Study on the Behavior of Rigid Pavement Using Quarry Dust as a Partial Replacement of Sand and Sulfonated Naphthalene Formaldehyde (SNF) as an Admixture

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Abstract: Quarry dust is considered as a possible source of natural sand or fine aggregate in concrete construction work. This could reduce the problem of dumping of quarry dust as a byproduct from stone crusher factory. The experimental work investigates the optimum quarry dust percentage which can be adopted as replacement of fine aggregate in concrete mainly for rigid pavement. The quarry dust is added at different percentages of 0%, 20%, 40%, 60%, 80%, and 100% replacement of fine aggregate for M35 grade concrete thereby to find out the optimum content of quarry dust that can give better strength in concrete. Mix design has been developed for M35 grade of concrete as per IRC 044 – 2017 (Mix Design for Concrete Pavement) and mix design ratio is found as 1: 1.6: 2.62 by using Sulfonated naphthalene formaldehyde (SNF) as an admixture at 1%, and 2%. The required water cement ratio was obtained as 0.39 according to table no.9 of IRC 044 for the target strength of 42.5 N/mm². Optimum strength and workability test values of concrete made up for various proportions of quarry dust along with SNF are compared with conventional concrete of natural fine aggregate after 7 days and 28 days curing. It is found that the strength increased with the increase in curing time and the maximum strength at 28 days curing and 60% quarry dust replacement with 2% addition of SNF. The maximum strength of quarry replaced concrete is obtained as 40.3MPa, 5.6MPa, and 5.1MPa for compressive, flexural, and split tensile respectively.

Key Words: Quarry dust, Concrete pavement, Sulfonated Naphthalene Formaldehyde (SNF), Optimum, Compressive strength, workability.

1. Introduction
Concrete are considered as most durable construction material used to carry heavy load in highways, bridge decks, airports etc. Road plays an important role in infrastructure of every nations. In India also, Ministry of Road Transport and Highway (MoRTH) has opted that the construction of concrete pavement is a primary mode of construction along the National Highway. Rigid pavement are significantly less susceptible to wear and tear defects such as rutting, cracking, stripping, texture loss, and potholes that can occur on flexible pavement surfaces [1]. Construction of concrete pavement encourages a sustainable way of construction.
without affecting the environment like burning coal or bitumen products. The Quarry dust replacement method is also a means of reducing construction cost and sustainability of resources. Fine aggregate is obtained by sand mining along with the river sites. It may cause adverse environmental problems and degradation of natural resources. Increased demand for fine aggregate, combined with dwindling natural resources, has necessitated the search for new sources. So, we need to identify the feasibility to restore the sands by quarry dust [2].

Quarry dust is obtained as a byproduct of crushing rock and gravel to obtain fine and coarse aggregate. About 17 million tonnes of dust are produced every year. The disposal of this huge quantity of dust has serious environmental problems in the country of strongly populated like India. To rectify this great issue of disposal and demand recycling techniques are very much necessary. Chemical admixtures like sulfonated naphthalene formaldehyde are also using widely as a superplasticizer [3]. It can work in less water-cement ratio with better workability and high-strength concrete. We can use normally this super plasticizer up to 2% [IRC 44] in hot climatic regions like India. Some previous related studies are discussed as follows:

