# A comparative study on dry lean concrete manufactured with OPC vis-a-vis PPC to be used for the construction of concrete roads

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The current practices of the construction of cement concrete road for highways in India require a layer of dry lean concrete (DLC) as a base course over which pavement quality concrete slabs rest. Even the Municipal's concrete roads including white-topping are being constructed using DLC base course. DLC is mostly manufactured with ordinary portland cement as per Indian Road Congress specification SP-49: 1998. IRC SP-49: 1998, advocates the use of portland pozzolana cement (PPC) and portland slag cement (PSC) also in the manufacture of DLC but says nothing about the concrete mix proportioning i.e. the amount of such cement, aggregate-to-cement ratio and moisture content for the DLC to be manufactured with PPC and PSC. PPC is widely available in market all over the India, however, PPC has properties significantly different from OPC. Hence, in this research study the amount of cement (OPC and PPC), maximum aggregate-to-cement ratio and moisture content for the manufacture of DLC with OPC and PPC meeting the requirement of IRC specification in term of strength development has been presented. The study suggests the following important conclusions:

- The minimum quantity of PPC for the manufacture of DLC satisfying the compressive strength requirement is at least 10% higher than that of OPC.
- The aggregate to cement ratio satisfying the strength requirement criteria of the IRC SP-49 is significantly lesser in the case of PPC than that of OPC.
- The optimum moisture content of DLC containing PPC is about 16-17% higher than that of OPC.

## INTRODUCTION

The total road network of the India is about 4.69 million km in length. Out of which about 53.8% (2.53 million km) are paved. Approximately, 2% of the total road length of the country is made of with concrete [1]. Due to overall economy and added advantages of a longer service life with a little maintenance cost, hundreds of kilometers of concrete pavements are constructed/being constructed in the country under the Government of India's National Highway Development Programme (NHDP). Government of India is encouraging the construction of concrete pavements even at rural levels. The performance of cement concrete pavements is greatly influenced by the uniform support offered by the base or sub-base layer. The current practices of the construction of cement concrete road for highways in India require a base layer of dry lean concrete (DLC) over which pavement quality concrete slabs rest. It is one of the common and popular cement treated sub-base/base for concrete pavements. DLC is a no slump plain concrete with a large ratio of aggregate-to-cement in comparison with conventional concrete. It contains less amount of cement paste as compared to conventional concrete. A properly constructed DLC layer plays an important role in enhancing the service life of modern concrete roads. The major advantages of using DLC as base layer includes: provision of a uniform and strong support, high resistance to deformation, enhanced load transfer efficiency at joints, proper fixing of form work and proper placement of dowel bar cradles in semi-mechanised construction, movement of construction equipment during construction of roads, all weather construction, and finally a reduction in the depth of pavement slab required from the point of view of axle load consideration [2-3]. DLC is being

**Table 1. Basic properties of OPC vis-à-vis PPC**

| Cement type | Fineness ($m^2$/kg) min | Fly ash content, % mass | Compressive strength, MPa | | | Sp. Gravity* | Normal consistency*, % |
|---|---|---|---|---|---|---|---|
| | | | 3-day | 7-day | 28-day | | |
| 43 grade OPC (IS 8112:1989) | 225 | Nil | 23 | 33 | 43 | 3.1 – 3.15 | 28 - 30 |
| 53 grade OPC (IS 12269:1987) | 225 | Nil | 27 | 37 | 53 | 3.1 – 3.15 | 28 - 30 |
| Portland pozzolana cement (IS 1489:1991)PartI | 300** | 10 - 35 | 16 | 22 | 33 | 2.9 – 3.0 | 32 - 36 |

**Notes**:
* These data are experimentally determined during study
** Some PPCs are found to be coarser than OPC. Properties of PPCs keeps on changing with manufacturers i.e. cement brand to brand

also used during rehabilitation and strengthening of existing distressed bituminous roads with white topping. A typical conventional white-topping constructed over half width of the distressed bituminous road in Delhi has been shown in Figure 1.

DLC is generally manufactured with ordinary Portland cement (OPC) as per IRC: SP-49: 1998 specification [2]. This specification (IRC SP-49, 1998) advocates the use of other cement such as portland pozzolana cement (PPC), portland slag cement (PSC) also in the manufacture of DLC. It sets a requirement of 10 MPa compressive strength of DLC at 7-day and minimum ordinary portland cement (OPC) content of 150 kg/$m^3$ is prescribed for it. But it does not give details such as cement content, aggregate-to- cement ratio, moisture content etc., for DLC manufactured with PPC and PSC.

