# Development of High Strength Concrete Using Quarry Dust as Fine Aggregate

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## *Abstract*

*High strength and high performance concretes are being widely used nowadays all over the world. In developed countries, use of high strength concrete in structures today has resulted in both technical and economical advantages. In high strength concrete, it is necessary to reduce the water-cement ratio and which in general increases the cement content. To overcome low workability problem, different kinds of pozzolanic mineral admixtures and super plasticizer are used to achieve the required workability. A conventional M30 grade concrete mix design was made using ACI, BS and IS methods and based on the 7 day strength an optimum mix was recommended for experimental studies. In the designed mix sand replacement by weight of 0%, 20%, 40%, 60%, 80% and 100% with quarry dust was considered. Concrete with these six different mix ratios were prepared and for the sake of exclusive reality, no plasticizer was used. Workability tests were conducted; relevant specimens were cast, cured and tested for strength and water absorption characteristics. Irrespective of the percentage replacement of sand with quarry dust, as the variations in the strength results were found negligible, a total 100% sand replacement with quarry dust was considered for further research.*

***Keywords:*** *Compressive strength, splitting tensile strength, modulus of rupture, bond strength, Quarry dust, workability.*

## 1. Introduction

The environmental impacts of the concrete industry by conservation of cement, aggregates, water or additives and admixtures can be reduced through resource productivity by conserving materials and energy for concrete making and by improving the durability of concrete products. Even though the task is most challenging as it results and experiences in the scarcity of resource materials, it can be accomplished if pursued diligently through a possible way without much affecting the basics and requirements of concrete technology and construction techniques so far applied. In this series, globally, the problem of exploitation of conventional river sand is predominantly referred by all.

Quarry dust is a byproduct of quarrying, crushing, and sieving activities resulting in the production of about 10-15% non valued waste in the stone quarries which are invariably named as quarry dust(QD), quarry waste (QW), quarry sand(QS), rock powder dust (RPD), crushed sand(CS), crushed rock powder(CRP) or artificial sand(AS) by different authors.. Utilization of quarry dust reduces the burden of dumping dust on earth causing pollution.

## 2. Literature Survey

Quarry dust has been used along with some additives and admixtures for enhancement of certain properties of concrete. Karthikeyan and Ponni (2007) have successfully produced flyash based bricks with lime, gypsum, sand using quarry dust as the main filler material. Safiuddin et al (2007) also have tried the partial replacement of sand with quarry dust in fly ash/silica fume based concrete and concrete having 20% sand replaced with quarry dust and 10% weight replacement of cement with flyash and same 10% weight replacement of cement with silica fume by consideration. It was found that quarry dust as fine aggregate enhanced the slump and slump flow of the fresh concretes without affecting the unit weight and air content of the concrete. In hardened concretes, the compressive strength was decreased, the dynamic modulus of elasticity and initial surface absorption were marginally increased. However, the best performance was observed when quarry waste was used in the presence of silica fume.

Joseph et al (2012) investigated the structural characteristics of concrete using various combinations of lateritic sand and quarry dust as complete replacement for conventional river sand. The laterite was varied from 0-100% against quarry dust at intervals of 25%. Workability tests were earlier carried out to determine the optimum w/c ratios for three different grade mixes (1:1:2, 1:1.5:3 and 1:2:4). The results compared favorably with those of conventional concrete and the concrete was found to be suitable for use as structural concrete for buildings and related structures, where laterite content did not exceed 50%.

Quarry dust has also utilisation in other areas of application. quarry dust with equal addition of flyash by 20-30% weight of soil found to improve the geotechnical properties of expansive soil (Mir and Shubhada, 2011). Research has also been undertaken to regenerate the poor soils into highly productive systems and proved the use of rock dust (RD) for soil remineralization in Scotland (Robin and John Ferguson, 2004). It is reported that the Research and Development contributes to the Scottish environment, soil sustainability, national agricultural productivity and assist in meeting targets such as those for recycling and the mass-balance of industrial carbon through sequestration. Jaison (2008) tried quarry dust successfully as a silica ingredient for the production of CPP Manure to be used for pest infestation and disease control for crops.

