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Effect of silica fume on mechanical properties of concrete containing recycled asphalt pavement

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Abstract. This paper presents the results of a study that investigated the improvement of the mechanical properties of coarse and fine recycled asphalt pavement (RAP) produced by adding silica fume (SF) with contents of 5%, 10%, and 15% by total weight of the cement. The coarse and fine natural aggregate (NA) were replaced by RAP with replacement ratio of 20%, 40% and 60% by the total weight of NA. In addition, SF was added to NA concrete mixes as a control for comparison. Twenty eight mixes were produced and tested for compressive, splitting tensile and flexural strength at the age of 28 days. The results show that the mechanical properties decrease with as the content of RAP increases. And the decrease in the compressive strength was more in the fine RAP mixes compared to the coarse RAP mixes, while the decrease in the splitting tensile and flexural strength was almost the same in both mixes. Furthermore, using SF enhances the mechanical properties of RAP mixes where the optimum content of SF was found to be 10%, and the mechanical properties enhancement of coarse RAP were better than fine RAP mixes. Accordingly, the RAP has the potential to be used in the concrete pavements or in other low strength construction applications in order to reduce the negative impact of RAP on the environment and human health.

Keywords: recycled asphalt pavement; silica fume; compressive strength; flexural strength; splitting tensile strength

1. Introduction

The use of recycled materials has been increasing in the last decade to save non-renewable resources. For example natural aggregates (NA) in concrete were replaced by recycled aggregates (Saravanakumar and Dhinakaran 2013, Shah *et al*. 2013, Pedro *et al*. 2014, Yildirim *et al*. 2015, Seo and Choi 2014, Pedro *et al*. 2015, Bravo *et al*. 2015, Katkhuda and Shatarat 2016) and waste rubber (Youssf *et al*. 2016, Mansour and Farshad 2016, Bilondi *et al*. 2016, and Abendeh *et al*. 2016). Other potential recycled material is Reclaimed or Recycled Asphalt Pavement (RAP). RAP is generated from milling old asphalt pavements that is removed for resurfacing or reconstruction, or produced from removing part of asphalt pavements due to maintenance or excavations to access buried utilities. The United State of America highway industry produces over 100 million tons every year (Huang *et al*. 2005), while there are no specific records available in the developing countries.

The RAP contains coarse and fine aggregates that are coated with aged asphalt cement. In the developing countries there are no sufficient financial resources to get rid of RAP so it is usually stockpiled and disregarded. While in the well developed countries, millions of dollars are paid every year to transport and bury RAP in landfill areas. Stockpiling or landfilling could have a very negative impact on environment and human health due to air and ground water pollutions. Recently RAP has been used: (1) in hot plant mixes to be used again in asphalt paving; (2) in concrete pavement in many countries such as United State of America, Canada, France and Austria (Tompkins *et al*. 2009); (3) as granular base and sub-base; (4) in embankment or fill; and (5) in non-structural concrete such as road barriers.

The effect of using RAP as aggregate in concrete was studied by many scholars in the literature (Delwar *et al*. 1997, Hassan *et al*. 2000, Topcu and Isikdag 2009, Mathias *et al*. 2009, Han *et al*. 2012, Jeevan *et al*. 2016, Bermel 2011, Settari *et al*. 2015, Yang *et al*. 2015, Tia *et al*. 2012). Hung *et al*. (2005) manufactured RAP material in the laboratory to study the effect of using RAP on mechanical strengths, toughness, and failure behavior of concrete. The authors used 100% coarse RAP with fine NA, 100% fine RAP with coarse NA, and 100% coarse and fine RAP mixes. The results showed that the compressive and splitting tensile strengths of RAP mixes decreased and the toughness increased compared to NA mixes. The authors concluded that using fine RAP had more negative effect than coarse RAP. Hossiney (2008) evaluated four concrete mixes with coarse and fine RAP replacements at 0, 10, 20, and 40% and used the tested material properties to create a finite element model to assess their behavior as a pavement under typical roadway situations. The test results showed that slump, unit weight, shrinkage and mechanical strengths

