Design of Rigid Pavement by Self Cured Concrete Utilizing Coarse Fly Ash Aggregates and Curing Admixture

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Abstract
In concrete industry, a huge amount of natural aggregates is used in the making of concrete every day. The environment is being exploited by mining for the gain of natural aggregates, resulting in an environmental instability in nature. As a result, an alternate source to substitute natural aggregates in concrete is required. A lot of waste materials have gain attention now a days into the concrete industry as a substitute to natural materials. Fly ash, a waste product of thermal power plants, meets the criterion for being utilised as an aggregate substitute in concrete because of its pozzolanic activity. Coarse fly ash is manufactured using a good manufacturing method and is light in weight. Keeping this into view, the impact of partial replacement of natural coarse aggregates with coarse fly ash aggregates produced using the colds bonded method is explored in this paper. The major focus of this study is on testing for flexural strength of self-cured concrete, as flexural strength is a key criterion for rigid pavement design. In this study, coarse fly ash aggregates are utilised in concrete in different proportions to substitute natural aggregates, and the optimal value for flexural strength is determined using a curing additive. The findings of this experiment indicated that when fly ash aggregates and curing additives were used optimally, the flexure strength improved, which is enough for the construction of rigid pavement as criteria fixed by Indian Standards.

Keywords: Flexural strength; rigid pavement; fatigue; axle load; fly ash aggregates.

1. Introduction
The use of concrete in the construction industry has escalated dramatically in recent years due to its long durability. However, its production is hazardous to the environment and depletes natural resources. On the other hand, the conventional concrete curing process is still inadequate for cement hydration. For skyscraper structure and mass concrete construction, curing is very difficult. Wastage of water is there for conventional curing process. To overcome these problems, concrete with self curing and waste utilization will be the appropriate answer [1–3]. Self curing or internal curing is a process in which the water is feed by the water reservoir inside the concrete in form of light weight aggregates. Aggregates manufactured by cold bonding technique utilising fly ash are porous and absorb high water quantity, which may be employed for self curing [4,5].

The influence of utilization of fly ash in concrete has been explored by different researchers for the strength characteristic of concrete. From the previous literature study, it has been observed that
different curing admixture have been tested in concrete. The durability of concrete by using different curing admixture of content having high fly ash content have been used. Fifty percent of total cement was replaced with fly ash, and spinacia oleracea, polyethylene glycol was used for internal curing. When 50 percent of the cement is replaced with fly ash, the strength was significantly reduced at 7 and 14 days. However, due to the pozzolanic effect of fly ash [6–8], significant strength was acquired after 56 days. Self cured concrete showed greater durability against the action of acids as compared to conventional concrete. It was revealed that by using sintered fly ash aggregates concrete having strength in between 23 MPa to 74MPa can be produced. Sintered fly ash aggregates have a superior interfacial transition zone in terms of thickness and quality, and the pozzolanic reactivity between the aggregates and paste increases as the temperature rises. It was found that the compressive strength of geopolymer concrete based on low calcium fly ash increases by up to 20%, when OPC was used as a fly ash replacement. The inclusion of calcium-based products resulting in the hydration process, which coexisted with the alumina silicate polymer product, enhanced the strength. It was revealed that concrete mix with a water cement ratio of 0.44 using pre wetted vacuum saturated lightweight aggregate, the strength enhanced after 365 day. At a volume replacement of 8.9 to 13.8 percent, lightweight aggregates were employed to replace standard weight aggregates, and according to the findings of study all lightweight aggregates concrete combinations shrunk less than normal conventional concrete. It was observed that in self compacting concrete by using cold bonded fly ash as substitute fine aggregates in varying percentages increases the workably of concrete and a slump of 25 cm was found. The compressive strength of fly ash aggregates was low at first due to their reduced specific gravity of aggregates, but as time went on, the compressive strength rose due to the pozzolanic activity of fly ash. It was revealed that self-curing concrete mixes have a greater water retention rate, as indicated by weight loss over time [9–11]. Under sealed conditions, self-curing concrete experienced less self-desiccation than traditional concrete and water absorption and water permeability values for self-curing concrete declines with age as a consequence of the cement's continuous hydration, implying a reduced proportion of permeable pores. It was found that concrete shrinkage and mechanical qualities are affected by self-curing process done by water-saturated fine aggregates and admixture. Zeolite is a reactive mineral additive having certain ion-exchange ability in concrete and enhanced the cement hydration. It was revealed that adding fly ash (10%) and superplasticizer (0.25– 0.35%) to concrete improves workability and marginally enhances compressive strength. Concrete produced was fulfilling the requirements of self compacting concrete [12–15].