## 3. Materials Used

The constituent materials, additives and admixtures planned for use both in the preliminary and primary investigation for the development of quarry dust concrete are given below:

1. Cement
2. Sand
3. Quarry dust
4. Coarse aggregate
5. Silica fume
6. Fly ash
7. Water
8. Super plasticizer

The design and general parameters as engineering properties were determined for the constituent materials as per the Indian standards.

**Table 1. Properties of the concrete constituents**

| No | Material | Properties | | Relevant codes |
|---|---|---|---|---|
| 1 | Cement OPC 43 grade | Fineness | 5 % | IS: 12269-1987 |
| 2 | | Specific gravity | 3.15 | |
| 3 | | Initial setting time | 55 min | |
| 4 | | Final setting time | 525 min | |
| 5 | Aggregate(Sand) | Fineness modulus | 2.71 | 36 (Part-I) -1963 |
| 6 | | Specific gravity | 2.56 | |
| 7 | | Bulking factor | 35% | |
| 8 | Fine Aggregate (Quarry Dust) | Fineness modulus | 3.36 | |
| 9 | | Specific gravity | 2.60 | |
| 10 | | Bulking factor | 47% | |
| 11 | Coarse Aggregate | Maximum size | 12 mm | IS 383 – 1987 |
| 12 | | Fineness modulus | 7.14 | |
| 13 | | Specific gravity | 2.61 | |

**Table 2. Details of Low calcium flyash and Silica fume**

| No | Low calcium flyash | | Silica Fume | | |
|---|---|---|---|---|---|
| | Chemical compounds | % Fraction | Properties | Results | |
| | | | | By supplier | By testing |
| 1 | $SiO_2$ | 54.04 | Bulk density | 1.96 kN/$m^3$ | 1.96 kN/$m^3$ |
| 2 | $A1_2O_3$ | 26.69 | Loss on ignition | Max. 3% | Max. 2% |
| 3 | $Fe_2O_3$ | 11.31 | Specific gravity | 2.20 | 2.20 |
| 4 | CaO | 01.46 | Specific surface | 22000 $m^2$/kg | 22150$m^2$/kg |
| 5 | $Na_2O$ | 00.41 | $SiO_2$ | Min. 90 % | Min. 92 % |
| 6 | $K_2O$ | 00.85 | Moisture content | Max. 1.5 % | Max. 1.5 % |
| 7 | $TiO_2$ | 01.61 | - | - | - |
| 8 | MgO | 00.79 | - | - | - |
| 9 | $SO_3$ | 01.60 | - | - | - |
| 10 | LOI | 01.24 | - | - | - |

**Table 3. Details of Super Plasticizer**

| No | Properties | Results reported |
|---|---|---|
| 1 | Type (Conplast SP 430) | Sulphonated Naphthalene Formaldehyde |
| 2 | Specific gravity | 1.220 - 1.225 |
| 3 | Recommended dosage | 0.6 - 1.5 liters per 100 kg of cement |
| 4 | Solid content | 40% |
| 5 | Compatibility | All type of cement except high alumina |
| 6 | Workability | highly workable flowing without segregation |
| 7 | Compressive strength | Early strength up to 40 -50% |
| 8 | Durability | Increase in density and impermeability |

| | | |
|---|---|---|
| 9 | Chloride content | Nil (IS 456-2000 and BS 5075) |

## 4. Mix designations:

**Table 4. Mix proportions by various methods for M30 grade concrete**

| No | Parameters | IS Method | ACI Method | BS Method |
|---|---|---|---|---|
| 1 | Mix proportion | 1: 1.2: 2.3 | 1: 1.22: 2.34 | 1: 1.34: 2.36 |
| 2 | w/c ratio | 0.37 | 0.38 | 0.42 |
| 3 | Target strength ( MPa) | $f_{ck} = 37.51$ | $f_{ck} = 42.36$ | $f_{ck} = 43.75$ |
| 4 | Cement (kg/m$^3$) | 456 | 396 | 443 |
| 5 | FA (kg/m$^3$) | 528 | 741 | 710 |
| 6 | CA (kg/m$^3$) | 1166 | 1031 | 1061 |
| 8 | Slump (mm) | 15 | 21 | 27 |
| 9 | 7 day strength (MPa) | 24 | 22 | 20 |
| 10 | 28 day strength (MPa) | 36 | 40.3 (32) | 39.6(34) |

As referred the IS method of design is taken for consideration.