Today, as OPC is not readily available in open market even in megacity like Delhi, the consumers have no option but to go for PPC. The distinct differences between these two types of cement (PPC and OPC), include the presence of fly ash and much higher value of normal consistency of PPC[3], slower early age strength gain, thorough requirement of curing etc. It is to be noted that PPC was introduced as a substitute for OPC-33. Table 1 presents some codal as well as generally encountered values for the basic properties of OPC and PPC [3-4].

*Figure 1. A typical surface of the constructed portion of a conventional white-topping over existing distressed bituminous road in Delhi*

On testing the compressive strengths of various cement brands available in the market, a wide variation in the development of compressive strength was noticed for PPCs. As per August 2014 data, about 70% of total India's cement production, that is, 272 million tonnes, is PPC. Therefore, the know-how and data generated through this research work will encourage use of correct amount of PPC in the manufacture of DLC. This study presents results of an extensive experimental investigation conducted to compare DLC manufactured with OPC and PPC in light of the requirement of IRC: SP-49 specification in terms of strength development, aggregate-to-cement ratio, and moisture content etc.

## EXPERIMENTAL STUDIES

The experimental program included evaluation of the suitability of materials, development of trial mixes for DLC, preparation of DLC specimens, and finally testing of dry lean concrete specimens. A Jack Hammer was used for the preparation of the DLC specimens.

### Materials

Ordinary Portland cement (OPC) and portland pozzolona cement (PPC) were used in this investigation. The fact that PPC is not an OPC, since the earlier one contains fly ash up to 35 percent by mass resulting in significant differences in the basic properties such as normal consistency, specific gravity, and strength development at early ages etc. PPCs being fly-ash based, the proportions of fly ash are not specified and

hence, they do not follow any strength pattern at different ages at 3, 7 or 28 days as is the case with OPC [4]. The bags containing this cement have the marking IS 1489 [5] – part I. There is no 43/53 grading in IS 1489. There are cases when the PPCs showed more than prescribed strength at 7 days and in some cases, the strengths did not reach the precise level. Therefore, in this study a PPC which gave 28-day compressive strength similar to OPC 43 Grade [6] was used. Table 2 shows normal consistency, of one OPC and five PPC. From these five PPCs one PPC (PPC1) which gave similar compressive strength to OPC was taken for further study. The normal consistency, setting times and compressive strength of both cements used in this study are given in Table 3.

The aggregate i.e. coarse aggregate and fine aggregate were evaluated as per relevant specification for their suitability for the use in dry lean concrete [7-8]. The important physical properties of the aggregate are presented in Table 4.

The maximum size and gradation of coarse aggregate and fine aggregate are given in Table 5 and Table 6, respectively. Table 7 shows the combined grading of aggregates used for the manufacturing of DLC mixes. The combined grading for aggregate satisfies the requirement for the grading of aggregate to be used in the manufacturing of DLC.

Portable water fit for drinking available at CRRI laboratory was used for the mixing of concrete as well as curing of the concrete specimens.

**Table 2. Normal consistency of OPC and few PPC**

| Cement | Normal consistency (%) |
|---|---|
| OPC | 30.0 |
| PPC1 | 36 |
| PPC2 | 35 |
| PPC3 | 32 |
| PPC4 | 36 |
| PPC5 | 34 |

**Table 3. Normal consistency and setting times of OPC and PPC used in the study**

| Cement type | Normal consistency (%) | Initial setting time (Min.) | Final setting time (Min.) | Average compression strength at 28 days (MPa) |
|---|---|---|---|---|
| OPC | 30.0 | 120 | 180 | 44.0 |
| PPC | 36 | 150 | 250 | 45.5 |

**Table 4. Important properties of aggregate**

| Parameters | Fine aggregate | Coarse aggregate |
|---|---|---|
| Specific gravity | 2.66 | 2.61 |
| Aggregate impact value (%) | - | 5.35 |
| Aggregate crushing value (%) | - | 22.57 |
| Bulk density (kg/m$^3$) | 1600 | 1590 |
| Moisture absorption (%) | 1.07 | 0.46 |
| Silt content (%) | 4 | - |