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decreased when the contents of RAP increased, while the coefficient of thermal expansion was not affected. The finite element model results pointed out that the maximum stresses in pavement decreased with the use of RAP suggesting that RAP could extend the life performance of concrete pavements. Al-Oraimi *et al*. (2009) replaced the coarse aggregates with coarse RAP at 0, 25, 50, 75, and 100% and for water-to-cement (w/c) ratios of 0.45 and 0.5. The authors reported that slump, unit weight, modulus of elasticity and compressive and flexural strengths decreased as the percentage of RAP increased, while surface permeability showed no significant changes. Okafor (2010) compared the 100% coarse RAP to NA gravel. The results showed that the RAP was more durable because it absorbed more impact loads, while the compressive and flexural strengths decreased compared to NA. Also, it was noted that the failure in compression for RAP occurred from the crushing between the mortar interface and aggregate while in NA the crushing was in the aggregate itself.

To map the laboratory results with real life applications, Berry *et al*. (2015) evaluated the field performance of two concrete mixes; High RAP (HR) mix with 50% of fine NA and 100% of coarse NA replaced by RAP, and High Strength (HS) mix with 25% of fine NA and 50% of coarse NA replaced by RAP. The field application was conducted through constructing two RAP concrete test slabs that were placed on a roadway. The performance of the slabs was monitored for two years through strain gauges and site visits. There was no cracking observed on these slabs and the strain gauges readings showed that the slabs did not experience excessive shrinkage or curling. However, the HR slab had slightly more shrinkage and curling compared to HS slab. Wang (2016) studied the long term performance of asphalt concrete overlays using RAP mixtures. Data from eighteen sites were evaluated using a program. The selected indicators were longitudinal, transverse and fatigue cracking, roughness and rutting. The analysis showed that the performance of RAP mixtures were undesirable for relatively thin overlay and minimal pre-overlay treatment while favorable specially in roughness and rutting for relatively thick overlay and intensive pre-overlay treatments.

Lately many researchers studied the enhancement in properties of concrete containing RAP by adding different materials such as: (1) high-range water reducing agent (HRWRA) (Huang *et al*. 2006); (2) ground granulated blast furnace slag (GGBS) (Erdem and Blankson 2014); (3) rice husk ash (RHA) (Modarres and Hosseini 2014); (4) fly ash (Saride *et al*. 2016, Brand and Roesler 2015, Solanki and Dash 2015); and (4) steel fibers (Bilodeau *et al*. 2011). Unfortunately, the results of those studies revealed that adding some materials enhanced certain part of properties only while others did not show any improvements at all. Based on this extensive literature review, it is obvious that there is a great need to enhance the mechanical properties of concrete that contains RAP.

Silica fume (SF) was used broadly by many researchers in the literature to improve the properties of normal, lightweight, and self-compacted concrete (Shaikh *et al*. 2015, Prusty *et al*. 2015, Mastali and Dalvand 2016, Zhang *et al*. 2016, Nili and Ehsani 2015, Youm *et al*. 2016, Wongkeo *et al*. 2014). But there is a lack of studies on using SF in RAP mixes. Therefore, the objective of the study of this paper is to investigate the mechanical strengths of concrete containing SF at various ratios (0-5-10-15%) with replacing coarse and fine NA by RAP. For this purpose, the coarse and fine NA were replaced by RAP with replacement ratio of 20%, 40%, and 60%. Twenty eight mixes were produced and tested for compressive, splitting tensile and flexural strengths at the age of 28 days.

Table 1 Chemical composition of Ordinary Portland cement and SF

Chemical Composition	Cement	SF
SiO_2 (%)	21.5	> 85
Al_2O_3 (%)	5.8	---
Fe_2O_3 (%)	3.4	---
CaO (%)	63.5	< 1
MgO (%)	1.1	---
SO_3 (%)	2.8	< 2
Specific gravity (g/cm^3)	3.2	0.55-0.7
Structure of material	---	Densified silica fume
Chloride content (%)	---	< 0.1

2. Experimental program

2.1 Materials

2.1.1 Cement and Silica Fume

Type I Ordinary Portland cement and SF were used in this study. The cement conforms to the “Standard Specification for Portland Cement” (ASTM C150-16) and the SF complies with the “Standard Specification for Silica Fume Used in Cementitious Mixtures” (ASTM C1240-15). The chemical compositions of cement and SF are shown in Table 1. The specific gravity of the cement was 3.20 g/cm^3, while the SF was powder grey in color with a specific gravity of 0.55-0.7 g/cm^3.