## 5. Results & Discussions

### 5.1. Workability

The QD is coarser than sand but the amount of finer particles retained in sieve size between 300 micron to 150 micron is almost double that of sand that increased the water requirement. The QDC required water-cement ratio ranging between 0.42 and 0.45 with 60% to 100% replacement respectively. From the figure 1, it was observed that the workability goes on reducing according to the percentage of sand replacement level in the slump test as well as compaction factor. But the percentage flow increased due to increase of quarry dust content therefore more segregation. For the concrete having totally sand replaced quarry dust concrete QDC, the same trend existed compared to standard concrete SC as detailed in figure 2.

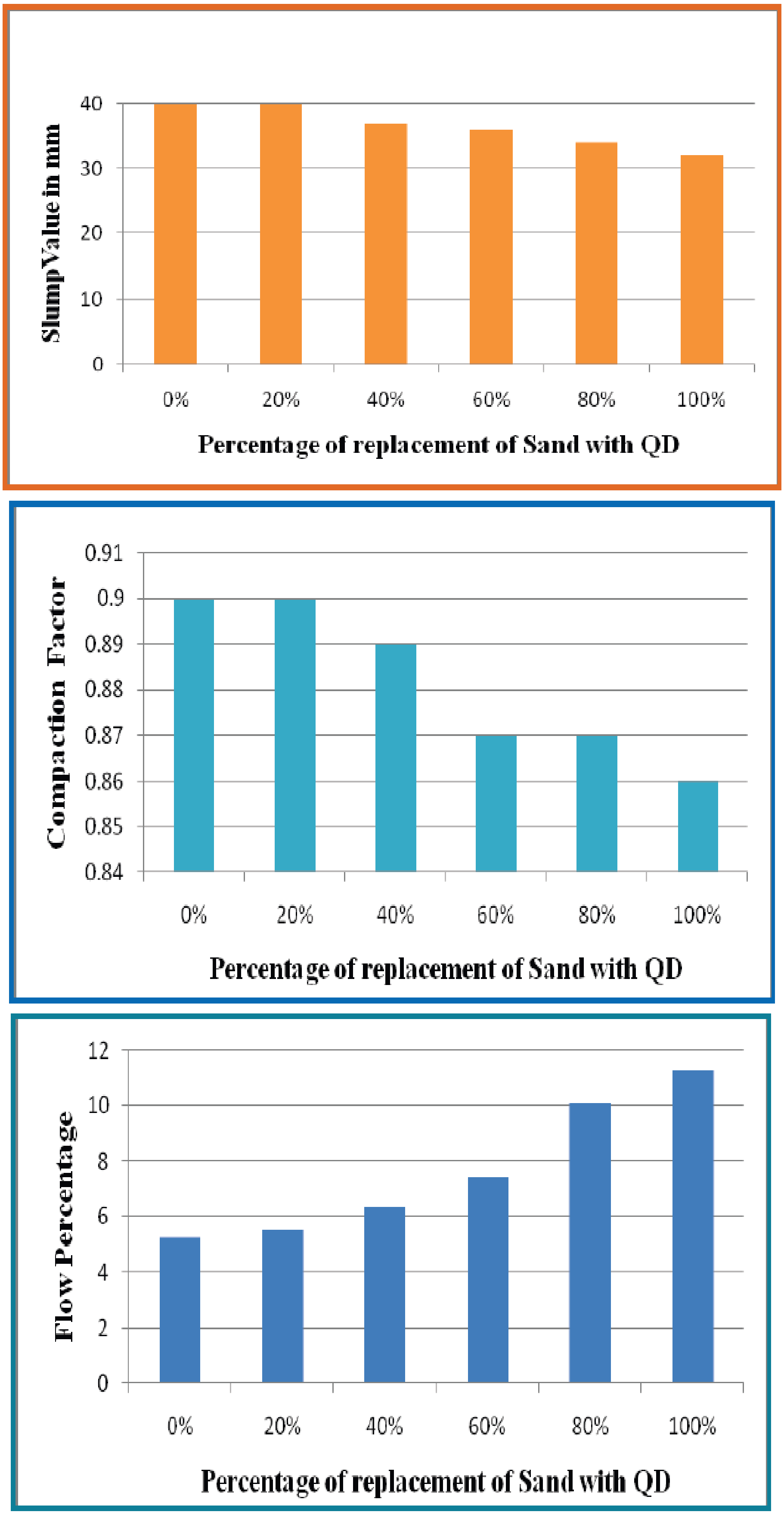


**Figure 1. Comparison of workability characteristics for M30 Concrete**

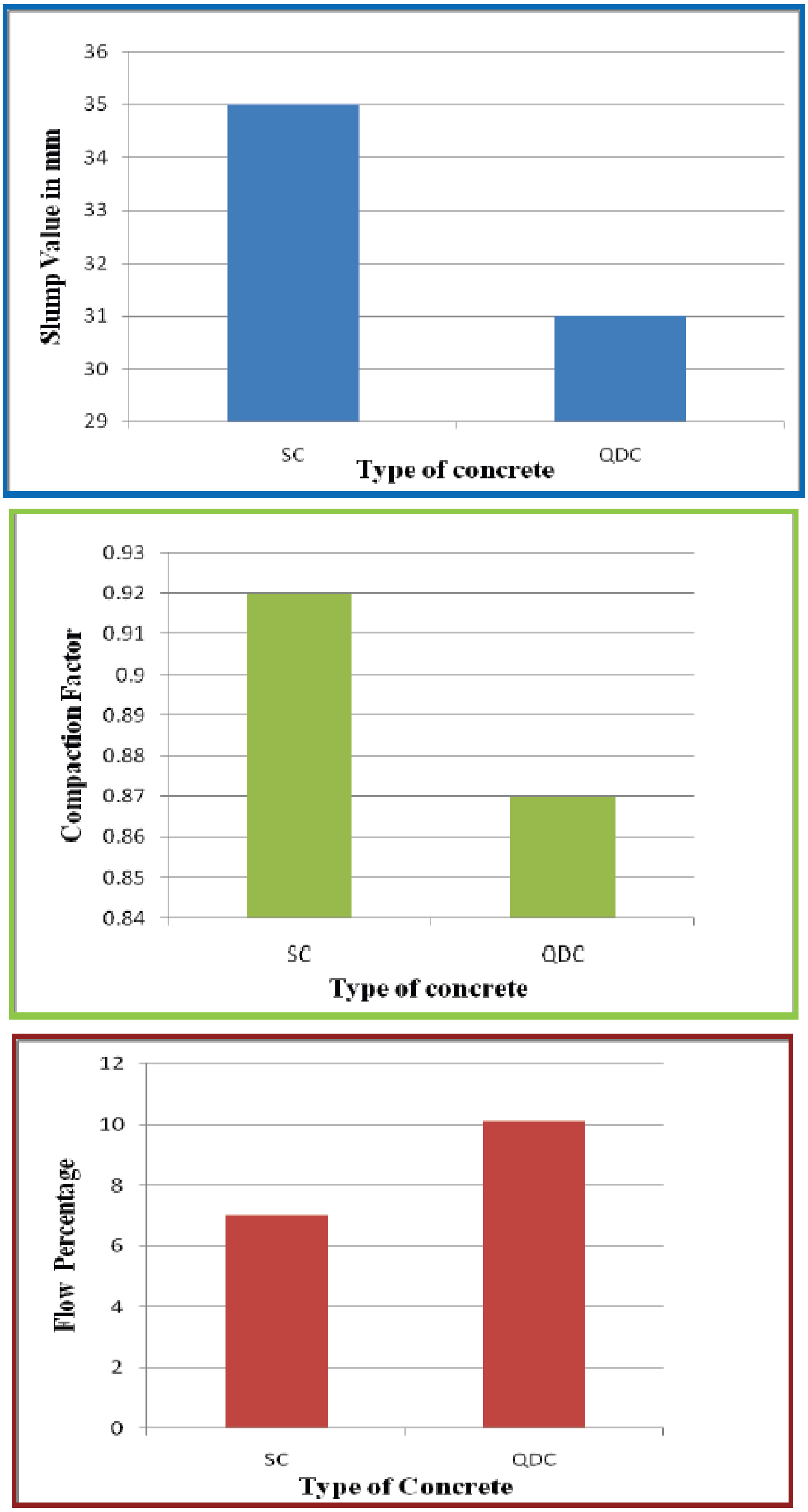


**Figure 2. Workability characteristics of SC and QDC for M30 grade**

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### 5.2. Analysis for Strength Characteristics:

Even though the 7 day strength was used to assess the quality of the trial mix proportions, the rate of gain of strength in 3, 7 and 28 days of curing was made for comparison to study the variations if any due to percentage variation in the sand replacement levels.

