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Using Supplementary Cement Materials To reduce CO2 Emissions From Cement Manufacturing

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ABSTRACT: *The cement industry is a significant CO_2 emitter, contributing approximately 6% of all global CO_2 emissions. These emissions primarily result from the fuel combustion and calcination of raw materials. However, it is possible that using fly ash and silica fume—recycled byproducts from other industries—in the concrete mix will help the environment. In this study, effects of adding fly ash and silica fume on the compressive strength of concrete containing supplementary cement materials (SCM) were experimentally investigated. By using SCM, we will be able to obtain high-performance concrete (HPC) which lead to reduce the cross-section area of the concrete structure and that will reduce the amount of cement which means reduce the amount of CO_2 emission from cement manufacturing to the atmosphere. By comparing traditional concrete mix with our new concrete mix containing SCM, we were able to see the difference between the amount of cement consumed by each. We prepared and tested 12 mixes of concrete with different compressive strengths, which had varying effects on reducing cement amount and CO_2 emission.*

KEYWORDS: *Supplementary Cementitious Materials, Fly Ash, Silica Fume, CO2 Emission, Cement Manufacturing*

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I. INTRODUCTION

Cement is an important construction material produced all over the world. During the cement manufacturing process, a huge amount of carbon dioxide (CO_2) is emitted. Each ton of cement produced results in 0.9 tons of CO_2.[1] The cement industry is responsible for around 6% of the world's man-made CO_2 emissions.[2]Carbon dioxide, the most abundant greenhouse gas, has the greatest impact on global warming.[3] 61% of global CO_2 releasing are produced by industrial activities such as heat generation, electricity, transportation, and agriculture.[4]The main source of CO_2 in cement manufacturing is the calcination process and the combustion of fossil fuels, which are responsible for 90% of CO_2 released from cement production processes.[5] Because of the increase of industries all over the world, global greenhouse gas emissions are quickly rising, with CO_2 levels projected to reach 14 gigatons by 2030.[6]

Fly ash—residue from unburned coal—is a byproduct from electrical generation plants. It is taken up by the flue gases, moved out of the burning zone, and collected by electrostatic or mechanical separators.[7] Fly ash is finer than Portland cement and has a spherical shape ranging in size from10-100 micron. Fly ash is categorized by its chemical composition. Class C ash is high calcium fly ash because it contains more than 20% CaO. Class F ash is low calcium because it has less than 10% CaO.[8]Fly ash is a pozzolan, meaning that when it is mixed with lime (calcium hydroxide or $Ca(OH)_2$), which is a byproduct produced from mixing cement and water, it will react to form cementitious compounds.[9] As a result, concrete that contains fly ash is stronger and has higher compressive strength. Also, it has small particles that can perfectly fill voids in the concrete.[9]

Silica fume is an extremely fine non-crystalline silica produced as a by-product of silicon or silicon alloy production.[10]A highly reactive pozzolanic material, silica fume has highly elevated amorphous silicon dioxide content. When cement and water compound together, they produce the binder C-S-H (calcium silicate hydrate) and calcium hydroxide as a byproduct. Silica fume then reacts with the calcium hydroxide to produce an additional binder compound (C-S-H).[11]Silica fume consists of spherical particles or microspheres that are around 100 times smaller than the typical grain of cement.[12]Therefore, introducing silica fume into a concrete mix adds millions of tiny particles that fill the spaces between cement grains. This micro-filling or particle-packing process could significantly improve concrete.[13]

Partially replacing Portland cement with industrial byproducts such as fly ash and silica fume decreases the amount of cement required per cubic yard of concrete. Because producing cement requires a large amount of energy, using less cement will decrease the amount of CO_2 emissions and, as a result, the carbon footprint of cement production. Additionally, utilizing fly ash and silica fume in cement will lower the amount of both that must be disposed in landfills.[12,14] In this study, we added silica fume and fly ash to cement mix as supplementing cementitious materials (SCM) in order to reduce the amount of cement required and, as a result, reduce the amount of CO_2 emitted into the environment. 13 mixes were created and tested for compressive strength in order to find the ideal amount of fly ash and silica fume to reduce CO_2 emissions while maintaining adequate concrete strength.