2.1.2 Aggregates

The coarse NA used in this study was crushed limestone from local sources with a maximum size of 19 mm. The fine NA was natural sand having a calculated fineness modulus of 1.73. The RAP was prepared by crushing waste asphalt pavement rubbles that was obtained from the waste of a road reconstruction site. The rubbles were crushed and then separated by sieving on 5 mm sieve size into coarse and fine RAP. Fig. 1 shows a photo of coarse and fine RAP that was used in this study where it can be shown that the aggregates were coated with aged asphalt cement. The coarse and fine NA and RAP were graded separately and the gradation curves are shown in Fig. 2. The gradation of NA and RAP aggregates was very similar which ensured that the effects of the gradation changes on the mechanical properties of all the mixes were kept to a minimum. The specific gravity and absorption of aggregates were measured using ASTM C127-15 and the hardness of the

Fig. 1 Coarse and Fine RAP

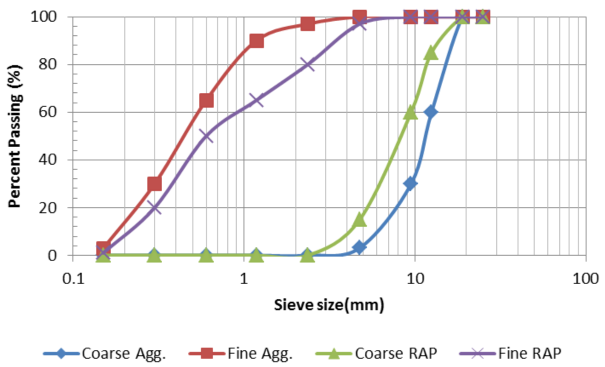


Fig. 2 Grain size distribution for NA and RAP

Table 2 Properties of NA and RAP

Property	Coarse	Fine NA	Coarse	Fine RAP
Bulk specific gravity	2.55	2.62	2.43	2.36
Bulk specific gravity (Dry)	2.51	2.54	2.37	2.31
Water absorption (%)	1.95	1.63	1.80	1.55
Los Angeles (LA) abrasion (%)	22	---	33	---

aggregates was obtained using ASTM C131-14. Table 2 shows the properties of the coarse and fine NA and RAP. The water absorption of coarse NA, fine NA, coarse RAP, and fine RAP was 1.95, 1.63, 1.8, and 1.55, respectively. The Los Angeles abrasion value for coarse RAP was higher than that of coarse NA.

2.2 Mix proportions

Twenty eight mixes were designed for this study using a constant water-to-cement (w/c) ratio of 0.5 for all the mixes to achieve a compressive strength of 25 MPa after 28 days. Table 3 shows the mix proportions. The mixes were divided by aggregate into three groups: (1) NA (control), (2) coarse RAP, and (3) fine RAP. The coarse and fine NA were replaced by coarse and fine RAP, respectively with replacement ratio of 20%, 40%, and 60% by the total weight of specified NA . Also, SF had replaced the cement with ratios of 5%, 10%, and 15% by the total weight of cement to study the effect of using SF on concrete mixes with RAP. The NA and RAP were air dried before used in the mixing.

The codified names of the mixes are presented in Table 3. The names consist of three parts. The first part indicates the type of the mix: NA for natural aggregates, RAP for recycled asphalt pavement. The second part indicates the type of RAP used and replacement percentage: C-coarse, F-fine, 20-20%, 40-40% and 60-60% by weight of specified aggregate. And the third part indicates the percent of content of SF by the total weight of cement: 0-0%, 5-5%, 10-10%, and 15-15%.

2.3 Specimen preparation, curing, size and testing

All concrete mixes were mixed using a mechanical mixer and applying standard compaction. The specimens were cured in the laboratory in a water bath at a temperature of 20^{o}C until the day of testing. All the mixes were tested for workability, compressive, splitting tensile and flexural strength at 28 days. For compressive strength, standard cubes of 100 mm side length were used. For splitting tensile test, standard cylinders of 150 diameters×300 mm were adopted, and for flexural test, standard prisms of 100×100×500 mm were used.

The slump of the specimens was measured using the slump test ASTM C143. The compressive, splitting tensile and flexural strengths were measured in accordance with ASTM standards. For each mix, three specimens were tested and the average of three values was reported the strength of the concrete.