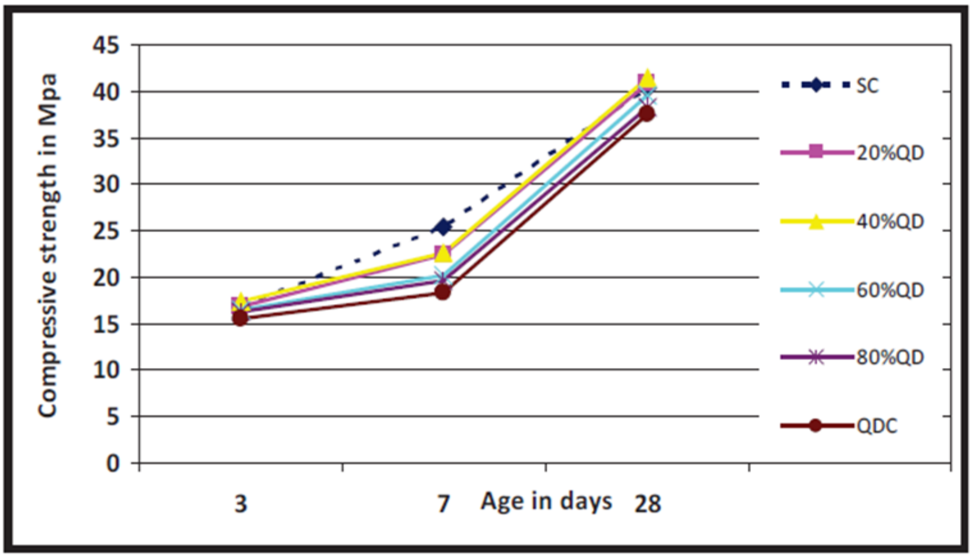


**Figure 3. Rate of Strength development of M30 grade concrete**

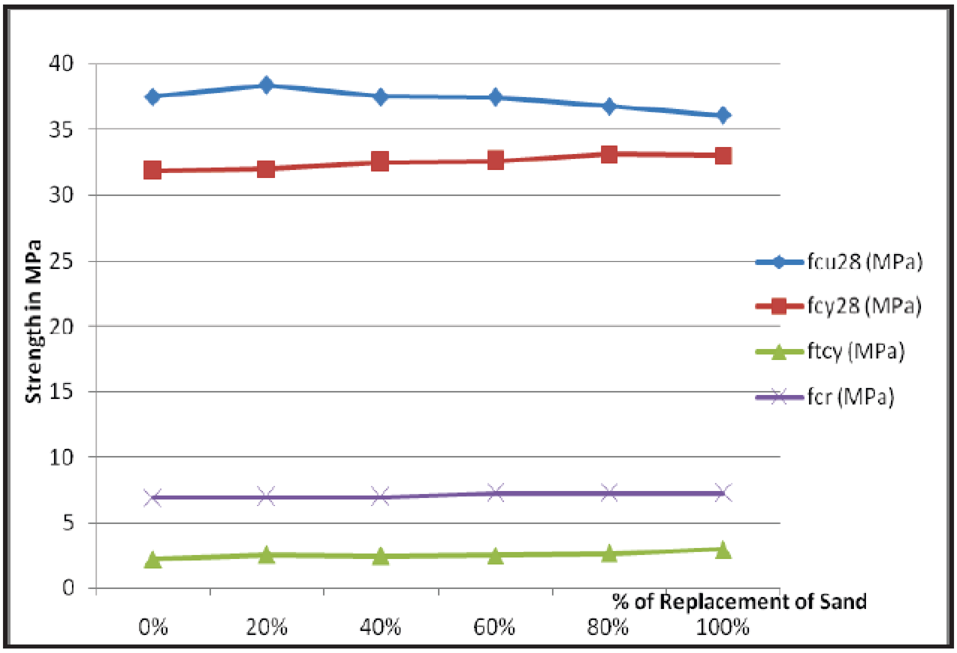


**Figure 4. Comparison of 28 day Strength of M30 grade concrete**

### 5.2.1. Discussions:

*Rate of gain of compressive strength:*

The rate of gain of cube compressive strength up to 28 days is compared. The cube Compressive strength for concrete mixes with replacement of fine aggregate using quarry dust is presented in figure 3. It is observed that there is a reduction of only

7.09 % for QDC compared to SC and is directly proportional to the increase of sand replacement.

*Compressive strength in 28 days:*

The 28 day compressive strength of concrete grades based on testing cubes and cylinders are presented in figure 4. As seen, there is not much variation for the 28 day strength due to the variations in the percentage replacement of sand with quarry dust.

*Splitting tensile strength in 28 days:*

The splitting (indirect) tensile strength based on testing cylinders on 28 day of curing are presented in figure 4. As observed, there is not much variation for the 28 day splitting tensile strength due to the variations in the percentage replacement of sand.

*Modulus of rupture:*

The modulus of rupture value by flexure test using prisms are also presented in figure 4 and it is clear that there is not much variation with respect to variations in the percentage replacement of sand with quarry dust.

**5.3. Total replacement of sand with quarry dust:**

For the concrete grade of M30, exclusively sand concrete and quarry dust concrete were made to determine and compare various strength parameters.