Polyethylene glycol-400 was used as the curing admixture by many researchers. By using three different curing technique water ponding, curing through wax based curing compounds and self curing through PEG-600, it was revealed that at 28 days curing trough wax compressive strength was 91% of that cured in water tank. Strength for self cured cube was 95% of that cured in water tank. It was observed that with increase in percentage of PEG-400 (0%,0.5%, 1%, and 1.5%) the workability also increased, and the strength was also high for self cured concrete. It was found that by incorporating super absorbent polymer at 0.05-0.2%, PEG at 2–4% and light weight aggregate at 15 % dosage in concrete showed the same strength as normal concrete. It was revealed that the self compacting concrete prepared by replacing up to 60% cement with fly had a compressive strength of 40N/mm². With increase in fly ash content in concrete the water absorption of concrete also increased which reduced the durability of concrete. It was revealed that for architectural concrete when 1.5 percent polyethylene glycol and 2 percent steel fibre were added, the compressive strength improved by 4.13%and split tensile strength got improved by 4.49%. It was found that by using steel fibre, polypropylene fibre and glass fibre by 1% volume fraction in pavement concrete, the flexure strength obtained by using steel fibre was almost double as compared to other fibres. By using fibre reinforced concrete, the design thickness can be lowered. It was revealed that the stresses computed in pavement concrete using IRC techniques are greater than those calculated using PCA methods. The stresses were found to be 40 percent to 50 percent greater for 8 tonne loads, and around 22 percent higher for 16 tonne tandem axle loads. From the past study it was revealed that, maximum stresses occur in edge region in case of finite element method, for empirical method at corner region [16,17].
2. Materials and their Properties.

2.1 Cement
In this study, Ordinary Portland Cement 43 grade was used confirming to IS: 269-1989 for casting of concrete. The cement was bought from local material market and stored in air tight bag in laboratory. The properties of cement are mentioned in Table 1.

Table 1. Physical properties and composition of ordinary Portland cement

| Physical properties          | 3 days | 7 days | 28 days |
|-----------------------------|--------|--------|---------|
| Fineness (%)                | 2.1    |        |         |
| Standard consistency (%)    | 34     |        |         |
| Initial setting time (minutes) | 32     |        |         |
| Final setting time (minutes) | 570    |        |         |

| Compressive strength (N/mm²) |        |
|------------------------------|--------|
| 3 days                       | 24     |
| 7 days                       | 32     |
| 28 days                      | 43     |

| Chemical composition         |        |
|------------------------------|--------|
| Constituent                  | CaO    |
|                              | SiO₂   |
|                              | Al₂O₃  |
|                              | Fe₂O₃  |
|                              | MgO    |
|                              | SO₃    |
|                              | Cl     |
|                              | Loss on ignition |
| Content (%)                  | 49.25  |
|                              | 30.32  |
|                              | 7.51   |
|                              | 4.25   |
|                              | 1.25   |
|                              | 1.95   |
|                              | 0.02   |
|                              | 5.4    |

2.2 Natural Aggregates
Fine aggregate and coarse aggregates procured from local stone crusher are utilised for this work. The fineness module for fine aggregates is 2.90. The size of coarse aggregates used in the study is 10-20 mm.

2.3 Fly ash aggregates
Fly ash aggregates manufactured by cold bonded process are utilised for research purpose having size 10-20 mm. A fly ash brick made by cold bonded technique was broken into small pieces to procure coarse fly ash aggregates, see Table 2.

Table 2. Properties of normal and fly ash aggregates

| Type of Aggregates | Water Absorption | Specific Gravity | Impact Value |
|--------------------|------------------|------------------|--------------|
| Coarse Aggregates  | 4%               | 2.22             | 8.45%        |
| Fly ash Aggregates | 12.18%           | 1.67             | 46.27%       |

2.4 Polyethylene glycol
Polyethylene glycol was bought from online shopping market. The atomic weight of polyethylene glycol is 400 (PEG-400) and the density of PEG-400 is 1.26 gm/ml at 4 °C for and viscosity is 85-105 cm² s⁻¹ at 20 °C as supplied by the manufacturer.