3. Results and discussion

3.1 Properties of fresh concrete

The results of the slump for twenty eight mixes used in this study are shown in Table 4. It can be seen that the slump decreased when the coarse and fine RAP contents increased, and the workability of fine RAP was lower compared to coarse RAP mixes. Furthermore, the SF had a great influence on decreasing the workability due to its high specific area compared with cement. The lowest slump was for RAP-F60-15 mix that was measured to be 48 mm. In general, these results were similar to the results reported by Tia *et al*. (2012), Huang *et al*. (2006). It is worth to mention here that the concrete made with coarse and fine RAP and SF could be mixed using the same equipment and method for normal concrete.

3.2 Properties of hardened concrete

3.2.1 Compressive strength

The effect of RAP and SF contents on the compressive strength after 28 days is shown in Table 4 and Fig. 3. It can be realized that there was a reduction in the compressive strength with the increase of the content of coarse and fine RAP without using SF and compared to the control mix NA-0. The tendency of the reduction in compressive strength with RAP replacement ratio is shown in Fig. 4. The reduction in strength for coarse RAP with replacement ratio of 20%, 40% and 60% was 15.8%, 25.5%, and 40.5%, respectively. While the reduction in strength for fine RAP with replacement ratio of 20%, 40% and 60% was 24.3%,

Table 3 Details of mix proportions

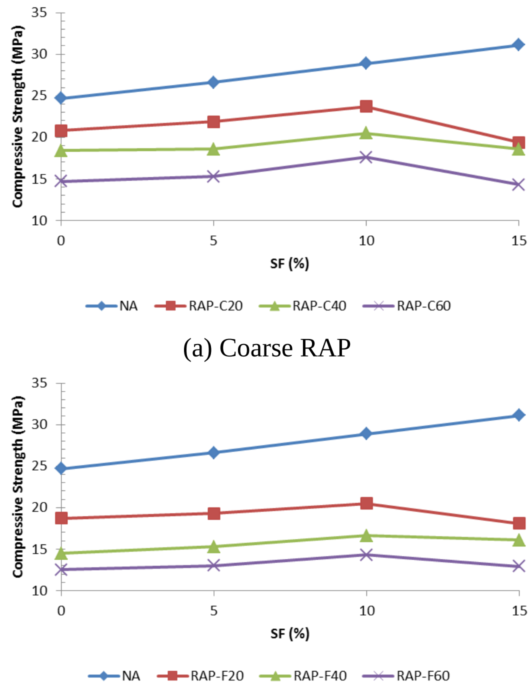
Mix type	Cement (kg/m^3)	Water (kg/m^3)	Silica Fume (kg/m^3)	Coarse NA (kg/m^3)	Fine NA (kg/m^3)	Coarse RAP (kg/m^3)	Fine RAP (kg/m^3)
NA-0	396	198	0	1160	780	0	0
NA-5	376.2	198	19.8	1160	780	0	0
NA-10	356.4	198	39.6	1160	780	0	0
NA-15	336.6	198	59.4	1160	780	0	0
RAP-C20-0	396	198	0	928	780	232	0
RAP-C20-5	376.2	198	19.8	928	780	232	0
RAP-C20-10	356.4	198	39.6	928	780	232	0
RAP-C20-15	336.6	198	59.4	928	780	232	0
RAP-C40-0	396	198	0	696	780	464	0
RAP-C40-5	376.2	198	19.8	696	780	464	0
RAP-C40-10	356.4	198	39.6	696	780	464	0
RAP-C40-15	336.6	198	59.4	696	780	464	0
RAP-C60-0	396	198	0	464	780	696	0
RAP-C60-5	376.2	198	19.8	464	780	696	0
RAP-C60-10	356.4	198	39.6	464	780	696	0
RAP-C60-15	336.6	198	59.4	464	780	696	0
RAP-F20-0	396	198	0	1160	624	0	156
RAP-F20-5	376.2	198	19.8	1160	624	0	156
RAP-F20-10	356.4	198	39.6	1160	624	0	156
RAP-F20-15	336.6	198	59.4	1160	624	0	156
RAP-F40-0	396	198	0	1160	468	0	312
RAP-F40-5	376.2	198	19.8	1160	468	0	312
RAP-F40-10	356.4	198	39.6	1160	468	0	312
RAP-F40-15	336.6	198	59.4	1160	468	0	312
RAP-F60-0	396	198	0	1160	312	0	486
RAP-F60-5	376.2	198	19.8	1160	312	0	486
RAP-F60-10	356.4	198	39.6	1160	312	0	486
RAP-F60-15	336.6	198	59.4	1160	312	0	486

41.3%, and 49.4%, respectively.

