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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 watercement 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. At the same time, scarcity of concrete constituents and their cost are increasing day by day demanding the promotion of utilization of suitable waste materials as alternatives. Particularly, substitute to conventional sand in concrete are given prime importance due to many social, environmental, economical and budget oriented problems. The present work deals with the development of quarry dust concrete with total replacement of conventional sand with quarry dust and the study is made with systematic approach with sequential steps.

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.

However as the water consumption is slightly more compared to sand concrete, it was decided to use minimum dosage of plasticizer and same recommended for the next phase of study after conformation. To study the feasibility and adoptability of using quarry dust for concrete instead of conventional sand, quarry dust concrete was further considered for thorough investigation.

M30 grade quarry dust concrete was designed with the properties of quarry dust as fine aggregate and workability and strength characteristics were determined. The results are compared with that of sand concrete also.

Similar trials were made for higher grades that include M40, M50 and M60 grades exclusively with quarry dust as fine aggregate. M30 and M40 grades concrete were designed using IS method and M50 and M60 grades by ACI method. To modify, based on the observations on concrete, additives to concrete namely fly ash and silica fume were also considered. Cement replacement by 10%, 20% and 30% of flyash and silica fume by 5% and 10% replacement were considered. For comparison, sand concrete of the above four grades were also considered then and there. Including sand concrete and quarry dust concrete with additives like flyash and silica fume, totally twenty six different mix proportions were considered for experimentation. For these different grades of concrete the workability, strength in various nature and durability characteristics were obtained. Compressive strength at 90 days of curing was also obtained in addition to 7, 28 and 60 days of curing.

Based on the observation from the test results, workability of fresh concrete was gradually improved with super plasticizer and for higher grades of concrete including silica fume, when compared to control concrete. The strength and durability characteristics of quarry dust concrete was increased up to 15% by adding silica fume with QDC when compared to control concrete. The overall test results revealed that quarry dust as fine aggregate with silica fume as a partial replacement of cement up to 10% is an excellent substitute to yield higher strength of concrete.

ANN model has been proposed to predict the compressive strength of concrete for different grades. A reasonably close agreement has been obtained between the experimental and the predicted values.

The qualitative and quantitative conclusions are presented. It is concluded finally that, development of quarry dust concrete by totally replacing conventional river sand is possible, viable and feasible with all positive and negative strategies similar to conventional river sand concrete promoting cost effective technologies at same time promoting the environmental protection against sand mining.

CHAPTER 1

INTRODUCTION

1.0 GENERAL

Concrete is the most popular building material in the world and as such by its ecstasy, there is no substitute for concrete with conventional constituents. But sustaining the building activity in the long-term to meet the future demand for buildings by using the currently available energyintensive materials and building techniques or technologies have become seldom possible. The construction industries contribute green house gas (GHG) emissions (22%) into the atmosphere and as the public concern are responsibly addressed regarding climate change resulting from the increased concentration of global warming and sea level rise; concrete technologists are facing the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice. Of course, the current environmental problems to technology choices that object the production of durable and environmentally friendly concrete are well related.

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.

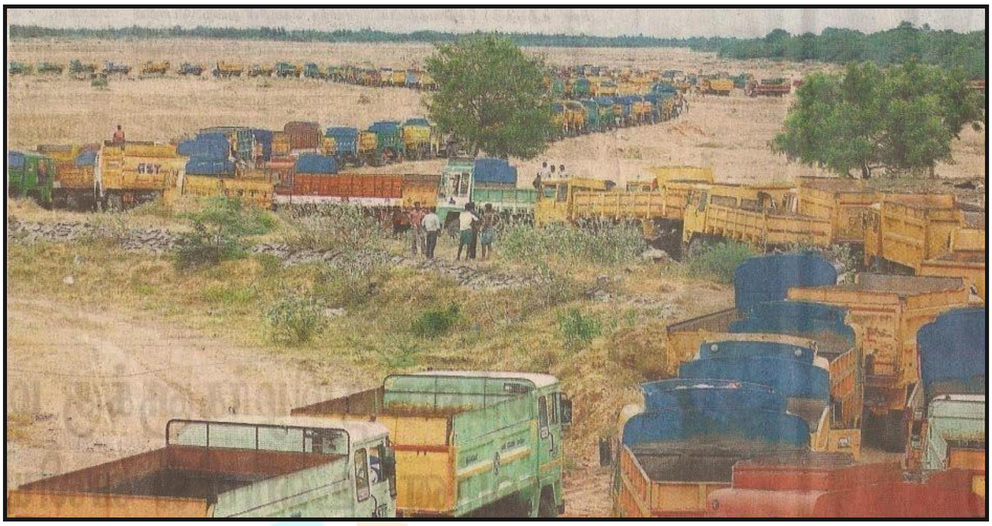
Even though the task is most challenging as it results and experiences in the scarcity of resource materials, it can be accomplished if pursued diligently through a possible way without much affecting the basics and requirements of concrete technology and construction techniques so far applied. In this series, globally, the problem of exploitation of conventional river sand is predominantly referred by all.

1.1 PROBLEM OF SAND MINING

Sand mining from river bed is hazardous to the natural environment. By the over exploitation and use of the material and the deep pits dig in the river bed for sand mining either legally or illegally affects the ground water level and erode the banks and nearby land. In most of the rivers in the east coast of Tamil Nadu, backwater problem exists. The sand mining in rivers has made this more vulnerable by sea water intrusion. Indian Government has imposed ban on mining sand from riverbeds. Dwindling sand resources poses the environmental problem and hence government restrictions on sand quarrying resulted in scarcity of sand and significant increase in its cost. Frequently, the communities residing near the river sides are also make agitations against the sand mining. The legal and illegal activities of sand mining and the response of the affected communities can be viewed through figure 1.1.

The construction industries expect a serious shortage of sand in the near future due to over exploitation of river sand and led to a concomitant price increase in the material. In such a critical situation, the identification of alternatives to river sand is an essential one, otherwise the entire construction industry will be paralyzed if there are no alternative sources. Therefore, it is desirable to obtain cheap,
environmentally friendly substitutes for river sand that are preferably byproducts.

Sand mining and scarcity of sand and similar construction materials and related problems are very typical in remote islands. **Appendix A** highlights the scenario of sand problems in Maldives where sand is imported and supplied in limited quantities to the construction industries. However, the promotional use of artificial sand will conserve the natural resources for the sustainable development of the concrete in construction industries.



(a)Trucks waiting for river sand loading

(b) Illegal sand mining in river bed when objected

(c) Agitation against sand mining

Fig.1.1 Features of Sand mining in river bed leagal and illegal 1.2 ALTERNATIVES TO RIVER SAND

Concrete is a major building material which is used in construction throughout the world. It is extremely versatile and for its feasibility it is used for all types of structures. Due to rapid growth of construction activities, the consumption of concrete is increasing every year in all countries. Even bitumen roads are converted into concrete roads and new roads are laid with concrete only. This results in excessive extraction of natural aggregates. The use of these materials is being constrained by urbanization, zoning regulations, increased cost and environmental concern. Thus, it is becoming inevitable to use alternative materials for aggregates particularly fine aggregate in concrete.

The use of alternative materials not only results in conservation of natural resources but also helps in maintaining good environmental conditions. Offshore sand, nearshore marine sand, dune sand, quarry dust, manufactured sand (M-sand), marble dust, ceramic waste, glass waste, bottom ash and other artificial aggregates produced from industrial waste are some of the referred other alternative sources in recent investigations. Among these, the quarry dust not being used for any applications other than road surfacing was identified as a potential source in the last decade for replacement of conventional river sand in concrete.

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.

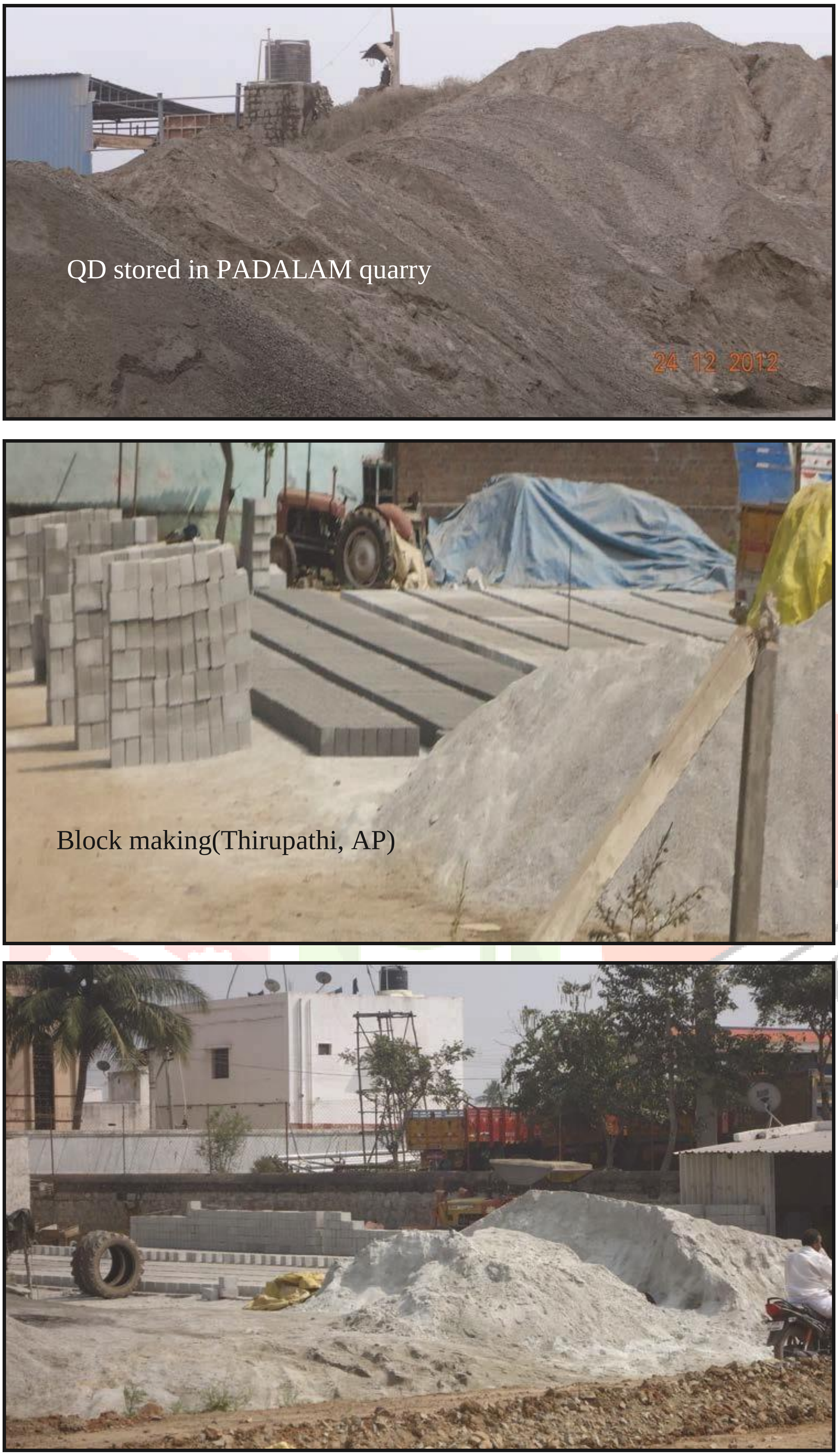


Fig.1.2 Quarry dust as available and use in block making

1.3 QUARRY DUST IN STRUCTURAL CONCRETE

The level of utilisation of quarry rock dust in industrialized nations such as Australia, France, Germany and the United Kingdom has touched more than 60 percent of its production. In Japan, unprocessed crusher dust is usually regarded as only suitable to be incorporated in a blend with natural sand, and only then if it is of good quality, and cheap enough to make the substitution worthwhile. Even though, quarry dust is a problem for the people residing nearby quarries by dumping of quarry dust and an environmental issue causing serious respiratory problems, the potential use as aggregate becomes a positive solution which is an added advantage.

Many researchers in different countries studied the potential use of quarry dust in concrete. Quarry dust is known to increase the strength of concrete over concrete made with equal quantities of river sand, but it causes a reduction in the workability of concrete. When examining the above qualities of fly ash and quarry dust, it becomes apparent that if both are used together, the loss in early strength due to one may be alleviated by the gain in strength due to the other, and the loss of workability due to the one may be partially negated by the improvement in workability caused by the inclusion of the other. The decrease in workability by the addition of quarry dust is reduced by the addition of pulverized fuel ash. The addition of quarry dust causes a loss in slump; though such loss in slump can be significantly reduced by the addition of fly ash. The loss in early strength due to the addition of fly ash can be completely negated by the addition of quarry dust. But the characteristic strength has not been adversely affected at all by the addition of up to certain percentage of fly ash.

However 100% replacement of sand with quarry dust also tried and reported to be successful. For a fine to coarse aggregate ratio of 0.6 in concrete was found to enhance the compressive strength and elastic modulus. When the quarry dust has high fineness, its usage in the normal concrete is limited because it increases the water demand to ensure workability and hence reduction in strength.

Quarry dust could be used for partial or full replacement of conventional sand, but deleterious substances like particles finer than 75µm quarry dust are considered harmful to concrete as results in the different grading, more surface area consuming higher water content and thus reducing the strength and durability characteristics. However, the filler effect is more advantageous and therefore has potential application for SCC and for its flaky nature of texture having an interlocking trend responds for higher tensile strength as well as modulus of rupture.

A 10 percent replacement of sand with quarry dust in the self-compacting filling grouts was found to lead the best performance at fresh state rheological properties and also compressive strength and drying shrinkage at hardened state. Limestone powder (LSP) has been the traditional material used in controlling the segregation potential and deformability of fresh self compacting concrete (SCC) in Singapore. An alternative to this as quarry dust was tried for SCC applications Results from rheological measurements on pastes and concrete mixes incorporating LSP or quarry dust were compared and it was found that the quarry dust, as supplied, could be used successfully in the production of SCC, because quarry dust is flakier and more elongated than lime stone. However, due to its shape and particle size distribution, mixes with quarry dust required a higher dosage of superplasticiser to achieve similar flow properties.

It is reported that the finer fraction of quarry dust increased the stability during flowing and increased the viscosity of the cement matrix. However, the presence of low quantity of quarry dust found to improve the

deformability to a great extent. It is also reported that the incorporation of quarry waste as a partial replacement of sand did not significantly affect the non-destructive properties of the flowing concretes except for initial surface absorption and a slight reduction in the compressive strength due to excessive flakiness. This property is enhanced in presence of silica fume as well as well gradation respectively.

1.4 NEED OF THE HOUR

Unquestionably, the greatest challenge that the concrete industry faces during the 21st century is to achieve a sustainable pattern of growth. The task is formidable but the ideas and examples show that it can be accomplished provided we make a paradigm shift from the culture of accelerating construction speeds to a culture of conservation of energy and material. Unbridled urbanisation fuelling the growth of the construction sector has resulted in excessive mining of sand and this is likely to increase in the years ahead, and sand as a freely available resource may become totally depleted by the year 2050. Therefore, the promotional use of such artificial sand will conserve the natural resources for the sustainable development of the concrete in construction industries.

Currently, research and development (R&D) efforts in developing sustainable building technologies are very much limited in the Indian context. There is a large scope for R&D efforts in developing alternative building technologies and building materials, addressing several issues. Scarcity of concrete constituents and their cost are increasing day by day leading to the promotion of utilization of suitable waste materials. Particularly, alternate material to conventional sand in concrete is given prime importance due to many social, economical and budget oriented problems.

However, it is important to point out that as a waste material, the properties of quarry fines are expected to vary over time and over different quarries. Furthermore, the crushed waste is flaky, badly graded and rough textured and very fine aggregates. Being with more fines, water requirement becomes more and therefore may result in the reduction of strength and granite fines also could promote durability problems. Such issues would need to be first addressed if the material is to be used with confidence in the construction industries.

1.5 ORGANISATION OF THE THESIS

The programme of the present thesis is planned first to analyse

systematically the activities promoted in the utilisation of quarry waste for replacement of conventional river sand in India as well as in other countries through a good quantum of literature collection to identify the problem. Secondly to study and promote the development of quarry dust based concrete by total replacement of sand. The details of the research activities and their degree of viability and feasibility in partially or totally replacing the river sand with alternatives like quarry dust also with additives admixtures were included on the data collected, summarised and detailed in Chapter 2. Based on the selected literature and review, the scope and objectives of the present study are formulated and presented in Chapter 3.

Dealing with the available materials and proposed techniques, preliminary study and the main experimental part made are reported in Chapter 4. The experimental results analysed and comparisons with conventional river sand concrete are presented in Chapter 5. Chapter 6 introduces the theoretical prediction USING Artificial Neural Networks. Finally, Chapter 7 presents the summarized results of the research work as conclusions and recommendations derived from the research study. A list of related references from referred journals and the relevant codes used is also given.

CHAPTER 2

LITERATURE SURVEY

2.0 GENERAL

The need for finding an alternative for river sand arises due to the over exploitation of river sand and its related harmful consequences. Quarry dust has been identified as the next potential substitute for river sand. The crushing activities result in the production of about 10-15% non valued waste in the quarries which are differently referred as quarry dust (QD) by many authors. The use of quarry dust has been dealt almost all parts of the world, but the structural use of quarry dust is still in the research level. A good quantum of studies was made in the area of quarry dust utilization in structural concrete in India and other countries. The attempts made by several authors have been collected and for brevity the important papers are presented here.

2.1 TECHNOLOGY AND ENVIRONMENT

The greatest challenge that the concrete industry is facing the 21st century is how to achieve a sustainable pattern of growth. The task is formidable but can be accomplished provided we make a paradigm shift from the culture of accelerating construction speeds to a culture of conservation of energy and material. The current environmental issues to technology choices objecting the production of durable and environmentally friendly concrete are related as $D = f(P\times I\times W)$ by Kumar Mehta (2001). The environmental damage (D) is a function of three interlinked factors P, I and W where, P- represents the population, I- is an index of industrial and urban growth and W- an indicator of the degree to which a culture promotes wasteful consumption of natural resources. The W-factor has a multiplier effect on the environmental damage due to population growth and by controlling this factor; the degree of damage can be controlled. It is suggested that, we have to examine our current economic models and technological choices that promote wasteful consumption of natural and manufactured materials.

2.2 CONSERVATION OF ENERGY AND MATERIALS

In the conservation of energy and materials, the observation on the utilisation of recycled materials for concrete constituents is brought for prime consideration. Xiao, et al (2006) conducted investigation to analyze the relationships between the mechanical properties of recycled aggregate concrete (RAC) from 1200 test results covering as many recycled materials as possible. In the first phase, the published experimental results during 1985-2004 were analysed and data base developed. The relations between the compressive strength, density, splitting tensile strength, flexural strength, and the elastic modulus were investigated. It is reported that the interrelationships between the mechanical properties of RAC could be quite different from those of normal concrete. Some improved new equations are proposed for the prediction of the relations between the mechanical properties of RAC based on the statistical regression analysis with the least squares method.

Quarry dust is a problem for the people residing nearby quarries and dumping of quarry dust is an environmental issue. It’s a daily ordeal for residents of Trisulam (Chennai, Tamil Nadu) and surrounding areas whose houses, streets, shops and vehicles are invaded by pollutants from the granite quarries and stone crushing units. Exposure to such suspended particulate matter, as pollution experts call it, for long durations can cause serious respiratory problems. Most houses in Trisulam quarries keep their windows shut even in the searing heat to prevent particulate matter from seeping in as highlighted in **Appendix B.**

2.3 PROBLEM OF RIVER SAND

Sand mining from river bed for overuse of the material has led to environmental concerns, the depleting of securable river sand deposits and a concomitant price increase in the material. The deep pits dig in the river bed effects on ground water level and erode the banks and nearby land. A 100 year old steel-concrete composite bridge (Hintze Ribeiro bridge, Portugal, 2001) collapsed killing 70 people is shown in Figure 2.1(a). Another in figure 2.1(b), is an erosion problem near piers due to illegal sand mining. The collapse was due to two decades of illegal but allowed sand extraction which compromised the stability of the bridge pillars.

It will be interesting to note that hours after the accident, the then Minister of Transportation Jorge Coelho resigned. Indian Government has also imposed ban on mining sand from riverbeds. The massive sand mining operations are regulated as with greater monitoring and strict controls imperative to save river beds. However, illegal mining are still going on during night and day time as indicated in **Appendix C.** The local communities in many sand mining areas have objected the sand mining operations and frequently make agitations against the legal as well as illegal mining. The construction industries expect a serious shortage of sand in the near future due to over exploitation of river sand and seeking for alternatives.

2.4 ALTERNATIVES TO RIVER SAND

Potential Alternatives for River sand are near shore marine sand, dune sand, land based sand, offshore sand, quarry dust and manufactured sand (Ekanayaka et al, 2007). Bottom ash is also recommended as substitute for river sand (Aggarwal et al, 2007). With respect to availability, ease of extraction, environmental impact and cost, offshore sand was already used in Sri Lanka mainly for road filling and it was also used for construction in all over the world.

Figure 2.1 Collapsed and eroded bridges due to sand mining

A survey was conducted (Ekanayaka et al, 2007) in Kaluthara-Benthota sea area and a resource distribution map was plotted, samples from Muthurajawela offshore sand stick piles were collected and Cl-content was around 0.3%, where as if the seawater is gravity drained; it reduced to around the acceptable limit of 0.075%. It is found that the action of an average rain fall would be enough to reduce the Cl- contents to below acceptable levels. It is reported that offshore sand was much better than manufactured sand and shows equal average properties as river sand.

2.5 QUARRY DUST WITH ADDITIVES AND ADMIXTURES

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.

2.6 QUARRY DUST IN SPECIAL CONCRETE

Sand replacement by quarry dust up to 30% found to improve the properties of foam concrete as reported by Norazila and Kamarulzaman(2010) that the compressive and flexural strength of foam concrete with quarry dust were nearly 40% more than the control foam concrete. Rock flour had also been tried as a total replacement for sand in concrete with the conventional coarse aggregate partially/fully replaced by ceramic scrap (Reddy and Reddy, 2007) and concluded that the 28 days strength in compression, split tension and modulus of rupture found increased for total replacement of sand with up to 20% replacement of coarse aggregate by ceramic scraps.

2.7 QUARRY DUST IN SCC

A 10% replacement of cement with quarry dust self-compacting filling grouts was found to lead the best performance at fresh state rheological properties and also compressive strength and drying shrinkage at hardened state %XUDN)HOHNRJÙOX 2008). The positive effects of quarry dust on fresh and hardened properties of selflevelling binders make this material a feasible additive besides its economical and environmental advantages. Limestone powder (LSP) has been the traditional material used in controlling the segregation potential and deformability of fresh self compacting concrete (SCC) in Singapore. An alternative to this, quarry dust was tried for SCC applications by Ho, et al (2002). Results from rheological measurements on pastes and concrete mixes incorporating LSP or quarry dust were compared and it was found that the quarry dust, as supplied, could be used successfully in the production of SCC, because quarry dust was flakier and more elongated than lime stone. However, due to its shape and particle size distribution, mixes with quarry dust required a higher dosage of superplasticiser to achieve similar flow properties.

The use of quarry dust as alternative for sand has been attempted by Kamalanathan and Sivakumar (2008) to achieve the self flowing ability in ordinary concrete making materials through Marsh cone test. It is reported that the finer fraction of quarry dust increased the stability during flowing and increased the viscosity of the cement mortar. However, the presence of low quantity of quarry dust found to improve the deformability to a great extent. Revathi et al (2009) made experimental investigation on the performance of quarry waste in fly ash gypsum slurry. The flow ranges selected for the study were 500± 25mm, 425±25mm, 375±25mm, 300±50mm, &
150±50mm. The content of the quarry waste in the mix was increased from 0% to 50% for each of the above flows. Results of twenty mixes proportioned and used in the study evaluated for flowability and compressive strength indicated that quarry waste in fly ash gypsum slurry showed satisfying performance and suitable for a wide range of applications.

Raman et al (2007) investigated the properties such as dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption through nondestructive testing in addition to properties like slump flow, V-funnel flow, air content and compressive strength of flowing concrete made of quarry dust. It is reported that the incorporation of quarry waste as a partial replacement of natural mining sand did not significantly affect the non-destructive properties of the flowing concretes except for initial surface absorption and a slight reduction in compressive strength due to excessive flakiness, which were improved in presence of silica fume and good gradation respectively.

2.8 CHARACTERIZATION OF QUARRY PRODUCTS

Baalbaki et al (1991) reported the results of the tests carried out on high-strength concrete made with different types of crushed rocks, highlighting the role played by

coarse-aggregate through the elastic properties of the parent rock. The results obtained open an opportunity to review the present formulas relating E_c to f_c recommended by some codes. After a long gap, studies are initiated to use quarry dust as fine aggregate to replace partially or fully the conventional river sand.

Jayawardena and Dissanayake (2008) identified the most suitable rock types for manufacture of quarry dust in Sri Lanka, conducting laboratory tests on fresh rock samples from different quarries and determined the mineral composition and reactive forms of silica minerals. Charnockite and charnockitic gneiss and granitic gneiss because of having less than 5% mica are suggested to be suitable rocks to operate as quarries and supply quarry dust to use as an alternative source for river sand in the future. Hornblende biotite gneiss, biotite gneiss, migmatite and migmatitic gneiss showed mica percentages higher than 5% (up to 20%) are not recommended. However, testing of quarry dusts for each quarry is needed while it is producing.

2.9 STRATEGIES AND ISSUES

Venkatarama Reddy (2004) discussed the impacts of alternative building technologies on energy and environment in the Indian context, and presented some thoughts about utilizing industrial and mine wastes as well as recycling of building wastes for meeting the demand for buildings in a sustainable fashion.

In Australia the ranges of products like backfill, geopolymer concrete, light weight building panels, and precast concrete products with the applications of the geopolymer technology are implemented in the quarrying industry to produce commercially viable products from its waste materials. Probably about 10% of Australia's quarry and sand pit production is non-valued production (Mark Drechsler and Andrew Graham, 2005). Many quarry dust/sand products and tailings materials

are high in silica/alumina contents and these wastes have the potential to be a raw material for the production of a range of geopolymer concrete products. The quarrying industry shall recognize that geopolymer technology is complementary to current technologies and increase funding of research into environmentally sustainable initiatives to maintain their competitive advantages.

According to Draft (2005), a strategy was developed to provide plan for the continued supply of construction sand to the Sydney Region over the next 20 years. Extraction of sand resources from lakes are likely to be completed in the next 5-10 years and alternative sources are needed to meet the growing demand of the Sydney construction market. The strategy will provide the basis to manage supply for the Sydney market in the short and longer term; identify primary and secondary sources of construction material resources; provide frameworks for continued access to these resources in land use planning instruments; provide an assessment and approval regime for quarry proposals; develop best practice standards for quarry operation; and encourage the use of substitutes such as recycled material and manufactured sand.

An inescapable fact is that South Wales has very limited land-based sources of natural sand for concrete manufacture and other building purposes and rely almost exclusively on marine dredged sand Hugo Pettingell (2006). Over 90% of the sand used in South Wales comes from the Bristol Channel and Severn Estuary with huge opposition to the exploitation of marine resources. At present, only a small fraction of the requirement comes from land-based sand pits. Wet processing brings additional environmental challenges in silt disposal and other factors. While suitable deposits exist in this area, there is equal or even greater opposition to their exploitation compared to marine sources.

Shaviyani Atoll (2007) has reported the condition of sand mining in Maldives where construction is one of the major activities being carried out in the islands and sand mining has become a common practice, increasing islands vulnerability. Lack of space is a greater constrain in some of the islands for construction of new houses and to develop new infrastructure facilities. An international team of expertise conducted a field mission to the five selected Islands (Milandhoo, Funadhoo, Komandhoo, Foakaidhoo and Kandithem of Maldives) and reported that land reclamation has been found a common denominator in all islands.

In Funadhoo the Island, official introduced a new regulation where 1,000 bags of sand are given as a quota to the existing families of the islands for new construction. At the national level, Government of Maldives promotes safer Island programme through which the households could be relocated in to a new island. Appendix A highlights the scenario of sand problems. In Japan, unprocessed crusher dust is usually regarded as only suitable to be incorporated in a blend with natural sand, and only then if it is of good quality, and cheap enough to make the substitution worthwhile (Hugo Pettingell, 2008).

Alternative building technologies developed by ASTRA (Application of Science and Technology for Rural Areas formed in 1974 at Indian Institute of Science, Bangalore,) are energy efficient and the embodied energy of buildings using these technologies is less than half of the energy consumed by conventional buildings (Venkatarama Reddy, 2004). It becomes inevitable to steadily switch over to the use of energy efficient building materials and technologies and devise methods and mechanisms to utilize industrial/mine wastes and recycling and reuse of building wastes for the manufacture of building materials and products for the sustainable practices.

Limited research has been undertaken to regenerate the poor soils into highly productive systems using potential of techniques and proved the use of rock dust for soil remineralization in Scotland (Robin and John Ferguson, 2004). The rock dust contributes to the Scottish environment, soil sustainability, national agricultural productivity and assist in meeting targets such as those for recycling and the massbalance of industrial carbon through sequestration.

2.10 MIX DESIGN FOR QUARRY DUST BASED CONCRETE

Shanmugavadivu, et al (2008) made mix design for concrete with washed quarry dust as fine aggregate. M20, M30 and M40 grades of concrete were prepared and tested. It was reported that the fine aggregate content was increased while increasing the quantity of washed fine aggregate and simultaneously the coarse aggregate content was reduced accordingly, water cement ratio was decreased while increasing the proportions of washed fine aggregate and the cost of the concrete has reduced with increase in percentage of washed fine aggregate.

2.11 PARTIAL REPLACEMENT WITH QUARRY DUST

Raman et al (2004) reported after experimentation that incorporation of quarry dust of Malaysia as partial replacement material to sand up to 40% in concrete resulted in a reduction of compressive strength, and this was more evident when the replacement proportion was increased due to the weaker aggregate properties compared to sand, but was compensated by the inclusion of fly ash and silica fume into the concrete mix. Prachoom Khamput (2008) reported about the possibility of 70-100% replacement of sand with quarry dust in Thailand and added that the designed w/c ratio was inadequate for workability. Type E admixture found to improve the workability and compressive strength of quarry dust concrete compared to sand concrete.

An experimental study for producing paving blocks using crusher dust was made by Radhikesh et al (2010). Physical and mechanical properties of paving blocks with fine aggregate (sand) replaced by various percentages of crusher dust were investigated. The test results showed that the replacement fine aggregate by crusher dust up to 50% by weight had a negligible effect on the reduction of any physical and mechanical properties while there was a saving of 56% of cost. The percentage of saving would be more and highly beneficial for mass production of paving blocks. Raman et al (2010) investigated the mechanical properties of HSC produced for 28 days strength of 60 MPa having up to 40% replacement of sand with quarry dust and 10% cement with RHA. It is reported that substitution for sand with quarry dust in HSC may contribute some negative efforts in mechanical properties, but can be compensated with CRM such as RHA coupled with good mix design.

Rajendra Prasad et al (2011) studied 0, 10, 20, 40, 60, 80 and 100% replacement of sand with CRP in concrete together with 10% cement replacement with RHA for all mixes and compared the effect of 6 hours of carbon dioxide curing, 12 hours of air curing and 138 hours of water curing on the compressive strength. It was noticed that, there was a cost saving of up to 22% for sand replacement with CRP, a saving up to 40% in the CO_2 curing and a saving up to 40% by the addition of rice husk ash.