II. EXPERIMENTAL DETAILS

Materials

Cement: In this research, Type I Portland cement was obtained from Ash-Grove cement company and used in all mixtures to avoid variables in results. The properties of the Portland cement are shown in the Table 1 as obtained from the company.

Table 1. Portland cement properties

Component	Percent by weight
SiO2	20.08%
Al2O3	4.65%
Fe2O3	4.11%
CaO	63.63%
MgO	0.94%
SO3	3.19%
Na2O	0.16%
K2O	0.54%
Limestone	2.7%

Coarse aggregate: Coarse aggregate was obtained from Webco Mining, Inc. The coarse aggregate complied with the grading requirements of ASTM C-136.[15] It has an absorption capacity of 1.2% and specific gravity of 2.57. Table 2 shows the coarse aggregate gradation.

Table 2. Coarse aggregate gradation

Sieve Size	% passing as tested
1.5 inch (38 mm)	100
¾ inch (19.05 mm)	95.1
3/8 inch (9.5 mm)	28.55
#4 (4.75 mm)	5.2
#8 (2.36 mm)	0.4
#16 (1.18 mm)	0.3

Fine aggregate: Fine aggregate (sand) with a specific gravity of 2.62 and absorption capacity of 0.48% was obtained from Jeffery Sand Co. The fine aggregate complied with ASTM C-136[15] as presented in Table 3.

Table 3. Fine aggregate gradation

Sieve Size	% Passing as tested
3/8″ (9.5mm)	100
#4 (4.75) mm	97
#8 (2.36) mm	86
#16 (1.18) mm	80
#30 (600 micro meter)	45
#50 (300 micro meter)	13
#100 (150 micro meter)	0.5

Fly Ash: Class C fly ash was obtained from Ash Grove Company and had the characteristics represented in Table 4.

Table 4. Chemical compositions of fly ash as obtained from company

Chemical Component	Percent by weight %
Silica (SiO2)	40
Alumina (Al2O3)	16
Ferric Oxide (Fe2O3)	6
Calcium Oxide (CaO)	24
Magnesium Oxide (MgO)	2
Sulfate Oxide (SO3)	3
Loss of ignition (LOI)	6

Silica Fume: Silica fume was obtained from Elkem Company; Table 5 shows its chemical characteristics.

Table 5. Chemical composition of silica fume as obtained from company

Chemical composition	**Percent by weight %**
SiO2	94.3
Al2O3	0.09
Fe2O3	0.1
CaO	0.3
MgO	0.43
SO3	----
K2O	0.83
Na2O	0.27

High Range Water Reducer (HRWR):HRWR was obtained from Euclid Chemical Company.
Water: Fresh drinking water with no impurities was used in all mixes.
Mixes of concrete: There are 13 mixes of concrete in this research; one was the control mix without SCM, and the other mixes contained SCM. Table 6 shows all the mixes used in this paper.Fig.1 represents the compressive strength of the control mix after 1,3,7,14, and 28 days.Fig.2 shows the compressive strength values for all SCM mixes after 1,3,7,14, and 28 days.

Table 6. Mixes of concrete

Material Ib/yd3	control	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12
Cement	730	1050	1050	1050	1050	1050	1050	1050	1050	1050	1050	1125	1050
Fine aggregate	1994	2440	2440	2440	1700	2440	1460	1740	2250	2450	1800	2250	1600
Coarse aggregate	983	----	----	-----	725	-----	625	740	-----	-----	675	-----	675
Fly ash	------	150	150	150	150	150	150	150	300	150	150	240	150
Silica fume	------	150	150	150	150	150	150	150	150	150	150	240	150
HRWR	------	55	40	25	25	35	25	40	60	35	60	70	70
Water	400	260	230	285	285	285	280	230	225	260	240	240	235
24hrs comp. st. (psi)	1020	9172	8390	8175	8310	8820	8010	8255	9330	8978	9870	9020	9772
28days comp. st. (psi)	4720	14780	12660	13880	12340	13200	11950	12700	15900	14100	17100	14400	16100