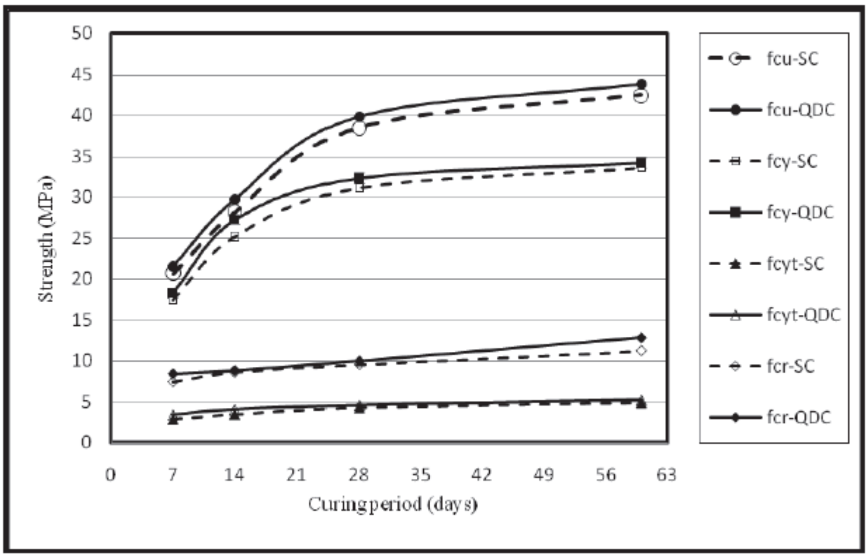


**Figure 5. Strength Comparison of SC and QDC for M30 grade**

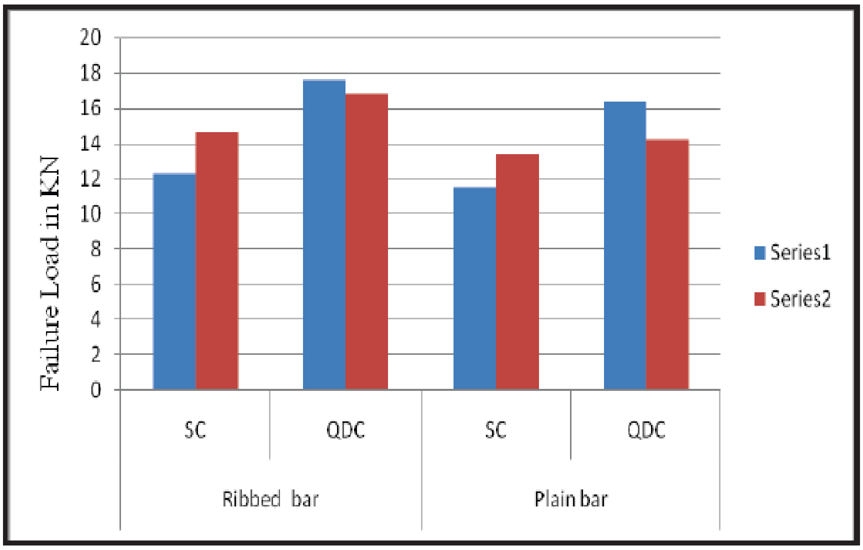


**Figure 6. Pull out test for SC and QDC for Plain and Ribbed bar**

**5.3.1. Discussions:**

*Compressive strength:*

It is observed from figure 5 that the cube compressive strength of QDC is uniformly more (2 to 4 %) than SC in 7, 14, 28 and 60 days of testing. This increase in the strength of QDC is due to interlocking nature of particles in the QD. Similarly, the cylinder based compressive strength also has the same trend as cube compressive strength (1 to 3%).

*Splitting tensile strength and modulus of rupture:*

Even though, the split tensile strength and modulus of rupture are more for QDC in all days of testing than SC, the difference is marginal. It is only 1-2% for split tensile strength and 1-3% for modulus of rupture.

*Pullout test:*

The comparison of pullout test results an indication of bond between concrete and rebar is made in figure 6. It is seen that QDC has performed better than the sand concrete, since the presence of rough textured particles in QD. By comparison, QDC took more load. In case of plain bars the difference is 5 % and for ribbed bars 13% only.

## 6. Conclusions:

1. Mix design can be made using the properties of quarry dust as fine aggregate for low, medium and higher grades of concrete as done for conventional river sand concrete. The design procedure is similar as that of conventional sand concrete.
2. In the preliminary study for the conventional M30 concrete having sand replaced from 0-100 percent with quarry dust, the water-cement ratio ranges between 0.42 and 0.45 with 60% to 100% sand replacement respectively. The workability goes on reducing according to sand replacement level (0, 20, 40, 60, 80 and100%) by slump and compaction factor. But the percentage flow increased due to increase of quarry dust content therefore leading to more segregation. For the concrete having totally sand replaced QDC, the same trend existed as standard concrete SC.