Safiuddin et al (2007) considered a conventional 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. It was found that quarry dust as fine aggregate enhanced the slump and flow of the fresh concretes, the unit weight and air content of the concretes were unaffected. In hardened concretes, the compressive strength was decreased in presence of quarry waste due to excessive flakiness, resistance to water penetration decreased, the dynamic modulus of elasticity and initial surface absorption were marginally increased, and the ultrasonic pulse velocity was unaffected. However, the best performance was observed when quarry waste fine aggregate was used in presence of silica fume due to efficient microfilling ability and pozzolanic activity.

Lohani et al (2012) studied the effect of 0%, 20%, 30%, 40%, and 50% partial replacement of sand with quarry dust for a design mix of M20 grade concrete. Due to its high fines of quarry dust it was provided to be very effective in assuring very good cohesiveness of concrete. Thorough reaction with the concrete admixture, quarry dust improved pozzolanic reaction, micro aggregate filling and concrete durability. Aggregates with higher surface area were requiring more water in the mixture to wet the particle surfaces adequately and to maintain a specific workability. Obviously increasing in water content in the mixture would adversely affect the quality of concrete. It was observed that the slump value increases with increase in percentage replacement of sand with quarry dust. Due to flaky particles shape and higher percentage of fines, concrete did not give adequate workability and the concrete had segregation. The increase in dust content up to 30% increased compressive strength of concrete and decreased gradually beyond 30%. But the compressive strength of quarry dust concrete continued to increase with age for all the percentage of quarry dust contents.

The durability of concrete was studied by immersing the concrete cube in 5% solution of MgSo4, 5% solution of NaCl and 2N solution of HCl for 28 days and 91 days and results were compared with the standards. The water absorption percentage of quarry dust concrete decreased for dust content from (0-20) % and then it started to increase for 30%, 40%, and 50% of dust contents. Lower the particle size results in faster absorption and greater surface area resulted in faster evaporation leading to concrete setting quickly.

It was observed that the density of concrete increases with increase in percentage of dust content. There was no loss of strength for immersion in Magnesiumsulphate (MgSO4) and Sodium-chloride (NaCl) solution in comparison with immersion in normal water and the strength gain continued in almost all specimens with no loss in weight. But in case of hydrochloric acid (HCl) solution, It was observed that there was a loss of strength and weight in comparison with immersion in normal water. The deteriorating effect increased with increase in time of exposure of concrete to HCl solution.

Nagabhushana and Sharada bai (2011) studied the properties of mortar and concrete in which crushed rock powder (CRP) was used as a partial and full replacement for natural sand. For mortar, replacement of 20% 40%, 60%, 80% and 100% and for concrete at levels of 20%, 30% and 40% were considered. The strength of mortar containing 40% CRP was found to be much higher than normal mortar containing only sand as fine aggregate. It is reported that it is better to use CRP without removing the finer particles. For lean mortar mixes, CRP can be replaced up to 100% and for rich mortar mixes, up to 40%. It is concluded that the compressive strength, splitting tensile strength and flexural strength of concrete are not affected with the replacement of sand by CRP as fine aggregate up to 40%.

2.12 TOTAL REPLACEMENT OF SAND WITH QUARRY DUST

Sivakumar and Prakash (2011) have reported that 100% replacement of sand with quarry dust for a fine to coarse aggregate ratio of 0.6 in concrete was found to enhance the compressive strength and elastic modulus. When the quarry dust had high fineness, its usage in the normal concrete was limited because it increased the water demand.

Shahul Hameed and Sekar (2009) studied the feasibility of using quarry dust and marble sludge powder as total substitute for sand. It is concluded that the combined use of quarry rock dust and marble sludge powder exhibited excellent performance in strength and durability characteristics due to efficient micro filling ability and pozzolanic activity.

Shaikh and Daimi (2011) presented the comparison of the strength and durability performance through micro-structure related properties of concrete made with natural sand and artificial sand with dust available in the Indian state of Maharashtra. It was found that there was consistently higher strength and the sharp edges of the particles provided better bond with the cement than the rounded part of the natural sand. The weight loss after immersion up to 90 days, chloride permeability and water absorption were same for both concrete.

Waziri and Muazu (2008) examined the properties of thoroughly washed quarry sand (Gwoza, Borno State) as fine aggregate in concrete. The washed and dried aggregates were graded in accordance with BS 812 part 1:1975 and its specific gravity, bulk density, porosity, water absorption, impact value and the aggregate crushing value were well satisfactory. The compressive strength increased with age but decreased with increasing water cement ratio. All mixes used in the study attained over 60% of their 28 day strength at 7 days. Ilangovan et al (2008) studied the strength and durability properties of concrete containing quarry rock dust as fine aggregate. It is found that the strength and durability characteristics of quarry dust are nearly 10% more than the conventional sand concrete.

2.13 HIGH STRENGTH CONCRETE

High-strength concrete (HSC) has undergone many developments based on the studies of influence of cement type, type and proportions of mineral admixtures, type of superplasticizer and the mineralogical composition of coarse aggregates. Most studies were carried out using natural sand with rounded and smooth grains. In practice, crushed sands from various sources are frequently used in concrete.

H Donza, O Cabrera, E.F Irassar (2002) reported that two aspects of the effect of crushed sands on HSCs are presented. First, the performance of crushed sands in relation to natural sand using a low water/cement (w/c) ratio and fixed coarse aggregate and cement content is analyzed. Results show that concrete with crushed sand requires an increase of superplasticizer to obtain the same slump. It also presents a higher strength than the corresponding natural sand concrete at all test ages, while its elastic modulus is lower at 28 days and is the same after that. Studies on the development of hydration and mortar phase of concrete show that the increase of strength can be attributed to the improvement of paste–fine aggregate transition zone. Second, the influence of the mineralogical source of the crushed sands was studied using three different types of crushed sands (granite, limestone and dolomite) with similar grading. Two mixtures containing 450 and 485 kg/m^{3}cement and low w/c ratio are analyzed. Results show the adverse effects of shape and texture on workability of concrete, but the compressive strength of concrete is improved. Granite crushed sand appears as the most advantageous sand for this purpose.

2.14 STRUCTURAL APPLICATIONS

Kyung and Hun (2011) introduced the current efforts to utilize the mineral waste materials from metals industry in Korea. For utilizing waste stone and stone powder sludge generated from domestic quarry and cutting process of stone plates, Korea Institute of Geology, Mining and Materials has developed the manufacturing technologies of artificial stone plate as a building material with firing method and hydrothermal synthesis. It was shown that the manufacturing cost of the artificial stone plate was (18,000 won/m^2), which was merely half that of natural stone plate and the application of those on the building stone industry could be possible.

Arivalagan and Kandasamy (2008) made experimental study on quarry waste concrete filled steel hollow sections and reported that the ultimate moment capacity had increased by 25% compared to normal mix concrete.

2.15 PROBLEMS WITH QUARRY DUST

However, it is important to point out that as a waste material, the properties of granite fines are expected to vary over time. Furthermore, the fineness of granite fines could promote durability problems, such as alkali–silica reactions. These two issues would need to be addressed if the material is to be used with confidence (Ho, et al (2002). Quarry dust may not be suitable for the civil constructions due to the mixture of various broken minerals. Hence, research is in progress in finding the mineralogical quality of the quarry dust (Jayawardena and Dissanayake,2006).

As the use of quarry dust leads to a reduction in the workability of concrete, the concurrent use of quarry dust and fly ash in concrete will lead to the benefits of using such materials being added and some of the undesirable effects being negated (Kapugamage, et al, 2008). The decrease in early strength by the addition of fly ash is ameliorated by the addition of quarry dust. The decrease in workability by the addition of quarry dust is reduced by the addition of fly ash. The concurrent use of the two byproducts will lead to a range of economic and environmental benefits. However, washing of aggregates with raw water (less than 1,000 ppm chlorides; TDS less than 3,500 ppm) may be allowed, provided it is ascertained that this process does not contribute additional water to the concrete mix. Also, cleaning of the aggregates by blowing air or vacuum suction to remove all the dust may also be allowed. For the removal of fines from the quarry dust, dry processes (Clive Mitchell, 2007) and wet processes are available for practice.

2.16 MANUFACTURED SAND

Manufactured sand (M-Sand) as an alternative for river sand has caught the attention of the construction industry in Kerala state of India for its quality and the minimum damage it causes to nature (Kerala TC Draft, 2009). It is recommended that associated with the existing crusher units M-Sand production unit can be promoted by utilising the waste granite metals of the crusher units, and waste generated from quarries for M-Sand productions. The Tamil Nadu government has initiated and encouraged the production of M-Sand and many M-sand producing units are functioning and one such unit of Coimbatore unit is shown in figure 2.2.

The effect of water cement ratio on fresh and hardened properties of concrete with partial replacement of natural sand by manufactured sand was investigated by Priyanka Jadhav and Dilip Kulkarni, (2012). Concrete mix design of M20 grade was made according to IS: 10262. Concrete specimens were tested for evaluation of compressive, flexural and splitting tensile strength respectively. It was concluded that, the concrete exhibited excellent strength with 60% replacement of natural sand, so it could be used in concrete as viable alternative to natural sand.

Fig. 2.2 M-sand manufacturing unit near Coimbatore (Tamil Nadu) Japanese manufacturers began, around the turn of the millennium, to seek a potential niche to fill in the quarrying market. The only growth area seemed to be in the production of

manufactured sand (Hugo Pettingell, 2008); despite a plummeting overall aggregate requirement, natural sand supplies were dwindling faster than the need for concrete. Material described as manufactured sand can range from unprocessed quarry dust to, at best, carefully processed fine aggregate specifically designed for use in concrete or other products. It can be gritty, flaky, and full of filler, or it can be well shaped and graded, assisted perhaps by a fortuitous tendency of the parent rock to produce equidimensional. In some instances serious attempts have been made to mimic the characteristics of natural sand using milling machines and sophisticated classification, but this is usually very expensive.

2.17 SUMMARY

Viable natural sand resources in many areas across the world are running out, either because of extinction or sterilisation of rivers, cost of extraction or transportation, shortage of water for processing in some areas or because of environmental concerns.

The current status of concrete industries facing the scarcity of fine aggregate and quarry dust utilisation as an alternative are reviewed from a thorough literature study and the features are summarized here:

Excessive extraction of sand from rivers carried out almost to the level of complete depletion and further mining is not feasible at all. Therefore it is imperative to stop further extraction of river sand and find alternative solutions immediately. Use of near shore marine sand, dune sand, land based sand, offshore sand, quarry dust manufactured sand and bottom ash have been identified as alternatives to river sand for use as fine aggregate in concrete and carried out studies on concrete. But for viability and feasibility quarry dust is recommended for further research.

The laboratory investigations carried out have shown that quarry dust could be used for partial or full replacement of sand. Deleterious substances like particles finer than 75µm Quarry dust are considered harmful to concrete as results in the different grading, more surface area consuming higher water content thus reducing the strength and reduced durability characteristics. As the filler effect is positive, it has potential application in SCC and the flaky nature has an interlocking trend that responds for higher tensile strength and modulus of rupture. However, by suitably incorporating mineral additives like flyash or silica fume and appropriate admixtures, the quarry dust based concrete could be recognized as a potential replacement for conventional sand based concrete. Further, durability studies have to be considered. Further theoretical model for prediction of the characteristics of QDC has been reported

CHAPTER 3

OBJECTIVES AND SCOPE

3.0 GENERAL

The current status of concrete industries facing the scarcity of fine aggregate like river sand and quarry dust utilisation as an alternative to river sand are reviewed. Based on the literature review the problem was identified. The aim of the thesis is confined to the development of quarry dust based concrete with total replacement of conventional river sand. The scope and objectives are presented here.

3.1 SCOPE AND OBJECTIVES

The scope and objectives are planned in two phases, the first being the preliminary study and the second the main study in the development of quarry dust concrete as detailed here.

3.1.1 Preliminary study

1. Determinatives of the engineering properties for all the constituent materials as well as for the additives and admixtures to suitably incorporate in the mix design and other assessment.
2. Making a conventional concrete mix design for M30 grade concrete using ACI, BS and IS methods and proposing an optimum mix based on the 7 day strength, for all experimentation.Investigation on the workability and strength characteristics of quarry dust based concrete for sand replacement levels of 20%, 40%, 60%, 80% and 100% with quarry dust.

3.1.2 Main study for 100% sand replaced quarry dust concrete (QDC) by making

1. Mix design for M30 grade quarry dust concrete using IS method and investigating the workability, strength and durability characteristics.
2. Assessment on the possibility of 100% replacement of sand with quarry dust in M30 grade concrete.
3. Mix design for M40, M50 and M60 grades of high strength quarry dust concrete using relevant methods and investigating the workability, strength and durability characteristics.
4. Assessing the requirement of additives like flyash and silica fume for enhancing the properties.
5. Analyzing the results for comparison between sand concrete and quarry dust concrete.
6. Study on the compressive strength relationship and create a theoretical model for the quarry dust concrete.
7. Arriving at solid conclusions and recommendations.

CHAPTER 4

EXPERIMENTATAL INVESTIGATION

4.0 GENERAL VIEW

The experimental part of the thesis consists of a preliminary study for fundamental and primarily thorough a detrimental study. The former preliminary study consists of studying the strength development of M30 grade concrete containing quarry dust as a partially replaced material for conventional river sand. The replacement levels of sand with QD consisted of 0% (control) to 100%. The later detrimental one consists of studying the feasibility of using quarry dust based concrete with total replacement of conventional river sand. The workability, strength and durability as the three dimensional characteristics of concrete are considered.

4.1 CONSTITUENT MATERIALS

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

only was used. Besides, river sand (Palar River) and both quarry dust and crushed stone granite coarse aggregate (Padalam quarry) were used. Additives like fly ash and silica fume and admixtures were also used in conjunction with other constituents of concrete wherever necessary. Cement and admixtures were brought one day before using. In order to maintain uniformity, all other constituents except cement and admixtures were procured and stored as heaps in a dry place of the laboratory.

4.1.1 Fine Aggregate

The design and general parameters as engineering properties were determined for the constituent materials as per the Indian standards. The test results on constituents are presented in Table 4.1. The comparison of particle fraction and the chemical composition are given in Table 4.2 and Table 4.3.The views of QD fractions are shown in

Appendix D.

Table.4.1 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	Fine Aggregate (Sand)	Fineness modulus	2.71	IS: 2386 (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 4.2 Comparison of Percentage passing of aggregates

No	Sieve size	% Passing (IS 383: 1970)		
		Fine aggregate		Coarse aggregate
		QD	Sand	
1	40 mm	-	-	100
2	20 mm	-	-	100
3	10 mm	-	-	94.2
4	4.75 mm	94.20	99.00	07.3

5	2.36 mm	77.40	95.70	-
6	1.18 mm	44.60	73.70	-
7	600 ȝ	31.60	42.40	-
8	ȝ	13.00	07.00	-
9	ȝ	02.90	01.00	-
10	0ȝ	00.40	00.10	-
11	Residue silt	00.40	00.10	-
12	Fineness modulus	03.36	02.71	07.14
13	Grading zone	III	III	-

Table 4.3 Chemical composition of Quarry Dust and Sand

No	**Constituents**	**QD (%)**	**Sand (%)**
1	Loss of ignition	01.81	00.61
2	Silica as SiO_2	61.77	97.60
3	Iron as Fe_2O_3	06.03	00.028
4	Titanium as TiO_2	Nil	00.18
5	Aluminium as Al_2O_3	16.74	01.31
6	Calcium as CaO	07.57	00.06
7	Magnesium as MgO	06.08	00.01

4.1.2 Additives and Admixtures

For improving the workability, strength and durability characteristics, certain additives and admixtures are always used for concrete making. In this direction, flyash and silica fume are considered as additives for the present investigation. Coal based low calcium flyash (Mettur

Thermal power station) was used. The chemical composition of such flyash is presented in Table 4.4. The properties of silica fume used (ASTRRA chemicals private Ltd, Chennai, India) are given in Table 4.4. Brown solution of sulphonated naphthalene formaldehyde based super plasticizer (Conplast super plasticizer –SP430) is used. The details of which are presented in Table 4.5.

Table 4.4 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	A12O3	26.69	Loss on ignition	Max. 3%	Max. 2%
3	Fe2O3	11.31	Specific gravity	2.20	2.20

4	CaO	01.46	Specific surface	22000 m^2/kg	22150m^2/kg
5	Na_2O	00.41	SiO_2	Min. 90 %	Min. 92 % [2]
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 4.5 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)

4.2 PRELIMINARY STUDIES

The details of the preliminary study are shown schematically in figure 4.1. A Mix design for M30 grade concrete was made for conventional concrete using IS, ACI and BS methods and optimum proportions were obtained by trial and testing as reported with details in Table 4.6.

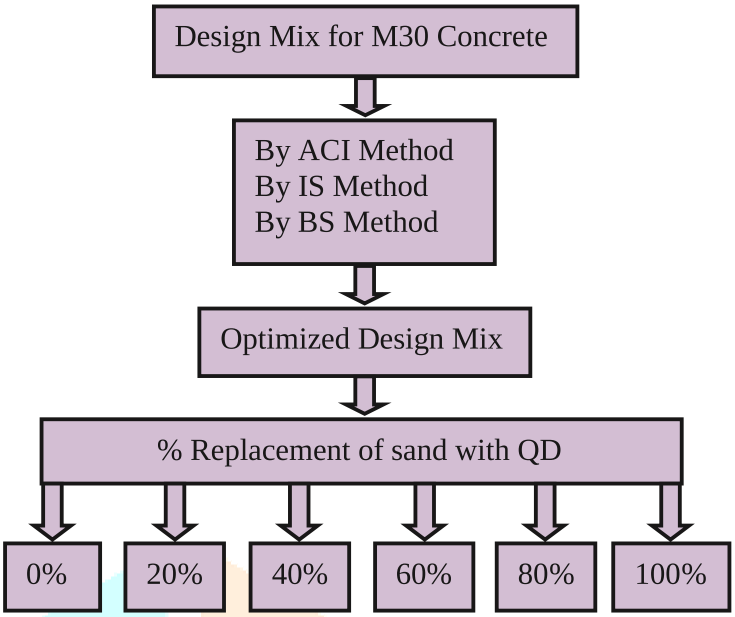


Fig. 4.1 Trial Mix details for M 30 Concrete

Table 4.6 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. For brevity, the IS method of design for M30 concrete only is explained in **Appendix E.**

4.2.1 Partial and full replacement of sand with quarry dust

Totally six different concrete mixes were considered having partial replacement of sand with QD as detailed in figure 4.1 (0% as control and 20%, 40%, 60%, 80% and 100%as replacement levels). Workability tests were conducted for fresh concrete. To obtain the strength in different aspects, control specimens like cubes, cylinders and prisms shown in Appendix F were cast. The details of test specimens are also given in Table 4.7

Table 4.7 Specimen details for various tests

No	Concrete specimens	Nature of test
1	100mm cubes	Compressive and indirect tension* tests
		Water absorption test up to 24 hours
		Ultrasonic pulse velocity (UPV) Test
		Rebound value (Schmidt's hammer)
		Sulphate resistance/ Acid resistance tests
2	100×200mm cylinders	Compression and indirect tension tests
3	100×200mm cylinders	Rapid chloride penetration test
4	100×100×500mm prisms	Modulus of rupture (flexural strength)
5	150 × 300mm cylinders	Modulus of Elasticity of concrete
7	100mm cubes with rebar	Pull out test
	* only limited specimens	

In order to produce a standard mix, weigh batching is adopted throughout the casting. The constituents were thoroughly mixed until a good consistency mix was obtained in mixer machine and workability tests performed on each batch. The specimens were cast over a table vibrator and moulds covered with polythene sheets in the laboratory for 24 hours and then demoulded and cured in water until one day before testing at specified periods. A total of 288 specimens were cast for each grade of concrete. (60 cube specimen for compression, 60 cylinder specimens for compression, 60 cylinder specimens for split tension, 48 prisms for Modulus of rupture,12 cube specimen for acid test,12 cube for alkaline test, 12 cube for water absorption test,12 cylinder specimen for RCPT test and 12 cylinders for modulus of concrete.

Table 4.8 Details of testing and curing days for various tests

No	Nature of test	Days of curing before testing					
1	Compression tests(Cube)	3	7	14	28	60	90
2	Compression test(Cylinder)	3	7	14	28	60	90
3	Split(indirect) tension (cylinder)	3	7	14	28	60	90
4	Modulus of rupture ((flexure)	3	7	14	28	60	90
5	Split (indirect)tension (cubes)*				28	60	90
6	Modulus of Elasticity of concrete*				28	60	90
7	Water absorption				28	60	90
8	Porosity				28	60	90
9	Rapid chloride permeability test				28	60	90
10	Sulphate resistance				28	60	90

11	Acid resistance tests				28	60	90
12	Alkaline resistance				28	60	90
* only for limited days or cases							

Workability tests were conducted for all the six different concrete mixes as demonstrated in figure 4.2. Weigh batchin, machine mixing, vibrated compaction and pond curing were employed for the fabrication of the control specimens planned for various tests. The specimens were taken out of curing tank 24 hours before testing and kept for open drying. The tests for determining the various strength were conducted as per the relevant standards as shown in figure 4.3. The characteristics of workability and strength of the six different concrete made without plasticizer are presented in Table 4.9.

(a)Slump cone test

(b)

(b) Flow table test (c) Compaction factor test

Fig. 4.2 Workability tests

(a) Compression test (b) Splitting (indirect) tension test

(c) Flexure test (d) Pullout test

Fig. 4.3 Strength test on Control specimens

Spiral in the mould Specimen With plain bar With ribbed bar

(Specimen after Pullout test) **Fig. 4.4 Details of pullout test**

(As per IS 2770 Part I – 1967)

Table 4.9 The Workability and Strength Characteristics of M30 Concrete

Factors	Sand replacement by Quarry dust for M30 Grade Concrete (1: 1.34: 2.36 w/c 0.42)					
	0%	20%	40%	60%	80%	100%
Slump(mm)	40	40	37	38	34	32
Compaction factor	00.90	00.90	00.89	00.87	00.87	00.86
Flow %	05.23	05.54	06.34	07.43	10.10	11.30
f_{cu7} (MPa)	25.53	23.40	23.10	23.81	22.58	21.11
f_{cu28} (MPa)	37.51	38.40	37.52	37.48	36.78	36.08
f_{cy28} (MPa)	31.87	32.02	32.51	32.59	33.10	33.03
fcy / fcu	0.849	0.836	0.854	0.869	0.891	0.915
f_{tcy} (MPa)	02.21	02.50	02.43	02.46	02.60	02.94
f_{cr} (MPa)	06.90	06.93	06.92	07.20	07.23	07.21

4.2.2 Total replacement of sand with Quarry dust

Referring to Table 4.9, as the variations in the sand replacement levels towards the 28th day cube compressive strength of concrete are negligible, a concrete of grade M30 was again designed by considering the properties of QD by totally replacing the sand with QD. The details of Mix design for Quarry dust concrete is presented in **Appendix E.**

With this designed proportion, quarry dust concrete was prepared and the workability by slump, compaction and flow and strength in compression, tension like characteristics were determined as done for the previous set of cases. The results for all the testing are presented in Table 4.10.

Table 4.10 Workability and strength characteristics of SC and QDC

No	Factors	SC	QDC	Remarks
1	Concrete Grade	M30		
2	Mix proportion	1: 1.15: 2.54 w/c = 0.42	1:1.22: 2.54 w/c = 0.44	IS Method of design
3	Slump mm	35	31	SC is workable and QDC has segregation
4	Compaction factor	0.92	0.87	
5	Flow %	07.03	10.12	
6	f_{cu7} (MPa)	20.67	21.50	Difference (+4)%
7	f_{cu28} (MPa)	39.05	40.25	Difference (+3)%
8	f_{cy} (MPa)	32.80	34.34	Difference (+4.5) %
9	f_{tcy} (MPa)	04.54	04.95	Difference (+9)%
10	f_{cr} (MPa)	06.65	07.11	Difference(+7)%
11	$0.7\sqrt{f_{ck}}$	04.37	04.44	Conservative
12	f_{cy} / f_{cu}	00.84	00.85	Agreeable
13	Modulus of Elasticity of concrete (MPa)	3.71×10^4	3.65×10^4	Difference (- 1.6)%

The test results of pullout test for sand concrete and quarry dust concrete specimens detailed already in figure 4.4 and the bond stress with plain bars or ribbed bars inserted are presented in Table 4.11.

Table 4.11 Comparison of Pull out test results

No	**Bond Stress for Concrete type and Rebar (N/mm^2)**			
	Ribbed bar		**Plain bar**	
	SC	**QDC**	**SC**	**QDC**

1	3.26	4.66	3.05	4.35
2	3.87	4.45	3.55	3.76

4.2.3 Modulus of Elasticity of Concrete

For the determination of modulus of elasticity concrete, cylindrical specimens of size

150×300 mm were used. A 2000kN capacity Compression testing machine was utilized. The cylindrical specimen was fit into the strain measuring apparatus called compressometer and kept between the jaws of the compression testing machine. The instrumented specimen fixed in the compression testing machine is shown in figure 4.5. Three specimens from each concrete type were tested. The stress and strain relationship at various load levels up to failure is shown in figure 4.6. The modulus of elasticity of concrete at 28 days is determined from the stress-strain curve.

Fig. 4.5 Determination of Modulus of Elasticity of concrete

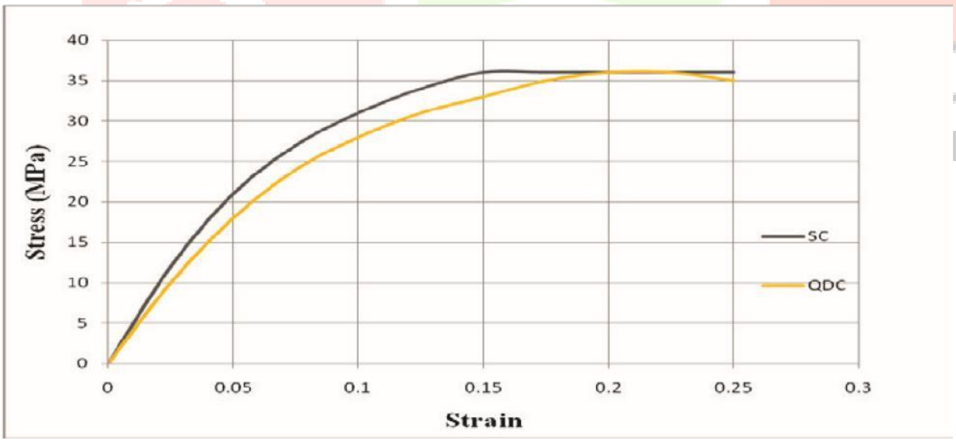


Fig. 4.6 Comparison of Stress-Strain relationship for M30 Grade

4.3 QUARRY DUST CONCRETE OF HIGHER GRADES

After confirming the workability and strength characteristics of M30 grade concrete, this experimental work extended to medium and higher grades of concrete. The higher grades considered are M30, M40, M50 and M60. For the four different mix proportions of both sand concrete and quarry dust concrete about 26 mix proportions were totally arrived with the incorporation of silica fume and fly ash as the two additives. The details of different grades of sand concrete and quarry dust concrete for experimenting with workability, strength and durability characteristics and the individual tests conducted for all the 26 mix proportions are

shown in Figure 4.7. The designed mix proportions for the four grades of concrete namely M30, M40, M50 and M60 are presented in the Table
4.12.

4.3.1 Mix Design for QD Concrete

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability, and workability as economically as possible, is the mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in both plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. For the investigation, the mix design for M30 and M40 concrete was made using IS method and that of M50 and M60 grade was made using ACI method. Superplasticiser was not required for M30 grade concrete but used for all others. To enhance the three dimensional properties of quarry dust concrete, additives are also considered. Silica fume by 5% and 10% replacement and fly ash by 10%, 20% and 30% were tried as indicated in figure 4.7.

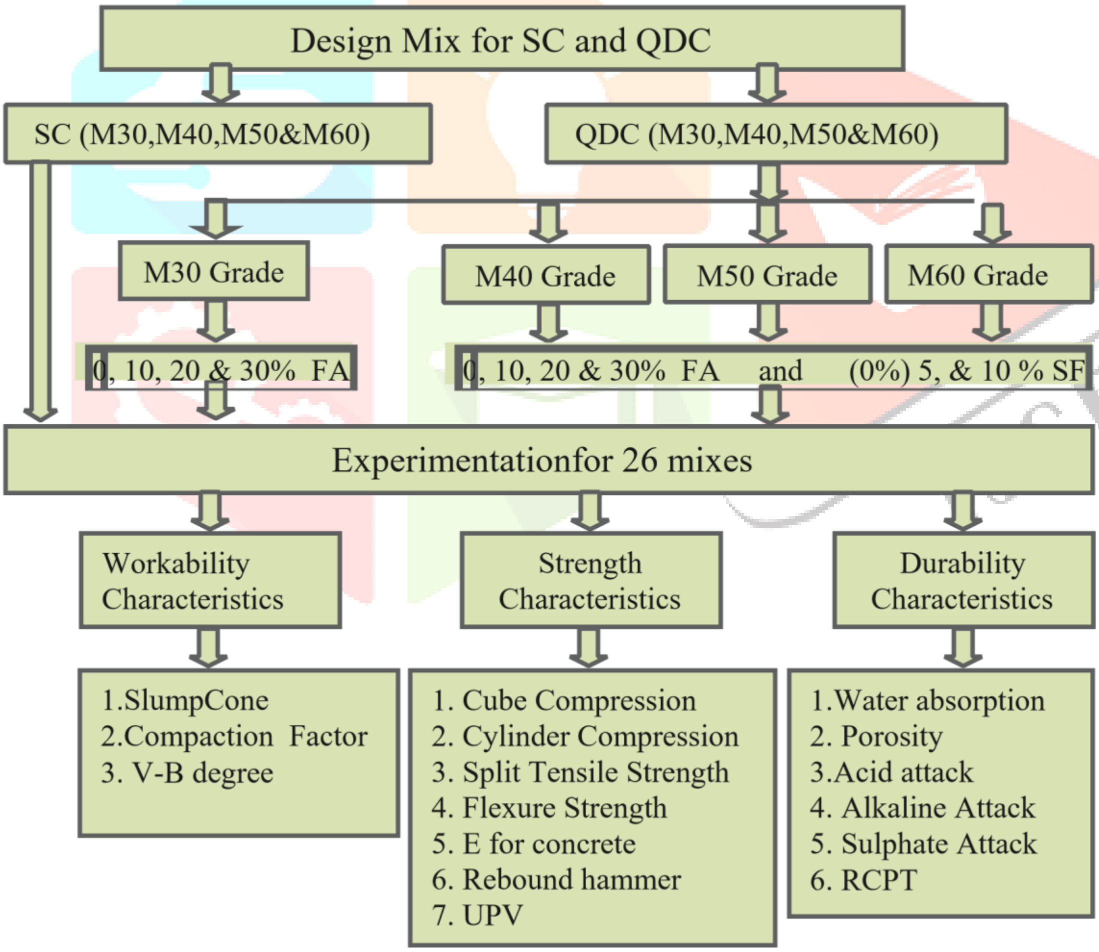


Fig. 4.7 Design Mix and Experimentation for QDC Table 4.12 Details of Mix proportions of medium and Higher Grades

No	Concrete Grade	Mix proportion		Remarks
		Standard concrete	Quarry dust concrete	
1	M30	1:1.33:2.64 w/c: 0.45	1:1.66:2.64 w/c: 0.45	Designed by IS Method
2	M40	1:1.43:1.7 w/c: 0.43	1:1.37:1.7 w/c: 0.43	
3	M50	1:1.4:1.8 w/c: 0.38	1:1.25:1.8 w/c: 0.38	Designed by ACI Method
4	M60	1: 0.9 :1.9 w/c: 0.38	1: 0.9 :1.9 w/c: 0.38	

4.3.2 Workability Tests on Fresh Concrete

Concrete mix of the twenty six different proportions was prepared and workability tests like slump test, flow table test and compaction factor test (IS: 5516 - 1996) conducted.