Proposed that replacement of sand by quarry dust by a proportion of up to 75 percent increase the strength of concrete. By incorporating fly ash, 100 percent replacement method can be achieved, [3] Stated that if the amount of quarry dust that replaced the fine aggregate is increased then there is suddenly decreased in a slump (mm). However, it is also mentioned that the optimum strength is obtained at 60 percent replacement. So, it is recommendable to be used stone dust as an alternative ingredient of concrete instead of fine aggregates if natural sand is not available at a fair cost. [4] Stated, if we used superplasticizer together with quarry dust, enhances its concrete mechanical properties [4]. When the quarry dust completely replaced those fine aggregate, the strength in compression test is increased by around 85 percent with 1 percent dose of superplasticizer. [4] Showed that cement mortar for brickwork fines obtained from quarry dust has better performance than mortar made up of natural sands. There is a cost reduction of about 12.5% in brickwork and 20.80% in stone masonry by replacing the sand. The utilization of quarry dust leads to eco-friendly construction and economic construction. showed that the optimal results were obtained when replacement of quarry dust and fly ash at 15 percent [5–8]. At this percentage of replacement, the concrete is quite durable when it is supposed to curing for 28 days in Sulphuric acid and sodium chloride. [7] Observed that at 28 days, 25% replacement of quarry dust give better compressive and bond strength in mortar. [8] Proposed, the compressive strength can be promoted by replacing the cement in concrete by combined effects of quarry dust and rice husk together. But the density is decreased when the percentage of additive is increased. It can reduce construction costs and increased. The maximum percentage was found to be 35 percent of replacement for a better performance. stated that for rigid pavement construction replacement of 20% of fine aggregates by quarry dust with 28 days curing is recommended for an economical cost of construction. [9] stated that because of the presence of a lot of finer in quarry dust than sand results in decreased the workability of concrete. After the experimental investigation, it was found that by using superplasticizer and optimum fiber content of 1 percent can compensate the workability issue. Reported that using of stone dust as an alternative component of fine aggregate in construction concrete at 40% or 50% replacement has more strength characteristics than made with other percentages. [8] Mentioned that to attain rheological properties, the fine quarry dust was prone to consume a greater quantity of super plasticizer to achieve the design quarry mixes. High fineness quarry dust has few uses because it induced more w/c ratio. [9] Observed that a concrete mixture of ratio of 1:1.5:3 has been stated to provide maximum strength in their experiment. Up to 50 percent, compressive strength is increased along with increases in the percentage of dust content. However, the strength value for 28 days is greater than the strength for 7 days [9,10].

Chemical admixtures are widely used in concrete construction work to achieve the target strength without any effect in workability or water cement ratio of the concrete mixes. But the previous research works were mostly focused with natural admixtures like fly ash, fiber, bagasse ash, lime etc. Chemical superplasticizers like SNF can also be used in many concrete works to improve the concrete quality. It can be shown that the performance of quarry dust replaced concrete incorporating with SNF for future production of concrete pavement in economical manners [9–15].

2. Material Used

2.1 Cement
As per IRC 015 – 2011, it is mentioned that any of the available cement can be used. But the condition to be satisfied is that the minimum compressive strength at 28days should be greater than or equals to 43 MPa. In this experiment, PPC having the followings properties given in table 1 is used [16–18].

Table 1: Characteristic of Cement

| S. No. | Characteristic properties                        | Value obtained as per IS : 1489 |
|--------|--------------------------------------------------|---------------------------------|
| i)     | Fineness (by Blaine's apparatus)                 | 308 m2/Kg                       |
| ii)    | Setting Time of cement                           |                                 |
| a)     | Initial Setting                                  | 36 min                          |
| b)     | Final Setting                                    | 520 min                         |
| iii)   | Specific Gravity                                 | 3.12                            |
| iv)    | Normal consistency                               | 29 %                            |
| v)     | Compressive Strength at 7days                    | 29.04 MPa                       |

2.2 Coarse Aggregate
The physical characteristics of the coarse aggregate test are conformed to as per IS 383:2016. According to IRC 044 – 2017, it is recommended that the aggregate should be passed in 31.5 mm and retained on a 4.75 mm sieve. In this experimental work, the maximum nominal size of the aggregate is taken as 20 mm. Followings are the results of test conducted on coarse aggregate [19–23], see table 2.

