Self-Compaction concrete behaviour containing nano fly ash used in rigid pavement

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Abstract. As cement production causes 7% to 8% of global carbon dioxide emissions, many efforts have been made to reduce the consumption of cement. Using pozzolan (usually fly ash) as additional material with cement is one of these methods. In this paper, the impact of adding Nano fly ash as a partial substitution of cement weight was studied in self-compacting concrete for rigid pavement. Three replacement ratios were used which are (5, 10 and 15)% of cement weight. The results showed that the greater substitution ratio gave better workability with higher slump flow value and better passing ability of concrete. Also, the use of Nano fly ash improved the mechanical properties of the self-compacting concrete by increasing the compressive and splitting tensile strength. The best increase in the strength at the replacement ratio (10%) of cement weight. The slump flow for concrete mixes is between (658 to 732) mm and the compressive strength was improved with the increase of Nano fly ash replacement (10%) by about (20%) compared with conventional concrete. The rigid pavement strength able to provide a surface of good riding quality.

Keywords: self-consolidating concrete, Self-compacting concrete, Nano fly ash, concrete compressive strength, Concrete splitting tensile strength.

1. Introduction
Fly ash can be used as an auxiliary cementing material for the production of Portland cement concrete. Fly ash is a manufacturing waste that needs to be recycled or disposed of in an appropriate manner. Generally, fly ash is added to structural concrete in a proportion (5-30%) of the weight of cement, but as high as (70%) is added for mass concrete. It involves Nano fly ash and conventional fly ash. There are many benefits of using fly ash in concrete, it can improve the performance of concrete in the hardened and fresh case also it is cost-effective. (Nanyakkara k. et al., 2017 and Alaa A. et al., 2018). Self-consolidating concrete may be known as concrete that must flow and compacted under its weight and can be filled the formwork even in the being of intensive reinforcement while preserving homogeneity and without any further consolidation. All elements that control its filling capacity, passing capacity, and anti-segregation properties want to be precisely controlled to secure that its placement capacity is still acceptable. The high fluidity of self-compacting concrete is due to very careful mixing ratios, usually, fine powder and cement are used to replace much of the coarse aggregates, and chemical admixtures are added.

Sri, T., and Kartikas (2014) studied the possibility of replacing cement with fly ash. In this study, the percentage of Nano fly ash used is (0, 2.5, 5, 7.5, 10, 12.5, and 15)% . The results show that when the percentage of fly ash is less than 20%, the compressive resistance of the mortar made of fly ash will be slightly lower than that of cement mortar under 20 days, while the strength at 90 days will be significantly improved. Roychand et al. (2016) investigated the characteristics of high-capacity ultrafine fly ash class F by substituting (80%) cement weight. The results showed that the use of silica fume and a large volume of ultra-fine fly ash improved the resistance of cement mortar (for 7 and 28) days. Alaa et al. (2018) Realized the influence of Nano fly ash on the performance of cement mortar. The results show that the concrete structure has been significantly improved. With the development of the calcium silicate hydration (C-S-H) stage, the disappearance of porosity, high density, and improvement of
compression and thermal properties. Seong et al. (2014) reported the comparison between Nano fly ash and traditional fly ash. The results show that the mortar with smaller binder particles has superior carbonization resistance and provides a strong dense charging influence. Hussein et al. (2018) investigated the uses of Nano-waste materials with fly ash in concrete production. In this study, Nano fly ash from waste show worthy pozzolanic properties. This is due to the high specific surface area, the high silica content, and as well as low ignition loss. As a result, using Nano size materials can decrease the cement demand in the production of concrete. Veerendra Kumar et al. (2019) studied the effect of Nano-silica on the self-compacting mortar with high-volume fly ash. The results indicated that a loss of compressive resistance due to high fly ash volume with a flow capacity of (240 to 260) mm. Anayakara (2017) studied the effect of a high-proportion of nano-silica and fly ash on concrete mixtures. The results showed that in the early stage of concrete, the compressive strength decreased with the increase of the percentage of fly ash, and the replacement of (30%) fly ash had sufficient strength at age of 100 days. Gaurav et al. (2016) studied the strength characteristics of geopolymer concrete rigid pavement using low-calcium fly ash, coconut fibre, and NaOH solution. The results display that the concrete age has no effect on the compressive resistance of geopolymer concrete and indicating that coconut fibre is a suitable material for road construction.

Nagsh et al. (2012) believe that using fly ash in concrete road construction can resolve the disposal trouble and reduce costs of construction without reducing the strength. Vallabumi et al. (2018) investigated the effect of replacing different percentages of fly ash (0, 20, 30, 40, 50, and 60)% with cement. The results show that, compared with ordinary concrete, the strength of the concrete sample is increased by more than 30%.

2. Materials

2.1. Cement
Sulphate resisting Portland cement (SRPC) grade 42.5 type Of Tashuja Cement Companies was used identical to the Iraqi standard (IQS No.5/ 1984). The specific surface, specific gravity, initial and final setting times of cement were (3438 cm²/g, 3.15, 105 minutes and 260 minutes) respectively.