The workability characteristics of concrete are compared in Table 4.13.

Table 4.13 Results of Workability Tests

No	Grade of concrete	Type of Concrete	Workability Characteristics		
			Slump (mm)	Compaction Factor	Flow %
1	M 30 (Without SP)	SC	100	0.92	46
2		QDC	90	0.87	40
3		QDCF1	85	0.84	34
4		QDCF2	85	0.80	36
5		QDCF3	80	0.80	41
6	M 40 (With SP)	SC	100	0.84	40
7		QDC	90	0.94	36
8		QDCF1	85	0.80	41
9		QDCF2	78	0.77	44
10		QDCF3	76	0.74	51
11		QDCS1	85	0.80	41
12		QDCS2	80	0.77	44
13	M50 (With SP)	SC	95	0.90	50
14		QDC	80	0.96	40
15		QDCF1	85	0.94	38
16		QDCF2	85	0.82	42

17		QDCF3	87	0.76	35
18		QDCS1	85	0.85	48
19		QDCS2	82	0.80	52
20	M60 (With SP)	SC	75	0.93	42.4
21		QDC	50	0.80	38
22		QDCF1	80	0.86	40
23		QDCF2	78	0.82	38
24		QDCF3	75	0.80	36
25		QDCS1	82	0.84	38
26		QDCS2	78	0.92	36

4.3.3 Compressive and tensile strength of concrete

The compressive strength on testing cubes and cylinders was calculated by using the formula and the results are presented in Tables 4.14 and 4.15.

Failureload P
Compressive strength ______________________ __ for cube/
cylinder Area of cross section A

Table 4.14 Results of Cube Compressive strength

No	Grade of concrete	Type of Concrete	Cube Compressive Strength (N/mm^2)					
			3 Days	7 Days	14 Days	28 Days	60 Days	90 days
1	M 30 (With out SP)	SC	17.60	20.67	28.17	38.5	40.10	42.40
2		QDC	18.23	21.50	28.67	39.83	42.23	44.60
3		QDCF1	12.2	18.67	24.67	26.37	37.50	38.20
4		QDCF2	13.5	21.67	29.17	35.26	40.33	46.67
5		QDCF3	12.6	20.33	24.67	25.83	36.00	37.15
6	M 40 (With SP)	SC	22	34	38	51	51.4	51.46
7		QDC	20.1	27.2	32	43.3	44	45.06
8		QDCF1	17	24	32.4	44.6	45.3	47.6
9		QDCF2	17.4	25	31	44.2	45.8	47.5
10		QDCF3	17.2	24.8	31	44.8	45.7	47.4
11		QDCS1	21	27	35	49	49.06	49.20
12		QDCS2	22.5	30	33	48	48.26	48.40
13	M50	SC	28.6	38	49	58.56	58.73	59.0

14	(With SP)	QDC	26.0	34.64	46	56	56.58	56.76
15		QDCF1	24.6	25.83	34.83	42.60	48.60	52.10
16		QDCF2	24.2	25.00	28.62	41.15	46.22	53.3
17		QDCF3	22.4	24.3	33.3	42.00	48.50	56.30
18		QDCS1	28	34	49	57.65	58	58.90
19		QDCS2	28.30	34.60	49	58	58.40	59
20	M60 (With SP)	SC	23	41	48	53	64	66
21		QDC	21	38	43	45	48	50
22		QDCF1	21	24	36	38	40	44
23		QDCF2	24	28	33	42	44	46
24		QDCF3	25	29	40	44	52	54
25		QDCS1	26	31	52	56	68	70
26		QDCS2	24	34	49	59	80	86

Table 4.15 Results of Cylinder Compressive Strength

No	Grade of concrete	Type of Concrete	Cylinder Compressive Strength (N/mm^2) on					
			3 Days	7 Days	14 Days	28 Days	60 Days	90 days
1	M 30 (With out SP)	SC	12.42	17.42	25.15	31.15	36.30	39.50
2		QDC	14.30	18.30	28.20	32.30	37.20	42.10
3		QDCF1	11.40	13.62	22.42	28.62	34.20	39.20
4		QDCF2	11.33	12.20	20.10	26.40	30.40	38.15
5		QDCF3	10.50	11.60	18.65	26.20	32.84	40.20
6	M 40 (With SP)	SC	17.6	27	30.31	40.42	41.18	41.27
7		QDC	15.96	21.4	25.0	34.2	35.24	36.00
8		QDCF1	15.9	21	27.2	36.0	33.3	34.2
9		QDCF2	15.80	21.60	27.00	35.6	33.3	34.1
10		QDCF3	15.60	21.10	27.7	35.40	33.10	34.00
11		QDCS1	16.80	21.65	28.00	39.15	39.23	39.32
12		QDCS2	18.00	24.00	26.40	38.4	38.64	38.72
13	M50 (With SP)	SC	22.88	30.4	39.2	46.84	46.98	47.20
14		QDC	20.80	27.71	36.8	44.8	45.2	45.4
15		QDCF1	15.7	21	27.2	36.0	33.3	34.2
16		QDCF2	15.8	21.6	27	35.6	33.3	34.7
17		QDCF3	16.8	21.65	28.0	39.15	39.23	39.32
18		QDCS1	22.4	27.2	39.2	46.12	46.40	47.12

19		QDCS2	22.64	27.68	39.20	46.47	46.72	47.2
20	M60	SC	14.00	24.00	38.00	44.00	48.00	51.00
21	(With SP)	QDC	13.00	34.00	37.00	40.00	45.00	48.00
22		QDCF1	13.00	30.00	34.00	38.00	40.00	42.00
23		QDCF2	14.22	21.60	26.00	33.30	39.23	40.00
24		QDCF3	16.00	22.00	26.00	35.00	40.00	42.00
25		QDCS1	20.00	34.00	36.00	40.00	52.00	55.00
26		QDCS2	21.00	35.00	38.00	43.00	53.00	67.00

The splitting tensile strength (indirect tensile strength) based cylinders are calculated by the following formulae and compared for various mixes in Table 4.16.

$$\frac{\text{Indirect tensile strength}}{\text{Area of cross section}} \qquad \frac{\text{Failureload}}{{}^{SDL}{}_{2}\,SDL} \qquad \frac{P}{\ /\ } \; \frac{2P}{\ }$$

Table 4.16 Results of Splitting Tensile Strength

No	Grade of concrete	Concrete Type	Split Tensile Strength (N/mm^2) at					
			3 days	7 days	14 days	28 days	60 days	90 days
1	M 30 (With out SP)	SC	1.32	2.87	3.47	4.28	4.32	4.65
2		QDC	2.03	3.39	4.03	4.55	4.65	4.82
3		QDCF1	1.32	2.92	3.47	4.32	4.42	4.65
4		QDCF2	1.20	2.85	2.87	3.47	4.32	4.46
5		QDCF3	1.20	2.87	3.30	3.40	4.03	4.32
6	M 40 (With SP)	SC	2.99	3.44	3.81	4.14	4.24	4.26
7		QDC	3.12	4.33	4.46	4.52	4.54	4.60
8		QDCF1	2.2	3.4	3.7	3.8	4.0	4.10
9		QDCF2	2.1	3.3	3.7	3.8	3.8	4.10
10		QDCF3	2.0	3.4	3.8	3.9	3.8	4.0
11		QDCS1	3.37	4.77	4.93	5.09	5.16	5.20
12		QDCS2	3.82	4.93	4.97	5.20	5.28	5.41
13	M50 (With SP)	SC	3.46	3.94	4.40	4.98	5.0	5.15
14		QDC	3.00	3.60	4.25	4.60	4.68	4.80
15		QDCF1	2.20	3.40	3.7	3.8	4.0	4.10
16		QDCF2	2.6	3.3	3.7	3.8	3.8	4.10
17		QDCF3	3.21	4.21	4.25	4.64	5.02	5.24
18		QDCS1	3.2	3.52	4.25	4.84	4.96	5.0

19		QDCS2	3.52	4.30	4.75	5.20	5.26	5.39
20	M60	SC	2.60	3.30	3.80	3.90	4.10	4.30
21	(With SP)	QDC	2.30	3.20	3.40	3.70	3.90	4.00
22		QDCF1	2.00	2.30	2.30	3.20	3.30	3.80
23		QDCF2	2.30	3.00	3.30	3.70	3.80	4,00
24		QDCF3	2.50	3.00	4.00	4.50	5.00	5.10
25		QDCS1	260	3.40	4.00	5.15	5.70	6.30
26		QDCS2	2.80	3.80	4.40	5.00	6.30	6.40

4.3.4 Flexural strength of concrete

Flexural strength is one of the measures of tensile strength of concrete. It is the ability of a beam to resist failure in bending. It is measured by loading plain concrete prism as shown in **Appendix F.** The maximum tensile stress reached in the rupture and the flexural strength is expressed as Modulus of Rupture in N/mm^2 and the results are presented in Table 4.17

WL

M 6 WL

Flexural strength Z 2 a3 bd 6

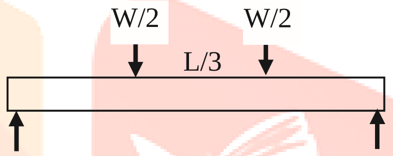


Table 4.17 Results of flexural strength test

No	Grade of concrete	Concrete Type	Flexural Strength (N/mm^2) at					
			3 Days	7 Days	14 Days	28 Days	60 Days	90 days
1	M 30 (Without SP)	SC	5.4	5.4	5.6	5.8	6.2	7.39
2		QDC	5.2	5.4	5.4	6.2	6.8	7.50
3		QDCF1	5.4	5.6	5.6	5.6	5.9	6.20
4		QDCF2	5.6	5.6	5.8	5.8	5.9	6.40
5		QDCF3	5.4	5.6	5.8	5.9	6.2	6.4
6	M 40 (With SP)	SC	6.0	6.7	7.0	7.5	7.7	7.86
7		QDC	5.8	6.5	6.8	7.13	7.23	7.50
8		QDCF1	5.2	5.7	5.7	5.9	6.2	6.20
9		QDCF2	5.0	5.6	5.6	5.8	6.1	6.20
10		QDCF3	5.0	5.5	5.8	5.9	6.2	6.30
11		QDCS1	6.2	6.8	7.1	7.6	7.73	7.80
12		QDCS2	6.2	7.0	7.4	7.83	7.9	7.96
13	M50	SC	6.5	6.7	7.8	8.2	8.3	8.50

14	(With SP)	QDC	6.0	6.5	7.1	7.8	7.9	8.00
15		QDCF1	5.2	5.7	5.7	5.9	6.2	6.20
16		QDCF2	5.2	5.4	5.6	5.8	6.1	6.20
17		QDCF3	5.95	6.21	7.11	7.62	7.92	8.21
18		QDCS1	6.5	6.9	7.6	8.0	8.25	8.30
19		QDCS2	6.65	7.1	7.7	8.2	8.4	8.58
20	M60 (With SP)	SC	7.1	7.8	8.0	10.0	10.4	10.8
21		QDC	5.0	5.2	5.7	8.50	8.80	9.00
22		QDCF1	5.2	5.2	5.7	5.8	6.1	6.20
23		QDCF2	5.2	5.5	5.8	5.8	6.2	6.30
24		QDCF3	5.5	5.5	6.3	6.21	6.80	6.80
25		QDCS1	6.5	6.8	7.11	8.80	9.00	10.4
26		QDCS2	7.1	7.1	8.2	9.40	10.0	10.8

4.3.5 Non destructive testing

Non destructive testing (NDT) is becoming popular as it has several advantages over destructive type of testing. Out of several types of NDTs some relevant ones are presented here. The experimental results are given in Table 4.19

4.3.5.1 Rebound Hammer Test

Rebound hammer commonly adopted equipment for measuring the surface

hardness. It consists of a spring control hammer that slides on a plunger within a tubular housing. When the plunger is pressed against the surface of the concrete, the mass rebound from the plunger. It retracts against the force of the spring. The hammer impacts against the concrete and spring control mass rebounds, taking the rider with it along the guide scale. By pushing a button, the rider can be held in position to allow the reading to be taken. The distance travelled by the mass, is called the rebound number, indicated by rider moving along a graduated scale. The testing of the specimen as shown in figure 4.8

4.3.5.2 Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity testing involves measurement of the time of travel of electronically generated mechanical pulse through the concrete. UPV consists of measuring the time of an ultrasonic pulse, passing through the specimen to be tested. The pulse generator circuit consists of electronic circuit for generating pulses and a transducer for transforming this electronic pulse into mechanical energy having vibration frequencies in the range of 15 to 50 KHZ. The quality of concrete is assessed from the value of the velocity as given in Table 4.18. The time of travel between initial onset and reception of the pulse is measured electronically. The details are shown in figure 4.9

Table 4.18 Standard classification by UPV Testing

Velocity(km/sec)	Classification(quality)
4.0 and above	Very good

3.5 to 4	Good
3.0 to 3.5	Medium
3.0 and below	Poor

Fig. 4.8 Rebound Hammer Test in progress

Fig 4.9 Details of Ultrasonic pulse Velocity testing The path length between transducer divided by the time travel gives the average velocity of wave propagation. The equipment used for this testing of specimen is named as PUNDIT (Portable Ultrasonic Non-destructive Digital-Indicator Tester). The test results are presented in Table 4.19.

4.3.6 Durability Studies

Concrete was considered to be a highly durable material requiring a little or no maintenance. The assumption is largely true, expect when it is subjected to highly aggressive environments. Concrete durability is a subject of major concern in many countries. In IS 456-2000, durability aspect is one of the major revision, in line with codes of practices of other countries, dealing with durability of concrete structures. The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. Durability tests have been planned to evaluate the following:

(i) Porosity and saturated water absorption

(ii) Acid attack

(iii)Alkaline attack and

(iv)Rapid chloride Penetration test (RCPT)

4.3.6.1 Determination of Porosity and Saturated water absorption

Porosity test was conducted on 100mm cubes only. Cubes were immersed in water for

24 hours and then dried in a oven for 24 hours at 100° C. The difference in weight was noted. The water immersion views are shown in figure 4.10(a). The saturated water absorption (SWA) and porosity were calculated from the formulae given below and the results are given in Table 4.19:

$$SWA = \frac{Wet\ weight - Dryweight}{Dryweight} \times 100 \quad \text{and Porosity} = \frac{Wetweight - Dryweight}{Densityof\ water} \times 100$$

4.3.6.2 Acid Resistance Test

In order to assess the weight loss, concrete cubes are exposed to chemical media. For acid test, hydrochloric acid was prepared by mixing 5% of HCl with one liter of water as per ASTM G20-8. After the normal curing for 28 days, the cubes were taken out and weight noted. Weighed cubes were then immersed in the prepared hydrochloric acid for 60 days. After 60 days of immersion the cubes were taken out from acid and weight of cubes was noted. Finally the weight loss is obtained. The acid immersion views are shown in figure 4.10(b) and the results are given in Table 4.19.

4.3.6.3 Alkaline Test

Sodium hydroxide solution was prepared by mixing 5% of sodium hydroxide with one liter of water as per ASTM G20-8. The 28 days cured cubes were taken out and weight noted. The weighed cube specimens were immersed in the prepared sodium hydroxide solution for 60 days. After 60 days of immersion concrete cubes were taken out and weighted. The weight loss is then calculated. The alkaline immersion views are shown in figure 4.10(c) and the results are given in Table 4.19.

4.3.6.4 Rapid Chloride Penetration Test

Rapid Chloride Penetration Test (RCPT) was carried out on cylindrical disc specimens. 100×50mm sized discs cut from100×200mm concrete cylinders of various types of concrete were used.

(a) **Details of SWA and Porosity tests**

(b) **Acid resistance Test**

(c) **Immersion in Alkaline solution (sodium hydroxide)** **Fig.**

4.10 Views of some durability tests

The specimens are submerged in clean fresh water and kept until taken out just prior to test. The specimens are allowed to become dry at an oven for 3 hours and after that the specimens were tested.. This test was conducted as per ASTM–C 1202–97. This RCPT test method consists of monitoring the amount of electrical current passed through h (50 mm) thick slices of 100 mm nominal diameter cylinders during a period of 6 hours. A potential difference of 60 volts DC is maintained across the ends of the specimen, one of which is immersed in a Sodium Chloride (NaCl) solution, the other in a Sodium Hydroxide (NaOH) solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

A 3% sodium chloride (NaCl) and 3% sodium hydroxide (NaOH) solutions are separately prepared. The cut discs were arranged in the RCPT apparatus in two compartments one sodium chloride solution and the other sodium hydroxide solution. Sealant (Anabond 666T plus) is applied around specimen cell boundary. The exposed face of specimen is covered with an impermeable material (silicon rubber sheeting). They are connected to positive and negative terminals of the equipment. Current readings for every 30 minutes are recorded for a total duration of 6 hours. The details of specimen preparation and testing are illustrated in figure 4.11. By trapezoidal rule and using the following formula, charge (Columbs) is obtained and the results are given in Table 4.19:

$$Q\ 900u10^{3}[(I_{o}\ \ I_{360})\ \ 2(I_{30}\ \ I_{60}\ \ I_{90}\ldots\ldots\ldots I_{330})]$$

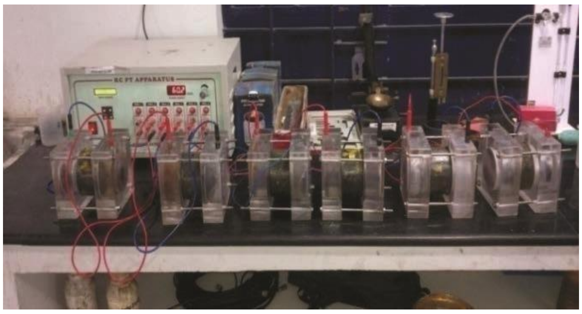
Where, Q = Charge passed in Columbs,

I_0 = Current (amperes) immediately after the voltage is applied, and I_t = Current (amperes) at 't' minutes after the voltage is applied.

(a) Cutting of slices

(b) Cut slices put in water

(c) Slices in vacuum chamber



(d) Multiple cells of RCPT

(e) RCPT in progress

Fig. 4.11 Details of Rapid Chloride Penetration test

Table 4.19 Comparison of Results of NDT and Durability Tests

No	Grade of Concrete	Concrete Type	Compressive Strength for Rebound No N/mm^2)	UPV Charge in Columns	SWA	Porosity $\times 10^{-4}$	Acid attack Loss in Wt in %	Alkaline attack Loss in Wt in %	RCPT Charge Passed in Columns
1	) M 30 Without SP	SC	34	4.65	4.2	0.90	3,8	1.8	3123
2		QDC	32	4.76	4.44	0.95	2.6	1.6	3103
3		QDCF1	26	4.65	4.55	1.07	3.4	1.4	3075
4		QDCF2	26	4.67	4.76	1.00	3.2	1.5	3020
5		QDCF3	28	4.65	4,9	1.19	3.0	1.4	3002
6		SC	46	4.67	4.9	0.95	4.7	1.7	3093
7		QDC	44	4.75	4.55	1.04	2.6	1.6	3080.1
8		QDCF1	44	4.67	4.32	1.07	3.1	1.2	3066
9		QDCF2	40	4.58	4.76	1.19	3.2	1.5	3024
10		QDCF3	38	4.62	5.1	1.28	2.8	1.9	3020
11		QDCS1	46	4.67	4.50	1.09	2.2	1.4	2946
12		QDCS2	48	4.58	4.42	1.06	1.9	1.0	2888
13		SC	54	4.76	3.84	0.90	5.2	1.9	3106

14	M50 With SP	QDC	52	4.69	4.57	1.06	3.1	1.7	3102
15		QDCF1	50	4.75	4.07	1.28	2.6	1.4	3045
16		QDCF2	49	4.62	3.62	1.31	2.2	1.6	3028
17		QDCF3	49	4.58	3.52	1.17	2.1	1.2	3004
18		QDCS1	54	4.62	4.40	1.02	2.7	1.3	2929
19		QDCS2 56 4.62 4.28 0.99 2.4 1.1 2837 20 SC 56 4.41 3.87 0.38 5.5 2.1 2932							
21	M60 With SP	QDC	54	4.76	4.59	0.46	4.1	1.9	2898
22		QDCF1	52	4.69	4.59	0.42	4.1	1.7	2985
23		QDCF2	54	4.62	4.40	0.44	3.8	1.6	2849
24		QDCF3	54	4.67	4.44	0.44	3.1	1.4	2877
25		QDCS1	58	4.50	4.32	0.43	3.6	1.6	2682
26		QDCS2	62	4.62	4.18	0.39	3.2	1.4	2438

4.4 SUMMARY

The experimental part was satisfactorily conducted and results presented through tables in the order of conducting the test. For all the 26 different mix proportioned concrete grades, the three directional properties namely the workability, strength and durability characteristics were grouped for category and presented. The analysis and comparison of test results are dealt in the next chapter.

CHAPTER 5

ANALYSIS OF RESULTS

5.0 GENERAL VIEW

The experimental part satisfactorily conducted and results grouped and reported through chapter 5 in the order of conducting the test is analyzed in this chapter. For all the twenty six different mix proportioned concrete grades, the three directional properties namely the workability, strength and durability characteristics were grouped type wise and analyzed.

The analysis and comparison of test results are presented as detailed here.

5.1 ANALYSIS OF PRELIMINARY STUDY RESULTS

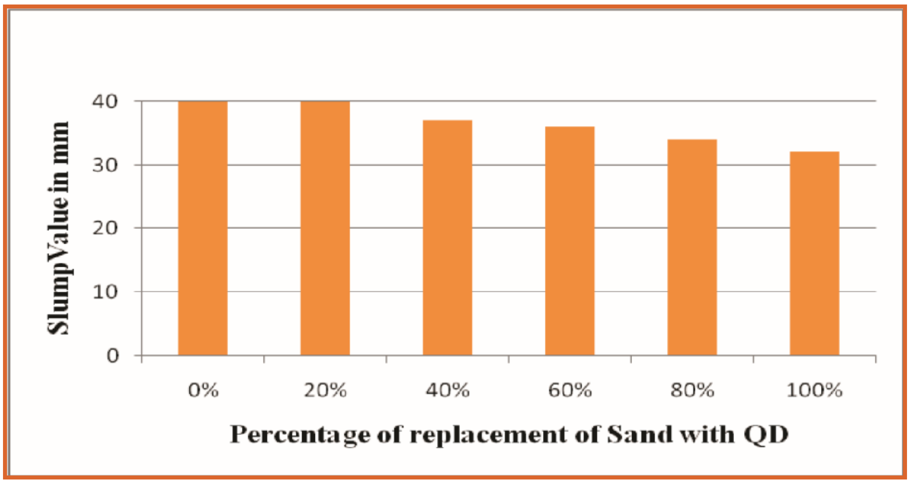
There were six different mix proportions considered for conventional sand concrete with sand replacements accordingly 0%, 20%, 40%, 60%, 80% and 100% with quarry dust.

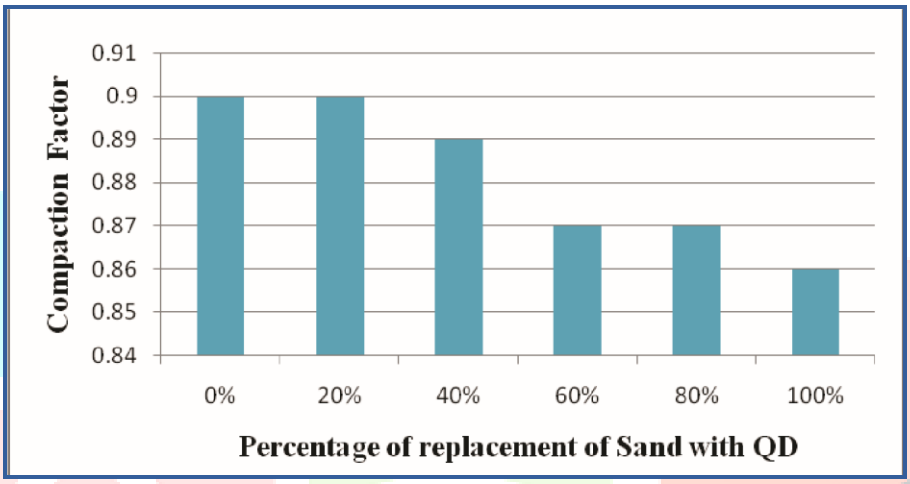
The workability and strength in different aspects are considered and analyzed here.

5.1.1 Analysis for Workability Characteristics

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 5.1, 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 5.2.


SlumpValue in mm
0
10
20
30
40
0%
20%
40%
60%
80%
100%
Percentage of replacement of Sand with QD


Compaction Factor
0.84
0.85
0.86
0.87
0.88
0.89
0.9
0.91
0%
20%
40%
60%
80%
100%
Percentage of replacement of Sand with QD

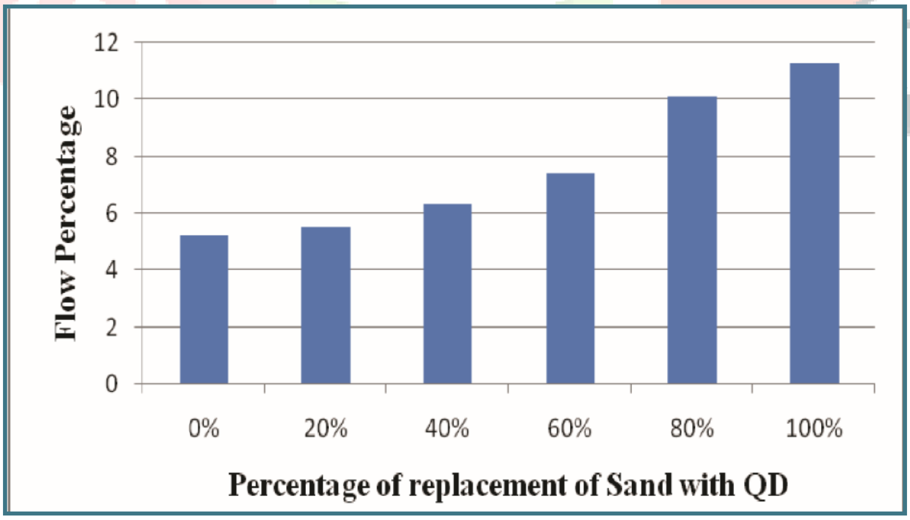

Flow Percentage
0
2
4
6
8
10
12
0%
20%
40%
60%
80%
100%
Percentage of replacement of Sand with QD

Fig. 5.1 Comparison of workability characteristics for M30 Concrete

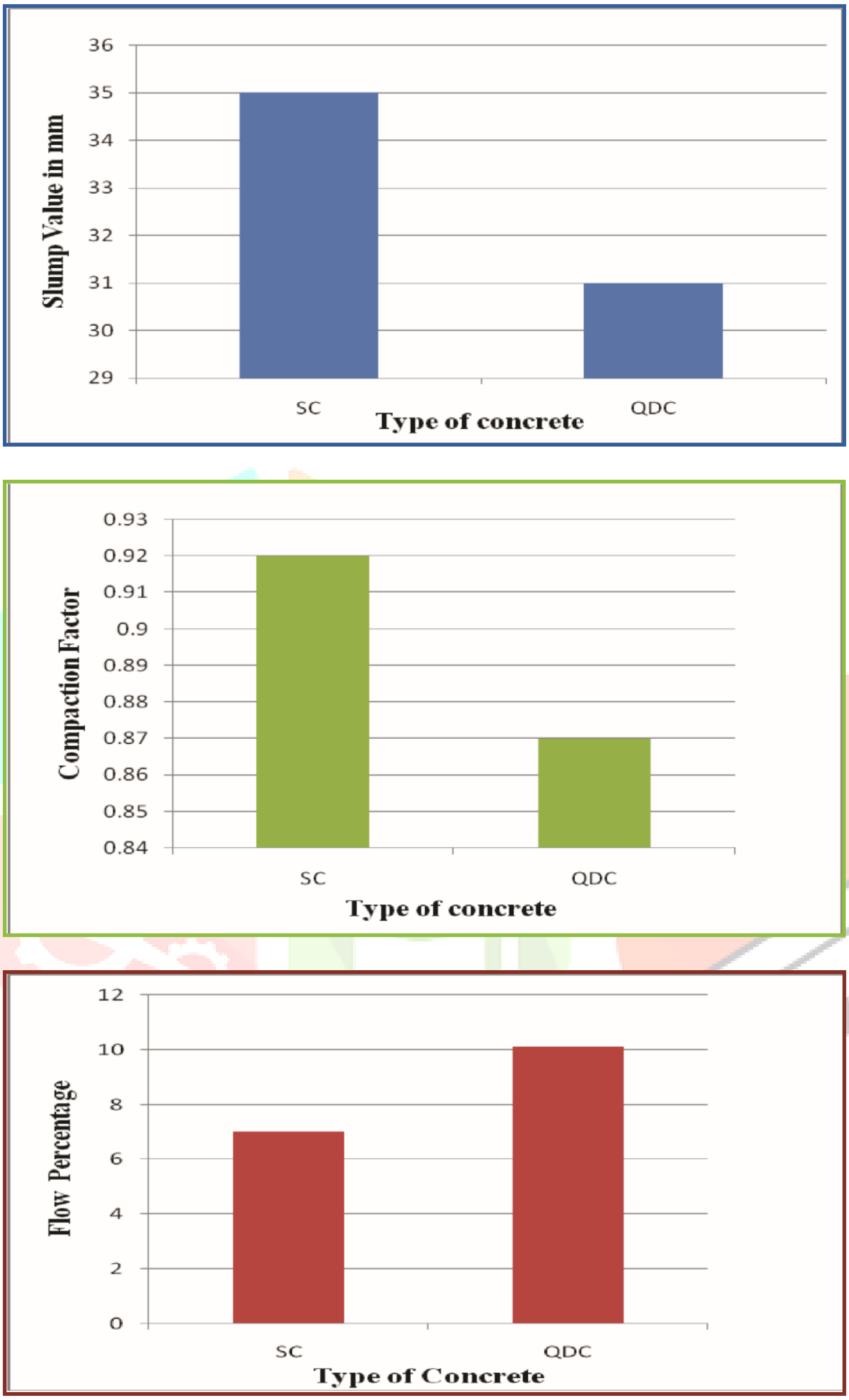


Fig. 5.2 Workability characteristics of SC and QDC for M30 grade

5.1.2 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.

5.1.2.1 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 5.3. 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.

5.1.2.2 Compressive strength in 28 days

The 28 day compressive strength of concrete grades based on testing cubes and cylinders are presented in figure 5.4. 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.

5.1.2.3 Splitting tensile strength in 28 days

The splitting (indirect) tensile strength based on testing cylinders on 28 day of curing are presented in figure 5.4. As observed, there is not much variation for the 28 day splitting tensile strength due to the variations in the percentage replacement of sand.

