CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a widely used material in the world. More than ten billion tonnes of concrete are consumed annually. Based on global usage it is placed at second position after water. Conventional concrete, a versatile material is a mixture of cement, sand, aggregate and water. Aggregate content is a factor, which has direct and far-reaching effects on the quality of concrete. Unlike water and cement, which do not alter any particular characteristic except in the quantity in which they are used, the aggregate component is infinitely variable in terms of shape and grading.

High quality aggregate, both coarse and fine for concrete, is of extreme importance. Aggregates occupy 65 to 80% of the total volume of concrete and affect the fresh and hardened properties of concrete. Out of the total composition of concrete, the fine aggregate consumes around 20 to 30% of the volume.

1.2 SAND

The term sand as used in the building and construction industry is synonymous with fine aggregate which is the material with a particle size less than 5mm. Coarse sand is defined as the material comprising particles of size less than 5mm and with less than 10% being finer than 0.15mm. Fine sand is generally regarded as the material finer than 1.0mm. The particle size
distribution of the sand determines its particular use such as roofing tile sand, plaster sand, concrete fine sand, concrete coarse sand, masonry sand, fill sand, grout sand, bedding sand, filter sand and so on.

Sand is used all over the world in the construction industry and is an essential raw material for providing infrastructure and shelter. The primary use of sand is in the manufacture of concrete and concrete products such as ready mixed concrete, masonry products, poles, stumps, manholes, pipes, panels, beams, walls, roof tiles and a diverse range of other products. Sand can be used as fine aggregate in asphalt manufacturing, as filter for water and other fluids, filler for manufactured products, bedding for pipes, slabs and cables, in drainage media, mortar, grout, landscaping, soft surfaces (playgrounds), recreation (artificial beaches, golf bunkers, tennis courts), filling for raising or levelling the land.

The river beds are the main sources for the natural sand. These natural resources are being depleted very fast, due to over exploitation and contamination by chemicals and waste from nearby industries. This causes scarcity of natural sand. The natural sand is transported from available places to the construction sites. Transporting river sand to the construction sites increases its sale price significantly.

Specifications which are generally guided by Australian and International Standards require sand to have particular physical and chemical characteristics such as particle size distribution limits, hardness, inertness, water absorption limits, density, mineral type, durability and to be free of deleterious matter.

1.2.1 **Drawbacks of Using Natural River Sand**

Natural Sand (NS) is deficient in many aspects when used directly for concrete production, due to some of the listed factors:
From the environmental point of view:

- Extraction of the sand from river bed in excess quantity is hazardous to the environment

- It is a common sight that well foundations of the bridges are exposed considerably, due to excessive extraction of sand around the sub structure endangering the sub structure of the bridges.

- Excessive mining of the sand from river beds reduces the water head. This is due to the less percolation of rainwater in the ground.

- The absence of sand in river bed results in more water being evaporated due to direct sunlight.

- The sand shortfall in river beds will affect the water filtration.

The arguments are mostly in regard to protecting river beds against the erosion and the importance of having natural sand as a filter for ground water. For these reasons, periodic restrictions are being introduced by governmental authorities against the collection of river sand.

Recently many countries have established policies aimed at utilizing the local materials as much as possible for building construction. The growing shortage and price rise of the natural sand also raise questions that a construction industry shall think about. Due to short supply of natural sand and the increased activity in construction sector, it has become an imperative to look for viable alternatives to natural sand. With natural sand deposits the world over drying up, there is an acute need for a product that matches the properties of natural sand in concrete.
The Manufactured Sand (MS), i.e. quarry sand which is available in abundance in various quarries is one of the major alternative material that can be used instead of natural sand in concrete. In this thesis, the various properties of manufactured sand concrete are compared with those of the natural sand concrete.

1.3 MANUFACTURED SAND

The Manufactured Sand (MS) is a by-product of the crushing and screening process in the quarries. Quarry generates considerable volumes of quarry fines while crushing the rock into aggregates. It is also referred to as crushed rock sand, stone sand, crusher sand and crushed fine aggregate. Quarry fines consist of a graded mix of coarse sand, medium sand and fine sand sized particles, plus clay/silt fraction known as the ‘filler’ grade. Filler grade material is defined by the industry as the material having less than 0.075mm (75 microns) in size.

The filler content is particularly important as it has a major impact on the technical properties. The limitation on the passing 75μm in specifications for natural sand for concrete is a response to the presence of deleterious clay minerals within this fraction size. Clay minerals are prone to cause cracking, dusting and shrinkage in hardened concrete, and they increase the water demand in the mix design. When designing the concrete with natural sand, it is necessary to restrict the passing 75μm to a level that prevents the possibility of clay minerals being present in quantities that would result in the potential issues described.