2.2. Fine Aggregate
Al-Ulchaidar sand was used according to Iraqi standard (IQS No.45/1984) with water absorption, bulk specific gravity, sulphate content as SO₃% and fineness modulus were (0.9%, 2.63, 0.23% and 2.30) respectively.

2.3. Coarse Aggregate
Crushed coarse aggregate with a nominal particle size (5-20) mm, water absorption, bulk specific gravity, fineness modulus and sulphate content as SO₃% were (0.5%, 2.67, 6.52 and 0.041%) respectively.

2.4 Superplasticizer
Superplasticizer (SP) can be used to reduce water demand for mixes. SP improves the flow properties of concrete. In this study, Glenium 51 has been used to prepare self-compacting concrete mixes.

2.5 Fly ash
Fly ash bought from Evonik Company, Turkey was used as an auxiliary cementing material with three replacement ratios were (5, 10 and 15) % of cement weight. Table 1 shows Nano fly ash properties that were used in this study.
Table 1. The composition of Nano fly ash

| Item                  | Value  |
|-----------------------|--------|
| SiO₂                  | 63.54  |
| Al₂O₃                 | 16.62  |
| Fe₂O₃                 | 4.3    |
| CaO                   | 6.38   |
| MgO                   | 1.86   |
| Na₂O                  | 2.60   |
| K₂O                   | 1.17   |
| Loose in ignition     | 1.64   |
| Specific gravity      | 2.3    |
| Particle size         | 100    |

3. Experimental Program

3.1. Mix Proportion

The mix ratio of self-compacting concrete must meet the standards of filling capability, passing capacity, and segregation confrontation. According to the indicative typical range of (EFNARC, 2002), the initial mixture composition was prepared by volume. After estimating the powder, water, and coarse aggregate content, the absolute volume method is used to calculate the sand that balances the amount of the other materials. Trial mixing was carried out in the laboratory to verify the properties of the initial mixture to determine the appropriate SP dose. Then make necessary adjustments to the composition of the mixture until the satisfactory self-compacting ability is obtained by evaluating new concrete tests. Accordingly, the four self-compacting concrete mixtures shown in Table (2) were arranged, namely (FL0, FL5, FL10, FL15).

Table 2. Mixture proportion of the rigid pavement concrete.

| Mix description | Cement kg/m³ | Nano fly ash kg/m³ | Sand kg/m³ | Gravel kg/m³ | Water kg/m³ | SP L/m³ | w/p ratio |
|-----------------|---------------|---------------------|------------|--------------|-------------|---------|-----------|
| FL0             | 450.0         | 0.0                 | 800        | 800          | 157.5       | 6.5     | 0.35      |
| FL5             | 427.5         | 22.5                | 800        | 800          | 157.5       | 6.5     | 0.35      |
| FL10            | 405.0         | 45.0                | 800        | 800          | 157.5       | 6.5     | 0.35      |
| FL15            | 382.5         | 67.5                | 800        | 800          | 157.5       | 6.5     | 0.35      |

3.2. Specimens preparation

An electric mixer was used to prepare the mixture. Coarse and fine aggregate, cement, and Nano fly ash were well blended in a dry state. Then one-half of the mixing water was introduced to the mixture and the all matters were well mixed. After that superplasticizer with the residual water was added then the concrete was mixed for 3 minutes.

After the blending process was completed, the fresh concrete was tested to determine the workability factors. 6 cylinders and 12 cubes were cast from each mix. Wet concrete was molding in one layer without being compacted. Use a hand trawl to smooth the upper surface of the fresh concrete sample. After 24 hours, the molds were stripped and the samples were placed in a curing water tank according to (BS. 1881: Part 111).
3.3 Specimens tests

3.3.1 Fresh concrete tests. There are many methods to test the characteristics of fresh self-consolidating concrete, such as U-box and slump flow tests. If the necessities (passing capacity, filling capacity, and segregation resistance) are met, the concrete mixture can only be categorized as self-consolidating concrete. Slump flow test finished ensuring the flowability of rigid pavement concrete according to the EFNARC (2002) guidelines. It can be obviously detected that Nano fly ash substitution to the cement had improved flowability.

3.3.2 Hardened concrete tests

- Compressive Strength test: Cubes used for this test have a dimension of (10×10×10) cm. The test had been carried out as stated by BS.1881: part 116. Three specimens were tested at each age for each mix.
- Splitting Tensile Strength test: This test was carried out using an indirect method of testing according to BS.1881: part 117. Two cylinders with dimensions of (10×20) cm had been tested at each age for each mix and reported the average value.

4. Results and Discussion

4.1. Fresh concrete

Nano fly ash particles are artificial pozzolan spherical materials with very high fineness spherical particles with a size range of (100 nm). Most natural pozzolans can be made into viscous mixtures to maintain aplastic consistency and increasing workability. By producing a more plastic paste for mixing, the concrete is easy to consolidate and flow freely under its weight.