5.1.2.4 Modulus of rupture

The modulus of rupture value by flexure test using prisms are also presented in figure 5.4 and it is clear that there is not much variation with respect to variations in the percentage replacement of sand with quarry dust

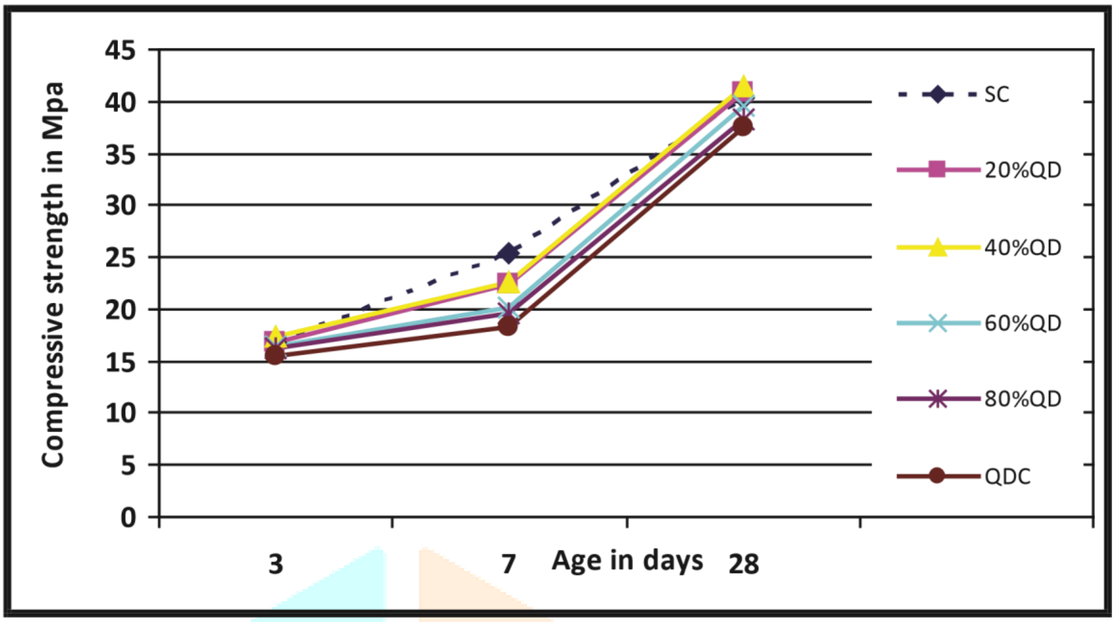


Fig. 5.3 Rate of Strength development of M30 grade concrete

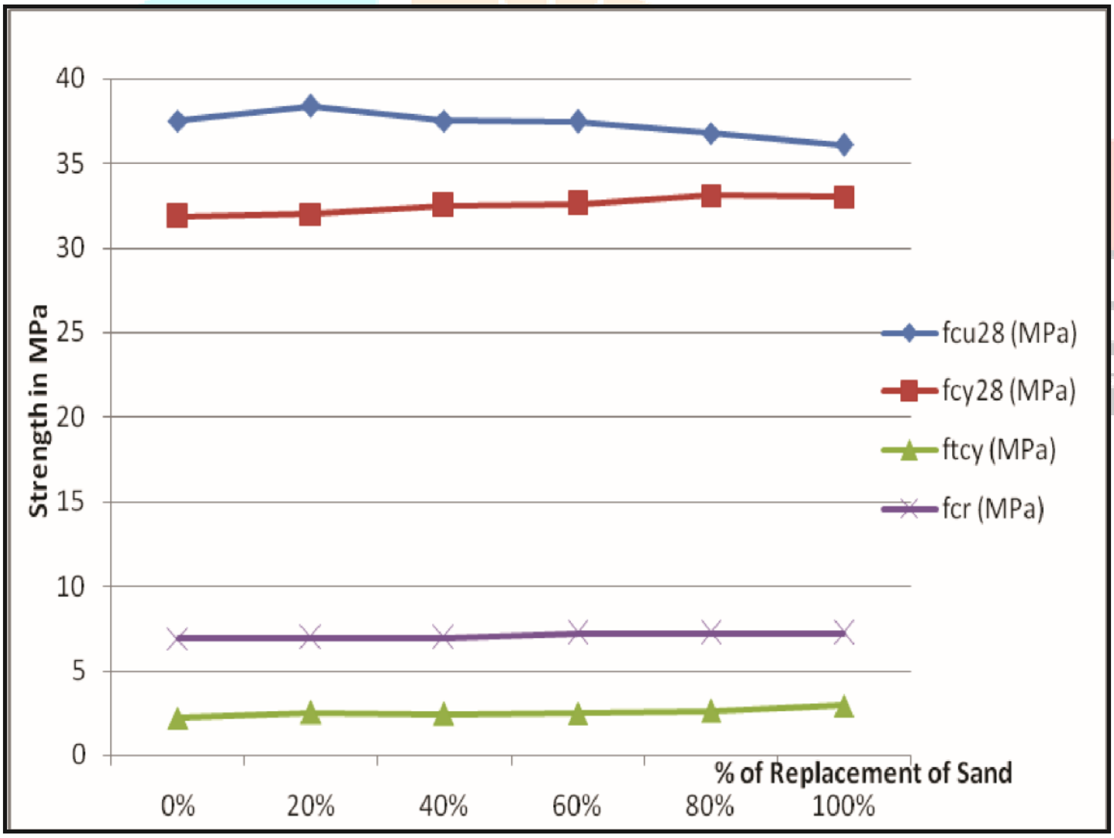


Fig. 5.4 Comparison of 28 day Strength of M30 grade concrete 5.2 TOTAL REPLACEMENT OF SAND WITH QUARRY DUST

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

5.2.1 Compressive strength

It is observed from figure 5.5 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%).

5.2.2 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 12% for split tensile strength and 1-3% for modulus of rupture.

5.2.3 Pullout test

The comparison of pullout test results an indication of bond between concrete and rebar is made in figure 5.6. 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.

5.2.4 Modulus of elasticity of concrete

The comparison of modulus of elasticity of concrete is already shown through stress strain curve in figure 4.6 of chapter 4, it is observed that the strain is more for QDC than
SC for the same stress. Thus the modulus of concrete is less by 15 %.

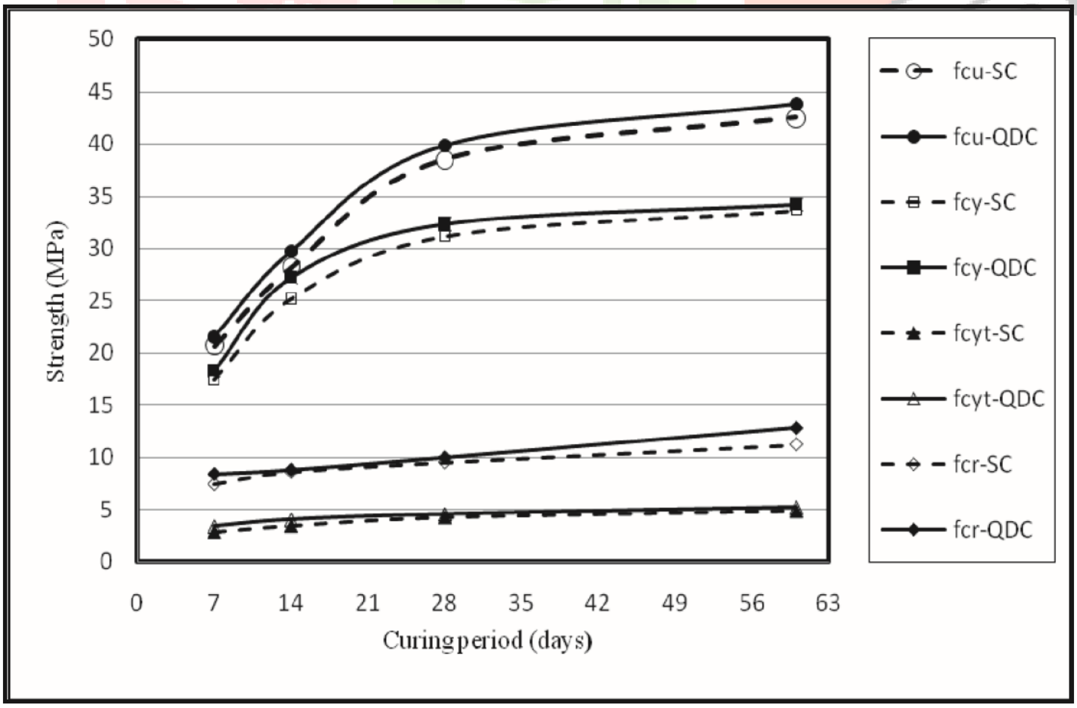


Fig. 5.5 Strength Comparison of SC and QDC for M30 grade

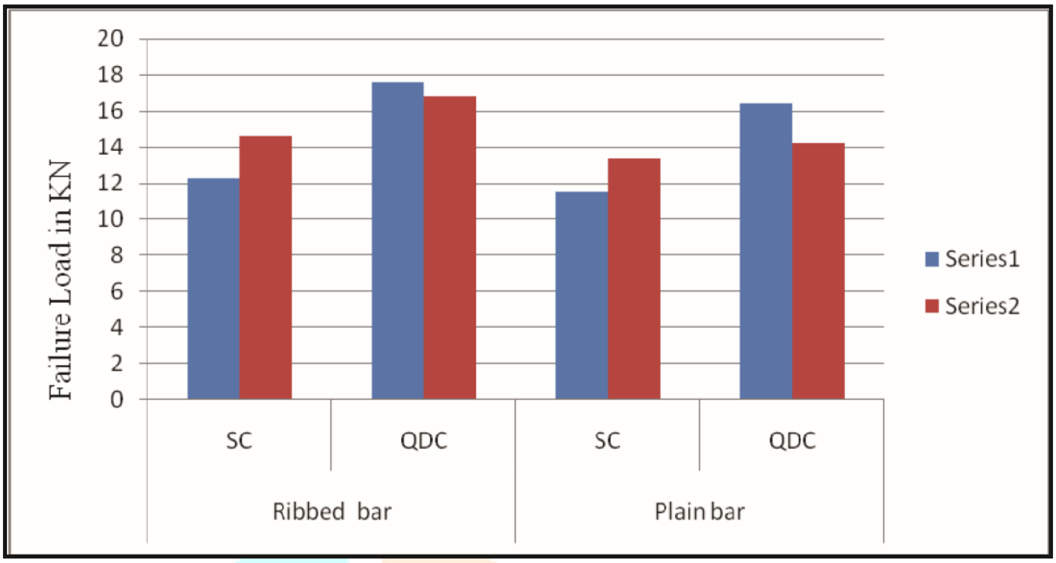


Fig.5.6 Pull out test for SC and QDC for Plain and Ribbed bar

5.3 QUARRY DUST CONCRETE OF HIGHER GRADES

After confirming the workability and strength characteristics of M30 grade concrete, the experimental work was extended to medium and higher grades of concrete. The higher grades considered other than M30 (without SP) are M40, M50 and M60 (always with SP) with the addition of mineral admixtures like fly ash and silica fume.

5.3.1 Workability Characteristics

The main problem of workability in the QDC is due to the presence of high

% of fines was easily handled by addition admixtures and additives. For M30 grade SC (without SP) the **slump** is more and reduces for other higher grades even though plasticizer is used. For M30 grade of QDC the trend is same as SC but the slump value is always less compared to SC for all grades of concrete. 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. The workability characteristics are compared in figure 5.7.

Due to the water absorption capacity of quarry dust at first workability decreases rapidly and then decreases gradually. The reasons for the reduction in workability of concrete are attributable to the properties of fine aggregates. The workability of concrete increases with addition of fly ash and decreases by the addition of quarry dust. The workability of nominal concrete is greater than that of fly ash mixed concrete with 10%, 20% and 30%.

Similarly for silica fume concrete with 5% and 10%. The workability is improved by the addition of Super plasticizer for M40, M50 and M60 grades.

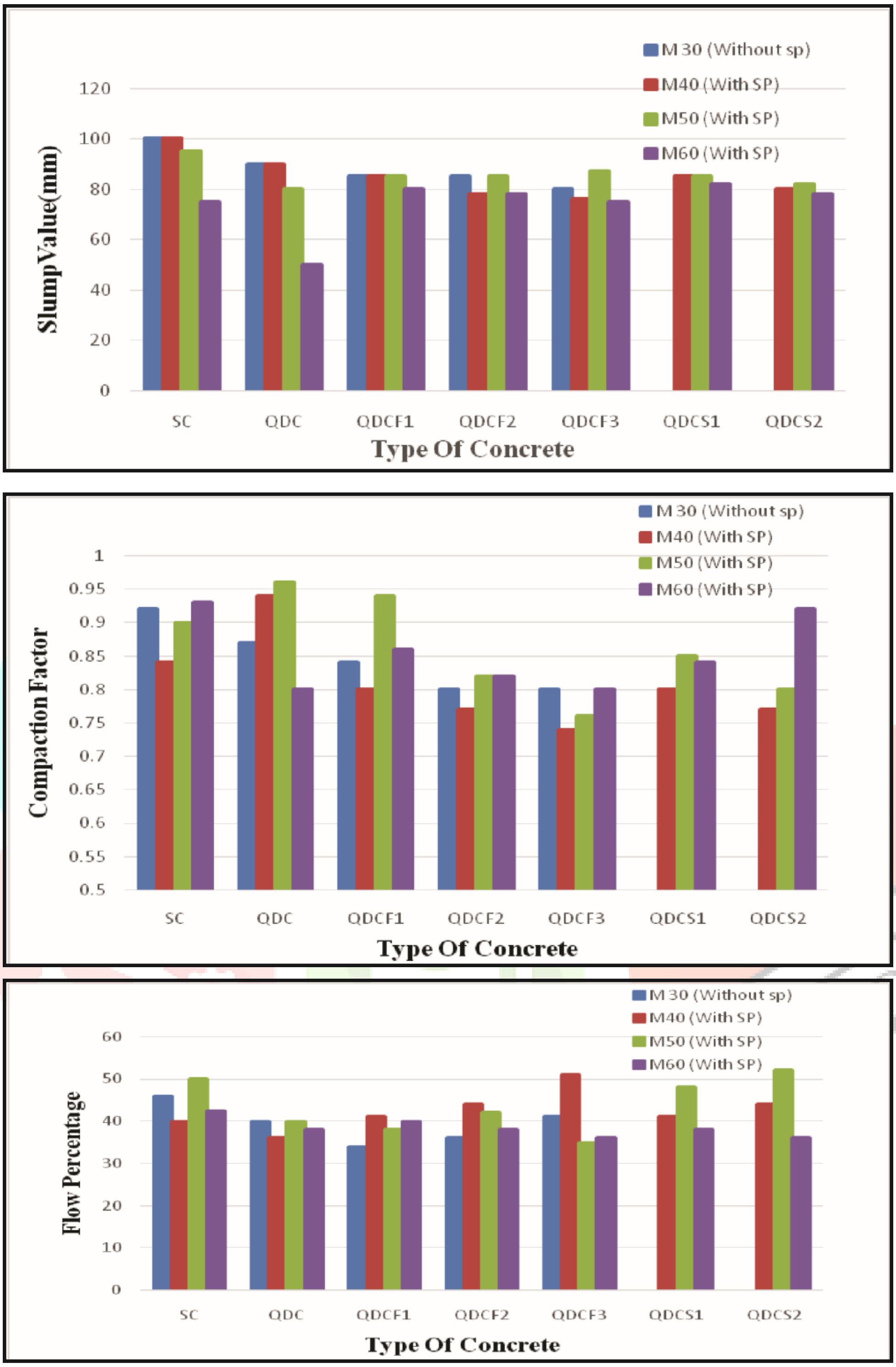
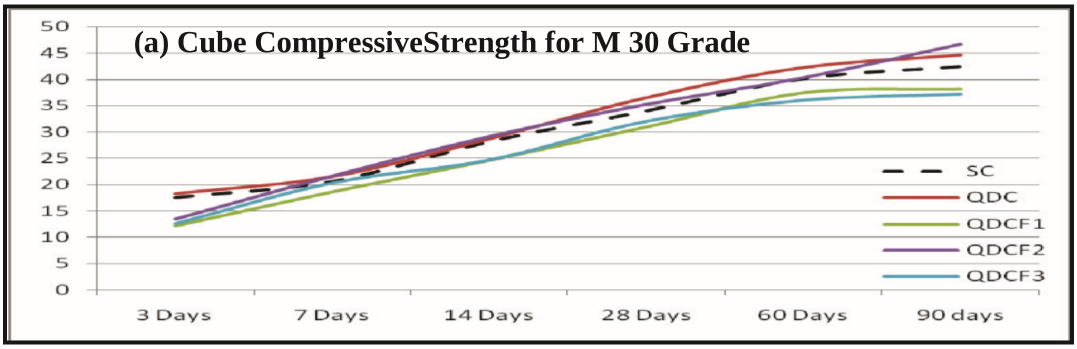


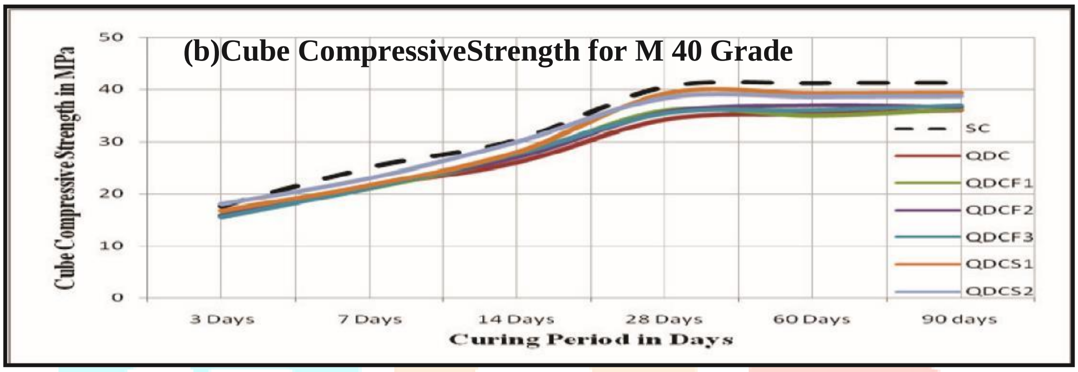
Fig. 5.7 Workability Test for Medium and Higher grades of Concrete

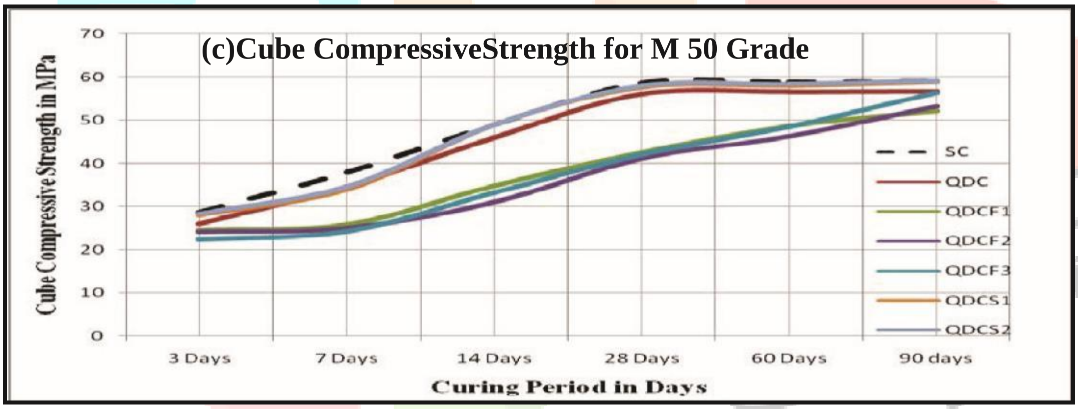
5.3.2 Compressive strength of concrete

By replacing cement by equal weight of fly ash in concrete, the strength decreases at early stages but increases gradually at later. The compressive strength of concrete made with 20% of fly ash is more than that made with 10% and 30%. The variation in strength is in the increasing order by replacing cement with silica fume by 5% and 10%. Figure 5.8 shows the cube compressive strength for various grades of concrete and for cylinder compressive strength presented in figure 5.9. From the results the cube compressive strength of quarry duct concrete with 10% of silica fume replaced to cement shows better compressive strength than control concrete. This is due to the reason that the minute pores are replaced by the silica fume (micro silica) in the concrete while in quarry dust without silica fume seems to less due to pores in the concrete.

Generally cube compressive strength of quarry dust with fly ash (20%) shown more or less same strength during 60 days and 90 days of curing. But for quarry dust concrete with silica fume (10%) shows improved strength of 20% during 60 days and 31% during 90 days for M60 grade concrete. Similar trend is shown for cylinder compressive strength also. Quarry dust with silica fume (10%) reflected 2% increase in 28 days when compared to sand concrete, 9% increase in 60 days and 23% increase in 90 days of curing.


(a) Cube CompressiveStrength for M 30 Grade
0
5
10
15
20
25
30
35
40
45
50
3 Days
7 Days
14 Days
28 Days
60 Days
90 days
SC
QDC
QDCF1
QDCF2
QDCF3


(b)Cube CompressiveStrength for M 40 Grade
Cube Compressive Strength in MPa
0
10
20
30
40
50
3 Days
7 Days
14 Days
28 Days
60 Days
90 days
Curing Period in Days
SC
QDC
QDCF1
QDCF2
QDCF3
QDCS1
QDCS2


(c)Cube CompressiveStrength for M 50 Grade
Cube Compressive Strength in MPa
0
10
20
30
40
50
60
70
3 Days
7 Days
14 Days
28 Days
60 Days
90 days
Curing Period in Days
SC
QDC
QDCF1
QDCF2
QDCF3
QDCS1
QDCS2

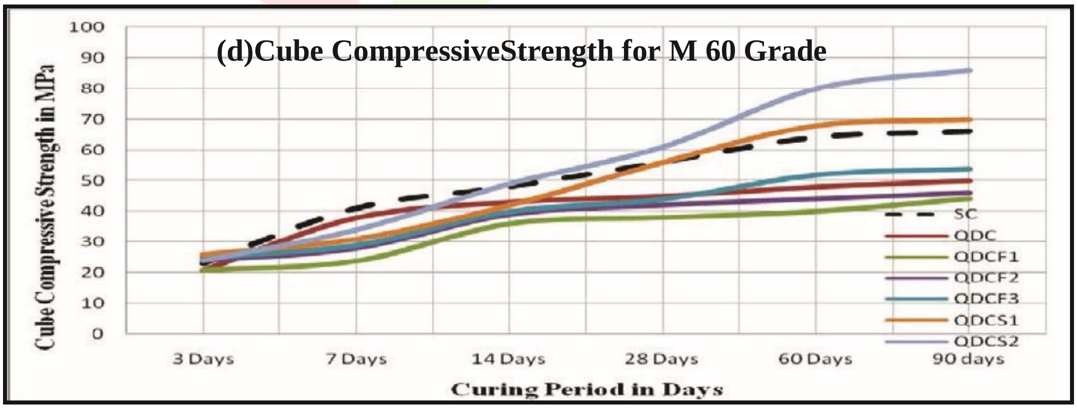
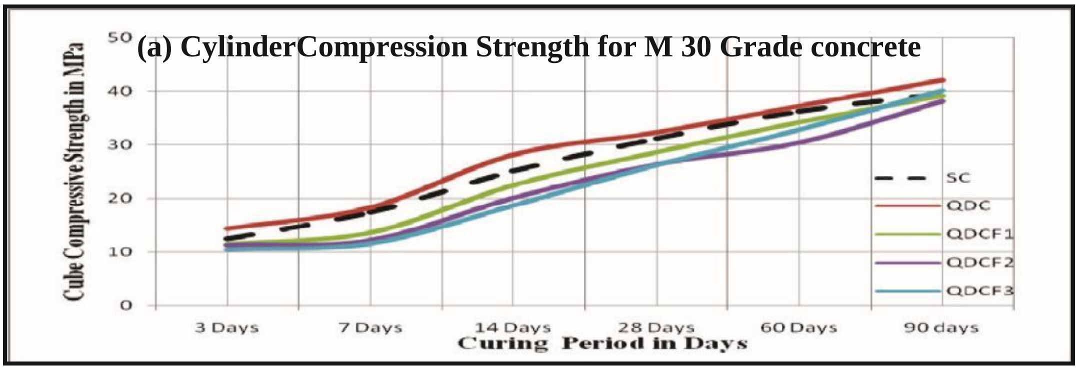
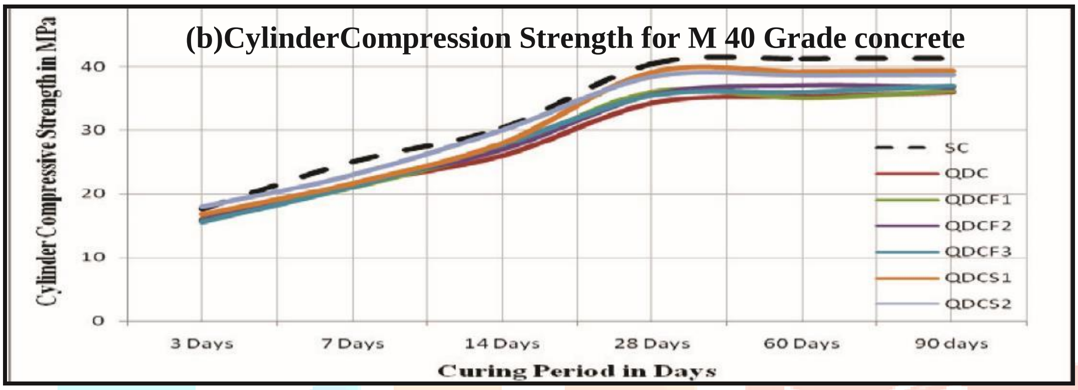
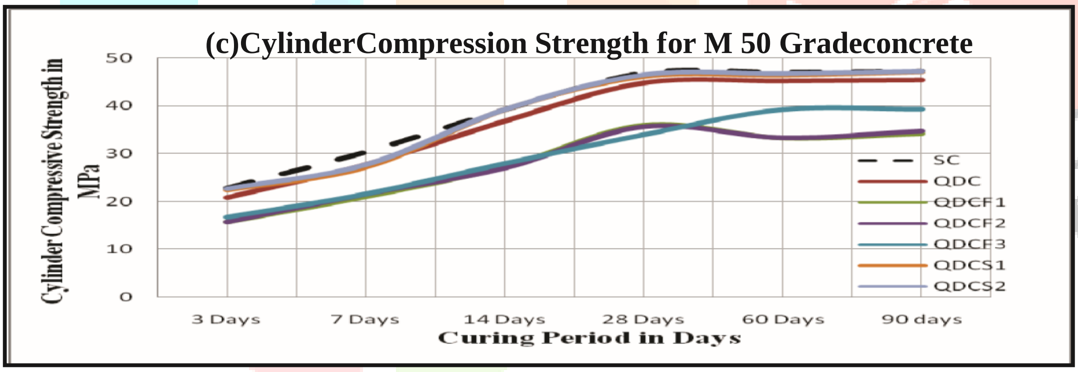

(d)Cube CompressiveStrength for M 60 Grade
Cube Compressive Strength in MPa
0
10
20
30
40
50
60
70
80
90
100
3 Days
7 Days
14 Days
28 Days
60 Days
90 days
Curing Period in Days
SC
QDC
QDCF1
QDCF2
QDCF3
QDCS1
QDCS2

Fig.5.8 Comparison of Cube Compressive Strength







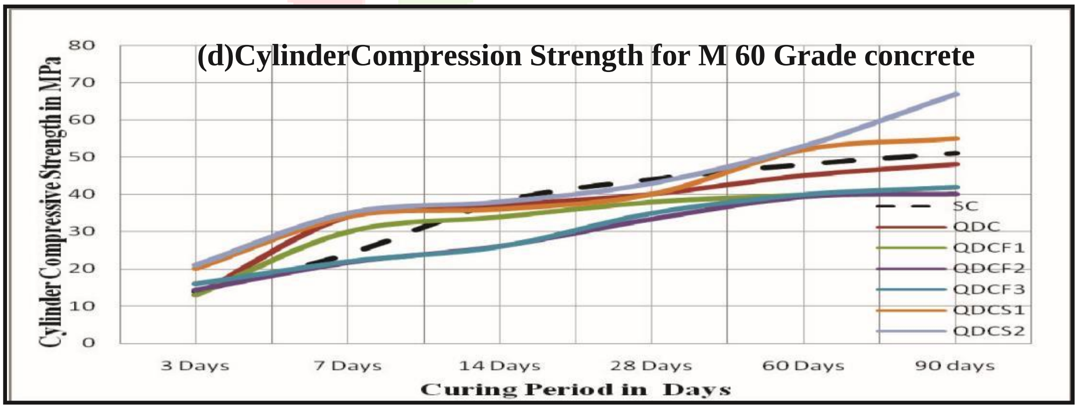


Fig. 5.9 Comparison of Cylinder Compressive Strength 5.3.3 Tensile strength of concrete

As mentioned above the concrete is not normally designed to resist direct tensile force to develop, as result of flexure, temperature change etc. and often cracking of concrete is result of the tensile strength being exceeded. It is observed from figure 5.10 that spiltting tensile strength of quarry dust concrete is increased, when compared to conventional concrete. Since all the ingredients of concrete expect fine aggregate are same, the variation in the tensile strength can be attributed to the properties of aggregate, particularly shape and texture. The test results show that the tensile strength of quarry dust concrete with silica fume is better than the control concrete. This is because that the quarry dust material is slightly flaky, which in turns helps to increase the tensile strength of concrete. For M60 grade concrete, splitting tensile strength is less than the sand concrete for QDC with fly ash of 10%, 20% and 30% replacement with cement. But the splitting tensile strength is improved for 22% for 28 days, 32% for 60 days and 34% for 90 days of curing.

5.3.4. Flexural strength of concrete

It is observed from the figure 5.11 that flexural strength (modulus of rupture) of quarry dust concrete is increased when compared to conventional concrete. The reasoning for the variation in flexural strength of concrete made with quarry dust is similar to that mentioned for the tensile strength. Experimental studies have shown that flaky aggregate particle within certain limits contributes towards the increase in flexural strength.

For M60 grade concrete, flexural strength is less than the sand concrete for QDC with fly ash, but for QDC with silica fume is more or less same for all curing periods.