2.5 Water
Potable water was used for the construction and curing of concrete.

2.6 Batching and mixing
Using a weighing machine, the materials were precisely measured. For the ingredients, weight batching was used. Hand mixing was used to ensure that all of the concrete materials were well mixed. The coarse aggregates and fine aggregates were thoroughly mixed first, and then the cement was added. The water was then carefully added so that no water was lost during the mixing process.
2.7 Concrete Mix Design
A M40 concrete mix design was done according to IS: 10262-2019. Coarse aggregates were replaced by fly ash aggregates by different proportion (5%, 10%, 15%, 20%, 25%, 30%) by weight. Water cement ratio used was 0.38 and Polycarboxlic ether based superplasticizer was used to attain workability. Beams of size 100mm × 100mm × 500mm was casted and tested for the flexural strength. The different concrete proportion are shown in Table 3. The concrete mix are designated with a code where “M” represents the standard concrete and “FM” represents the fly ash concrete and the number represents the amount of aggregates replacement.

| Mix Code | Cement (Kg/m³) | Fine Aggregates (Kg/m³) | Coarse Aggregates (Kg/m³) | Fly Ash Aggregates (Kg/m³) |
|----------|----------------|--------------------------|---------------------------|---------------------------|
| M        | 440            | 595                      | 1234                      | 0                         |
| FM5      | 440            | 595                      | 1172.3                    | 61.7                      |
| FM10     | 440            | 595                      | 1110.6                    | 123.4                     |
| FM15     | 440            | 595                      | 1048.9                    | 185.1                     |
| FM20     | 440            | 595                      | 987.2                     | 246.8                     |
| FM25     | 440            | 595                      | 925.5                     | 308.5                     |
| FM30     | 440            | 595                      | 863.8                     | 370.2                     |

2.8 Curing of samples
Concrete moulds were left for curing for a period of 24 hours so as to gain proper strength and then demoulded. The specimens were properly cleaned and were placed in curing tank for the period of testing. The samples prepared by self curing concrete were covered with plastic sheets in laboratory at room temperature.

3 Experimental results and discussions
3.1 Flexural Strength
3.1.1 Effect of fly ash aggregates on flexural strength
The natural coarse aggregates were replaced by fly ash aggregates in varying percentages by weight to check their efficacy on strength characteristics. The flexure strength of normal concrete mix was 4.49 N/mm² after the curing period of 28 days, on replacing natural coarse aggregates with fly ash aggregates in varying amount, the flexural strength increased. On replacing natural coarse aggregate with 15% fly ash the compressive strength was 4.72 N/mm² which was the highest. Fly ash aggregates concrete exhibited high strength than normal concrete at later ages. Thus 15% replacement with fly ash was considered as optimum replacement for strength. This may be due to the reason that the fly ash has pozzolanic properties as studied by various researcher [16]-[19] which contributes to the strength of concrete[20]-[22], see figure 1, 2 and 3.
3.1.2 Effect of PEG-400 on flexural strength
PEG-400 being a self-curing agent lowers the evaporation from concrete and help in continuous hydration and with saturated fly ash aggregates it enhance the flexural strength. For 15 % optimum replacement fly ash concrete, PEG-400 was added (0.5%, 1%, 1.5, and 2%) by weight of cement to evaluate flexural strength. As the percentage of PEG-400 increased the flexural strength also increased. The maximum strength obtained at 1% addition of PEG-400 was 4.94 N/mm². After further addition the flexural strength started decreasing. This may be due to the fact that at higher percentage polyethylene glycol-400 starts hindering the hydration process and eventually decreasing the flexural strength, see figure 4.

![Figure 1. Flexural testing machine](image1.png)

![Figure 2. Beam measurement before testing](image2.png)

![Figure 3. Flexural strength at different percentage of fly ash aggregates replacement](image3.png)
3.2 Design of rigid pavement

The design of the rigid pavement was done according to IRC: 58-2015 and pavement is designed for self-cured concrete with 1% PEG-400 and 15% fly ash aggregates.

3.2.1 Design Parameters

Design Life: 30 Years
Location of pavement: Mandi, Himachal Pradesh, India
Design value for wheel load (P) = 7000 Kg
Design tyre pressure = 8 Kg/cm²
Foundation strength consisting GSB and dry lean concrete of 150 mm thickness = 30 Kg/cm² according to IRC: 58-2015
Concrete Flexure Strength, fct = 4.94 N/mm²
Modulus of Elasticity of concrete = 3 × 10⁵ Kg/cm²
Poisson’s Ratio = 0.15
Thermal coefficient of concrete per °C (α) = 10×10⁻⁶ per °C
Assumed tentative design value of slab thickness h = 25 cm
Tyre Pressure = Wheel Load / Contact area
Radius of wheel load distribution (a) = \( \sqrt{\frac{7000}{8×3.14}} \) = 16.69 cm
Radius of Equivalent distribution of pressure, b
\[
\begin{align*}
    b &= (1.6 \times a^2 + h^2)^{1/2} - 0.675h \\
    b &= (1.6×16.69^2 + 25^2)^{1/2} - 0.675×25 \\
    b &= 15.84 \text{ cm}
\end{align*}
\]
Modulus of subgrade reaction K Value for 150mm DLC = 30 Kg/cm² by IRC 58 2015
Radius of Relative Stiffness (l) = \( \left[ \frac{Eh^3}{12k(1-u^2)} \right]^{1/4} \)