Tables 3 and 4 and Figures 1 and 2 show that with the increase of Nano fly ash as a substitute for cement, the filling capacity and passing capacity of new concrete increase. The slump flow rate increased from (650) mm for the conventional mixture to (732) mm for the mixture containing (15%) fly ash and reduce the filling height from (7mm) for the reference concrete to (zero) for (15%) Nano fly ash concert. It can be clearly seen from the results that adding Nano fly ash into rigid pavement concrete can significantly promote and enhance the workability of fresh concrete.

4.2. Hardened concrete

Concrete containing pozzolan typically provides higher strength at later ages. The impact of natural pozzolan on the mechanical properties of rigid pavement concrete varies markedly with the properties of the particular pozzolana.

Results of compressive resistance investigation show in Table (5) and figure (3). The results are conducted by testing the compressive strength development of rigid pavement concrete at the ages of (7, 28, 56, and 90) days. The results show that the rate of strength development of the concrete with Nano fly ash is slower in compressive strength to that of the control specimen at early ages (7 and 28) days. After that (56 and 90) days age, the concrete specimen containing Nano fly ash gained higher strength because of the existence of silicon oxide which can interact with (CH) to form. (C-A-H) and (C-S-H). These supplemental hydrated outputs fill the pores and Produce more a dense matrix that improves the concrete strength. It can be seen from Table (6) and Figure (4) that the higher values of splitting tensile strength in concrete specimens containing Nano fly ash compared with reference concrete. This is because of the high pozzolanic effectiveness of Nano fly ash and its role as a filler, thereby improving the interface transition zone and providing firm contact points between aggregated particles. It must be noted that the high specific surface of the Nano fly ash means that the material is easily ready to react with calcium hydroxide. The very fine Nano spherical particle is the main reason for its high pozzolanic reaction. (Alaa, A. et al., 2018 and Mohammed, K., 2018).
Table 3. Slump flow values (mm)

| Mix registration | Slump flow (mm) |
|------------------|-----------------|
| FL0              | 658             |
| FL5              | 687             |
| FL10             | 702             |
| FL15             | 732             |

Table 4. Filling height values (mm)

| Mix registration | Filling height (mm) |
|------------------|---------------------|
| FL0              | 7                   |
| FL5              | 2                   |
| FL10             | 0                   |
| FL15             | 0                   |

Figure 1. The relation between slump flow with Nano fly ash percentage

Figure 2. The relation between filling height with Nano fly ash percentage

Table 5. Compressive strength of rigid pavement concrete (MPa)

| Mix registration | Age (days) | 7   | 28  | 56  | 90  |
|------------------|------------|-----|-----|-----|-----|
| FL0              | 31.6       | 58.0| 61.4| 63.8|     |
| FL5              | 28.2       | 56.7| 63.2| 68.5|     |
| FL10             | 26.5       | 56.0| 69.0| 76.4|     |
| FL15             | 23.0       | 52.8| 62.7| 64.2|     |
Table 6. Splitting tensile strength of rigid pavement concrete (MPa)

| Mix registration | Age (days) | 28   | 56   | 90   |
|------------------|-----------|------|------|------|
| FL0              | 5.34      | 5.72 | 6.18 |
| FL5              | 5.51      | 5.84 | 6.21 |
| FL10             | 5.93      | 6.32 | 6.50 |
| FL15             | 5.86      | 5.96 | 6.33 |

Figure 3. The relationship between the percentage of Nano fly ash and the compressive strength

Figure 4. The relation between the percentage of Nano fly ash and the splitting tensile strength

Due to high compressive and tensile strength (over 64 and 6.0) MPa, respectively used in rigid pavement concrete slab, and hence the pavement structure can resist unlimited and carrying the same or very heavy traffic density loads during the service design life or rigid pavement concrete. High rigidity of concrete pavement of highway application tends to distribute the cumulative vehicle load over a relatively wide area of subgrade and preferred for high traffic volume and heavy resistance to water penetration, thus, the key factor that could affect the susceptibility of the road to loading.

5. Conclusions
It is clear, the advantage of the partial cement substitutes with Nano fly ash is very important and beneficial economically, environments and preserving of natural material by replacing a quantity of waste material with cement. Also, from this study, with the respect to the use of Nano fly ash as a replacement for cement, the following conclusions can be pointed out:
1- The fresh concrete flow to a great distance and remain homogeneous without segregation.
2- The values of slump flow and filling height for rigid pavement concrete mixes were improved from (658 to 732) mm and (0 to 7) mm respectively.
3- The increase of the Nano fly ash percentage addition from (zero to 15) % lead to an increase in the compressive and splitting tensile strength from (63.8 to 76.4) MPa and (6.18 to 6.50) MPa respectively at the age of 90 days.
4- The results obtained display that the Nano fly ash has useful influences on compressive and splitting tensile strength, especially at the later ages.
5- Increase in service life and improved performance of the pavement due to the high compressive and tensile strength of rigid pavement concrete.

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