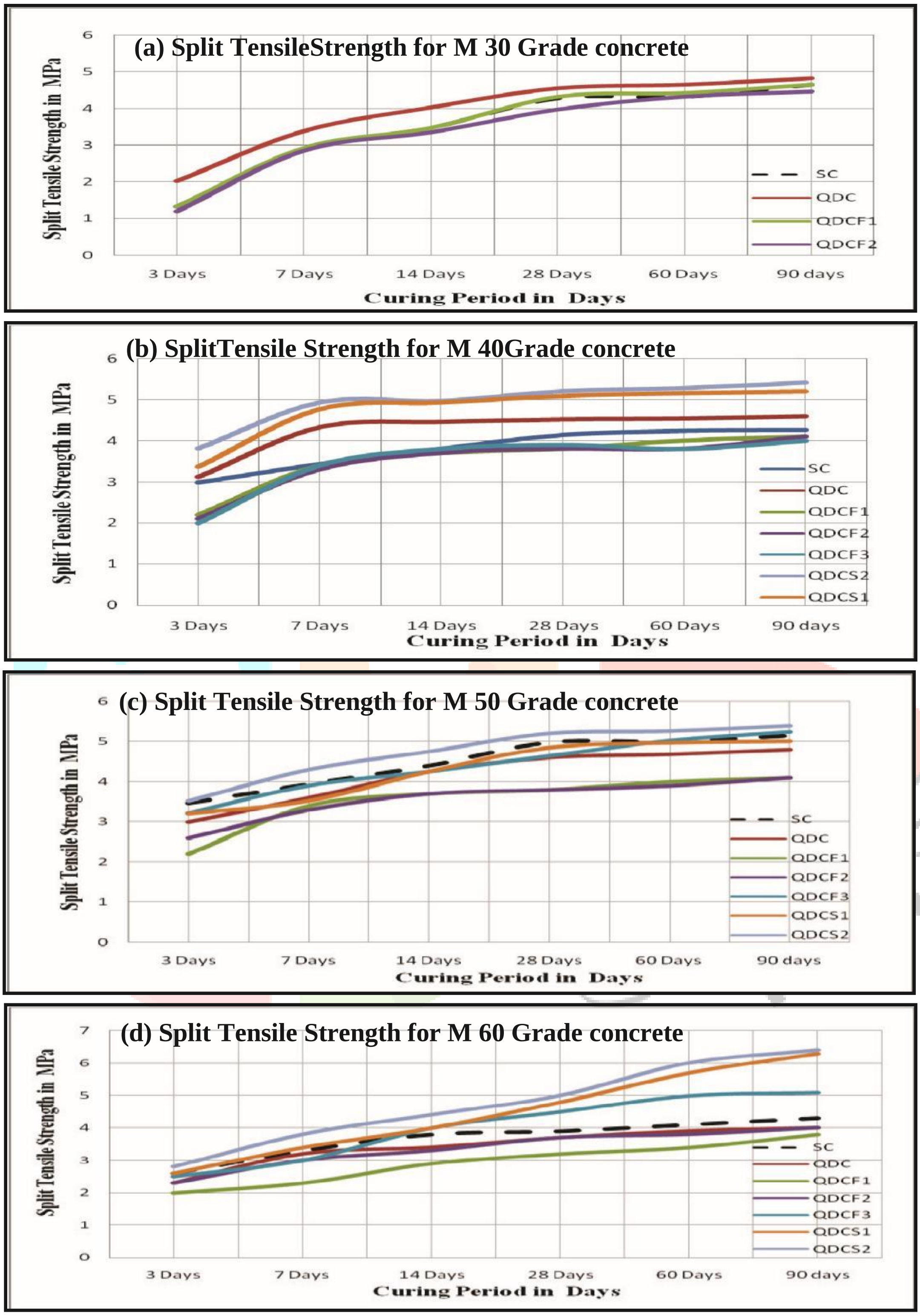
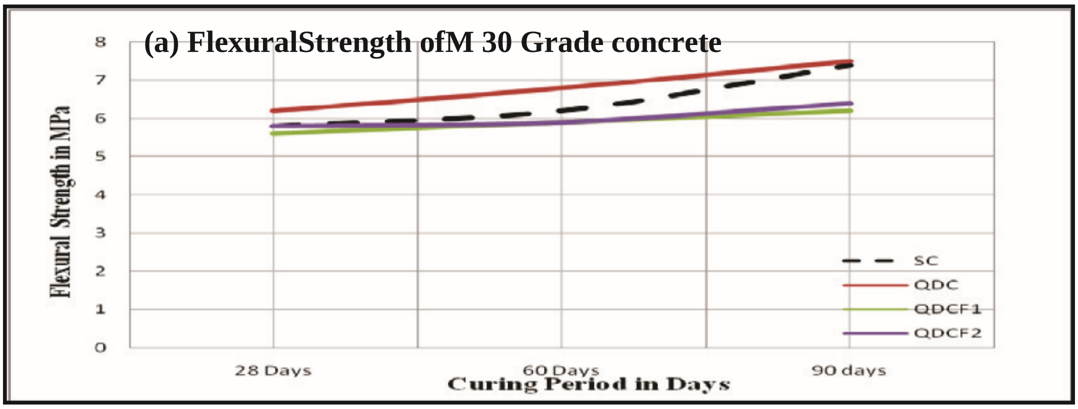
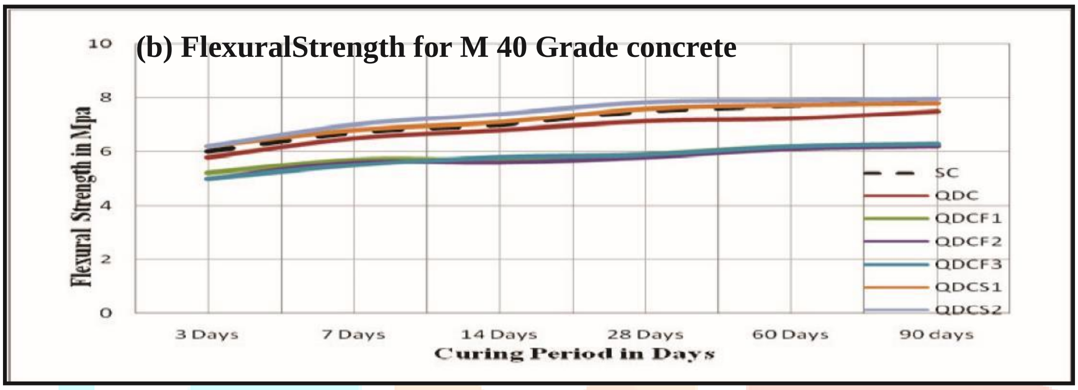
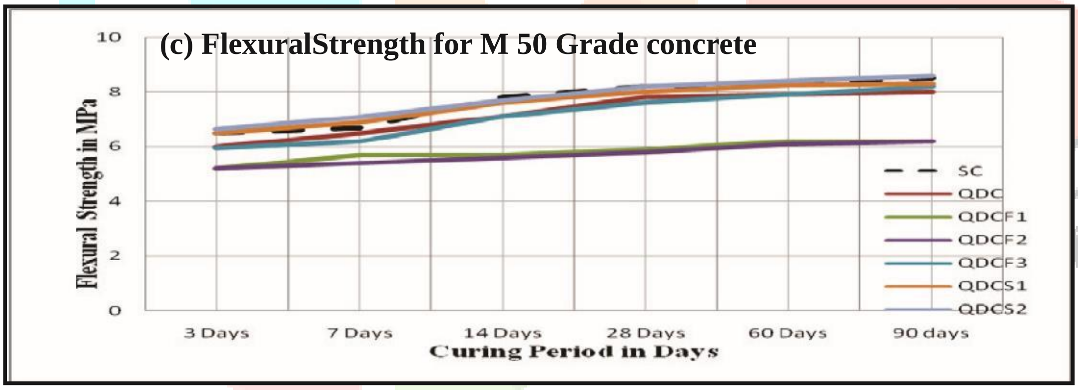


Fig. 5.10 Comparison of Splitting Tensile Strength of Concrete


(a) FlexuralStrength ofM 30 Grade concrete


(b) FlexuralStrength for M 40 Grade concrete


(c) FlexuralStrength for M 50 Grade concrete

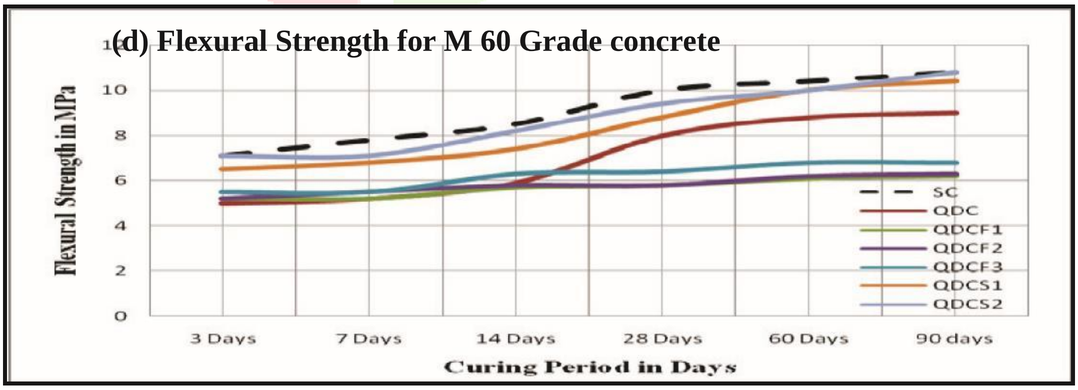

(d) Flexural Strength for M 60 Grade concrete

Fig.5.11 Comparison of Flexural Strength of Concrete

5.3.5 Rebound Hammer Test

Rebound hammer test being one of the non destructive tests, the results are presented in figure 5.12. M40 grade concrete reflects slightly less Rebound number than the sand concrete for all replacement levels. But for M60 grade concrete with silica fume 10%,

23.5% more than the SC and for concrete with fly ash more or less same with SC.

5.3.6 UPV test

Generally the UPV values are more for QDC compared to SC and better performance has been observed in all replacement levels of cement with fly ash and silica fume. Particularly for M60 grade concrete QDC with silica fume (10%), the UPV value is 7% more than SC.

5.4 DURABILITY CHARACTERISTICS

Totally five kinds of durability tests were conducted in order to study and compare for different grades and types of concrete.

5.4.1 Saturated water absorption and porosity

The water absorption and porosity values based on 100mm cubes of different type of concrete are shown in figure 5.14 and 5.15 for various grades of concrete. From the test result it is observed that the water absorption and porosity are less in control concrete when compared to other types of concrete, but addition silica fume decreases water absorption and porosity level. Because of the high pozzolanic nature of silica fume and its void filling ability SWA for QDC with silica fume (10%) of M60 grade concrete is slightly lower than the SC, but the porosity is more or less equal to QDC with fly ash and silica fume with sand concrete.

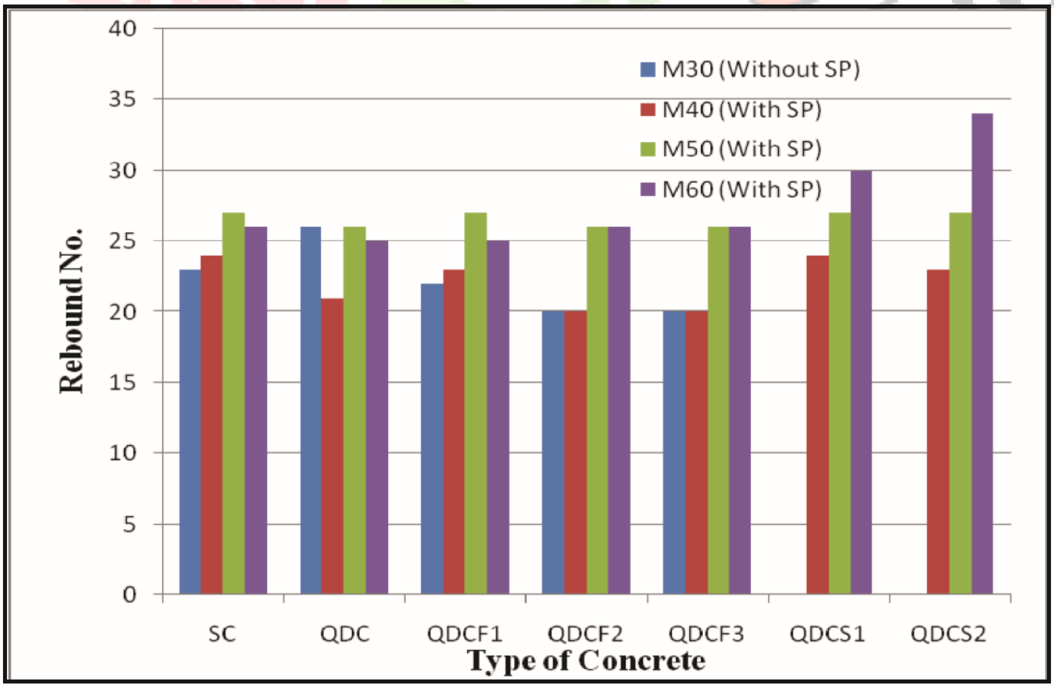


Fig.5.12 Comparison of Rebound Hammer Test results

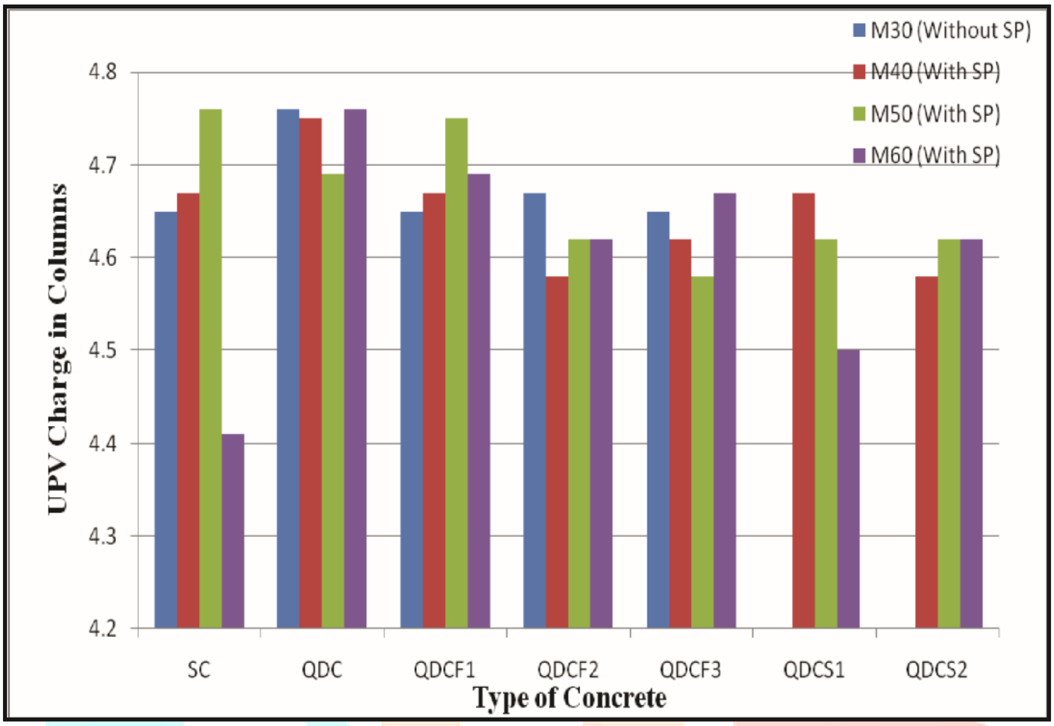


Fig. 5.13 Comparison of UPV test results

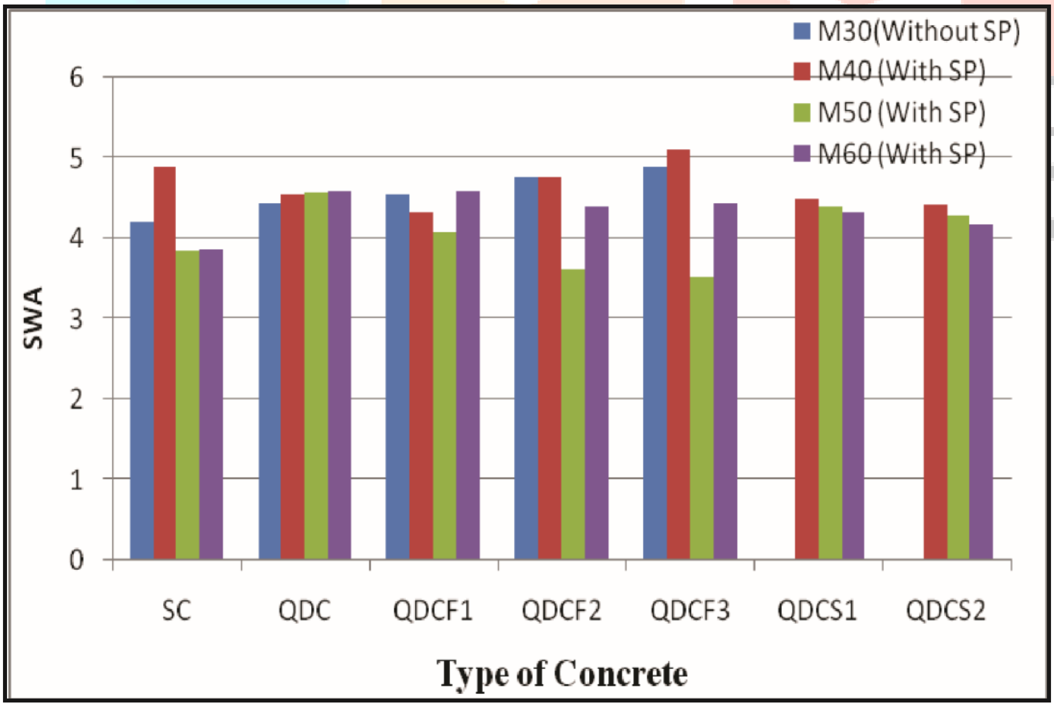


Fig.5.14 Saturated Water Absorption for various types of concrete

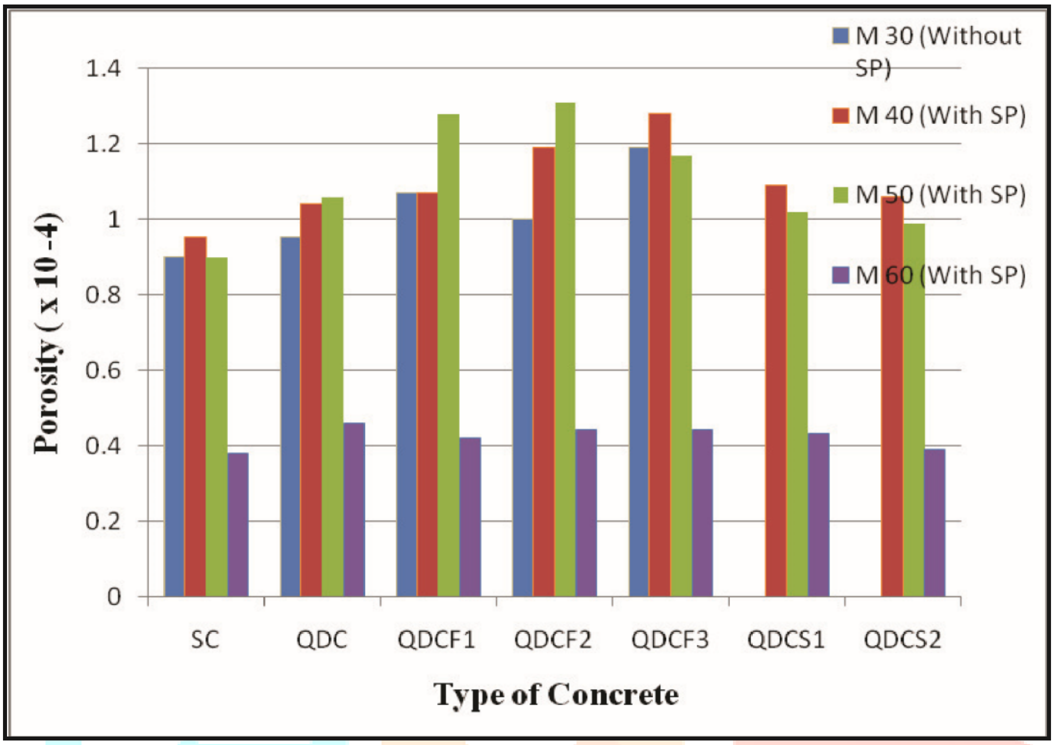


Fig.5.15 Porosity for various types of concrete

5.4.2 Acid resistance test

Tests were carried out according to ASTM G20-8 to obtain weight loss of different type of concrete after immersion in HCL. The Acid test results are shown in Figure 5.16. From the results it is observed that weight loss is more in control concrete when compared to silica fume added with quarry dust concrete. Because silica fume has void filling ability and it has ability to resist acid attack. M60 grade concrete with silica fume (10%) has shown better resistance than the sand concrete by more than 41.8% and all other replacement also shown better results.

5.4.3 Alkaline resistance test

Tests results of alkaline attack as weight loss of different type of concrete for alkaline attack are shown in figure 5.17. It is observed that weight loss is more or less same for all types of concrete because, the replacements with silica fume increases for quarry dust concrete to resist considerably. M60 grade concrete of QDC with silica fume (10%) has shown better performance by 33% more than the sand concrete.

5.4.4 Rapid Chloride Permeability Test

Test results of RCPT determined as per ASTM–C 1202–97 for various type of concrete is shown in figure 5.18. From the test results it is observed that QDC has only a slight reduction in the permeability compared to sand concrete for all the four grades of concrete without additives. But, the reduction in the permeability is significant with addition of admixtures (plasticizers) and additives (fly ash or silica fume). Addition of silica fume considerably reduced the permeability compared to addition of fly ash. M60 grade concrete of QDC with silica fume (10%) has shown better performance by 17% more than the sand concrete.

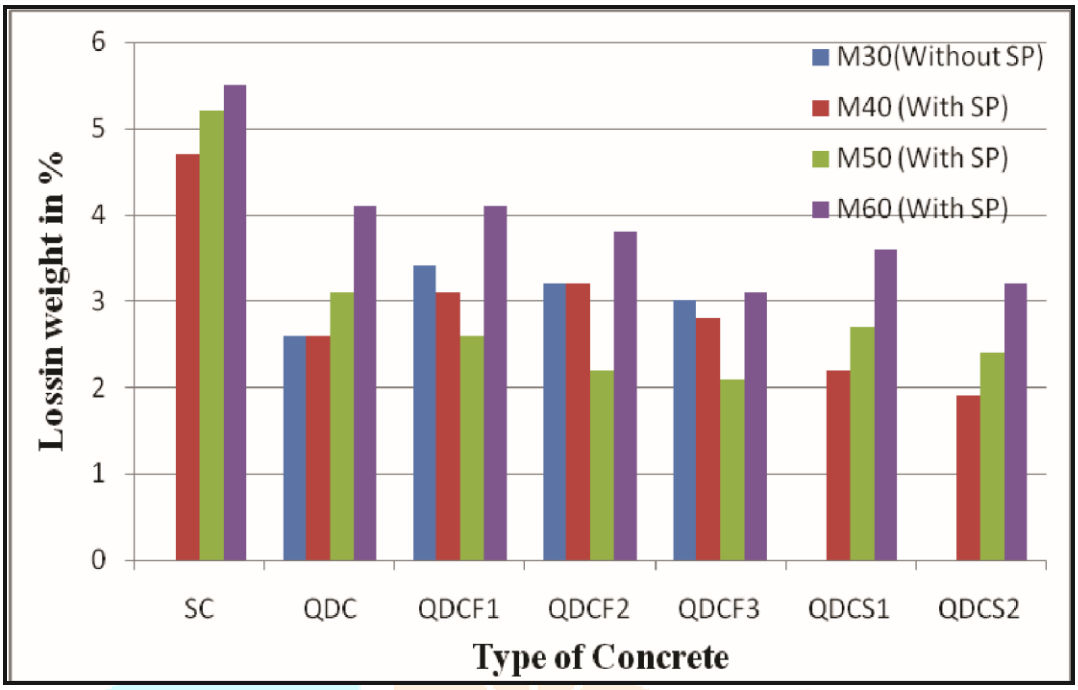


Fig. 5.16 Comparison of Acid resistance test

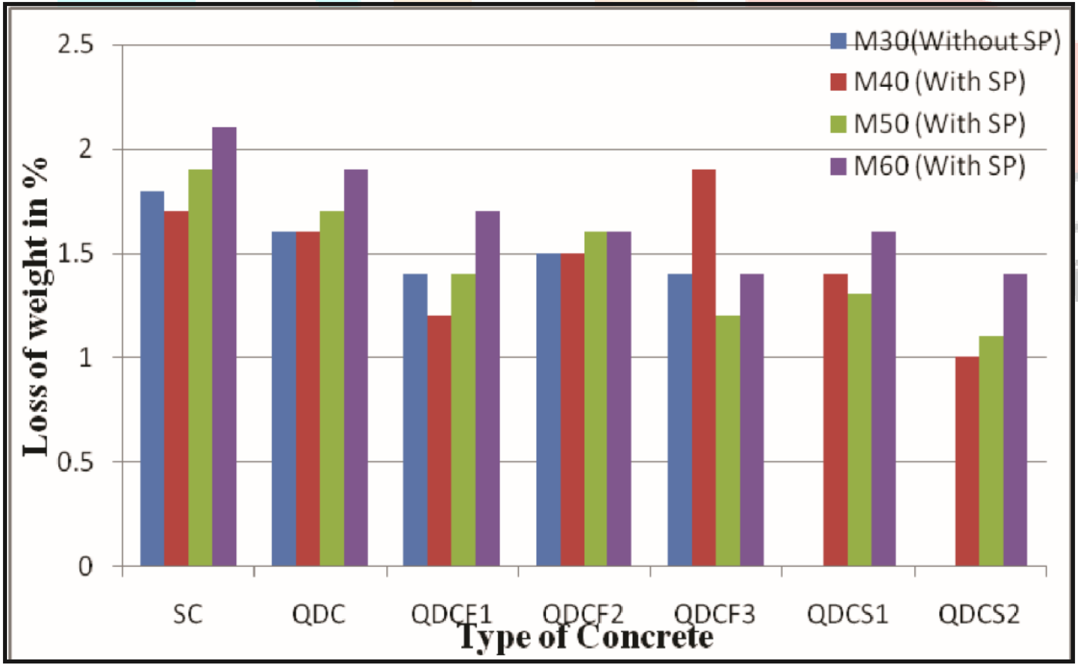


Fig. 5.17 Comparison of Alkaline resistance test

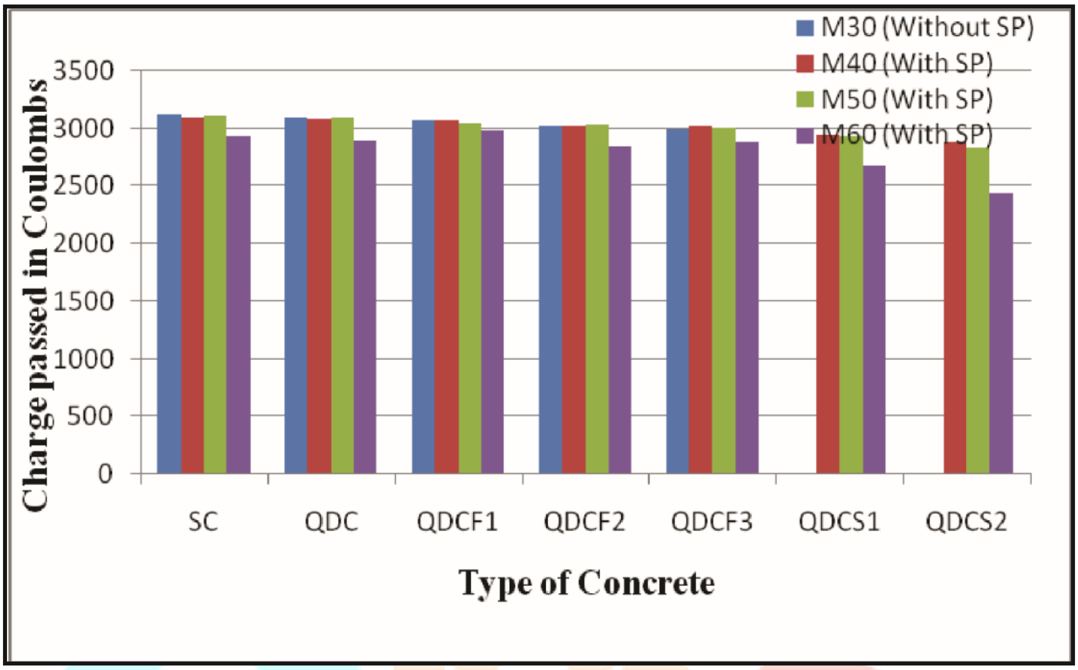


Fig.5.18Comparison of RCPT Test

5.5 SUMMARY

The development of quarry dust based concrete by totally replacing conventional sand with quarry dust has been considered. The workability, strength and durability characteristics were determined through relevant tests as per standards. The analysis of test results was made in all aspects to have the feasibility of replacing quarry dust with sand. The conclusions and recommendations are given in the chapter 7.

CHAPTER 6

THEORETICAL PREDICTION

6.0 INTRODUCTION

Regression analysis is a statistical tool for the investigation of relationships between variables. Regression analysis with a single explanatory variable is termed simple regression. Multiple regressions are a technique that allows additional factors to enter the analysis separately. It is valuable for quantifying the impact of various simultaneous influences upon a single dependent variable. Regression analysis is a procedure for relating known input variables and output parameter using statistical principles.

The general regression technique is to assume a form of relationship for the input parameters and the results, with a number of unknown coefficients. The unknown coefficients are found using the data available from experiments or other sources using the Legendre's principle of least squared errors.

Legendre's principle of least squared errors, is a general purpose curve fitting technique which helps to choose the values of unknown coefficients, also called as the regression coefficients, in such a way that the predicted results agree with the target results to the maximum extent possible. The data used for the regression analysis is presented in Table 6.1 and the regression equations are presented in Table
6.2.

Table 6.1 Data Used for Regression Analysis

No	Compressive Strength	Fly ash (%)	Days of curing	Compressive Strength (MPa)	
				Actual	Predicted
1	30	0	3	17.6	23.236867
2	30	0	3	18.23	23.236867
3	30	10	3	12.2	20.956717
4	30	20	3	13.5	18.676568
5	30	30	3	12.6	16.396418
6	40	0	3	22	29.710682
7	40	0	3	20.1	29.710682
8	40	10	3	17	27.430533
9	40	20	3	17.4	25.150383
10	40	30	3	17.2	22.870233
11	40	0	3	21	29.710682
12	40	0	3	22.5	29.710682
13	50	0	3	28.6	36.184497
14	50	0	3	26	36.184497
15	50	10	3	24.6	33.904348

Table 6.1 Data Used for Regression Analysis contd.

16	50	20	3	24.2	31.624198
17	50	30	3	22.4	29.344048
18	50	0	3	28	36.184497
19	50	0	3	28.3	36.184497
20	60	0	3	23	42.710874
21	60	0	3	21	40.324327
22	60	10	3	21	40.435439
23	60	20	3	24	42.445442
24	60	30	3	25	41.676582
25	60	0	3	26	42.345322
26	60	0	3	24	44.898962
27	30	0	7	20.67	24.417705
28	30	0	7	21.5	24.41770
29	30	10	7	18.67	22.137556
30	30	20	7	21.67	19.857406
31	30	30	7	20.33	17.577256
32	40	0	7	34	30.891521
33	40	0	7	27.2	30.891521
34	40	10	7	24	28.611371
35	40	20	7	25	26.331221
36	40	30	7	24.8	24.051071
37	40	0	7	27	30.891521
38	40	0	7	30	30.891521
39	50	0	7	38	37.365336
40	50	0	7	34.64	37.365336

No	**Compressive Strength**	**Fly Ash (%)**	**Days of curing**	**Compressive Strength (MPa)**	
				Actual	**Predicted**
41	50	10	7	25.83	35.085186
42	50	20	7	25	32.805036
43	50	30	7	24.3	30.524886
44	50	0	7	34	37.365336
45	50	0	7	34.6	37.365336
46	60	0	7	41	42.244529
47	60	0	7	38	44.324268
48	60	10	7	24	38.765428
49	60	20	7	28	40.534354

50	60	30	7	29	42.344549
51	60	0	7	31	37.987886
52	60	0	7	34	38.776442
53	30	0	14	28.17	26.484172
54	30	0	14	28.67	26.484172
55	30	10	14	24.67	24.204022
56	30	20	14	29.17	21.923873
57	30	30	14	24.67	19.643723
58	40	0	14	38	32.957987
59	40	0	14	32	32.957987
60	40	10	14	32.4	30.677838
61	40	20	14	31	28.397688
62	40	30	14	31	26.117538
63	40	0	14	35	32.957987
64	40	0	14	33	32.957987
65	50	0	14	49	39.431803
66	50	0	14	46	39.431803
67	50	10	14	34.83	37.151653
68	50	20	14	28.62	34.871503
69	50	30	14	33.3	32.591353
70	50	0	14	49	39.431803
71	50	0	14	49	39.431803
72	60	0	14	48	44.335592
73	60	0	14	43	42.464699
74	60	10	14	36	38.886592
75	60	20	14	33	34.926422
76	60	30	14	40	44.456844
77	60	0	14	52	48.887559
78	60	0	14	49	46.965784

Table 6.1 Data Used for Regression Analysis contd.

