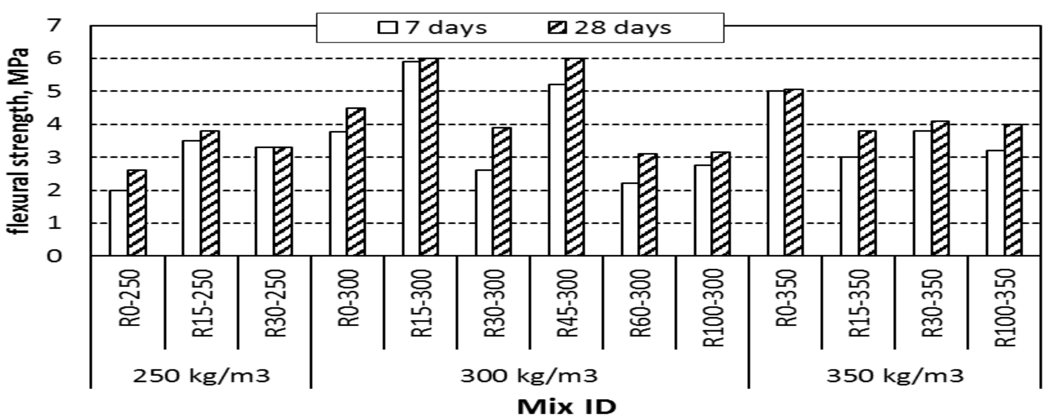


Fig. (21): Effect of using RAP with different cement content on flexural Strength

4. Conclusions

From the present study carried out to evaluate the performance of recycled asphalt pavement (RAP) as coarse aggregate in concrete, the following main conclusions can be drawn:

- RAP aggregate has lower specific gravity and water absorption than the natural aggregate.
- RAP concrete mixes did not pose any difficulties in terms of casting or placement. However, totally replacing the natural aggregate with a RAP one significantly reduces the workability of concrete.
- RAP concrete is less workable than the corresponding concrete produced with natural gravel aggregate. Consequently, concrete with RAP requires more water or superplasticizer to achieve the same workability as conventional concrete.
- The results from this study indicated that RAP could be incorporated into Portland cement concrete without any modification to the conventional equipment or procedures.
- The compressive, flexural and splitting tensile strengths of concrete produced with RAP as coarse aggregate were found to be lower than those made from natural aggregate.
- The strength of RAP concrete is dependent on the bond strength of the asphalt-mortar coating on the aggregate.
- The maximum compressive strength of concrete that can be produced using RAP as coarse aggregate is approximately 25 MPa with 350 kg/m^3 cement content.
- On the basis of this investigation, it is apparent that recycling of waste asphalt pavement for concrete aggregate is feasible and may become a viable and routine process for the generation of aggregate for middle and low strength concrete.

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