Table 2: Physical characteristic of coarse aggregate

| S. No. | Name of Test             | Value        |
|--------|--------------------------|--------------|
| i)     | Specific Gravity         | 2.64         |
| ii)    | Water absorption         | 0.3%         |
| iii)   | Fineness modulus         | 3.79         |
| iv)    | Impact Value             | 18.428 %     |
| v)     | Crushing Value           | 26.06 %      |
| vi)    | LA Abrasion Value        | 26.4 %       |

2.3 Fine Aggregate
Fine aggregate or sand are the essential component in concrete as a filler material to reduce air void and increase volume of the concrete. The river sand which are passing through 4.75mm and the zone classification of the sand which is conformed to zone II (IS 383:2016 specification) are used as the fine aggregate for this work. The sieve analysis results tested on fine aggregate is given below in table 3.

Table 3: Sieve analysis result of fine aggregate

| Sieve Designation | Weight of retained aggregate (Kg) | Percentage of retained (%) | Cumulative Percentage of passing |
|-------------------|-----------------------------------|-----------------------------|---------------------------------|
| 4.75 mm           | 0.068                             | 3.4                         | 96.6                            |
| 2.36 mm           | 0.218                             | 14.3                        | 85.7                            |
| 1.18 mm           | 0.234                             | 26                          | 74                              |
| 600 micron        | 0.190                             | 35.5                        | 64.5                            |
| 300 micron        | 0.894                             | 80.2                        | 19.8                            |
| 150 micron        | 0.356                             | 98                          | 2                               |
| pan               | 0.040                             | 100                         | 0                               |
Fineness modulus = \( \frac{357.4}{100} = 3.57 \)
Zone classification is obtained as zone II
And Specific gravity of fine aggregate = 2.6

### 2.4 Quarry Dust

The required tests for quarry dust are carried out according to the specification of IS 383:2016. The table 4 shows some physical properties of quarry dust related to this experimental work.

| S. No. | Properties          | Obtained value |
|--------|---------------------|----------------|
| i)     | Specific Gravity    | 2.72           |
| ii)    | Fineness Modulus    | 2.94           |
| iii)   | Water Absorption    | 0.73 %         |
| iv)    | Surface Texture     | Rough          |
| v)     | Particle Shape      | Fine powder    |

### 2.5 Water

The pH value is an essential parameter of water to produce good quality concrete as it chemically participates in the process of making C-S-H gel. Commonly, water used for drinking is considered for this experimental work as per IRC 015 – 2011.

### 2.6 Sulfonated Naphthalene Formaldehyde (SNF)

Sulfonated Naphthalene Formaldehyde (SNF) is also known as a superplasticizer because it works in a high range water reducer admixture. It reduces about 15% - 25% of water and give better results in hot climatic conditions like India. According to IRC 44, up to 2% of chemical admixture by mass of cementitious material is recommended to be used. The followings are some Technical values of SNF, see table 5

| S. No. | Description          | Value     |
|--------|----------------------|-----------|
| i)     | Specific Gravity     | 1.29      |
| ii)    | pH value             | 7.8       |
| iii)   | Bulk density         | 0.75 g/ml |
| iv)    | Sulphate content     | 10%       |
| v)     | Appearance           | Brown colour |

### 3. Methodology

Result and conclusion shown in figure 1
4. Experimental Results and Discussion

4.1 Properties of Fresh Concrete

The various tests conducted to determine the properties of fresh concrete are discussed below.

4.1.1 Slump Test for Workability

The corresponding value slump (mm) for different mixes is represented in the form of the following chart given in fig 2. The given chart is showing that the value of slump increases till the percentage of quarry dust is up to 60% then decreases the workability of concrete mixes. The decrease in slump value with increase in quarry dust addition is caused by the virtue of high water absorptivity of quarry dust. When water cement ratio is kept constant the required workability or slump value can be achieved by using of a SNF as an admixture.
Fig. 2: Showing the different values of the slump (mm) for different mixes.

4.1.2 Compaction Factor Test

The different value of workability according to compaction factor is determined when water-cement ratio is keeping constant at 0.39 (as per IRC 044). The corresponding value of compaction factor for different mixes is given in fig 3. The different proportions of quarry dust replacement are represented by different series with their respective percentage as shown in fig 3. The following given data chart represented the values for corresponding mixes. It is observed that when the doses of admixture increase the compaction factor value also increases up to 60% quarry dust replacement.