No	Compressive Strength	Fly Ash (%)	Days of curing	Compressive Strength (MPa)	
				Actual	Predicted
79	30	0	28	38.5	30.617106
80	30	0	28	39.83	30.617106
81	30	10	28	26.37	28.336956
82	30	20	28	35.26	26.056806
83	30	30	28	25.83	23.776657
84	40	0	28	51	37.090921
85	40	0	28	43.3	37.090921
86	40	10	28	44.6	34.810771
87	40	20	28	44.2	32.530622
88	40	30	28	44.8	30.250472
89	40	0	28	49	37.090921
90	40	0	28	48	37.090921
91	50	0	28	58.56	43.564736
92	50	0	28	56	43.564736
93	50	10	28	42.6	41.284587
94	50	20	28	41.15	39.004437
95	50	30	28	42	36.724287
96	50	0	28	57.65	43.564736
97	50	0	28	58	43.564736
98	60	0	28	53	46.986226
99	60	0	28	45	48.656422
100	60	10	28	38	40.735299
101	60	20	28	42	41.093324
102	60	30	28	44	42.897676
103	60	0	28	56	50.879922
104	60	0	28	59	52.887544
105	30	0	60	40.1	40.063812
106	30	0	60	42.23	40.063812
107	30	10	60	37.5	37.783662
108	30	20	60	40.33	35.503512
109	30	30	60	36	33.223363

Table 6.1 Data Used for Regression Analysis contd.

110	40	0	60	51.4	46.537627
111	40	0	60	44	46.537627
112	40	10	60	45.3	44.257477
113	40	20	60	45.8	41.977328
114	40	30	60	45.7	39.697178

No	Compressive Strength	Fly Ash (%)	Days of curing	Compressive Strength (MPa)	
				Actual	Predicted
115	40	0	60	49.06	46.537627
116	40	0	60	48.26	46.537627
117	50	0	60	58.73	53.011442
118	50	0	60	56.58	53.011442
119	50	10	60	48.6	50.731292
120	50	20	60	46.22	48.451143
121	50	30	60	48.5	46.170993
122	50	0	60	58	53.011442
123	50	0	60	58.4	53.011442
124	60	0	60	64	54.956442
125	60	0	60	48	46.637322
126	60	10	60	40	42.898748
127	60	20	60	44	44.787449
128	60	30	60	52	50.746296
129	60	0	60	68	63.565692
130	60	0	60	80	68.466429
131	30	0	90	42.4	48.920099
132	30	0	90	44.6	48.920099
133	30	10	90	38.2	46.639949
134	30	20	90	46.67	44.359799
135	30	30	90	37.15	42.079649
136	40	0	90	51.46	55.393914
137	40	0	90	45.06	55.393914
138	40	10	90	47.6	53.113764
139	40	20	90	47.5	50.833614
140	40	30	90	47.4	48.553464

Table 6.1 Data Used for Regression Analysis contd.

No	Compressive Strength	Fly Ash (%)	Days of curing	Compressive Strength (MPa)	
				Actual	Predicted
150	60	0	90	66	64.456642
151	60	0	90	50	58.864648
152	60	10	90	44	48.767922
153	60	20	90	46	48.365884
154	60	30	90	54	52.846322
155	60	0	90	70	68.996452
156	60	0	90	86	79.776459
141	40	0	90	49.2	55.393914
142	40	0	90	48.4	55.393914
143	50	0	90	59	61.867729
144	50	0	90	56.76	61.867729
145	50	10	90	52.1	59.587579
146	50	20	90	53.3	57.307429
147	50	30	90	56.3	55.02728
148	50	0	90	58.9	61.867729
149	50	0	90	59	61.867729

Table 6.2 Regression Equations

No	Prediction Parameter	Equation	Fitness	RMS Error	RMS % Error
1.	Compressive strength (MPa)	2.93 + 0.6474*fc - 0.2280*Psf + 0.2952*Cd	0.642	6.45	17.30

6.1 OBSERVATIONS ON THE REGRESSION EQUATIONS

The regression equations were used for predicting the compressive strength. An observation of the measures of fitness of regression shows that the multivariate linear regression can estimate the prediction values with reasonable levels of accuracy for compressive strength. Linear regressions are inherently limited in their ability to model very complex sets of data, since first order regression parameters try to fit a monotonically varying linear relationship curvature for the prediction parameter.

In spite of the apparently larger errors, regression equations are useful for estimating the values of parameters when no sophisticated computational tool is available. A computational model using Artificial Neural Network (ANN) or Sugeno type NeuroFuzzy Inference System might perform much better for the same data. Hence, the regression equations are supplemented by a computational model using ANN in the next chapter.

6.2 MODELLING WITH ARTIFICIAL NEURAL NETWORK (ANN)

Artificial Neural Network (ANN) is a versatile modeling tool for problems relating to function-approximation and pattern classification. Most of the problems in Engineering demand establishment of relationship between input parameters and the resulting values. In the previous days, establishing this relationship was a professional mathematician's work, since the solution required high level of mathematical background. The development of statistical regression for establishing relationships removed the burden of solving complex mathematical equations with the solution of a simple system of linear equations. This was further aided by the development of high power computing machines, which could solve linear equations instantaneously.

Apart from the approach based essentially equation solving, researchers in numerical computation tried to solve partial differential equations using the finite difference method and the more refined finite element method, which could produce models which could solve the equations based on standard procedure.

The Artificial Neural Network (ANN) is a result of extensive research carried out on machine learning algorithms through artificial intelligence. ANN mimics the human brain in its approach to solving problems. The fundamental unit of computing in ANN is a neuron. Several neurons may be organized in the form of layers. Neurons in one layer have connection to the neurons in the preceding and succeeding layers. The complexity of the network topology depends upon the number of layers chosen for the ANN and the number of neurons in each layer of the network.

6.3 BASIC DEFINITIONS

Some of the essential terms used in the neural network modeling are defined here.

Neuron

The fundamental unit of computation in ANN is neuron. This receives signals in the form of input from neurons in the previous layer. Each neuron has a specific way of combining individual all the inputs from preceding neurons, called a transfer function, which converts the inputs into a single value. Then, the computed input signal values are fired into the outgoing neural connections. Neurons function only as signal transfer agents and do not retain values.

Layer

Layer is contains collection of neurons. Each neuron in a layer is connected to the all the neurons in the previous and succeeding layers. No two neurons in the same layer have a connection.

Connection and Connection Weight

Connection is the link between two neurons, through which signals are transferred from one to the other. Connections have a weight, which means that the net signal arriving at the other end of the connection is the product of input signal and connection weight.

Bias

Bias is the ad-hoc value added to the sum of all weighted inputs arriving into a neuron.

Transfer Function

Each neuron with incoming connections is associated a transfer function. Transfer function is the function applied on the aggregate of the weighted sum of input values and the bias value for the neuron. The output of the transfer function is the net signal arriving at the neuron and this shall be fired through the succeeding connections.

Input Layer

This layer contains neurons equal to the number of input parameters supplied to the network.

Output Layer

This layer contains neurons equal to the number of outputs predicted by the network.

Processing Layer or Hidden Layer

Processing layer or hidden layer lies between the input layer and the output layer. The number of processing layers and the number of neurons per processing layer differ from one type of network to the other. Some networks like Feed Forward have flexibility in deciding the number of processing layers and the number of neurons per processing layer. But the flexibility comes at the cost of explicit training using the input and target data. Hence, these are called supervised networks.

Some networks like Radial Basis have rules governing the number of processing layers and the number of neurons per processing layer. Usually, those ANNs which do not permit alteration or tuning of the number of layers, number of neurons per layer and the transfer function associated with a layer belong to the radial basis family of ANNs.

Some of the members of radial basis family are Radial Basis Network, Generalized Regression and Probabilistic Neural Network. The radial basis family does not require explicit training, but creates a network topology based on the input data and the target data supplied to it at the time of creation. Hence, these networks are called unsupervised networks.

Training

Training is the process of making a supervised network to adjust the values of connection weights and bias in such way that the error between target values provided and the predicted values becomes a minimum. Training may be controlled by special algorithms developed for arriving at the optimal network configuration at the earliest.

Adapting

Adapting is the process of setting up a network to predict particular input-output pattern supplied to it. This process is not iterative, and usually leads to deterministic configurations based on the data supplied. In the case of some feed forward networks, the initial weights are randomly initialized and hence, the trained network might not reach the same state after each training session for the given data. Adapting is contrary to this indeterminate final state, where the given data usually results in the same status for the network after adapting.

6.4 TYPES OF ARTIFICIAL NEURAL NETWORK

The ANN's present a wide variety of networks, each one suited for separate applications. Following are some of the most commonly used neural networks:

i. Hopfield Network ii. Perceptron Network iii. Radial Basis
Network iv. Exact Fitting Radial Basis Network
v. Probabilistic Network

vi. General Regression Neural Network vii. Self Organizing Map viii. Linear Network ix. Feed
Forward Network with Back-propagation
x.Cascade-forward with Back-propagation Network

The typical applications of these networks are in areas of signal processing, function approximation and data classification problems. In the present case, neural networks are to be used for function approximation. Choosing a network and optimal set of control parameters is done by trial and error method, where the best suited architectures of several types of networks are trained or adapted to suite the training data. For the present case, the neural network toolbox available in MATLAB software was used for the modeling work.

6.5 MATLAB® SOFTWARE FOR DEVELOPING ANN MODEL

MATLAB is a versatile numerical computation platform founded on the basic notion of matrices. The core of MATLAB software is equipped with basic matrix operations, input and output and a script interpretation engine. MATLAB comes with a scripting system of its own. The extra-functionalities of the software are packed in the form of toolboxes, which are specialized libraries and functions possessing highly advanced application areas like aerospace engineering, data acquisition , instrument control, finite element toolbox, artificial neural network toolbox, fuzzy logic toolbox, genetic algorithm toolbox, financial and time series toolbox, image processing toolbox etc.. The logical relationship between the user, MATLAB software and its toolboxes is shown in Fig. 6.1.

6.5.1 Neural Network Toolbox for Developing ANN

The neural network toolbox available in MATLAB software provides implementations for several types of neural networks. It offers extensive customization facilities for each type of neural network. The toolbox is a collection of functions which can generate, train and plot the networks. Several functions for performance evaluation of the networks and errors estimation are provided. In addition to these facilities, the neural network toolbox comes with a graphical workbench called Network/Data Manager – invoked by the command *nntool*, which facilitates visual design, training and performance evaluation of neural networks. the Network/Data Manager is shown in figure. 6.2. The Network/Data Manager provides buttons for Help, New Data, New Network, Import, Export, View, Delete, Initialize, Simulate, Train and Adapt, all related to the data and networks. The purposes of these buttons are described in Table 6.3.

6.5.2 Considerations for Modeling with ANN

The process of modeling with ANN begins with identification of input parameters and the output to be predicted by the network. The input and target data are organized to suite the order of input and output parameters. After entering the data, the Network shall be used to generate several types of networks and tuning each type of network for better performance until the most suitable one is identified. Hence, modelling with ANN is only a random search problem, where a bit of experience would help quicken the identification of the most suitable network. The entire data should be divided into a training p8520/air which contains large amount of data and a testing pair which contains a small portion (about 10% to 20%) of the total data. The training pair is supplied to the network to help it set up the connection weights and bias values. The testing pair is used to evaluate the performance of the network against input data which is new to the network (i.e., not presented during training).

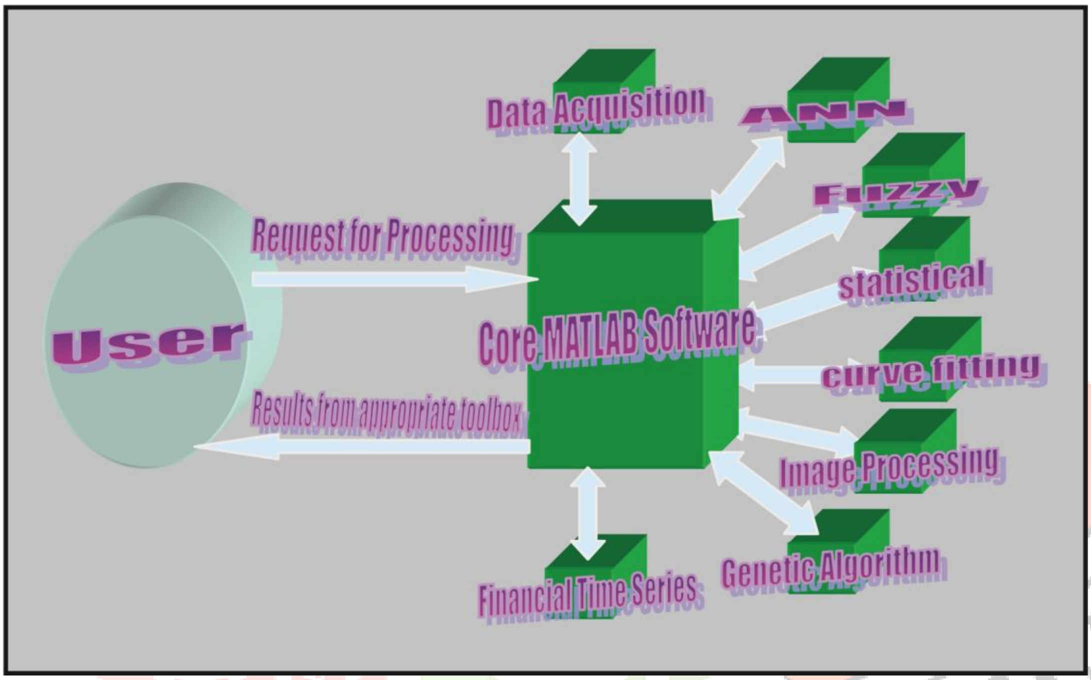


Fig. 6.1 Relationship between the User, MATLAB software and Toolboxes

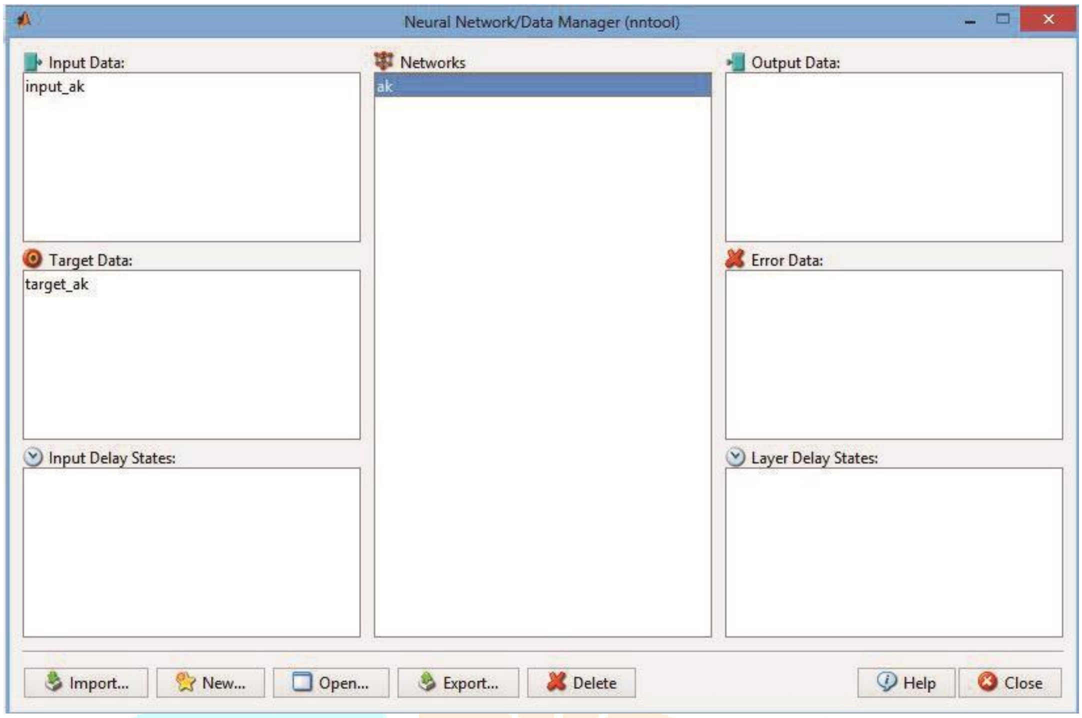


Fig. 6.2 Network/Data Manager

Table 6.3 Purpose of Buttons in Network/Data Manager

No.	Button	Purpose
1.	Help	Displays a very crisp help related on how to leverage the Graphical User Interface (GUI) for creating and configuring networks.
2.	New Data	Opens a dialog box for entering new data, which may be input data or target data. Name of the data might also be assigned from the same dialog.
3.	New Network	Provides single point entry for generating any type of neural network. The dialog takes a name for the network and displays the list of all available networks. Choosing any one type of network displays options related to that network, which might have some reasonable initial values.
4.	Import	Imports data from MATLAB work environment or from a disk file.
5.	Export	Exports the data to the MATLAB work environment or to a disk file.

6.	View	When pressed after selecting data, the values are displayed. Any modifications in this dialog shall be reflected in the actual data. When pressed after selecting a network, it displays the schematic layout of the network and options to train, adapt, initialize or inspect the network.
7.	Delete	Deletes the selected data or network.
8.	Initialize	Initializes the network specific input range.
9.	Simulate	Can be used to simulate the network using data entered in the input area. The input data should have already been defined.
10.	Train	Trains the network for a pair of input and target values defined in the input and target portions of the Network/Data Manager. Training is accompanied by the graphical display of RMS errors.
11.	Adapt	The network can be made to adapt a pair of input and target data. This is enabled only for networks which support Adapt operation. For other types of networks, the dialog shows a disabled interface.

The errors associated with the test data provide a reasonable estimate of the generalization achieved using the ANN model. Lower the error associated with test data, the higher the consistency of the network. High degree of caution should be exercised to ensure that generalization is achieved using ANN, since improperly constituted networks perform with high accuracy in the vicinity of training points and produce exorbitant error away from training points.

The present model was developed using General Regression Neural Network (GRNN), which belongs to the family of Radial Basis Neural Networks. The GRNN contains two layers to process the input data. The architecture and functions associated with GRNN are presented in the following section.

6.6 BASICS OF GENERAL REGRESSION NEURAL NETWORK (GRNN)

The GRNN is a fixed topology network, where the number of layers is fixed. It contains two layers for processing the input data. But, the number of neurons in each layer would differ based on the data provided at the time of initialization. The architecture of GRNN is shown in Fig. 6.3 (Howard Demuth et al., 2006).

The network contains an input layer, a radial basis layer processing and an output layer. The radial basis layer has Euclidean distance function for calculating input to the neuron, which differs from the traditional approach computing the weighted sums. The radial basis layer contains neurons counting exactly equal to the number of data sets presented to it. Each neuron in the radial basis layer has weight vector equal to one of the columns of input. The bias for the first layer neurons is calculated as the ratio between logarithm of two and the spread constant supplied at the time generating the network. Spread constant is a number, normally equal to 1, which determines the smoothness of the curve. The value of spread constant should be larger than the minimum value of the input data and smaller than the maximum range of the input data. The proper choice of spread constant value ensures that the network is neither over-fit nor too insensitive within the given range of inputs.

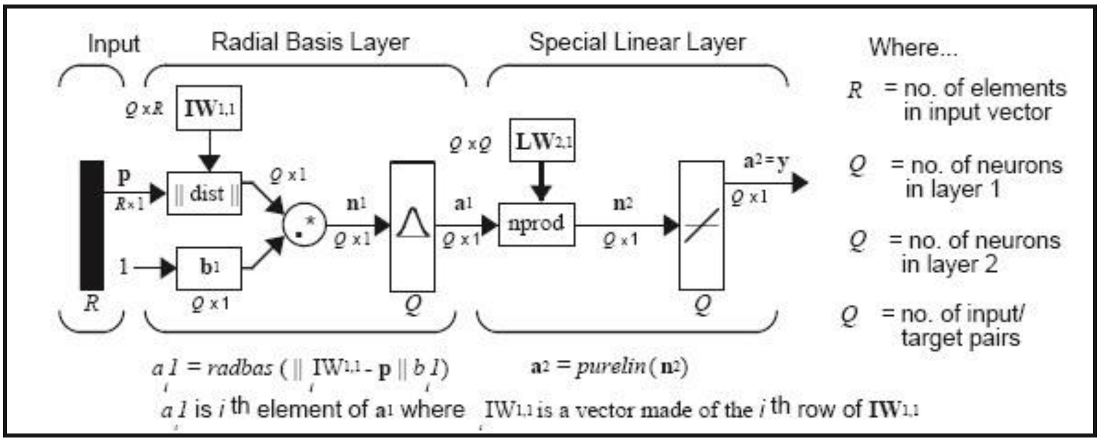


Fig. 6.3 Architecture of GRNN

The number of neurons in the output layer equals the number of outputs expected from the network. The weight of each neuron is equal to one row of target values. The second layer of GRNN uses normalized product transfer function, which calculates the dot product of the weight vector and input vector divided by the sum of the input vector. The outputs from this layer are simply passed out as predictions.

6.7 MODELLING WITH GENERAL REGRESSION NEURAL NETWORK

The GRNN model for the experimental data was developed using the Network/Data Manager available in the MATLAB software and invoked through the command *nntool*. The input parameters were the grade of concrete, type of concrete (SC, QDC, QDCF, QDCS). The type of concrete is converted into numeric values by assigning the number 1(SC), 0(QDC), 10(QDCF 10%), 20(QDCF 20%), 30(QDCF 30%), 5(QDCS 5%) and 110 (QDCS 10%). This change was necessitated by the fact that inputs for neural networks must be in the form of real numbers or integers.

One more aspect of the training was that the control specimens did not have any QDCF. This would result in zero values for all control specimens. But, the percentage of QDCF and QDCS is ambiguous. The prediction parameters were the compressive strength. The input parameters for the GRNN model are shown in Table
6.4. The training (Table 6.5) and test data are also indicated in the tables.

Table 6.4Input Parameters for the GRNN Model

							Input data		Output Comp. strength	
			Coarse Aggregate			sand	w/c	Cur days		
			%Sp.grFMSp grSizeSp grFMSp grFMw/b						without SP	with SP
5	6	7	8	9	10	11	12	13	14	15
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	3	17.6	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	3	18.23	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	3	12.2	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	3	13.5	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	3	12.6	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	7	20.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	7	21.5	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	7	18.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	7	21.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	7	20.33	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	14	28.17	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	14	28.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	14	24.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	14	29.17	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	14	24.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	28	38.5	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	28	39.83	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	28	26.37	-

No	concrete Grade	Concrete Type	Quarry dust	Cement
	1	2	3	4
1	M 30	1	0	2.6
2		0	100	2.6
3		10	100	2.6
4		20	100	2.6
5		30	100	2.6
6		1	0	2.6
7		0	100	2.6
8		10	100	2.6
9		20	100	2.6
10		30	100	2.6
11		1	0	2.6
12		0	100	2.6
13		10	100	2.6
14		20	100	2.6
15		30	100	2.6
16		1	0	2.6
17		0	100	2.6
18		10	100	2.6

Table 6.4Input Parameters for the GRNN ModelContd.

								Input data	Output Comp. strength	
			Coarse Agregate			sand	w/c	Cur days		
			%Sp.grFMSp grSizeSp grFMSp grFMw/b						without SP	with SP
5	6	7	8	9	10	11	12	13	14	15
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	28	35.26	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	28	25.83	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	60	40.1	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	60	42.23	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	60	37.5	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	60	40.33	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	60	36	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	90	42.4	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	90	44.6	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	90	38.2	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	90	46.67	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.45	90	37.15	-
3.36	2.59	12	2.61	2.61	2.56	2.81	0.43	3	-	22
3.36	2.59	12	2.61	2.61	2.56	2.81	0.43	3	-	20.1
3.36	2.59	12	2.61	2.61	2.56	2.81	0.43	3	-	17
3.36	2.59	12	2.61	2.61	2.56	2.81	0.43	3	-	17.4
3.36	2.59	12	2.61	2.61	2.56	2.81	0.43	3	-	17.2
3.36	2.59	12	2.61	2.61	2.56	2.81	0.43	3	-	21

Table 6.4Input Parameters for the GRNN ModelContd.

								Input data			Output Comp.			
			Coarse Agregate			concrete sand		Concrete w/c Type		Cur	Quarry dust strength			Cement
			%Sp.grFMSp grSizeSp grFMSp grFMw/b		No	Grade				days	without SP	with SP		
5	6	7	8	9		10	11	2 12	1	33	14	1	54	
3.36	2.59	12	2.61	2.61	19	2.56	2.81	0.43 20	3		-	100	22.5	2.6
3.36	2.59	12	2.61	2.61	20	2.56	2.81	0.43 30	7		-	100	34	2.6
3.36	2.59	12	2.61	2.61	21	2.56	2.81	1 0.43	7	0	-		27.2	2.6
3.36	2.59	12	2.61	2.61	22	2.56	2.81	0 0.43	7		-	100	24	2.6
3.36	2.59	12	2.61	2.61	23	2.56	2.81	0.43 10	7		-	100	25	2.6
3.36	2.59	12	2.61	2.61	24	2.56	2.81	0.43 20	7		-	100	24.8	2.6
3.36	2.59	12	2.61	2.61	25	2.56	M30 2.81	0.43 30	7		-	100	27	2.6
3.36	2.59	12	2.61	2.61	26	2.56	2.81	1 0.43	7	0	-		30	2.6
3.36	2.59	12	2.61	2.61	27	2.56	2.81	0 0.43	14		-	100	38	2.6
3.36	2.59	12	2.61	2.61	28	2.56	2.81	0.43 10	14		-	100	32	2.6
3.36	2.59	12	2.61	2.61	29	2.56	2.81	0.43 20	14		-	100	32.4	2.6
3.36	2.59	12	2.61	2.61	30	2.56	2.81	0.43 30	14		-	100	31	2.6
3.36	2.59	12	2.61	2.61	31	2.56	2.81	1 0.43	14	0	-		31	2.6
3.36	2.59	12	2.61	2.61	32	2.56	2.81	0 0.43	14		-	100	35	2.6
3.36	2.59	12	2.61	2.61	33	2.56	2.81	0.43 10	14		-	100	33	2.6
3.36	2.59	12	2.61	2.61	34	2.56	M40 2.81	0.43 20	28		-	100	51	2.6
3.36	2.59	12	2.61	2.61	35	2.56	2.81	0.43 30	28		-	100	43.3	2.6
3.36	2.59	12	2.61	2.61	36	2.56	2.81	5 0.43	28		-	100	44.6	2.6

Table 6.4Input Parameters for the GRNN ModelContd.

									Input data		Output Comp.			
				Coarse Agregate		concrete sand		Concrete w/c			Quarry dust	strength		Cement
			%Sp.grFMSp grSizeSp grFMSp grFMw/b		No	Grade		Type		Cur days	without SP		with SP	
5	6	7	8	9		10	11	2 12		1 33	14		1 54	
3.36	2.59	12	2.61	2.61	37	2.56	2.81	0.43	110	28	-	100	44.2	2.6
3.36	2.59	12	2.61	2.61	38	2.56	2.81	1 0.43		28 0	-		44.8	2.6
3.36	2.59	12	2.61	2.61	39	2.56	2.81	0 0.43		28	-	100	49	2.6
3.36	2.59	12	2.61	2.61	40	2.56	2.81	0.43 10		28	-	100	48	2.6
3.36	2.59	12	2.61	2.61	41	2.56	2.81	0.43 20		60	-	100	51.4	2.6
3.36	2.59	12	2.61	2.61	42	2.56	2.81	0.43 30		60	-	100	44	2.6
3.36	2.59	12	2.61	2.61	43	2.56	2.81	5 0.43		60	-	100	45.3	2.6
3.36	2.59	12	2.61	2.61	44	2.56	2.81	0.43	110	60	-	100	45.8	2.6
3.36	2.59	12	2.61	2.61	45	2.56	2.81 M40	1 0.43		60 0	-		45.7	2.6
3.36	2.59	12	2.61	2.61	46	2.56	2.81	0 0.43		60	-	100	49.06	2.6
3.36	2.59	12	2.61	2.61	47	2.56	2.81	0.43 10		60	-	100	48.26	2.6
3.36	2.59	12	2.61	2.61	48	2.56	2.81	0.43 20		90	-	100	51.46	2.6
3.36	2.59	12	2.61	2.61	49	2.56	2.81	0.43 30		90	-	100	45.06	2.6
3.36	2.59	12	2.61	2.61	50	2.56	2.81	5 0.43		90	-	100	47.6	2.6
3.36	2.59	12	2.61	2.61	51	2.56	2.81	0.43	110	90	-	100	47.5	2.6
3.36	2.59	12	2.61	2.61	52	2.56	2.81	1 0.43		90 0	-		47.4	2.6
3.36	2.59	12	2.61	2.61	53	2.56	2.81	0 0.43		90	-	100	49.2	2.6
3.36	2.59	12	2.61	2.61	54	2.56	2.81	0.43 10		90	-	100	48.4	2.6

Table 6.4Input Parameters for the GRNN ModelContd.

								Input data				Output Comp.			
			Coarse Agregate			concrete sand	Grade	Concrete	w/c Type	Cur days	Quarry dust	strength			Cement
			%Sp.grFMSp grSizeSp grFMSp grFMw/b		No							without SP	with SP		
5	6	7	8	9		10 1	11	2	12	13 3		14	15 4		
3.36	2.59	12	2.61	2.61	55	2.56	2.81	20	0.43	90		-	100		2.6
3.36	2.59	12	2.61	2.61	56	2.56	2.81	30	0.38	3		-	100	28.6	2.6
3.36	2.59	12	2.61	2.61	57	2.56	2.81	5	0.38	3		-	100	26	2.6
3.36	2.59	12	2.61	2.61	58	2.56	2.81		0.38	3	110	-	100	24.6	2.6
3.36	2.59	12	2.61	2.61	59	2.56	2.81	1	0.38	3	0	-		24.2	2.6
3.36	2.59	12	2.61	2.61	60	2.56	2.81	0	0.38	3		-	100	22.4	2.6
3.36	2.59	12	2.61	2.61	61	2.56	2.81	10	0.38	3		-	100	28	2.6
3.36	2.59	12	2.61	2.61	62	2.56	2.81	20	0.38	3		-	100	28.3	2.6
3.36	2.59	12	2.61	2.61	63	2.56	2.81 M40	30	0.38	7		-	100	38	2.6
3.36	2.59	12	2.61	2.61	64	2.56	2.81	5	0.38	7		-	100	34.64	2.6
3.36	2.59	12	2.61	2.61	65	2.56	2.81		0.38	7	110	-	100	25.83	2.6
3.36	2.59	12	2.61	2.61	66	2.56	2.81	1	0.38	7	0	-		25	2.6
3.36	2.59	12	2.61	2.61	67	2.56	2.81	0	0.38	7		-	100	24.3	2.6
3.36	2.59	12	2.61	2.61	68	2.56	2.81	10	0.38	7		-	100	34	2.6
3.36	2.59	12	2.61	2.61	69	2.56	2.81	20	0.38	7		-	100	34.6	2.6
3.36	2.59	12	2.61	2.61	70	2.56	2.81	30	0.38	14		-	100	49	2.6
3.36	2.59	12	2.61	2.61	71	2.56	2.81	5	0.38	14		-	100	46	2.6
					72					110			100		2.6

Table 6.4Input Parameters for the GRNN ModelContd.