It can be seen that the reduction in compressive strength for fine RAP mixes were more than coarse RAP mixes. These results were almost similar to the results obtained by Bermel (2011), Hung *et al*. (2005). The reduction in compressive strength is due to: (1) the weak bonding between the asphalt film coating the aggregate and the new cement matrix; and (2) the surface cracking in the asphalt aggregate within the concrete matrix because of aging.

Using SF increased the compressive strength for NA (control) mixes as expected, where the strength increased with the increase in the content of SF as shown in Fig. 3. Furthermore, using SF contents of 5% and 10% enhanced the compressive strength for coarse and fine RAP mixes but 15% content did not show any improvement. The change in strength with SF content is shown in Fig. 5. It can be seen that the maximum gain in strength for coarse RAP mixes was 18.9% for RAP-C60-10 mix while the maximum loose in strength was 6.73% for RAP-C20-15. And the maximum gain and loose in strength for fine RAP mixes was 13.9% for RAP-F60-10 and 3.21% for RAP-F20-15, respectively.

Accordingly, it can be indicated that using SF increased the compressive strength of coarse and fine RAP mixes and the optimum SF content was reported to be 10%.



(b) Fine RAP

Fig. 3 Compressive strength after 28 days

Table 4 Results of concrete mixes at 28 days

Mix type	Slump (mm)	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
NA-0	181	24.7	2.92	3.03
NA-5	172	26.6	3.10	3.28
NA-10	165	28.9	3.43	3.49
NA-15	157	31.1	3.86	3.65
RAP-C20-0	193	20.8	2.65	2.60
RAP-C20-5	184	21.9	2.51	2.85
RAP-C20-10	171	23.7	3.00	3.10
RAP-C20-15	159	19.4	2.60	2.62
RAP-C40-0	154	18.4	2.10	2.20
RAP-C40-5	146	18.6	2.30	2.40
RAP-C40-10	138	20.5	2.55	2.75
RAP-C40-15	121	18.6	2.23	2.32
RAP-C60-0	126	14.7	1.90	1.90
RAP-C60-5	111	15.3	2.00	1.80
RAP-C60-10	103	17.6	2.20	1.90
RAP-C60-15	94	14.3	1.70	2.10
RAP-F20-0	156	18.7	2.43	2.55
RAP-F20-5	142	19.3	2.50	2.80
RAP-F20-10	137	20.5	2.72	3.00
RAP-F20-15	130	18.1	2.11	2.59
RAP-F40-0	124	14.5	2.1	2.26
RAP-F40-5	111	15.3	2.3	2.42
RAP-F40-10	97	16.6	2.45	2.77
RAP-F40-15	82	16.1	2.20	2.10
RAP-F60-0	94	12.5	1.87	1.79
RAP-F60-5	79	13	1.70	1.69
RAP-F60-10	62	14.3	2.10	2.10
RAP-F60-15	48	12.9	1.60	1.65

Unfortunately, those increases in strength did not reach the compressive strength of the control mix NA-0 which was measured to be 24.7 MPa. The compressive strength for the maximum gained strength mixes were 23.7 and 20.5 MPa for RAP-C20-10 and RAP-F20-10, respectively. Furthermore, the increase in the compressive strength for coarse RAP was better than that of fine RAP due to the fact that the loose bonding between the fine RAP particles might cause less strength gain. Also, the influence of SF to enhance the compressive strength in the RAP mixes was lower than NA mixes. This can be attributed to the fact that the SF enhances the interfacial transition zone (ITZ) in normal concrete mixes better than RAP mixes because of organic (asphalt) and inorganic (aggregate and cement) phases.