3. For M30 grade of QDC the trend is same as SC but the slump value is always less compared to SC for all grades. The compaction factor also shows the same trend as slump value but, for higher grades, the addition of fly ash reduces the workability and silica fume increases the workability. Generally, the percentage flow is less for QDC compared to SC including the concrete with up to 20% addition of fly ash and 30% fly ash added concrete

shows little higher flow. But addition of silica fume does not show any significant difference.

4. The rate of gain of cube compressive strength of M30 grade concrete up to 28 days is typical for 0-100% replacement of sand with quarry dust. There is a reduction of only 7.09 % for QDC compared to SC and is directly proportional to the increase of sand replacement. There is not much variation for the 28 day strength due to the variations in the percentage replacement of sand with QD.
5. There is not much variation for the 28 day splitting tensile strength and modulus of rupture due to the variations in the percentage replacement of sand for M30 grade concrete.
6. For the M30 grade of QDC, the cube compressive strength is uniformly more (2 to 4 %) than sand concrete in 7, 14, 28 and 60 days. This increase in the strength due to interlocking nature of particles in the QD. Similarly, the cylinder based compressive strength also has the same trend as cube compressive strength (1 to 3%).
7. The split tensile strength and modulus of rupture are more for QDC than SC and the difference is only marginal. It is only 1-2% and 1-3% respectively.

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