							Input data							Output Comp. strength				
				Coarse Agregate			concrete	sand		w/c	Concrete	Cur		Quarry dust		Cement		
			%Sp.grFMSp grSizeSp grFMSp grFMw/b			No	Grade				Type	days		without SP		with SP		
5	6	7	8	9			10 1	11	2	12		13	3	14		15	4	
3.36	2.59	12		2.61	2.61	73	2.56	2.81 M40		0.38	15	14		-	100	34.83		2.6
3.36	2.59	12		2.61	2.61	74	2.56	2.81	1	0.38		14	0	-		28.62		2.6
3.36	2.59	12		2.61	2.61	75	2.56	2.81	0	0.38		14		-	100	33.3		2.6
3.36	2.59	12		2.61	2.61	76	2.56	2.81		0.38	10	14		-	100	49		2.6
3.36	2.59	12		2.61	2.61	77	2.56	2.81		0.38	20	14		-	100	49		2.6
3.36	2.59	12		2.61	2.61	78	2.56	2.81		0.38	30	28		-	100	58.56		2.6
3.36	2.59	12		2.61	2.61	79	2.56	2.81	5	0.38		28		-	100	56		2.6
3.36	2.59	12		2.61	2.61	80	2.56	2.81		0.38	110	28		-	100	42.6		2.6
3.36	2.59	12		2.61	2.61	81	2.56	2.81	1	0.38		28	0	-		41.15		2.6
3.36	2.59	12		2.61	2.61	82	2.56	M50 2.81	0	0.38		28		-	100	42		2.6
3.36	2.59	12		2.61	2.61	83	2.56	2.81		0.38	10	28		-	100	57.65		2.6
3.36	2.59	12		2.61	2.61	84	2.56	2.81		0.38	20	28		-	100	58		2.6
3.36	2.59	12		2.61	2.61	85	2.56	2.81		0.38	30	60		-	100	58.73		2.6
3.36	2.59	12		2.61	2.61	86	2.56	2.81	5	0.38		60		-	100	56.58		2.6
3.36	2.59	12		2.61	2.61	87	2.56	2.81		0.38	110	60		-	100	48.6		2.6
3.36	2.59	12		2.61	2.61	88	2.56	2.81	1	0.38		60	0	-		46.22		2.6
3.36	2.59	12		2.61	2.61	89	2.56	2.81	0	0.38		60		-	100	48.5		2.6

Table 6.4Input Parameters for the GRNN ModelContd.

								Input data		Output Comp.		
			Coarse Agregate			concrete sand		Concrete w/c	Quarry dust		strength	Cement
			%Sp.grFMSp grSizeSp grFMSp grFMw/b		No	Grade		Type	Cur days	without SP	with SP	
5	6	7	8	9		10	11	2 12	133	14	154	
3.36	2.59	12	2.61	2.61	90	2.56	2.81	0.38 10	60	-	100 58	2.6
3.36	2.59	12	2.61	2.61	91	2.56	2.81	0.38 20	60	-	100 58.4	2.6
3.36	2.59	12	2.61	2.61	92	2.56	2.81	0.38 30	90	-	100 59	2.6
3.36	2.59	12	2.61	2.61	93	2.56	2.81	5 0.38	90	-	100 56.76	2.6
3.36	2.59	12	2.61	2.61	94	2.56	2.81	0.38	110 90	-	100 52.1	2.6
3.36	2.59	12	2.61	2.61	95	2.56	2.81	1 0.38	90 0	-	53.3	2.6
3.36	2.59	12	2.61	2.61	96	2.56	2.81	0 0.38	90	-	100 56.3	2.6
3.36	2.59	12	2.61	2.61	97	2.56	2.81	0.38 10	90	-	100 58.9	2.6
3.36	2.59	12	2.61	2.61	98	2.56	M50 2.81	0.38 20	90	-	100 59	2.6
3.36	2.59	12	2.61	2.61	99	2.56	2.81	0.38 30	3	-	100 23	2.6
3.36	2.59	12	2.61	2.61	100	2.56	2.81	5 0.38	3	-	100 21	2.6
3.36	2.59	12	2.61	2.61	101	2.56	2.81	0.38	110 3	-	100 25	2.6
3.36	2.59	12	2.61	2.61	102	2.56	2.81	1 0.38	3 0	-	26	2.6
3.36	2.59	12	2.61	2.61	103	2.56	2.81	0 0.38	3	-	100 24	2.6
3.36	2.59	12	2.61	2.61	104	2.56	2.81	0.38 10	14	-	100 41	2.6
3.36	2.59	12	2.61	2.61	105	2.56	2.81	0.38 20	14	-	100 38	2.6
3.36	2.59	12	2.61	2.61	106	2.56	2.81	0.38 30	14	-	100 29	2.6

No	concrete Grade	Concrete Type	Quarry dust	Cement
	1	2	3	4
107	M50	5	100	2.6
108		110	100	2.6
109		1	0	2.6
110		0	100	2.6
111		10	100	2.6
112		20	100	2.6
113		30	100	2.6
114		5	100	2.6
115		110	100	2.6
116	M60	1	0	2.6
117		0	100	2.6
118		10	100	2.6
119		20	100	2.6
120		30	100	2.6
121		1	0	2.6
122		0	100	2.6
123		10	100	2.6

Table 6.4Input Parameters for the GRNN ModelContd.

							Input data		Output Comp. strength	
		Coarse Agregate				sand	w/c	Cur days		
			%Sp.grFMSp grSizeSp grFMSp grFMw/b						without SP	with SP
5	6	7	8	9	10	11	12	13	14	15
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	14	-	31
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	14	-	34
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	28	-	64
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	28	-	48
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	28	-	56
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	28	-	68
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	28	-	80
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	60	-	66
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	60	-	50
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	60	-	58
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	60	-	70
3.36	2.59	12	2.61	2.61	2.56	2.81	0.38	60	-	86

No	concrete Grade	Concrete Type	Quarry dust	Cement
	1	2	3	4
124	M60	20	100	2.6
125		30	100	2.6
126		1	0	2.6
127		0	100	2.6
128		10	100	2.6
129		20	100	2.6
130		30	100	2.6
131		1	0	2.6
132		0	100	2.6
133		10	100	2.6
134		20	100	2.6
135		30	100	2.6

Table 6.5 Training Parameters for the GRNN Model (for QDC)

Type of Concrete		0	0	0	0	0	0
Quarry dust	%	100	100	100	100	100	100
	Sp.gr	2.6	2.6	2.6	2.6	2.6	2.6
	FM	3.36	3.36	3.36	3.36	3.36	3.36
Cement	Sp gr	2.59	2.59	2.59	2.59	2.59	2.59
Coarse Aggregate	Size	12	12	12	12	12	12
	Sp gr	2.61	2.61	2.61	2.61	2.61	2.61
	FM	2.61	2.61	2.61	2.61	2.61	2.61
Sand	Sp gr	2.56	2.56	2.56	2.56	2.56	2.56
	FM	2.81	2.81	2.81	2.81	2.81	2.81
w/c	w/b	0.45	0.45	0.45	0.45	0.45	0.45
Cur days		3	7	14	28	60	90

6.7.1 Development of GRNN Model using Network/Data Manager

The model is developed on the MATLAB software using the Network/Data Manager. The procedure adopted for generating the model is described as follows:

a) The Network/Data Manager is invoked from the MATLAB command line using *nntool* command. The neural network design window shown in figure 6.4 opens.

b) The input data for training the network is entered by pressing the *New Data* button. (Fig. 6.5).

c) The target data for training are entered.

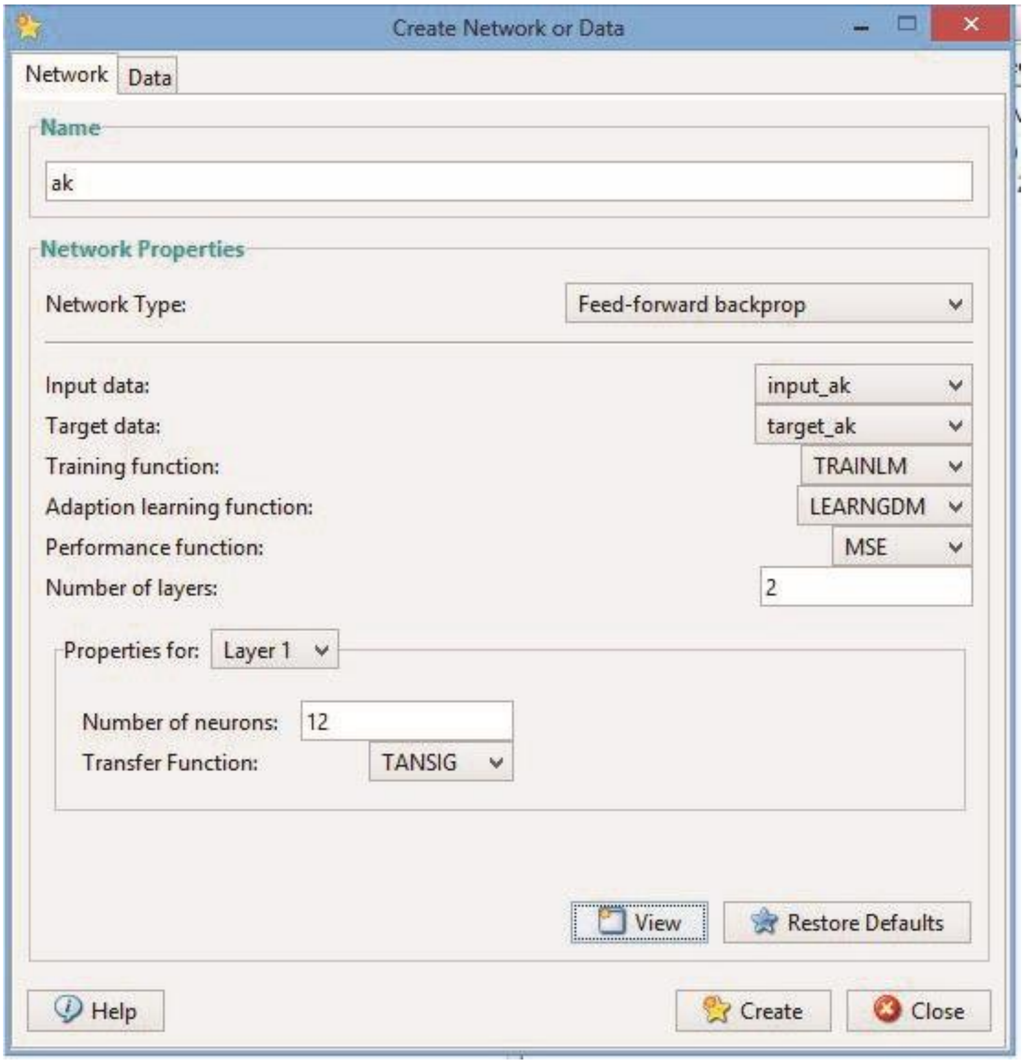
d) Input and target data for testing are entered (Fig. 6.5).

e) The dialog for creating GRNN is opened by pressing *New Network* button. The choice of network is ‘General regression’, input data box set to training input and target data box set to training target. The network is named *ak_network.*

f) Fig. 6.6 shows the structure of the GRNN data and network objects in the Network/Data Manager. The import to network is shown in Fig. 6.7 and export from network in Fig. 6.8.

g) The predictions of the *ak_network* for training data and test input data are shown in Figs. 6.9 and 6.10.

h) A Graphical User Interface (GUI) was developed using the Graphical User Interface Design Environment (GUIDE) available in MATLAB to serve as the front end for *ak_network*. The GUI obtains inputs from the user, loads the *ak_network* from disk file, supplies the input data to the ANN, obtains the results and displays the appropriate results in accordance with the choice made by the user (Figs. 6.11 and 6.12).



Name

ak

Network Properties

Network Type: Feed-forward backprop

Input data: input_ak

Target data: target_ak

Training function: TRAINLM

Adaption learning function: LEARNGDM

Performance function: MSE

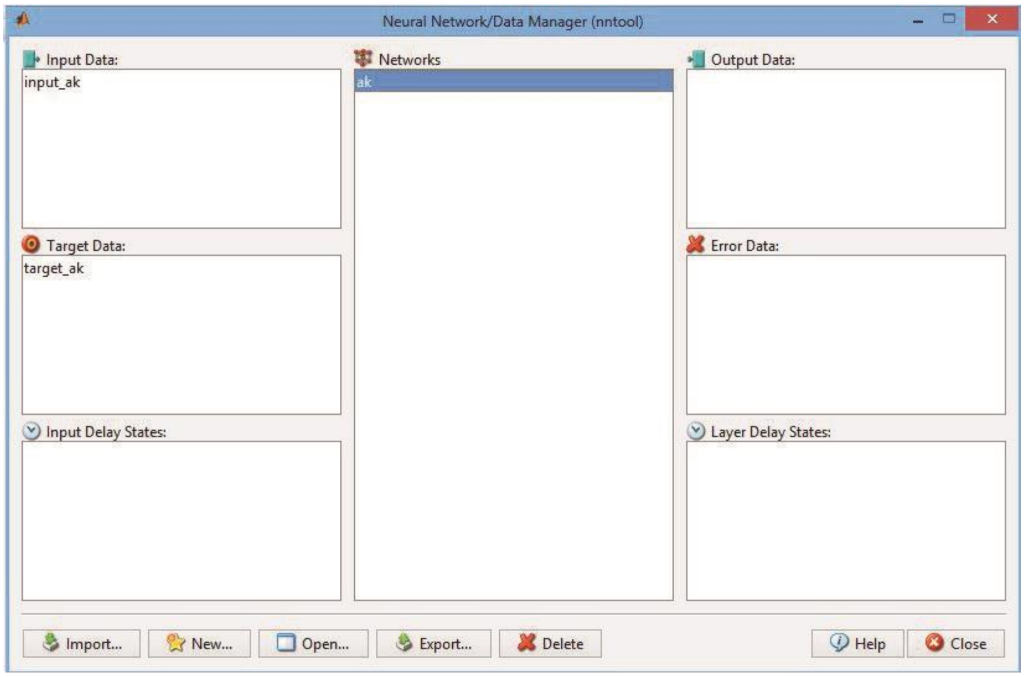
Number of layers: 2

Properties for: Layer 1

Number of neurons: 12

Transfer Function: TANSIG

Fig. 6.4 Create Network



Input Data: input_ak

Networks: ak

Output Data:

Target Data: target_ak

Error Data:

Input Delay States:

Layer Delay States:

Fig. 6.5 Input, Target and the GRNN Objects in Network/Data Manager

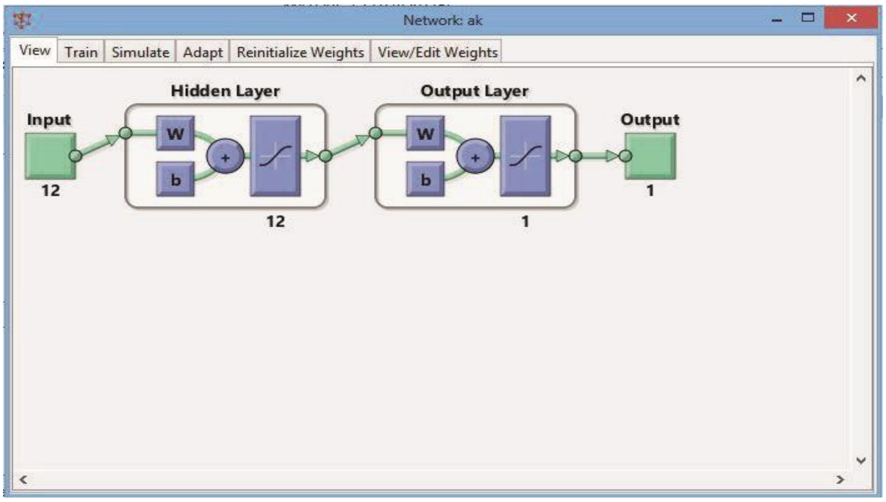
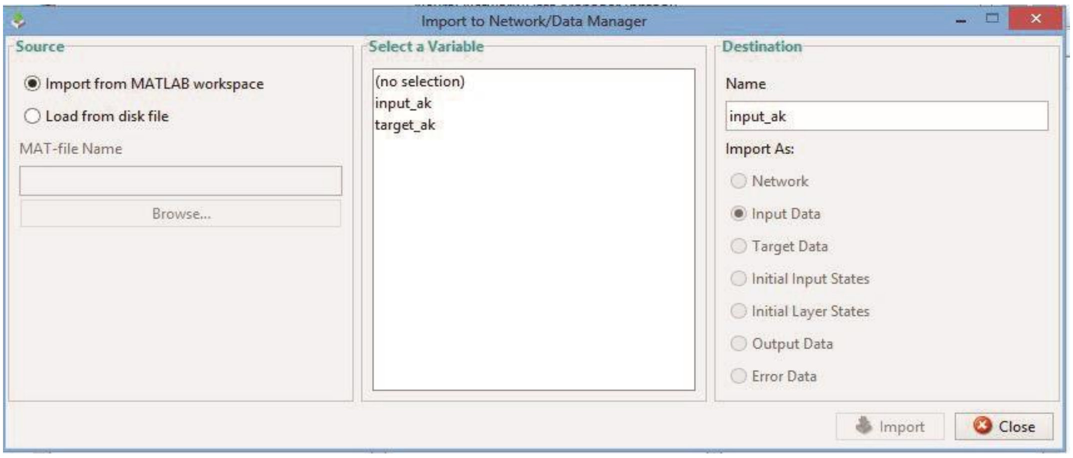


Fig. 6.6 Structure of the GRNN



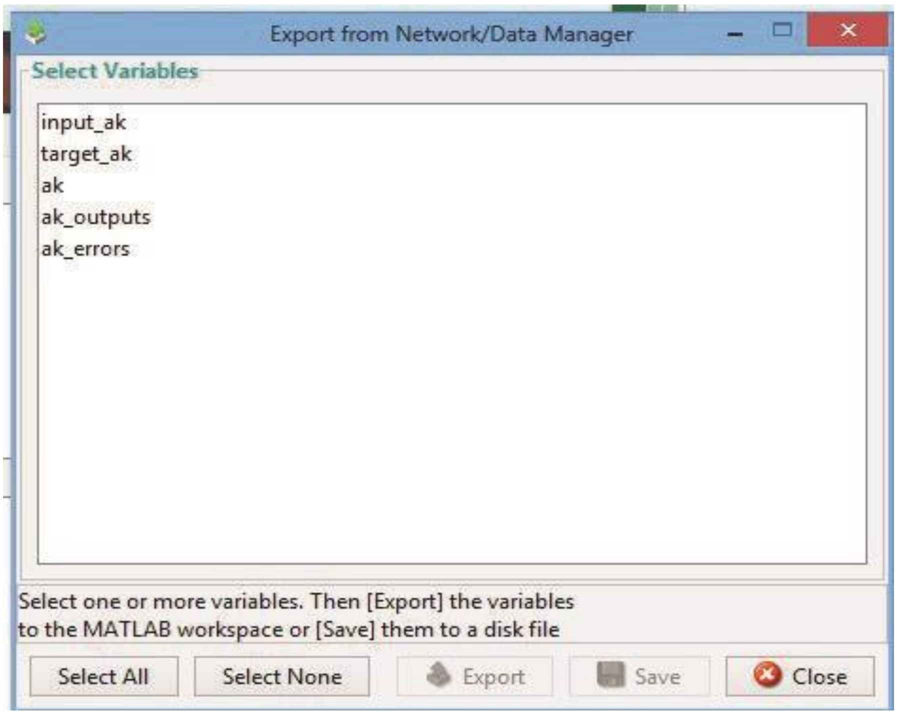
● Import from MATLAB workspace
○ Load from disk file

(no selection)
input_ak
target_ak

Name: input_ak

Import As:
○ Network
● Input Data
○ Target Data
○ Initial Input States
○ Initial Layer States
○ Output Data
○ Error Data

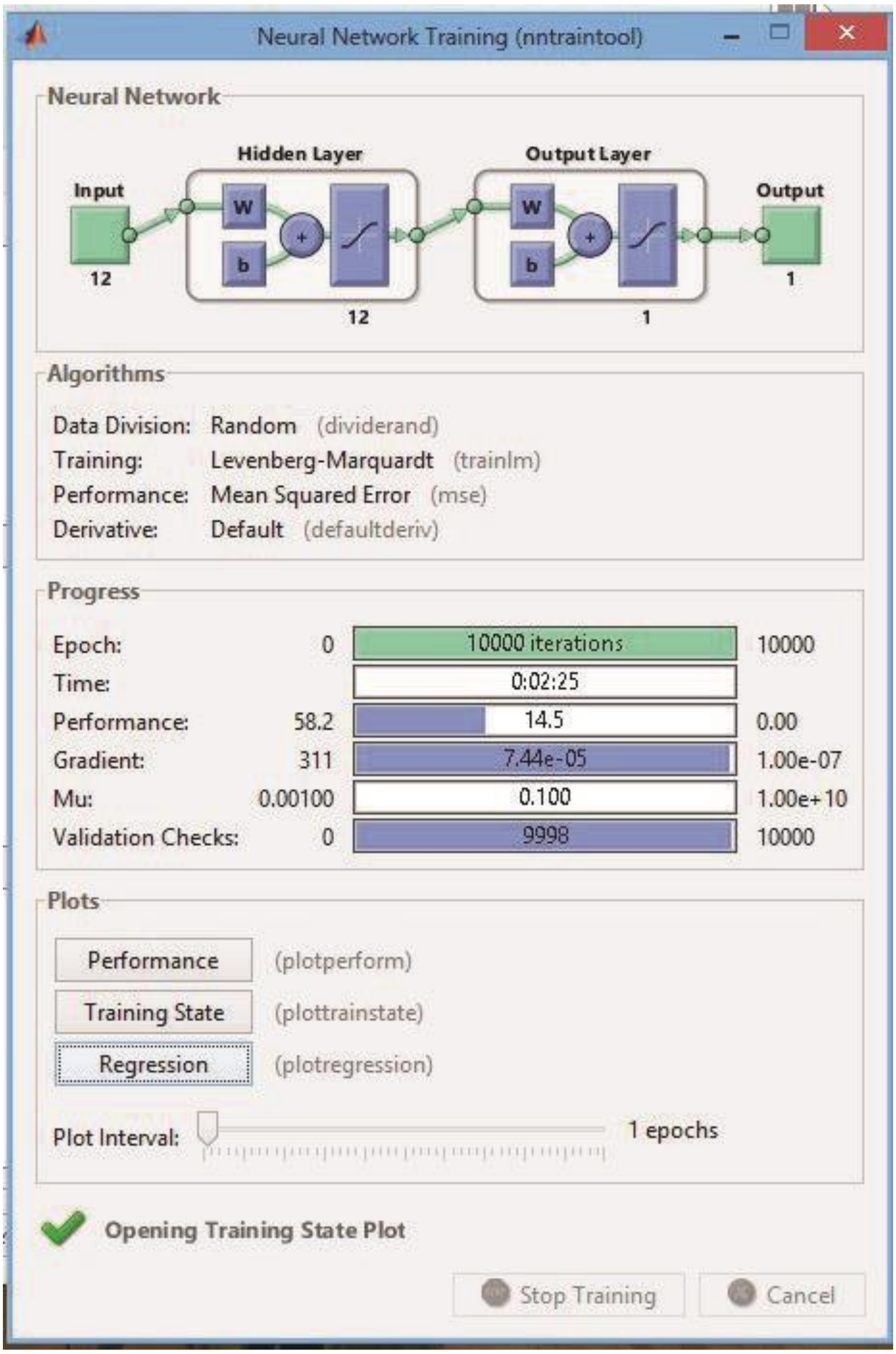
Fig. 6.7 Import to Network



input_ak
target_ak
ak
ak_outputs
ak_errors

Select one or more variables. Then [Export] the variables to the MATLAB workspace or [Save] them to a disk file

Fig. 6.8 Export from Network



Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Derivative: Default (defaultderiv)

Epoch:	0	10000 iterations	10000
Time:		0:02:25	
Performance:	58.2	14.5	0.00
Gradient:	311	7.44e-05	1.00e-07
Mu:	0.00100	0.100	1.00e+10
Validation Checks:	0	9998	10000

Plot Interval: 1 epochs

✓ Opening Training State Plot

Fig. 6.9 Neural Network Training

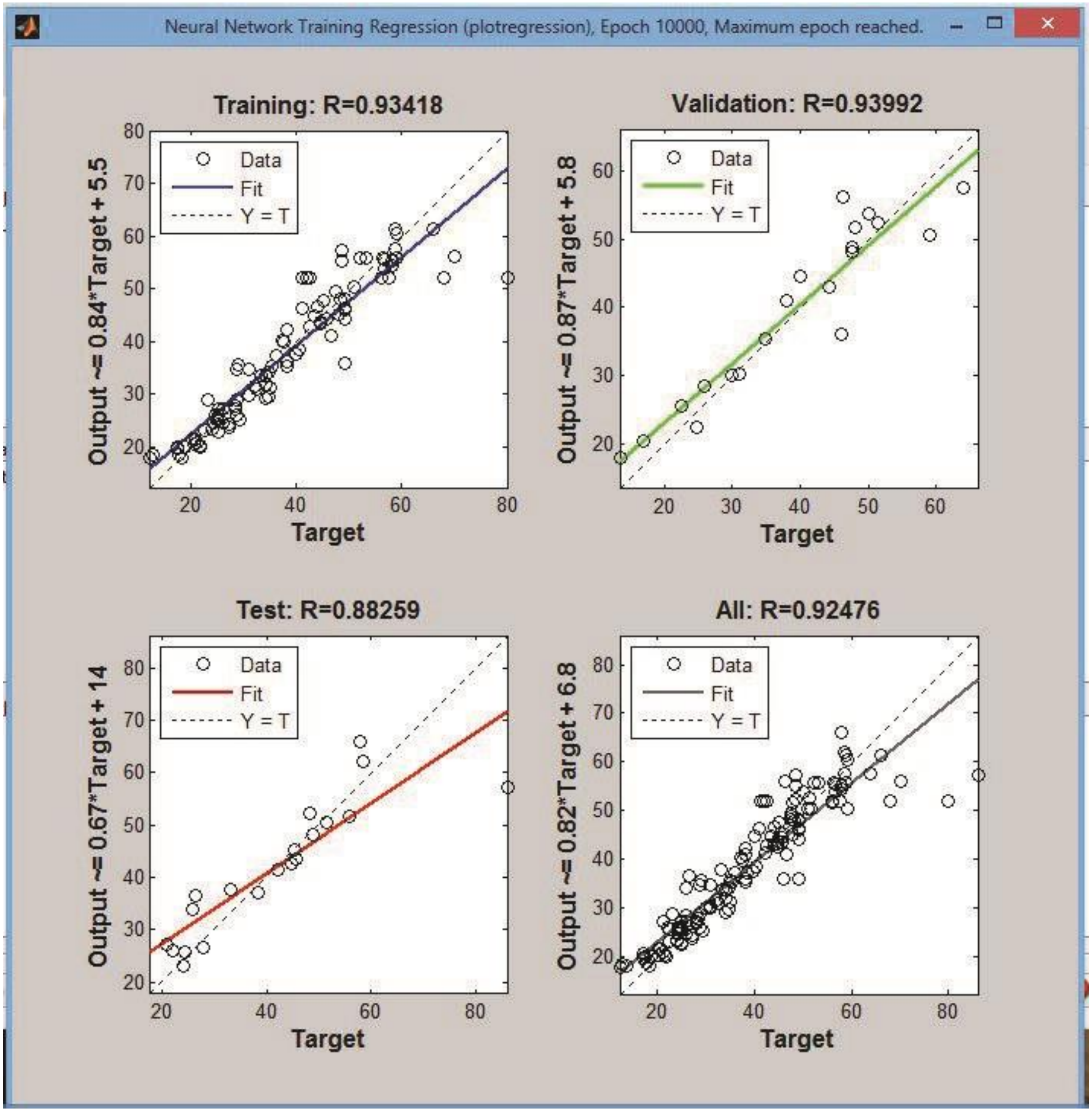


Fig. 6.10 Neural Network Training Regression

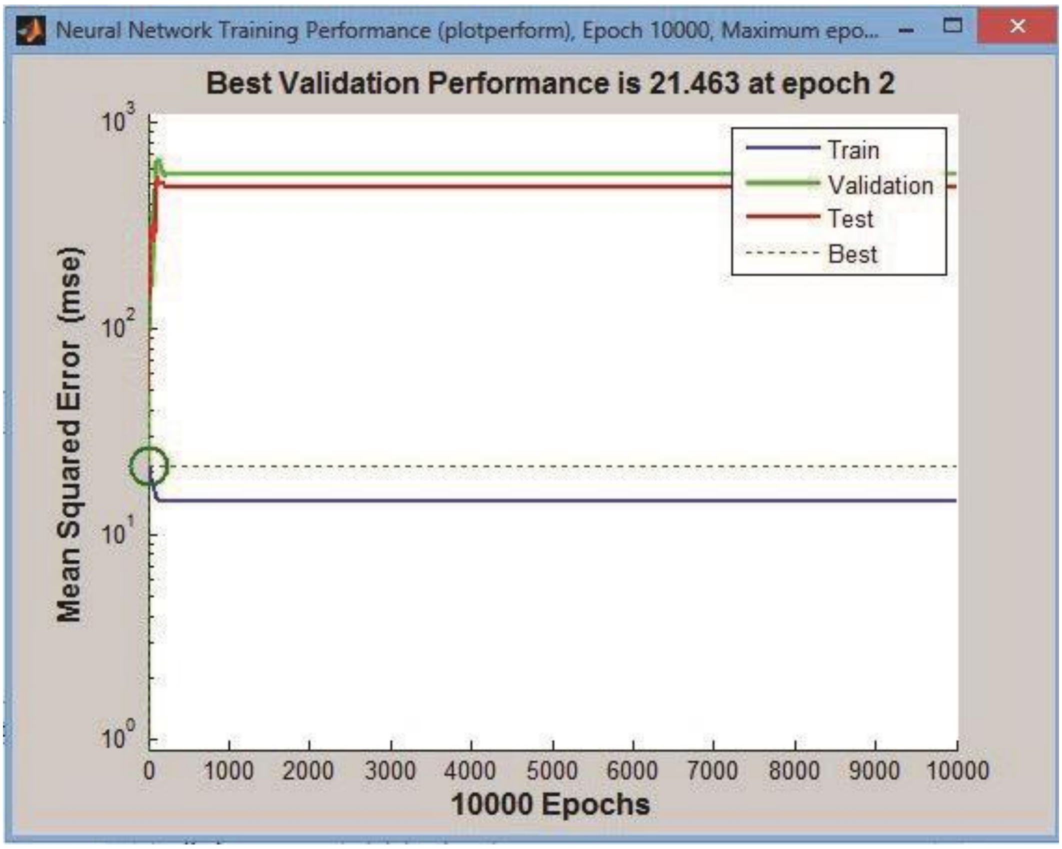


Fig. 6.11 Neural Network Training Performance

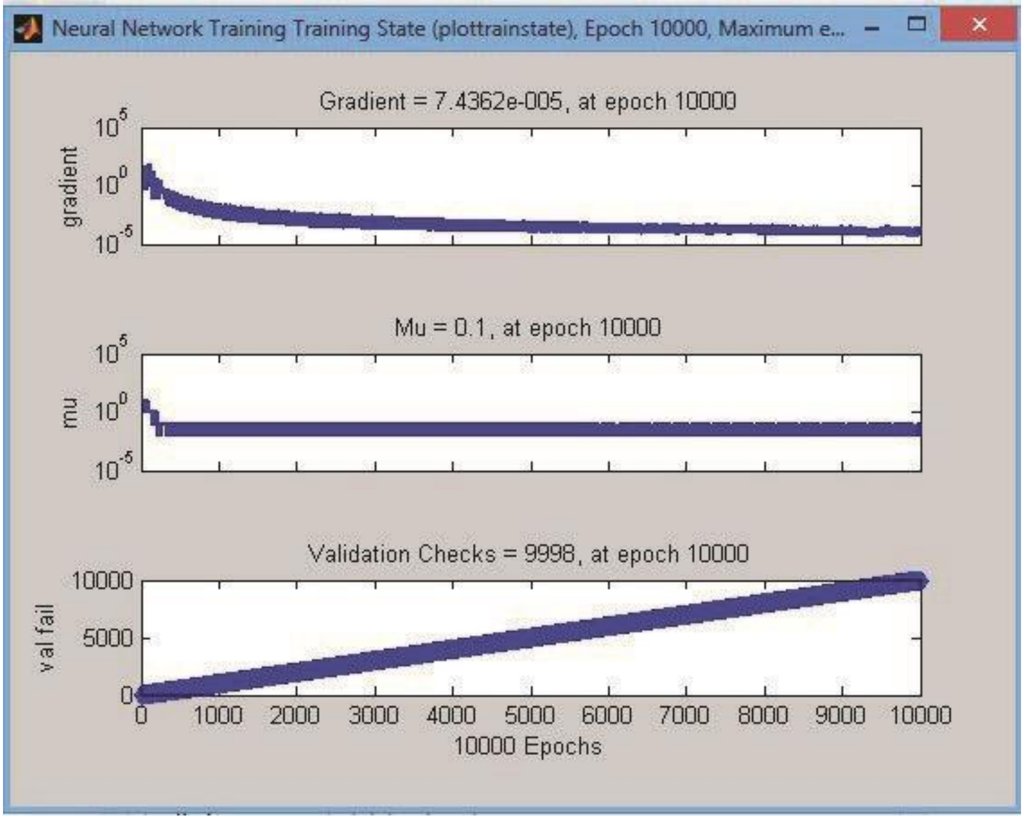


Fig. 6.12 Neural Network Training State

6.8 PERFORMANCE OF GRNN

The performance of the GRNN developed in the present study against various training and testing data were presented in Table 6.6.