3.2.2 Splitting tensile strength

The effect of RAP and SF contents on the splitting tensile strength after 28 days is shown in Table 4 and Fig. 6. The test results showed that there was a reduction in the splitting tensile strength with the increase of the content of coarse and fine RAP without using SF. This decrease in

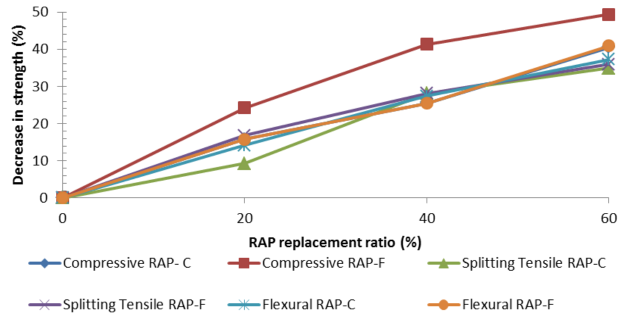


Fig. 4 Comparison of reduction rate in strength

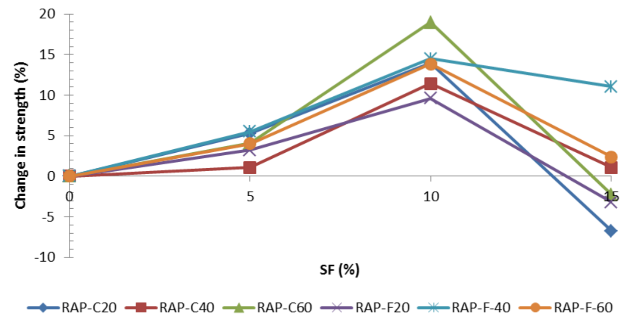
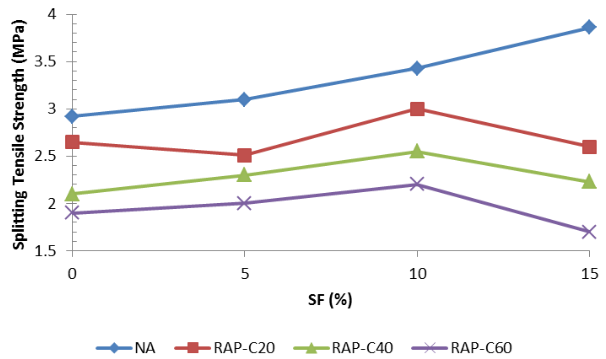
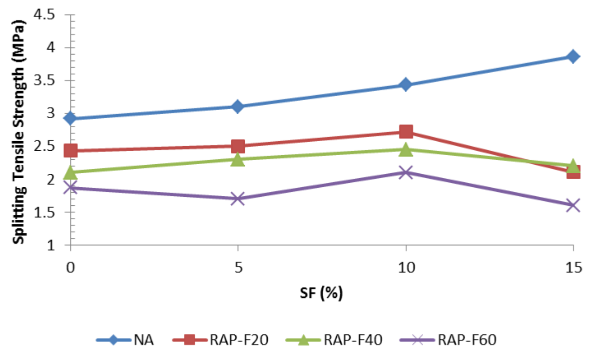


Fig. 5 Change in compressive strength with SF



(a) Coarse RAP



(b) Fine RAP

Fig. 6 Splitting tensile strength after 28 days

strength was slightly lower than the case in the compressive strength. The trend of reduction in the splitting tensile strength with RAP replacement ratio is shown in Fig. 4. The reduction in strength for coarse RAP with replacement ratio

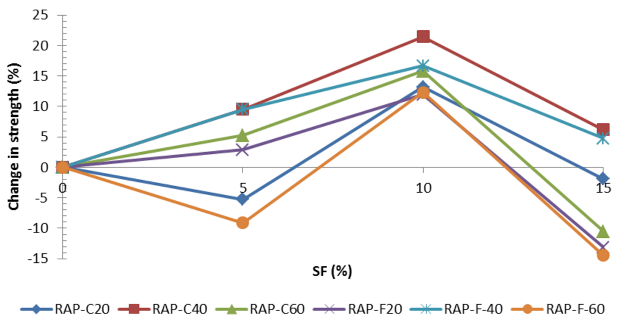
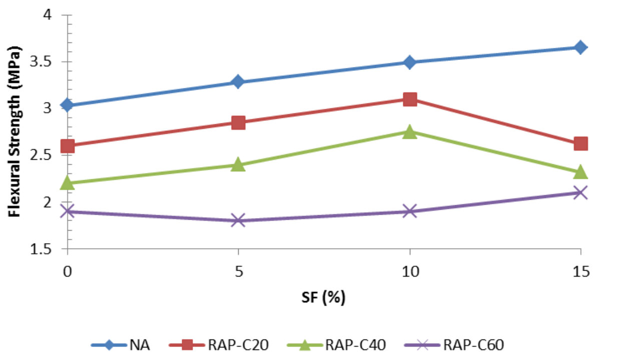
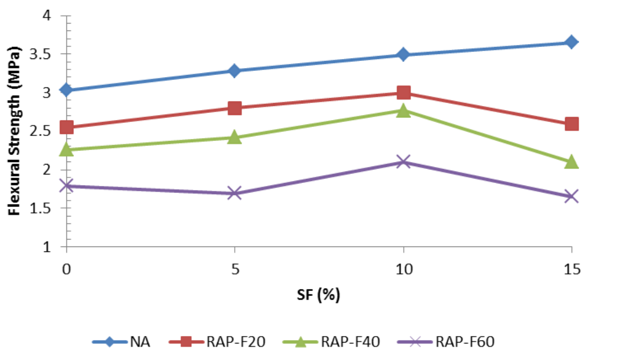