By putting the value of E, h, k, and u in above equation,
\[
l = 60.41 \text{ cm}
\]
3.2.2 Stresses in the Pavement Due to Wheel Load and temperature stresses

Stresses calculated by empirical formulas given by IRC: 58-2015 are tabulated in Table 4.

| Type of Stresses     | At Edge Kg/cm² | At Interior Kg/cm² | At Corner Kg/cm² |
|----------------------|----------------|--------------------|-----------------|
| Load Stresses        | 15.84          | 12.41              | 14.48           |
| Temperature Stresses | 22.52          | 22.76              | 8.50            |
| Total Critical Stresses | 38.36        | 35.17              | 22.98           |

3.2.3 Critical Combination of stresses

For the analysis and design of rigid pavement, both load stresses and temperature stresses were taken into consideration. The most critical stress combination was found in summer midday which is given below:

Critical Combination of Stress = Se + Ste
= 15.84 + 22.52
= 38.36 Kg/cm²

Flexure Strength of the concrete = 43.33 Kg/cm²

Factor of Safety = \( \frac{\text{Flexure Strength of concrete}}{\text{Maximum critical stresses}} \)
= \( \frac{43.33}{38.36} \)
= 1.12

Therefore, the total stresses in the pavement concrete were less than the flexure strength, and the factor of safety is more than one, so the given thickness 25 cm is safe for the design.

3.2.4 Fatigue Behaviour of cement concrete for overloaded vehicles

Due to repeated application of axle on pavements, flexure stresses lead to fatigue damage of concrete slab. Fatigue life is defined as the number of repetitions of axles which can pass through it without damaging it in its design life. Fatigue life of concrete is affected largely when the overloaded vehicles passes through it. The ratio between applied stress and the flexure strength is defined as stress ratio (SR).

Fatigue Life \( N \) = Unlimited for SR < 0.45

\[
N = \begin{cases} 
  4.2577 \left( \frac{SR}{0.4325} \right)^{3.268} & \text{When } 0.45 \leq SR \geq 0.55 \\
  0.9718 - \frac{SR}{0.0826} & \text{For } SR < 0.55 
\end{cases}
\]

The fatigue analysis was carried out considering the magnitude of load and number of repetitions of overloaded vehicles exceeding design axe load on single and tandem axis. The limit for legal axel load is 10 ton for single axle and 20 axles for tandem according to IRC: 58-2015. The value of edge stress for temperature difference of 13°C for single axle load of 12 ton and 16 ton was determined from Figure IV.38,39 IRC: 58-2015 and for tandem axle load of 20 tons, 24 tons, 32 tons, 40 ton were determined from Figure IV. 95-98 IRC 58-2015. The allowable number of repetitions for these overloaded vehicles are shown in Table 5.

Table 5. Fatigue life for different axle load
| Axle Load Type | Axle Load Tons | Edge Stress, Se Kg/cm² | Stress Ratio, SR=Se/Fct | Fatigue Life, N = number of axle repetitions |
|---------------|----------------|------------------------|-------------------------|---------------------------------------------|
| Single        | 12             | 20                     | 0.46                    | 14335235                                    |
|               | 16             | 23                     | 0.53                    | 229127                                      |
| Tandem        | 20             | 16                     | 0.36                    | Unlimited                                   |
|               | 24             | 18                     | 0.41                    | Unlimited                                   |
|               | 32             | 22                     | 0.50                    | 762042                                      |
|               | 40             | 23                     | 0.53                    | 229127                                      |

Thus, the pavement designed can sustain these number of repetitions, when overloaded vehicles with axle loads more than the design load passes through pavement.

4. Conclusions

The following are the results of the research in which natural coarse aggregates were partially replaced with fly ash aggregates and PEG-400 was introduced to self-curing concrete:

- The strength of concrete on replacing natural coarse aggregate partially by fly ash aggregates improves on later ages; the maximum improvement occurred for 15% replacement with fly ash aggregate. The flexure strength of concrete on 15% replacement was 4.72 N/mm² at 28 days; which is 5.12% higher than normal concrete.
- The addition of 1% PEG-400 to 15% fly ash aggregates enhanced the flexural strength to 4.94 N/mm²; which is 9.13% higher in comparison to normal concrete.
- The self-cured concrete of thickness 25 cm, prepared by the addition of 1% PEG-400 and 15% fly ash aggregates is safe for designing rigid pavements against all critical stresses with a design wheel load of 7000 Kg.

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