With the introduction of manufactured sand, there has been a gradual recognition that much of the passing 75μm materials are ground into primary minerals and not as clay minerals. These materials act as a rock flour or filler and have advantages in the concrete mix. The effect of this material
on water demand still requires careful monitoring and needs to be considered in mix design. The filler grade content of these fine materials is reduced by washing it with water to produce a clean, saleable ‘sand’ product.

1.3.1 Production of Manufactured Sand

Manufactured sand is produced and used in various countries such as Norway, USA, Australia, South Africa and India in the regions abundant with rock quarries. In USA limestone and granite account for 86% of the rock used to make manufactured sand, with the remainder made from basalt, dolomite, sandstone and quartzite, Ahn and Fowler (2001).

The quality (mineralogical, chemical and physical properties) of manufactured sand depends upon the type of rock quarries and the degree of processing it has undergone.

David Manning (2004) claimed that igneous rocks produce about 10 to 30% quarry fines. Limestone including dolomite and chalk quarries typically produces around 20 to 25% of fines, whereas sandstone quarries produce up to 35% of fines.

1.3.2 Crusher

A crusher is a machine designed to reduce large rocks into smaller rocks, gravel and rock dust. Crushing process of quarried rock is carried out mainly in three stages, namely Primary stage, Secondary stage and Tertiary stage. For each stage a different type of crusher is used to reduce the size of the quarried rock from upwards of 1.5m blocks to successively smaller sizes, until it reaches finer than 20mm. Each of these crushing stages produces quarry fines. The more the stages, the higher the proportion of fines generated.
Primary crushing is normally carried out by jaw or gyratory crushers and subsequent stages of crushing by cone or impact crushers (Hudson et al, 1997). The ‘rock-on-rock’ principle maximizes sand production without compromising either the shape or the texture. The reason for this lies in the crusher technology, which allows the material to crush itself by the action of centrifugal force and attrition, rather than by relying on breaker bars, hammers or cones. These result in lower energy consumption and wear costs than other types of crushers, providing further saving in the overall production cost.

1.3.3 Types of Crushers

1.3.3.1 Jaw Crusher

A jaw crusher is shown in Figure 1.1. It consists of a set of vertical jaws in which one jaw is fixed and the other one is moved back and forth relative to it by a mechanism. The jaws are farther apart at the top than at the bottom, forming a tapered chute so that the material is crushed progressively smaller and smaller as it travels downward until it is small enough to escape from the bottom opening. Quarried rock is fed into the top and is broken by the pressure of the two plates coming together. The rock is reduced in size and finally passes out through the bottom of the jaws being the discharge end. This has a variable aperture that can be adjusted to control the maximum size of the crushed material. The size of maximum opening is expressed as the open side setting and the minimum opening as the closed side setting. Jaw crushers have a tendency to produce the higher proportions of flaky materials (Wills, 1997).
1.3.3.2 Gyratory Crusher

A gyratory crusher is given in Figure 1.2. It consists of a concave surface and a conical head; both surfaces are typically lined with manganese steel surfaces. The inner cone has a slight circular movement, but does not rotate; the movement is generated by an eccentric arrangement.

Gyratory crushers are designated in size either by the gap and mantle diameter or by the size of the receiving opening. They can be used for primary or secondary crushing. The crushing action is caused by closing the gap between the mantle line (movable) mounted on the central vertical spindle and the concave liners (fixed) mounted on the main frame of the crusher. The gap is opened and closed by an eccentric on the bottom of the spindle that causes the central vertical spindle to gyrate. The vertical spindle is free to rotate around its own axis. The main shaft is suspended at the top and that the eccentric is mounted above the gear.
1.3.3.3 Impact Crusher

Impact crusher is shown in Figure 1.3. It involves the use of impact rather than pressure to crush the material. It operates by applying sharp blows at high speed to free-falling rock. This type of crusher is usually used for soft and non-abrasive material. Hammer mills (or swing hammer mills) are the form of impact crusher, which have hammers (often known as beaters) that swing freely on a rotating shaft within the crushing chamber. The other main type is the fixed impeller crusher where the hammers (otherwise known as impeller blades) are fixed onto the rotating shaft which is either horizontal or vertical. There are two types of impact crushers, namely Horizontal Shaft Impact crusher (HSI), Vertical Shaft Impact crusher (VSI).
1.3.3.4 Cone Crusher