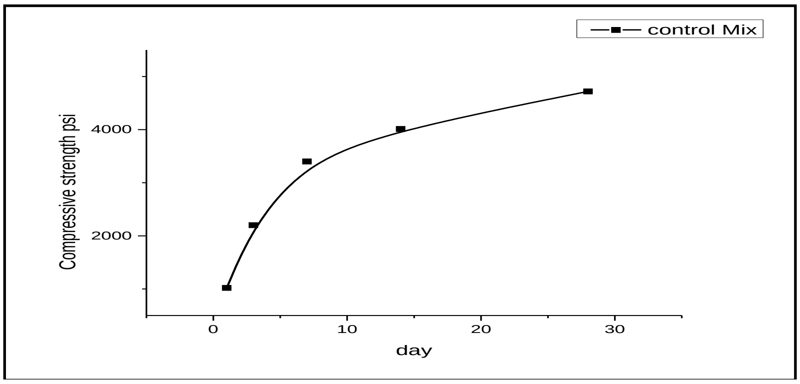

Figure1. Compressive strength vs. time for control mix

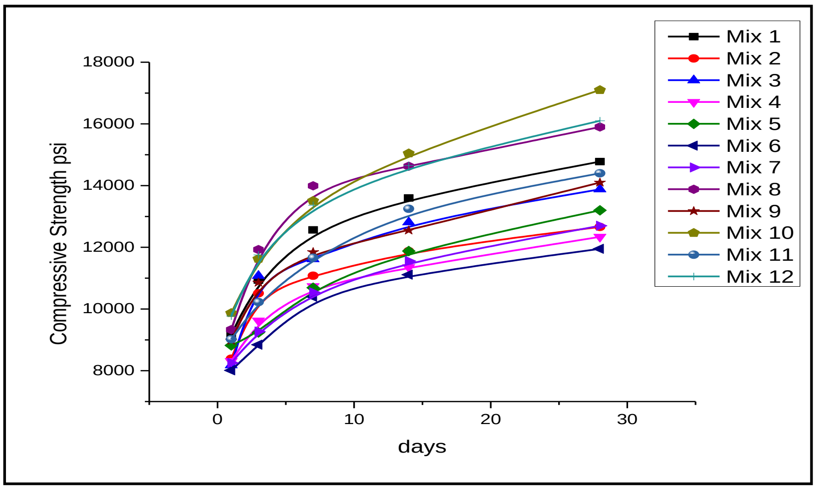

Figure2. Compressive strength vs. time for SCM mixes

Testing

Compressive strength was used to study the ability of fly ash and silica fume to reduce the amount of cement needed to produce strong concrete. Compressive strength was measured according to ASTM C39/C39M-17b.[16]

III. RESULTS AND DISCUSSION

A 28-day compressive strength study was carried out with all the SCM-cement mixes, as well as the control mix that did not contain SCM. Fly ash and silica fume significantly affected the compressive strength of the concrete. For the control mix, the compressive strength value was 4720 psi. For the mixes containing fly ash and silica fume, the compressive strengths ranged from 10550 to 17100 psi. The compressive strength represents an inverse relationship with a cross-section area of the concrete structure, which means that when the compressive strength is high, the cross-section area will be smaller, leading to a reduced the amount of concrete materials required, especially cement.

The results of this study enabled us to calculate the amount of cement needed in each supplemented mix and to then compare this with the amount of cement in the control mix. For example, by dividing the compressive strength of Mix1 by the compressive strength of the control mix [14780/4720 = 3.13],we found that the SCM mix has greater strength than the traditional mix. To achieve the same compressive strength for the control mix, the amount of cement would have to be multiplied by 3.13:730 × 3.13 = 2284 lbs. of cement, in comparison with the 1050 lbs. used in the SCM mix. Therefore, using Mix1 uses around 54% less cement, as shown in Fig.3.