**Table 5. Grading of coarse aggregate of maximum size 26.5 mm**

| Sieve opening size (mm) | % Passing |
|---|---|
| 26.5 | 100 |
| 19.0 | 91.6 |
| 9.5 | 11 |
| 4.75 | 0.2 |

**Table 6. Grading of fine aggregate**

| Sieve opening size (mm) | % Passing | Grading zone of sand |
|---|---|---|
| 10.0 | 100 | |
| 4.75 | 100 | Grading of sand lies in between zones II & III. |
| 2.36 | 99 | |
| 1.18 | 89 | |
| 0.6 | 59 | |
| 0.300 | 17 | |
| 0.150 | 6 | |

**Table 7. Combined aggregate gradation for dry lean concrete mixes**

| Sieve designation | Percentage passing | IRC SP:49 Requirements for % passing |
|---|---|---|
| 26.50 mm | 100 | 100 |
| 19.00 mm | 98.6 | 80-100 |
| 9.50 mm | 56.4 | 55-75 |
| 4.75 mm | 39 | 35-60 |
| 600 micron | 15 | 10-35 |
| 75 micron | 6 | 0-8 |

## Dry lean concrete mix proportioning requirements

The mix design for DLC is not similar to the conventional concrete mix. Unlike conventional concrete mixes the water-to-cement ratio is not the criteria for DLC mix design but it is the optimum moisture content (OMC) to ensure full compaction of concrete under rolling. The mix should not be too wet, as it gets stuck to the roller drums. Hence, it is important to determine the optimum moisture content for adequate compaction and the mix proportions i.e. aggregate-to-cement ratio to yield required compaction and compressive strength for the concrete.

## Optimum moisture content

Optimum moisture content for a DLC mix is determined to ensure full compaction under rolling. The optimum moisture content is determined to achieve full compaction and maximum dry density. It is commonly determined by compacting DLC cubes with the help of a vibratory hammer.

## Cement content

As per IRC SP-49, 1988, the minimum cement content in a DLC shall not be less than 150 kg/m$^3$ of concrete. If this minimum cement content is not sufficient to produce concrete of the specified strength, it shall be increased as necessary. However, this specified amount of cement is for OPC. In the case of PPC nothing is quantified about the amount of cement.

## Concrete strength

The average compressive strength of a DLC mix shall not be less than 10 MPa at 7 days.

## DLC trial mixes

As mentioned earlier, a DLC mix is designed on the basis of optimum moisture content (OMC) corresponding to the maximum aggregate to cement ratio and amount of cement satisfying the strength requirement along with maximum dry density. For this DLC trial mix (1:5:10) were prepared with varying moisture contents like 5.5, 6.0, 6.5, 7.0, and 8.0 (higher values for moisture content is used for mixes with PPC) per cent using different cement content and aggregate-cement-ratio specified (max. 15:1). Vee Bee Consistometer Test was adopted in laboratory to know approximate OMC of DLC mixes. 22.7 kg surcharge mass was placed on top of the test specimen just to simulate field condition before applying vibration on it. Alternatively, the OMC and density relationship can also be established by preparing cubes with varying moisture content and compacting the mix in three layers with vibratory hammer fitted with a square or rectangular foot. The OMC was about 7% for PPC mix and 5.5% for OPC, respectively. A simple calculation for Vee Bee consistometer test on concrete mix with PPC is shown in Table 8.

## Trial dry lean concrete mixes and specimen preparation

Several trial mixes of DLC, with variation in aggregates-to-cement ratio, moisture content near about the OMC obtained by Vee-bee test and cement content were used in this work. The DLC trial mix concrete cube specimens were compacted with the help of a Vibrating Jack Hammer as shown in Figure 2. This equipment is used for stiff to extremely dry concrete mixes i.e. no slump concrete mixes commonly used in roller compacted concrete construction [9]. This hammer is used for preparing test specimens from concrete when the standard procedures of rodding and internal vibration are not applicable.