Figure 1.4 shows the cone crusher. It is similar in operation to a gyratory crusher, with less steepness in the crushing chamber and more of a parallel zone between crushing zones. A cone crusher breaks rock by squeezing the rock between an eccentrically gyrating spindle, which is covered by a wear resistant mantle, and the enclosing concave hopper, covered by a manganese concave or a bowl liner. As the rock enters the top of the cone crusher, it becomes wedged and squeezed between the mantle and the bowl liner or concave. Large pieces of rock are broken once, and then fall to a lower position where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher. Cone crusher is suitable for crushing the varieties of medium and hard rocks. It has the advantage of reliable construction, high productivity, easy adjustment and less cost in operation. The spring release system of cone crusher acts as an overload protection that allows tramp to pass through the crushing chamber without damage to the crusher.
1.3.4 Technical Issues Leading to Production of Manufactured Sand

Fine particles are produced by abrasion or attrition of the rock as it comes into contact with other rock fragments. This is due to the shear failure, where projections from the rock surfaces are broken off, as the particles smash past each other. As a result of this, impact crushers tend to produce more granular or cubical particle shape and also produce much higher proportions of fine materials about 25 to 30% on average. This is higher than
the compressive crusher’s production of fine materials about 20 to 25% on average Hudson et al (1997). Ahn and Fowler (2001) said that the proportion of filler grade material produced by an impact crusher ranges from 5 to 20%. In 2000, the primary crusher was changed from an impact to a jaw crusher with the subsequent reduction in fines produced from 38% to 28%. In 2003, aggregate industries replaced its vertical shaft impact crusher with a cone crusher which reduced its fines and increased its production.

1.3.5 Technical Challenges

One of the main challenges in aggregate production, especially when producing crushed aggregates from hard rock quarries is to obtain a satisfactory mass balance. Unless special processing precautions are taken, the manufactured sand will end up with more or less uncontrolled fine content, far in excess of what can be tolerated. Any excess fraction that has to be kept on stock or even more deposited will create an economic as well as an environmental problem.

From the data found from manufacturers of manufactured sand, the production of crushed aggregate gives an imbalance of particle sizes. So the particle size distribution curve of manufactured sand is adjusted during manufacturing of the material.

Stress fractures, caused by compressive or impact crushing, will preferentially form along mineral grain boundaries and also across grain boundaries where internal weaknesses already exist. Therefore, manufactured sand tends to consist of more angular and irregularly shaped particles compared to natural sand, which tends to contain more rounded particles. This makes the manufactured sand (crushed sand) suitable for use in asphalt and concrete as angular particles give a better mechanical interlock. However, manufactured sand products, particularly if they are to be used in concreting
mixes, must be consistent in quality and be acceptable in grading. Therefore it necessitates to be manufactured in a purpose-designed crushing and screening process in contrast to crusher dusts from hard rock quarrying produced as residues of coarse aggregate production.

1.3.6 Production and Use of Manufactured Sand in Tamil Nadu

Tamil Nadu has been abundantly supplied with natural aggregates resources for construction purposes due to geographical location of the state. Deccan Traps are the main cause of the special geography and geology of South India. They are the good source material which can be used as the coarse aggregate and fine aggregate.

Manufactured sand is increasingly becoming more accepted as an alternative to natural sand where the traditional sources are becoming less available due to resources being depleted. Further, there is the need to make use of the ever growing stockpiles of quarry fines. Another advantage in manufactured sand is that quarries can be kept in the near vicinity to its place of end use. Therefore it shortens the transport distance and increases the employment opportunities for the locals. Table 1.1 shows the comparison between natural and manufactured sand.

Table 1.1 Comparison between natural and manufactured sand

<table>
<thead>
<tr>
<th>Natural sand</th>
<th>Manufactured sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has lots of fines</td>
<td>Has enough fines</td>
</tr>
<tr>
<td>Has smooth surface</td>
<td>Surface is rough</td>
</tr>
<tr>
<td>Rounded to sub - angular in shape</td>
<td>Particles are angular</td>
</tr>
<tr>
<td>Particles are in excellent shape for</td>
<td>Grains have sharp edges and are</td>
</tr>
<tr>
<td>concrete</td>
<td>sometimes irregular</td>
</tr>
<tr>
<td>High cost</td>
<td>Low cost</td>
</tr>
</tbody>
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1.3.7 Objectives of Using Manufactured Sand

- To minimize the waste
- To generate revenue
- To minimize volumes accumulating and taking up space in a quarry
- To reduce the costs of storage and disposal
- To satisfy the customer demand for products for which fines are a by-product
- To achieve sustainability
- To ensure landscape restoration
- To reduce the extraction of natural sand.