Fig. 7 Change in splitting tensile strength with SF



(a) Coarse RAP



(b) Fine RAP

Fig. 8 Flexural strength after 28 days

of 20%, 40% and 60% was 9.2%, 28.1%, and 34.9%, respectively. While the reduction in strength for fine RAP with replacement ratio of 20%, 40% and 60% was 16.8%, 28.1%, and 35.9%, respectively. The reduction in the splitting tensile strength for coarse and fine RAP mixes was almost the same.

Using SF increased the splitting tensile strength for NA (control) mixes and the rate of the increase was better than that of the compressive strength. As the case in the compressive strength, the coarse and fine RAP mixes using SF contents of 5% and 10% improved the splitting tensile strength but 15% content showed lose in strength.

The change in the strength with SF content is shown in Fig. 7 where the increase in the splitting tensile strength for coarse RAP was better than that of fine RAP. It can be realized that the maximum gain in strength for coarse RAP mixes was 21.5% for RAP-C40-10 mix while the maximum

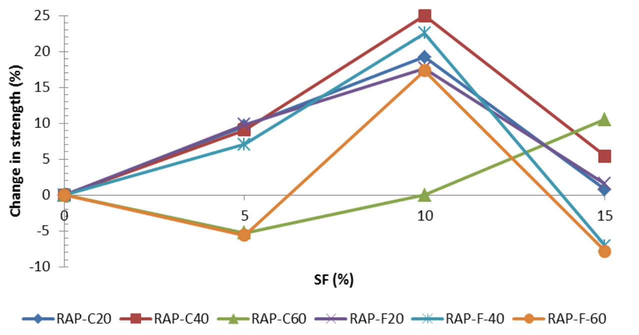


Fig. 9 Change in flexural strength with SF

loose in strength was 10.6% for RAP-C60-15. And the maximum gain and loose in strength for fine RAP mixes was 16.7% for RAP-F40-10 and 14.4% for RAP-F60-15, respectively.

It can be seen that the optimum SF content was 10% and the increase in splitting tensile strength did not reach the strength of the control mix NA-0 which was measured to be 2.92 MPa except for RAP-C20-10 mix that was measured to be 3.0 MPa.

3.2.3 Flexural strength

The effect of RAP and SF contents on the flexural strength after 28 days is shown in Table 4 and Fig. 8. As reported in the compressive and splitting tensile strength, there was a reduction in the flexural strength with increase of the content of coarse and fine RAP without using SF. The tendency of reduction in the flexural strength with RAP replacement ratio is shown in Fig. 4. The reduction in strength for coarse RAP with replacement ratio of 20%, 40% and 60% was 14.2%, 27.3%, and 37.3%, respectively. While the reduction in strength for fine RAP with replacement ratio of 20%, 40% and 60% was 15.8%, 25.4%, and 40.9%, respectively. The reductions in the flexural strength for coarse and fine RAP mixes were almost the same.