The mixing of DLC mixes was done in a tilted drum mixture as per the standard procedures. After proper mixing the standard cube specimens of concrete were prepared. Optimum moisture was used near about that determined by Vee-bee test. Several specimens of 150 mm cube were cast for the determination of compressive strength on 3, 5, 7, and 28 days to study the strength development and to

**Table 8. Vee Bee consistometer test results for DLC manufactured with PPC**

| **Moisture content (%)** | 5.5 | 6.0 | 6.5 | 7.0 | 8.0 |
|---|---|---|---|---|---|
| **Mass of cylindrical mould + Consolidated specimen ($M_1$ kg)** | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 |
| **Mass of the cylindrical mould ($M_2$ kg)** | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| **Mass of the specimen ($M_3$ kg)** | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| **Mass of the mould + Mass of specimen + Mass of water ($M_4$ kg)** | 22.20 | 22.25 | 22.30 | 22.50 | 22.30 |
| **Mass of mould + Mass of water ($M_5$ kg)** | 14 | 14 | 14 | 14 | 14 |
| **Dry density (kg/m$^3$)** | 2250 | 2269 | 2288 | 2368 | 2288 |

*Figure 2. Vibrating hammer used for the compaction of DLC cubes*

**Table 9. Dry lean concrete mix proportions with OPC**

| Mix No | O-1 | O-2 | O-3 | O-4 |
|---|---|---|---|---|
| OPC (kg) | 125 | 140 | 160 | 170 |
| Aggt/Cement | 14.9:1 | 14.2:1 | 12.7:1 | 12.4:1 |
| Water (kg) | 120 | 132 | 122 | 138 |
| M. C. (%) | 6.0 | 6.4 | 5.6 | 6.0 |
| Fresh density (kg/m$^3$) | 2140 | 2220 | 2310 | 2235 |

**Table 10. Dry lean concrete mix proportions manufactured with PPC**

| Mix no. | M-1 | M-2 | M-3 | M-4 | M-5 |
|---|---|---|---|---|---|
| PP cement (kg) | 153 | 150 | 176 | 200 | 165 |
| Aggt/Cement | 13:1 | 13:1 | 11:1 | 9.7:1 | 12.5:1 |
| Water (kg) | 140 | 155 | 139 | 138 | 144 |
| M. C. (%) | 6.6 | 7.4 | 6.5 | 6.5 | 6.5 |
| Fresh density (kg/m$^3$) | 2260 | 2247 | 2255 | 2270 | 2360 |

explore the possibility to reduce the curing period for the compressive strength required i.e. 10 MPa at early days for the same mix. Vibrating hammer was used to ensure proper compaction of cube specimens. Figure 3 shows the compaction of cube specimen being done by using vibrating hammer. The procedure to prepare dry lean concrete specimens for testing was followed in accordance with ASTM C1435, "Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer". Cube specimens were de-molded approximately 24 hours after the casting. Immediately after demolding, the specimens were submerged in a curing tank containing water for curing till the test age. Tables 9 and 10 present the details of DLC trial mix proportions manufactured with OPC and PPC, respectively.

The specification IRC-SP:49 requires determination of 7- day cube compressive strength as the acceptance criteria. The compressive strength of DLC mixes was determine as per standard procedure of Indian Standard [10]. As mentioned in previous section, the study also aimed to investigate the possibility to reduce the curing period for DLC mix satisfying the present criteria of its acceptance; however for this paper only strength developed at 7 days is being reported.

## RESULTS AND DISCUSSION

7-day cube compressive strength is the main acceptance criteria for the dry lean concrete mixes. Therefore, standard cubes prepared from DLC mixes were tested for strength development at 7-day.

*Figure 3. Compaction of DLC cubes using vibrating hammer*

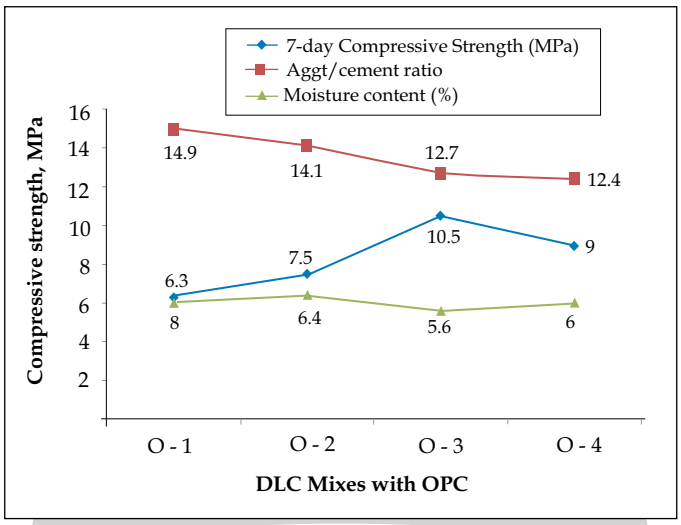


*Figure 4. 7-Day compressive strength, aggregate-to-cement ratio and moisture content of different DLC mixes manufactured with OPC*