Fig. 3: Showing the value of compaction factor for workability.

4.2 Properties of hardened concrete specimen

4.2.1 Compressive Strength
The corresponding value of compressive strength (MPa) for different mixes is represented in the following chart given in fig 4 & 5 for 7 days curing and 28 days curing respectively. The different proportions of quarry dust replacement are represented by different series with their respective percentage of SNF content. In fig 4 it is clearly indicates that the highest compressive strength is obtained as 40.3 MPa when the SNF addition is at 2% with the corresponding quarry dust replacement of 60% at 28 days curing. So, it is recommended that for a high strength pavement concrete the characteristic compressive strength of concrete can be enhanced by using SNF.

![Compressive Strength For 7 days chart](image1)

**Fig 4:** Showing the compressive strength (MPa) values for 7 days curing.

![Compressive strength for 28 days chart](image2)

**Fig.5:** Variation in the compressive strength (MPa) values for 28 days curing.

### 4.2.2 Split Tensile Strength

The recommended value of strength for split tensile test in cylindrical specimen for 7 and 28 days of M35 grade concrete is 2.6 MPa and 3.89 MPa respectively. The corresponding value of different mixes is represented in the form of data chart given in fig 6 & 7. The different proportions of quarry dust replacement
are represented by different series with their respective percentage of quarry dust content. The data chart for split tensile test results given in Fig 5. & 6. shows that the maximum strength that is achieved in different mixes as 5.1 MPa at 28 days curing.

![Split Tensile Strength for 7 days](image1)

**Fig.6:** Showing the value of Split tensile strength (MPa) for 7 days curing.

![Split Tensile Strength for 28 days](image2)

**Fig. 7:** Showing the variation of the split tensile strength (MPa) for 28 days curing.

### 4.2.3 Flexural Strength

The recommended value of flexural strength of beam for 7 and 28 days of M35 grade pavement concrete is 2.7 MPa and 4.2 MPa respectively. The different proportion of quarry dust replacement is represented by different series with their respective percentage as shown in fig.7 and 8. The maximum strength is obtained as 5.6 MPa at 28 days curing with 2% SNF and 60% quarry dust. So, it is shown that the water absorptivity of quarry dust can be adjusted by using SNF in the quarry dust replaced concrete.
Fig. 7: Showing the variation of flexural strength (MPa) of concrete for 7 days curing.

![Graph showing flexural strength value for 7 days curing.]

Fig. 8: Showing the variation of flexural strength (MPa) of concrete for 28 days curing.

![Graph showing flexural strength for 28 days curing.]

5. Conclusions

According to the data obtained, it is shown that the workability of concrete measured in term of slump value reached 62 mm and for compaction factor obtained 0.89 as maximum when quarry dust replacement of 60% and SNF addition of 2%. So, workability of concrete is increased efficiently using SNF for a given w/c ratio without losing the strength of concrete although quarry dust has higher water adsorption value.

- From the corresponding value obtained for compression test, split tensile test, and flexural strength test, the strength of the concrete is obtained as a maximum value of 40.3 MPa, 5.1 MPa and 5.6 MPa respectively. Most of the concrete specimen showed the maximum strength at 60% quarry dust replacement and 2% addition of SNF.
- It is observed that the optimum replacement percentage that can be used quarry dust instead of sand effectively is up to 60% with SNF doses of 1 to 2% to achieve high-strength concrete.
• But the strength of concrete reduced with increases in quarry dust content after 60% quarry dust replacement due to the increase in water absorption by quarry dust.
• So, it is found that the optimum percentage of quarry dust that can be used instead of sand in concrete is 60% using SNF as an admixture at a dose of 2%. For economical purpose SNF can be reduced up to 1%.
• It can also be recommended that Quarry dust can also be used as an alternative material that can replace the sand in concrete to conserve natural sand mining sites for future generations.

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