Using SF increased the flexural strength for NA (control) mixes but the rate of the increase was lower than that of the compressive and splitting tensile strength. As the case in the compressive and splitting tensile strength, the coarse and fine RAP mixes using SF contents of 5% and 10% improved the splitting tensile strength but 15% content showed lose in the strength except for RAP-C60-15 mix. The change in the strength with SF content is shown in Fig. 9 where the increase in the flexural strength for coarse RAP was better than that of fine RAP. It can be realized that the maximum gain in strength for coarse RAP mixes was 25% for RAP-C40-10 mix while the maximum loose in strength was 5.3% for RAP-C60-15. And the maximum gain and loose in strength for fine RAP mixes was 22.6% for RAP-F40-10 and 7.8% for RAP-F60-15, respectively.

It can be seen that the optimum SF content was 10% and the increase in flexural strength did not reach the strength of the control mix NA-0 which was measured to be 3.03 MPa except for RAP-C20-10 mix that was measured to be 3.1 MPa.

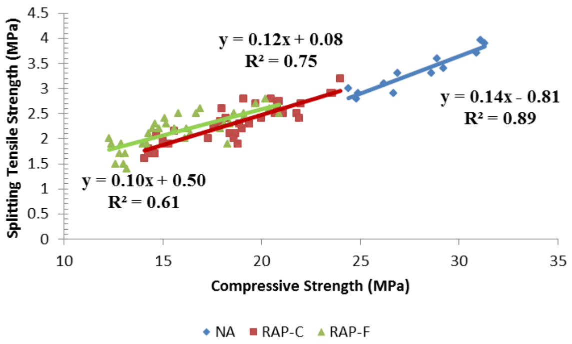


Fig. 10 Regression between splitting tensile strength and compressive strength for NA, coarse RAP, and fine RAP

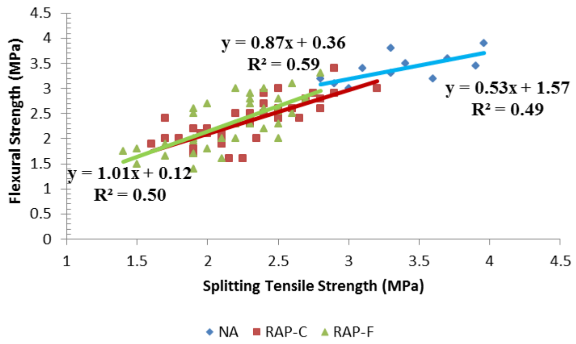


Fig. 11 Regression between flexural strength and splitting tensile strength for NA, coarse RAP, and fine RAP

3.3 Correlation between compressive strength and tensile splitting strength

The relationships between the compressive strength and the splitting tensile strength for NA, coarse RAP, and fine RAP mixes are shown in Fig. 10. The correlation coefficient between the compressive strength and the splitting tensile strength for NA, coarse RAP, and fine RAP was 0.89, 0.75, and 0.61, respectively as shown in Fig. 10. The low correlation coefficient for fine RAP in this study was not due to the high scatter in the strength results of the specimens but rather the different percentages of SF content in the mixes (ranging from 0% to 15%) as well as the positive effect of the SF content in enhancing the splitting tensile strength more than the concrete compressive strength.

3.4 Correlation between splitting tensile strength and flexural strength

The relationships between the splitting tensile strength and the flexural strength for NA, coarse RAP, and fine RAP mixes are shown in Fig. 11. The correlation coefficient between the splitting tensile strength and the flexural strength for NA, coarse RAP, and fine RAP was 0.49, 0.59, and 0.5, respectively. The correlation coefficient for all mixes was almost similar but lower than the correlation coefficient between the compressive strength and the splitting tensile strength. This could be due to the positive effect of the SF content in enhancing the flexural strength more than the splitting tensile strength.

4. Conclusions

This paper presented a study addressing the effects of SF on the mechanical properties of RAP. Based on the test results, the following conclusions were drawn:

• The workability of RAP decreased when the content of RAP and SF increased, and the workability of fine RAP was lower compared to coarse RAP mixes.

• In general, the mechanical properties of RAP decreased as the content of RAP increased.

• The compressive strength decreased more for fine RAP mixes compared to coarse RAP mixes, while the decrease in the splitting tensile and flexural strength was almost the same in both mixes.

• The SF enhanced the mechanical properties for RAP mixes and the optimum content of SF was reported to be 10%.

• The SF enhanced the mechanical properties of coarse RAP better than fine RAP mixes.

Accordingly, it is recommended that the RAP can be used in the concrete pavements or in other low strength construction applications in order to reduce the negative impact of RAP on the environment and human health.

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