Based on these results, we can estimate the real reduction of cement production in the 5 countries in 2017 that produce the largest amount of cement in the whole world[17]. Producing one ton of cement causes 0.9 tons of CO_2 emissions. Therefore, if cement production is reduced by 54%, the CO_2 emission will be reduced by about 54% as well. Fig.3 shows the projected cement reduction annually by country if SCM is added in the mix. If Mix 1 is used, cement production in China would decrease from 2410 to 1301 million tons and, in the USA, from 86 to 46 million tons—representing about 46% cement reduction.Mix1 could reduce cement production from 2410 to 1108 million tons for China and, for the USA, from 86 to 40 million tons. As a result, in China, CO_2 emissions would be reduced from 2169 to 997 million tons (Fig. 4) and, in the USA, from 77 to 36 million tons.

The same type of data and projections were recorded for each Mix (Fig. 3 and 4). By using Mix 3, cement production would be reduced from 86 to 51 million tons in the USA,a~41% decrease. Mix 4 would reduce the amount by 45%,from 86 to 47 million tons in the USA and from 77 to 42 million tons in Turkey. Mix 5 performed even better, having the potential to reduce cement production by49%.Mix 6 would reduce cement by 36% in the USA, from 86 to 55 million tons. Mix 7 could reduce cement by 42%—from 86 to 50 million tons in the USA and from 60 to 35 million tons in Brazil. Mix 8 could reduce the amount of cement from 86 to 37 million tons in the USA (a 57% decrease) and from 290 to 125 million tons in India. By using Mix 9, cement would be reduced from 86 to 42 million tons in the USA (52% decrease). Cement production would be reduced by 60% by Mix 10, making it the optimum mix in this research; this mix would reduce cement production from 86 to 34 in the USA and from 2410 to 964 million tons in China. Mix 11 and Mix 12 would reduce cement production by 53% and 58%, respectively.

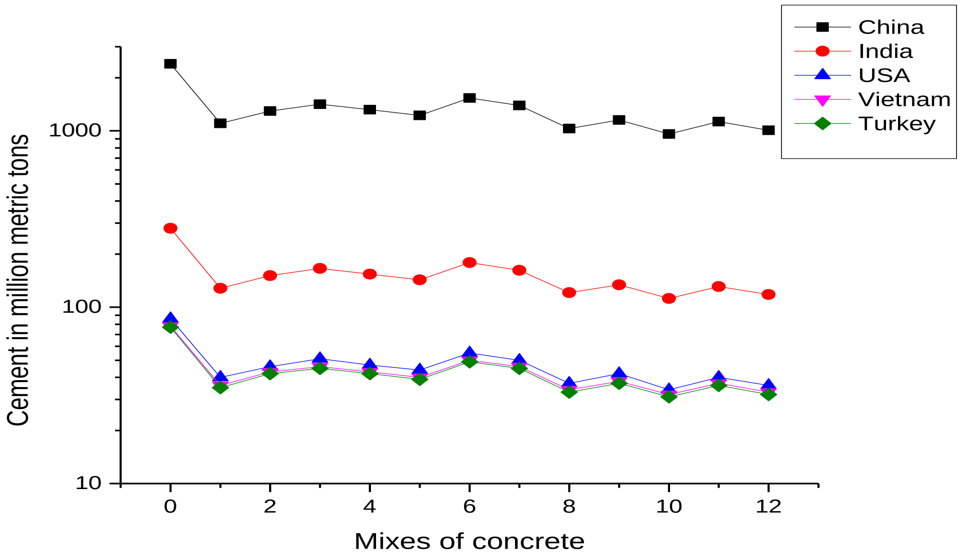

Figure3. Cement production reduction by using SCM mixes of concrete.