1.4 Scope of the Work

The scope of the present work includes the study of the following topics:

- Characterization of manufactured sand.
- Mix design for M 20, M 30 and M 40 grade concrete with various replacement levels of manufactured sand.
- Study on properties of fresh and hardened concrete with the replacement of fine aggregate by various proportions of manufactured sand.
- Durability studies on concrete for the optimum replacement level of manufactured sand.
- Studies on micro structural properties of concrete with manufactured sand.
• Experimental and analytical studies on structural behaviour of concrete with manufactured sand.

1.5 METHODOLOGY

The methodology is shown in Figure 1.5. The flow chart shows the step-by-step procedure of the present thesis work.

![Figure 1.5 Methodology]
1.6 OUTLINE OF THE THESIS

The thesis has been arranged in nine chapters. A brief description of each chapter is given below.

Chapter 1 Introduction: The first chapter provides the need for the alternative material of natural sand and presents an introduction to the manufactured sand. This chapter also includes the information on the production of manufactured sand, its technical issues and challenges during its production. Comparison between the natural sand and the manufactured sand has been brought out. Objectives of using manufactured sand are also pointed out. It also describes the scope of the research work and methodology of the project.

Chapter 2 Literature Review: The second chapter reviews the literature regarding the effects of manufactured sand as fine aggregate in concrete. This chapter also contains a brief review of literature about the influence of manufactured sand on the fresh concrete and its effects on mechanical, durability, micro structure and structural properties of hardened concrete.

Chapter 3 Characterization of Manufactured Sand: The third chapter describes the characterization of manufactured sand by conducting various tests on grain size, shape, texture and mineralogical composition and these properties are compared with the natural sand.

Chapter 4 Mix Design of Concrete with Manufactured Sand: The fourth chapter narrates the details about the materials used and the mix proportions arrived for M 20, M 30 and M 40 grades of concrete with the various replacement level of manufactured sand by considering their physical properties.
Chapter 5 Fresh and Hardened Properties of Concrete with Manufactured Sand: The fifth chapter demonstrates the fresh and hardened properties of concrete such as workability, compressive strength, splitting tensile strength, flexural strength, modulus of elasticity and Poisson’s ratio using various replacement levels of manufactured sand. This chapter also exhibits the optimum replacement level of manufactured sand from these fresh and hardened properties of concrete. It also presents the relationship between these hardened concrete properties.

Chapter 6 Durability properties of Concrete with Manufactured Sand: The sixth chapter explains the durability properties such as alkali aggregate reaction, drying shrinkage, impact resistance, abrasion resistance, rapid chloride ion penetration, corrosion, acid attack, water absorption, sorptivity and water permeability of the mortar and concrete with natural sand, manufactured sand and the optimum replacement level of manufactured sand.

Chapter 7 Micro Structural Properties of Concrete with manufactured sand: The seventh chapter explicates the micro structural analysis of the concrete such as Scanning Electron Microscopy (SEM) coupled with Energy Dispersive Spectroscopy (EDS) analysis and X-ray Diffraction (XRD) analysis of the concrete.

Chapter 8 Structural Behaviour of Concrete with Manufactured Sand: The eighth chapter reports the structural behaviour of Reinforced Concrete (R.C) beam with natural sand and manufactured sand by conducting the flexural test on beams. It also demonstrates the development of an analytical model for R.C beams with manufactured sand using finite element analysis software (ANSYS).
Chapter 9 Conclusions and Suggestions for Future Work: The ninth chapter includes the conclusions arrived at from the various experimental investigations and the scope for further work to be carried out.

1.7 CONCLUDING REMARKS

The availability of natural river sand which is widely used as fine aggregate to manufacture concrete in the construction industry has become scarce due to over mining and new regulations to protect the environment. This has led to find a suitable alternative for natural river sand which is viable and sustainable.

On the other hand, the fines from the quarry are mostly treated as waste or rejected material. These fines also cause huge environmental and economic problem. Each quarry produces fines depending upon its qualities, rock type and the crushers used. The use of fines in concrete products particularly depends on the specifications that need to be met.

In this research, the work has been focused on the characterization of manufactured sand to generate specifications that relate to their performance within the concrete products. Furthermore, experimental investigations have been conducted to optimize the various properties of concrete in which manufactured sand is used as fine aggregate.