Table 6.6 Error for Training and Test Data

No	GRNN Output	Lab Output	Error
1	18.57174	17.6	-0.97174
2	17.90511	18.23	0.324893
3	17.84981	12.2	-5.64981
4	17.9994	13.5	-4.4994
5	18.33313	12.6	-5.73313
6	21.43502	20.67	-0.76502
7	20.05328	21.5	1.446717
8	19.90251	18.67	-1.23251
9	19.98994	21.67	1.680057
10	20.31646	20.33	0.013536
11	27.16708	28.17	1.002916
12	25.99883	28.67	2.671172
13	25.50862	24.67	-0.83862
14	25.19695	29.17	3.973054
15	25.15919	24.67	-0.48919
16	37.00999	38.5	1.490012
17	37.54321	39.83	2.286789
18	36.52018	26.37	-10.1502
19	35.30561	35.26	-0.04561
20	33.93432	25.83	-8.10432
21	44.66486	40.1	-4.56486
22	41.39537	42.23	0.834633
23	39.76867	37.5	-2.26867
24	38.33104	40.33	1.998955
25	37.1276	36	-1.1276
26	42.76748	42.4	-0.36748
27	43.2569	44.6	1.343105
28	42.13292	38.2	-3.93292
29	41.01443	46.67	5.655574
30	40.16871	37.15	-3.01871
31	26.00429	22	-4.00429
32	21.31031	20.1	-1.21031

33	20.50496	17	-3.50496
34	19.95556	17.4	-2.55556
35	19.66368	17.2	-2.46368

Table 6.6 Error for Training and Test Data Contd.

No	GRNN Output	Lab Output	Error
36	20.87415	21	0.125848
37	25.62052	22.5	-3.12052
38	31.76591	34	2.234087
39	24.17898	27.2	3.021023
40	23.4004	24	0.599601
41	22.81949	25	2.180507
42	22.44742	24.8	2.352581
43	23.76174	27	3.238261
44	29.96214	30	0.037862
45	40.94696	38	-2.94696
46	31.56117	32	0.438829
47	30.87922	32.4	1.520782
48	30.32906	31	0.670945
49	29.81236	31	1.187642
50	31.19085	35	3.80915
51	37.70255	33	-4.70255
52	50.28558	51	0.714418
53	44.6921	43.3	-1.3921
54	43.64682	44.6	0.953177
55	42.99977	44.2	1.200234
56	42.47326	44.8	2.326745
57	44.10329	49	4.896712
58	45.11301	48	2.886993
59	52.5056	51.4	-1.1056
60	46.65428	44	-2.65428
61	45.34887	45.3	-0.04887
62	44.24268	45.8	1.55732
63	43.49561	45.7	2.204389
64	45.98197	49.06	3.078035
65	47.94981	48.26	0.310188
66	50.42034	51.46	1.039656
67	47.6664	45.06	-2.6064
68	48.11489	47.6	-0.51489

69	48.79569	47.5	-1.29569
70	49.4871	47.4	-2.0871

Table 6.6 Error for Training and Test Data Contd.

No	GRNN Output	Lab Output	Error
71	47.84926	49.2	1.35074
72	52.3295	48.4	-3.9295
73	28.76604	28.6	-0.16604
74	27.24764	26	-1.24764
75	26.00401	24.6	-1.40401
76	24.49311	24.2	-0.29311
77	23.03374	22.4	-0.63374
78	26.67558	28	1.324415
79	27.66918	28.3	0.630818
80	35.15614	38	2.843864
81	29.47633	34.64	5.16367
82	28.45664	25.83	-2.62664
83	27.08484	25	-2.08484
84	25.74175	24.3	-1.44175
85	29.02781	34	4.972192
86	33.93206	34.6	0.667936
87	46.1249	49	2.875103
88	35.99789	46	10.00211
89	35.51714	34.83	-0.68714
90	34.55141	28.62	-5.93141
91	33.56926	33.3	-0.26926
92	35.8353	49	13.1647
93	48.0284	49	0.971605
94	57.65669	58.56	0.903308
95	51.72502	56	4.274978
96	52.0699	42.6	-9.4699
97	52.06104	41.15	-10.911
98	52.05035	42	-10.0503
99	51.9539	57.65	5.696095
100	66.04865	58	-8.04865
101	61.44554	58.73	-2.71554
102	53.79083	56.58	2.789174
103	55.12149	48.6	-6.52149
104	56.16497	46.22	-9.94497

105	57.17116	48.5	-8.67116

Table 6.6 Error for Training and Test Data Contd.

No	GRNN Output	Lab Output	Error
106	54.50191	58	3.498085
107	62.01776	58.4	-3.61776
108	60.53205	59	-1.53205
109	55.51151	56.76	1.248491
110	55.794	52.1	-3.694
111	55.74806	53.3	-2.44806
112	55.6856	56.3	0.614398
113	55.71677	58.9	3.18323
114	50.51009	59	8.489906
115	28.76604	23	-5.76604
116	27.24764	21	-6.24764
117	26.00401	25	-1.00401
118	24.49311	26	1.506893
119	23.03374	24	0.966257
120	46.1249	41	-5.1249
121	35.99789	38	2.002109
122	35.51714	29	-6.51714
123	34.55141	31	-3.55141
124	33.56926	34	0.430735
125	57.65669	64	6.343308
126	51.72502	48	-3.72502
127	52.0699	56	3.930097
128	52.06104	68	15.93896
129	52.05035	80	27.94965
130	61.44554	66	4.554455
131	53.79083	50	-3.79083
132	55.12149	58	2.878514
133	56.16497	70	13.83503
134	57.17116	86	28.82884

6.9 Summary

The Artificial Neural Network (ANN) model developed for the present study performed well to predict the results of compressive strength. The following conclusions are drawn on the ANN model.

a) The Generalized Regression Neural Network (GRNN) performed well to predict the compressive strength.

b) The input parameters were the grade and type of concrete such as SC, QDC, QDCF, QDCS of different percentage, with and without SP and curing period. The type of concrete is converted into numeric values by assigning the number 1 for SC, 0 for QDC, 10 for QDCF 10%, 20 for QDCF 20%, 30 for QDCF 30% and 5 for QDCS 5% and 110 for QDCS 10%. The predicted results were sensitive to the changes in all the parameters.

c) The prediction errors in training and testing data showed reasonable agreement for each parameter. This ensures that the network is well conditioned even at locations away from the training points.

d) The Graphical User Interface (GUI) developed for accessing the GRNN object makes the use of the GRNN model easy.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.0 GENERAL

The experimental investigations were conducted with Quarry Dust as fine aggregate.

Totally four grades of concrete namely M30, M40, M50 and M60 were considered. Partial replacement and total replacement of sand with quarry dust and with partial replacement of cement with Fly ash and Silica Fume were studied. To improve the workability, Super plasticizer also used. Physical and Chemical Properties of the materials used in the concrete were determined. Based on this, concrete mix designs made, concrete prepared and the characteristics in Workability, Strength and Durability were studied and compared with natural sand concrete. Based on the test results following conclusions and recommendations are made.

7.1 QUANTITATIVE AND QUALITATIVE CONCLUSIONS

1. The **grading zone** is same for quarry dust and sand but, QD is coarser than sand. Sand particles are rounded and globular where as quarry dust particles are angular, flaky and irregular in shape.
2. The QD is coarser than sand but the amount of finer particles between 300 - 150 micron is almost double that of sand that increased the water requirement.
3. **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.
4. **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.
5. **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.
6. The **workability** of nominal concrete is greater than that of concrete with fly ash 10%, 20% and 30% and silica fume with 5% and 10%. The workability is improved by the addition of Super plasticizer for M40, M50 and M60 grades.
7. 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.

8. 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.

9. 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%).
10. 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.
11. The QDC has performed better than the sand concrete in rebar bond characteristics, since the presence of rough textured particles in QD. QDC experienced more failure loads. In case of plain bars the difference is 5 % and for ribbed bars up to 13%.
12. The compressive strain is little more for QDC than SC for the same stress and hence less modulus value. The modulus of concrete is less by 15 %.
13. **For higher grades of concrete** (M40, M50 and M60) by replacing cement by equal weight of fly ash in concrete, the strength decreases at early stages but increases gradually at later. The compressive strength of concrete made with 20% of fly ash is more than that made with 10% and 30%.
14. The variation in strength is in the increasing order by replacing cement with silica fume (5% and 10%) due to the filling of minute pores by the silica fume (micro silica) in the concrete while in quarry dust without silica fume seems to be less.
15. Cube compressive strength of QDC with fly ash (20%) shows more or less same strength during 60 and 90 days of curing, but with silica fume (10%) shows improved strength of 20% during 60 days and 31% during 90 days for M60 grade.
    Similar trend is shown for cylinder compressive strength also. QDC with silica fume (10%) reflected 2%, 9% and 23% increase in 28, 60 and 90 days of curing.

16. In general, the spiltting tensile strength of QDC is increased, when compared to conventional concrete. Since all the ingredients of concrete expect fine aggregate are same, the variation in the tensile strength can be attributed to the properties of aggregate, particularly shape and texture. The tensile strength of QDC with silica fume is better than the control concrete. For M60 grade concrete, splitting tensile strength is less than the sand concrete for QDC with fly ash of 10%, 20% and 30% replacement with cement. But it is improved for 22% for 28 days, 32% for 60 days and 34% for 90 days of curing.

17. **The flexural strength** (modulus of rupture) of QDC is increased when compared to conventional concrete in general. For M60 grade, flexural strength is less than the sand concrete for QDC with fly ash, but with silica fume is more or less same for all curing periods.
18. Rebound number reflects slightly less for M40 grade concrete of QDC than the sand concrete for all replacement levels. But for M60 grade concrete with silica fume 10%, 23.5% more than the SC and for concrete with fly ash more or less same.

19. Generally the **UPV values** are more for QDC compared to SC and better

    performance has been observed in all replacement levels of cement with fly ash and silica fume. Particularly for M60 grade concrete QDC with silica fume (10%), the

UPV value is 7% more than SC.

20. **The water absorption and porosity** values are less in control concrete when compared to other types of concrete, but silica fume addition decreases water absorption and porosity level. Because of the high pozzolanic nature of silica fume and its void filling ability SWA for QDC with silica fume (10%) of M60 grade concrete is slightly lower than the SC, but the porosity is more or less equal to QDC with fly ash and silica fume with sand concrete.
21. **The Acid resistance** measured by the weight loss yielded more in control concrete generally and still more for silica fume added with QDC. M60 grade concrete with silica fume (10%) has shown better resistance than the sand concrete by more than 41.8% and all other replacements also have shown better results.
22. **The alkaline resistance** as weight loss of different type of concrete is observed typically that the weight loss is more or less same for all types of concrete because; of the addition of silica fume that increases for quarry dust concrete the resistance considerably. M60 grade concrete of QDC with silica fume (10%) has shown better performance by 33% more than the sand concrete.

23. **RCPT** value which is a measure of permeability is found to less for QDC and of course has only a slight reduction in the permeability compared to sand concrete for all grades of concrete without additives. But, the reduction in the permeability is significant with addition of admixtures (plasticizers) and additives (fly ash or silica fume). Addition of silica fume considerably reduced the permeability compared to addition of fly ash. M60 grade concrete of QDC with silica fume (10%) has shown better performance by 17% more than the sand concrete.
24. **Development of** Quarry dust concrete can promote environmental protection and cost saving.
25. Quarry dust concrete is **viable, adaptable and feasible** to make with admixtures and additives but with proper identification similar to conventional sand concrete.
26. **The Artificial Neural Network** (ANN) model developed for the present study performed well to predict the results of compressive strength. The Generalized Regression Neural Network (GRNN) performed well to predict the compressive strength. The predicted results were sensitive to the changes in all the parameters.
27. **The input parameters** are the grade and type of concrete such as SC, QDC, QDCF, QDCS of different replacement levels, with and without SP and curing periods. The types of concrete is converted into numericals by assigning 1 for SC, 0 for QDC, 10 for QDCF 10%, 20 for QDCF 20%, 30 for QDCF 30% and 5 for QDCS 5% and 110 for QDCS 10%.
28. The **prediction errors** in training and testing data showed reasonable agreement for each parameter. This ensures that the network is well conditioned even at locations away from the training points.
29. The **GUI** (Graphical User Interface) developed for accessing the GRNN object makes the use of the GRNN model easy.

7.2 RECOMENDATIONS

Based on the research work carried out in developing a quarry dust concrete by totally replacing conventional river sand, the following recommendations are made:

1. Quarry dust can be used as fine aggregate (instead of river sand) in concrete.

2. Mix design can be made for quarry dust concrete similar to sand concrete for low, medium and high strength and SCC applications.

3. For more perfection, quarry dust procured from the quarry should be checked for its fine content and other impurities.

4. For specific purposes, quarry dust can be water washed and used instead of going for manufactured sand.
5. Use of additives in conjunction with admixtures similar to conventional sand concrete can be made.

7.3 SUGGESTIONS FOR FURTHER RESEACH

Having developed the quarry dust concrete and accepting the advantages of quarry dust as alternative fine aggregate to river sand, following suggestions are made for research:

1. Continuing similar research for using all types of quarry dust and waste from quarries of different rocks and origin.
2. Studying to ascertain on alkali aggregate reactions as the quarry dust has fine particles which may be more reactive than river sand.
3. Studying to ascertain on freeze and thaw resistance for the quarry dust for use in cold and hot weather concreting.
4. Studying the applications of quarry dust concrete for structural concrete for performance in flexure, shear, flexure and shear, torsion and for their combination.
5. Studying the applications of quarry dust concrete for prestressed concrete involved in sustained loading conditions.

APPENDIX A

IMPORTING SAND IN MALDIVES

Imported sand to Maldives

Arial view of Maldives

Importing sand

2.1

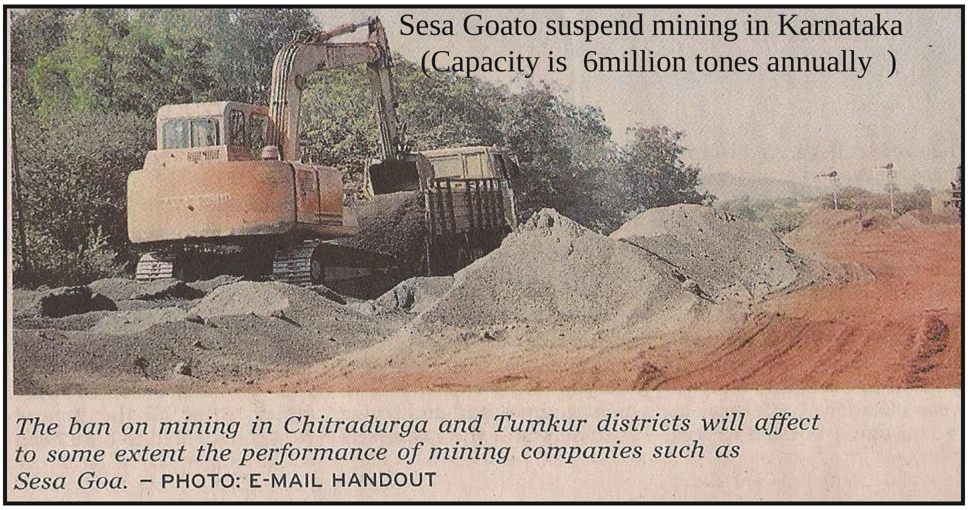
APPENDIX B

CLOUDY QUARRIES

The cloudy quarries in Trisulam (Tamil Nadu, INDIA)

Big amount of quarry dust at grindstone house in Saraburi (Thailand)

APPENDIX C ILLEGAL SAND MINING

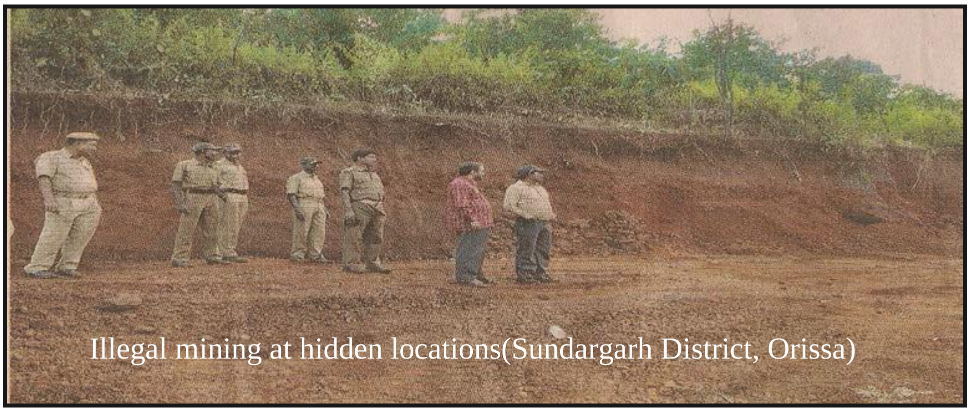


Sesa Goato suspend mining in Karnataka
(Capacity is 6million tones annually)

The ban on mining in Chitradurga and Tumkur districts will affect to some extent the performance of mining companies such as Sesa Goa. – PHOTO: E-MAIL HANDOUT

Residents see red as mining sand damages land
(Muthirapalayamand Dharmapuri)Tamil Nadu

ECOLOGICAL DAMAGE: *A part of the area quarried for red sand.* – PHOTO: T.SINGARAVELOU

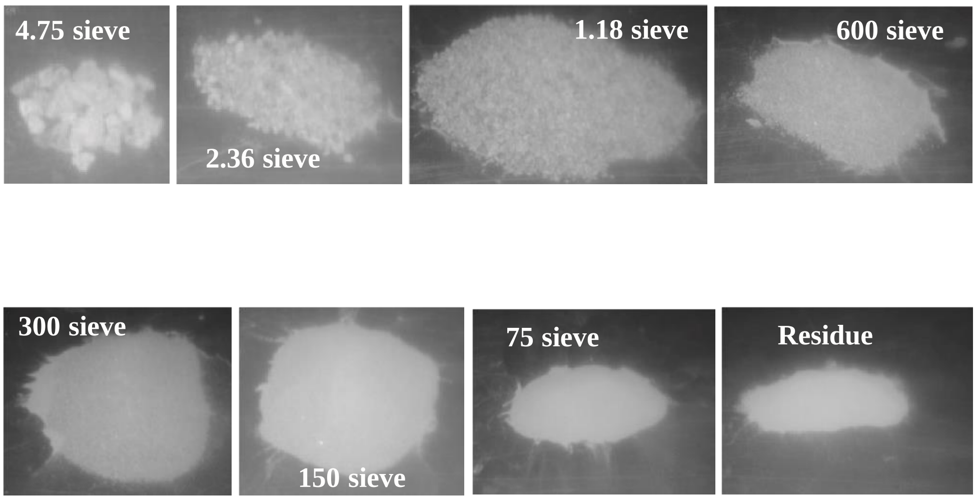


Illegal mining at hidden locations(Sundargarh District, Orissa)

APPENDIX D

VARIOUS FRACTIONS OF QUARRY DUST

Quarry dust as collected



View of QD and Quantities in various particle size

APPENDIX E

CONCRETE MIX DESIGN

GENERAL

The design of concrete mix specified grade involves the economical selection of relative proportions of cement proportion of cement, fine aggregate, coarse aggregate and water. Although compliance with respect to characteristics strength is the main criteria for acceptance, it is implicit that concrete must also have desired workability in the fresh state and impermeability and durability in hardened state.

Mix design on recommended guide lines is really a process of making an initial guess at optimum combination of ingredients and final mix proportion is obtained only on the basis of further rail mixes. As mentioned earlier under the project a comparative study is being carried, as such only type on fine aggregate is varied and all other ingredients are kept constant. To arrive at a concrete mix for this study mix design for kept constant. To arrive at a concrete mix design for this study is M30 concrete was carried as per IS code.

In this thesis work M_{30} grade is being used. The design procedure is detailed below.

(Based on IS: 10262 – 1982)

MIX DESIGN FOR NOMINAL CONCRETE

1. DESIGN STIPULATIONS

Characteristic compressive strength = 30 N/mm^2

Maximum size of aggregate = 20 mm

Degree of workability = 0.9 (compaction factor)

Degree of quality control = Good

Type of exposure = Mild

2. TEST DATA FOR MATERIALS

Specific gravity of cement = 3.15

Specific gravity of coarse aggregate = 2.61

Specific gravity of fine aggregate = 2.56

Specific gravity of Quarry Dust = 2.60

Sieve analysis conforming to grading zone –III of sand. Refer Is: 385-1980 table.

3. TARGET MEAN STRENGTH OF CONCRETE

The target mean strength for specified characteristic cube strength is fck = fck + t.s

where

t = Risk factor s = Standard deviation

As per IS : 456 – 2000 t can be taken as 1.65 and S = 5.0

Refer IS: 10262 0 -1982, table 1 and 2. fck = 20 + 1.65 × 5 = 38.25 N/mm^2

4. SELECTION OF WATER CEMENT RATIO

From fig "relation between free water cement ratios" required to target mean strength of

38.25 MPA is 0.42. this is lower than the value of 0.55 prescribed for mild exposure.

Therefore adopt water cement ratio= 0.42

5. SELECTION OF WATER AND SAND CONTENT

From table 11.24 for 20mm max size aggregate, sand confirming to grading zone II, water cement/ cubic meter of concrete = 186kg and sand as percentage of total aggregate by absolute volume = 35%. For change in value in water cement ratio, compaction factor, for zone belonging to zone III following adjustment is required.

Sand = 35% & Water = 186 litres

PERCENTAGE OF ADJUSTMENT

Change in condition	Percentage of adjustment required	
	Water content	**sand content**
For decrease in water cement by(0.60-0.42)	0	-3.6%
For increase in Compaction factor(0.9-0.8)	+3.0%	0
For sand confirming to zone III of table4 IS883-1970	0	-1.5%
Total	+3%	-6.1%

Therefore, required san content as percentage of total aggregate by absolute volume

= 35-1.785 = 33.215%.

Required water content = $186 + 186 \times \frac{3}{100}$

= 191.58 litres

6. DETERMINATION OF CEMENT CONTENT

Water – cement ratio = 0.42

Water = 191.58 kg/m^3

Cement = $\frac{191.58}{0.42}$ 456.14 kg/m^3

This cement content is adequate for mild exposure conditions,(Referred from minimum cement content IS456:2000)

MIX DESIGN FOR QUARRY DUST CONCRETE

1. DETERMINATION OF CEMENT CONTENT

Water – cement ratio = 0.42

Water = 191.58 kg/m^3

Cement = $\frac{191.58}{0.42}$ 456.14 kg/m^3

This cement content is adequate for mild exposure conditions,(Referred from minimum cement content IS456:2000)

2. DETERMINATION OF FINE AND COARSE AGGREGATE

From table (11.23) for the specified maximum size for aggregate 20mm, the amount of entrapped air in the wet concrete is 2% taking this into amount & adopt in equation.

V = «W — — u a »u —— ª C 1 f º 1
«¬ Sc P S fa »¼ 1000

0.98 = ª 456.14 1 u fa º»¼u10001 «¬191.58 3.15
0.3325 2.6

fa = 525.51kg/m^3

Ca = ª 1- ———— .33215
u555.42º»¼u ——2.602.61 «¬
0.33215

Ca = 1112.49 kg/m^3

3. MIX PROPORTION

From the mix design, quantity of cement, quarry dust, coarse aggregate and water cement ratio are calculated.

4. NOMINAL SAND CONCRETE

Water	**Cement**	**Fine aggregate**	**Coarse aggregate**
191.58	456.14 kg	555.42 kg	1159.72
0.42	1	1.22	2.54
Mix Design for M30 = 1: 1.22: 2.5 4			

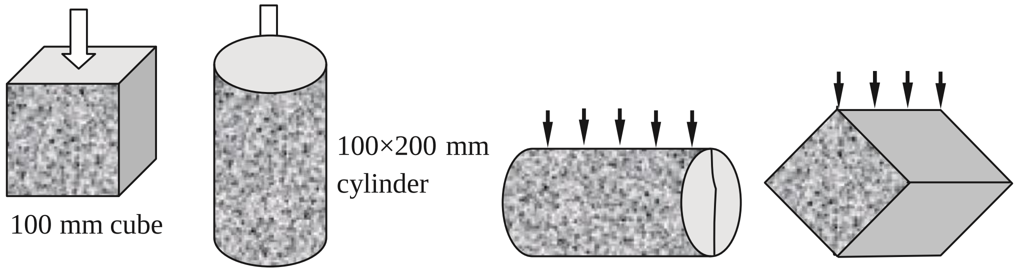
5. QUARRY DUST CONCRETE

Water	**Cement**	**Fine aggregate**	**Coarse aggregate**

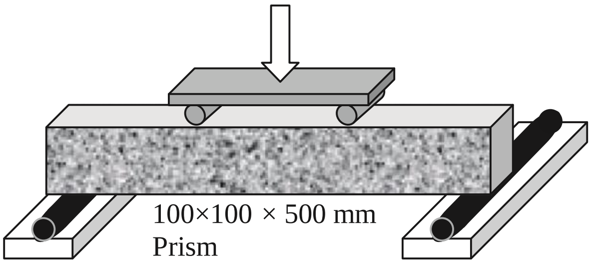
191.58	456.14 kg	525.51 kg	1151.72
0.42	1	1.15	2.54
Mix Design for M30 = 1: 1.15: 2.54			

APPENDIX F

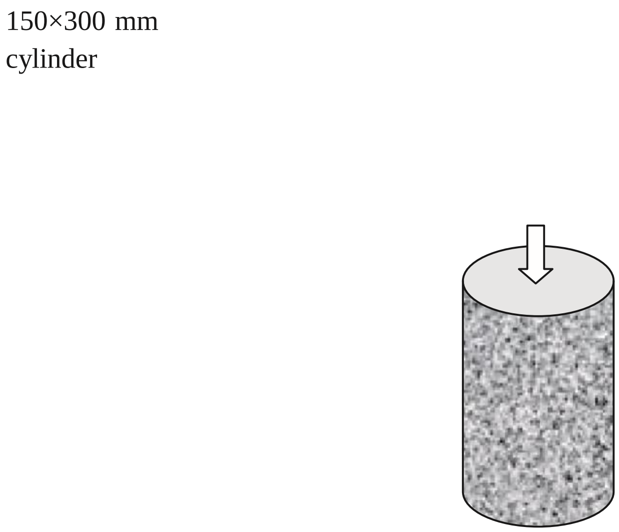
DETAILS OF SPECIMENS FOR VARIOUS TESTING



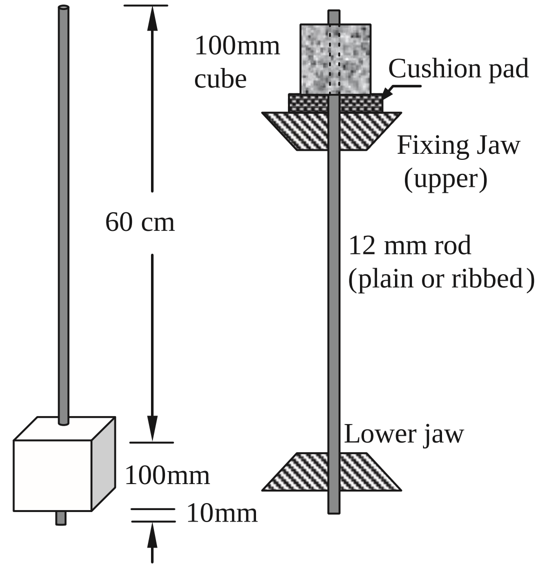
(a) Specimens for compressive strength and Split tension



(b) Prism for flexure test

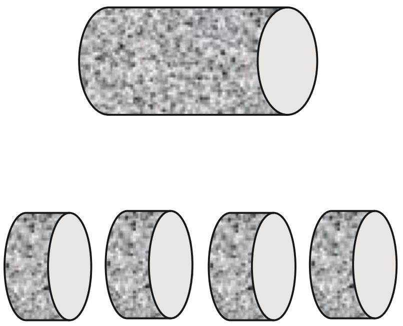


(c) E for concrete



(d) Specimen at pullout test (in UTM)

(IS 2770 Part I – 1967)



(e) Discs (100×50mm) cut out of 100×200mm cylinders (RCPT)

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