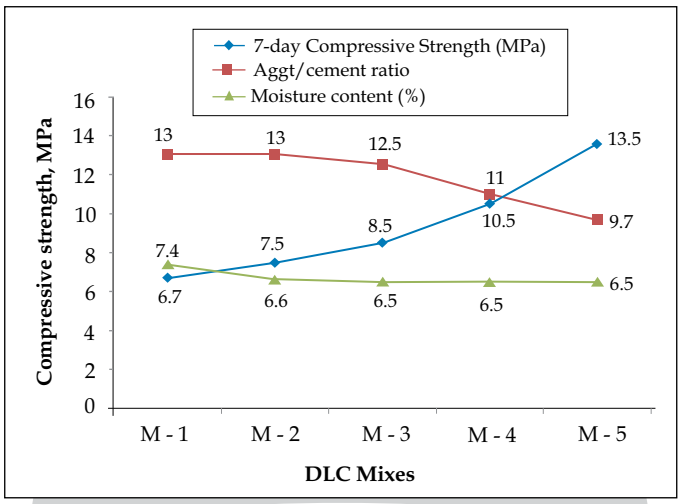


*Figure 5. 7-Day compressive strength, aggregate-to-cement ratio and moisture content of different DLC mixes manufactured with PPC*

## Compressive strength

The compressive strength determined at 7-day, aggregate to cement ratio and moisture content of different DLC mixes with OPC and PPC are shown in Figures 4 and 5, respectively. For DLC mixes with OPC, Mix O-3 developed required strength at 7-day. An increasing trend for the compressive strength with decrease in aggregate to cement ratio is also obvious (Figure 4). It is to be noted that even at the same moisture content, DLC mix with lesser aggregate – to-cement ratio developed higher strength. The requirement of compressive strength at 7-day age is satisfied at maximum aggregate-to-cement ratio of about 13. The maximum density of the fresh concrete was 2310 kg/m$^3$.

Figure 5 shows that 7-day compressive strength, aggregate-to-cement ratio and moisture content of DLC mixes manufactured with PPC. M-5 showed the maximum strength developed at 7-day followed by Mix-4. No other mixes developed a strength of 10 MPa at 7-day. The concrete mix M-5, which developed maximum compressive strength, had aggregate to cement ratio of 9.7:1 with a cement content of 200 kg/m$^3$. The concrete Mix-4 has developed a compressive strength (10.5 MPa) just exceeding the required minimum compressive strength criteria for DLC i.e. 10 MPa to be used in concrete pavement construction. The aggregate to cement ratio for this mix is 11:1. The moisture and cement contents for the mix are 6.5% and 176 kg/m$^3$, respectively which is about 16% and 10% higher that of the case with OPC. Similar to the trend seen in the case of DLC mixes manufactured with OPC, it is also obvious that decrease in aggregate-to-cement ratio strength of concrete increases.

The density of the dry lean concrete manufactured with PPC is 2255 kg/m$^3$ which are lesser about 2.5% than the DLC mix manufactured with OPC. The study reveals that the maximum aggregate to cement ratio i.e. 15:1 given as a guideline for DLC manufacture with OPC is not valid for the manufacturing of dry lean concrete either with OPC or PPC and hence needs to be realistic.

## CONCLUSIONS

From this extensive R&D study the following major conclusions may be drawn:

- The maximum aggregate-to-cement ratio for DLC to be manufactured with OPC satisfying the strength requirement is 13:1.
- The minimum OPC content for the manufacturing of dry lean concrete satisfying IRC:SP-49, strength requirement is 160 kg/m$^3$.
- The minimum portland pozzolona cement content for the manufacturing of dry lean concrete satisfying IRC: SP-49, strength requirement is 176 kg/m$^3$ which is 10% higher than the amount of OPC.

- The optimum aggregate to cement ratio for DLC manufactured with PPC is significantly lower (11:1) than the case of OPC i.e. 13:1.

- The optimum moisture content for DLC manufactured with PPC is significantly higher than the case of OPC. It is 6.5% for PPC and 5.6% for PPC indicating about 10% more requirement of water for DLC to be manufactured with PPC.

- The specification for manufacturing of DLC i.e. IRC: SP-49, needs improvement keeping in the mind the fact that PPC is not OPC.

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