Fig.4 represents the projected concrete production-related CO_2 emission reduction by country if the tested SCM mixes of concrete replaced current concrete production. Mix 1could reduce CO_2 from 2169 to 1171 million tons in China and from 77 to 41 million tons in the USA. Mix 3 could reduce CO_2 emission in the USA from 77 to 46 million tons and, in India, from 261 to 154 million tons. Mix 4 would reduce CO_2 emissionsby45%, lowering the amount in the USA from 77 to 42 million tons and, in Turkey, from 69 to 38 million tons. Mix 5 can reduce the amount of CO_2 from 77 to 50 million tons in the USA, while Mix 6 can reduce it from 2169 to 1388 million tons in China. CO_2 emission can be reduced from 77 to 45 million tons in USA by using Mix 7. Mix 8 can reduce USA CO_2 emissions from 77 to 33 million tons and India emissions from 261 to 112 million tons. CO_2 emission can be reduced from 77 to 38 for the USA by using Mix 9. Mix 10 would reduce CO_2 emission from 2169 to 868 million tons in China and from 77 to 31 million tons in the USA.CO_2 emission in China can be reduced from 2169 to 1020 million tons and from 77 to 36 million tons in the USA by Mix 11. Finally, Mix 12 would reduce CO_2 emission from 77 to 32 million tons in the USA and from 2169 to 911 million tons in China. Therefore, the optimum Mix is Mix10, which reduced the amount of cement by 60%, which would result in a 60% reduction in CO_2 emission into the environment.

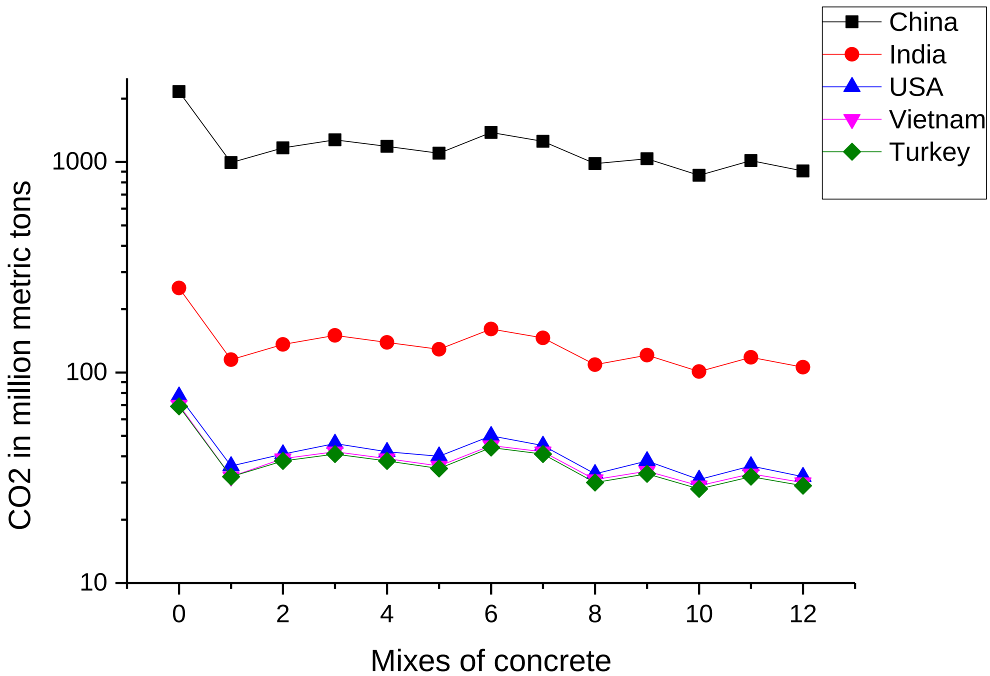

Figure4. CO_2 emission reduction by using SCM mixes of concrete

IV. CONCLUSION

Using supplementary cementing materials allows the amount of cement in a concrete mix to be greatly reduced, up to 36 to 60%.The optimum mix of concrete shows 60% reduction of the amount of cement in the concrete mix, which would also reduce CO_2 emissions from cement manufacturing by 60%.Therefore, by integrating fly ash and silica fume into concrete production, we can help the environment by not only recycling these materials from other manufacturing processes, but also by reducing one of the major global contributors of greenhouse gases.

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